Adaptations of cowpea varieties (*Vigna unguiculata* (L.) Walp.) to the environmental variability in Benin

A. ZANNOU[1], P. C. STRUIK[2], P. RICHARDS[3], R. C. TOSSOU[1] J. ZOUNDJIHEKPON[4]

[1]Faculté des Sciences Agronomiques, Université d'Abomey-Calavi, 01 BP 526 Cotonou, Benin

[2]Centre for Crop Systems Analysis, Wageningen University, P. O. Box 430, 6700 AK Wageningen, The Netherlands

[3]Technology and Agrarian Development, Wageningen University, P.O. Box 8130, 6700 EW Wageningen, The Netherlands

[4]Faculté des Sciences et Techniques, Université d'Abomey-Calavi, 01 BP 526 Cotonou

E-mailb : afiozannou@yahoo.com

Soumis le : 08 / 08 / 2014

Accepté le : 17 / 09 / 2015

ABSTRACT

The study was realized in the context of farmer management of genotype by environment interaction. The objective was to determine the agronomic and morphological characteristics commonly used by farmers to assess farmer named cowpea varieties through a joint farmer researcher characterization. The trial design was a completely randomized block with 70 varieties as treatments, replicated four times. Data were analyzed using Shannon-Weaver diversity Index and the Analysis of Variance. These varieties varied in growth habit, in colours of leaves, stems, flowers, pods and seeds, and in seed shape and texture. The Shannon-Weaver diversity index revealed a high global mean of morphological diversity among the varieties (H'=1.23), ranging from 1.02 for pod pigmentation to 1.61 for seed coat colour. Within regions, this index varied from 0.33 to 1.57, depending on considered characteristic. Farmers used the photoperiodic response of the late varieties to distinguish early-maturing from late-maturing varieties. In a 3-year experiment, the variety by environment interactions, as expressed by variety-specific effects of planting date, season, and year on yield and yield components, were highly significant. The late-maturing varieties have shown longer reproductive period and more pods and seeds per plant, and higher yield than the early ones.

Keywords : Diversity, *Vigna unguiculata*, photoperiodism, varieties, genotype by environment interaction, yield, Benin

RESUME

ADAPTATIONS DES VARIETES DE NIEBE (VIGNA UNGUICULATA (L.) WALP.) A LA VARIABILITE ENVIRONNEMENTALE AU BENIN

Dans un contexte de gestion d'interaction génotype x environnement, l'objectif était de déterminer les caractéristiques agronomiques et morphologiques couramment utilisées par les paysans pour évaluer les variétés de niébé. Le dispositif a été un bloc aléatoire complet avec 70 variétés comme traitements, répétés quatre fois. Les données ont été analysées avec l'indice de diversité de Shannon-Weaver et l'analyse de variance. Ces variétés diffèrent par la croissance, les couleurs des feuilles, des tiges, des fleurs, des gousses et des graines, la forme et la texture de la graine. L'indice de diversité a révélé une grande diversité morphologique globale moyenne entre les variétés (H'= 1,23), allant de 1,02 pour la pigmentation des gousses à 1,61 pour la couleur du tégument de la graine. Pour une région donnée, cet indice a varié de 0,33 à 1,57, en fonction de la caractéristique considérée. A partir du photopériodisme, les paysans ont pu séparer les variétés stardives des variétés précoces. Sur 3 ans, les interactions génotype x milieu exprimées par des effets spécifiques de date de semis, de saison, et d'année sur le rendement et ses composantes étaient significatives. Les variétés tardives ont une période de fructification plus longue et ont significativement plus de gousses et graines par plante et de plus hauts rendements que les variétés précoces.

Mots clés : *Diversité, Vigna unguiculata, variétés, photopériodisme, interaction génotype x environnement, rendement, Bénin.*

INTRODUCTION

The annual culti-group (var. *unguiculata*) is composed of cultivated cowpea varieties (Pasquet, 1999) on which this study is focused. Under farming conditions in Benin, cowpea (V*igna unguiculata*) varieties strongly interact with the environmental production factors, i.e. they show a strong genotype by environment interaction. This interaction determines the yield potential. Both farmers and breeders manage this interaction : farmers by managing the environment in a variety-specific way, and breeders by selecting varieties for specific environments. In Benin cowpea production areas, successive generations of farmers have selected cowpea varieties that flower at different periods during the growing seasons in response to the prevailing conditions at each location (Wien and Summerfield, 1980). Farmers proved to be aware of the differential response to photoperiod in early and late cowpea varieties (Zannou *et al.*, 2004). In such a context, developing new varieties, or developing strategies for improving and maintaining existing varieties, requires a clear understanding of the characteristics and diversity those varieties for which farmers have long-term experience. Joint research with farmers to analyze relevant agronomic and physiological traits and production constraints of the crop brought out the need to really understand the genetic diversity of the crop (Zannou *et al.*, 2004).

The objective of the current study was to develop best management practices that cope with specific environment of cultivated cowpea varieties in Benin. At a specific level, the study aimed at determining genetic characteristics of agronomic and morphological descriptors as commonly used, in a joint characterization involving farmers and researchers.

MATERIALS AND METHODS

PLANT MATERIALS

Plant material used in this study only included cowpea varieties grown by farmers belonging to *Vigna unguiculata ssp.unguiculata var. unguiculata* (Table 1). A global number of 70 farmer-named cowpea varieties were collected from farmers in the transitional Guinea Sudan areas and some fields in the south eastern of Benin.

FIELD TRIALS

Field trials were conducted in Dani, Savé district, in the central part of Benin during three years (2003 - 2005). Seventy varieties were assessed for their morphological and agronomic traits through a participative approach between researcher and farmers. The trials were conducted in a completely randomized bloc design with 70 cowpea varieties as treatments, replicated four times. Each variety was sown on a plot of 1 m x 20 m. On each plot, cowpea seeds were sown on a line at a spacing of 20 cm (i.e. 100 plants per line per variety) for early-maturing varieties, and at a spacing of 50 cm (i.e. 40 plants per line per variety) for late-maturing varieties, according to local farmer practices. During each farmer cropping season, and for each variety included, data were collected on 40 plants (10 plants per repetition x 4 repetitions).

JOINT CHARACTERIZATION BY FARMERS AND RESEARCHER

Data were collected and presented on various physiological,morphological and agronomic characteristics. Qualitative traits dealing with

Table 1 : List of cowpea germplasm accessions used for characterization and their collecting regions

Liste des accessions de niébé utilisées pour la caractérisation et leurs régions de collecte.

Codes	Cultivar names	Villages	Region	Codes	Cultivar names	Villages	Region
1	Adjaïkoun ancien	Bohicon	C	43	Sowétin	Gbékandji	SE
2	Yawari petit grain	Dani	C	44	Aïglo	Glazoué	C
3	Djohozin (Adjohozin)	Gbékandji	SE	45	Kacripia	Alfakpara	NW
4	Moussa	Dani	C	46	Atchawékoun (Bohicon)	Bohicon	C
5	Kpohoundjo	Dani	C	47	Malanville petit grain	Dani	C
6	Sèwékoun	Glazoué	C	48	Niger	Save	C
8	Tawa petit grain	Dani	C	49	Zerma soui	Marégourou	NE
9	Adjaïkoun	Bohicon	C	50	Kpodjiguèguè		SE
10	Wankoun	Ouèdèmè	C	51	Sokan	Gbékandji	SE
11	Tontouin	Gbékandji	SE	52	Yèringo		NW
13	Kpodji-Wéwé	Bohicon	C	53	Glessissoafoado	Dani	C
14	Djètè	Dani	C	54	Soui Kpika	Sonoumon	NE
15	Atchawe ou Tola (Bohicon)	Bohicon	C	55	Togo grain	Ouèdèmè	C
16	Kpeïkoun (Bohicon)	Bohicon	C	56	Tanguieta	Dani	C
17	Kakè	Bohicon	C	57	Boto wéwé	Dani	C
19	Soui Zerma	Marégourou	NE	58	Katché Django	Alédjo-Kpataba	NW
20	Tchabè Funfun	Diho	C	60	Kaki	Yagbo	C
22	Azobahundé (Kpodjiguèguè)	Dannou	SE	61	Olodjou Maria	Pira	C
23	Ewa Egbessi	Egbessi	C	63	Boto vovo	Dani	C
24	Olikpokpo-doudou	Dani	C	64	Yanti Kpika	Donga	NW
25	Assitchénongbinhami	DamèWogon	SE	65	Katché Koukpédon	Alédjo-Kpataba	NW
26	Mahounan	Yagbo	C	67	Soui Kerri	Sonnoumon	NE
27	Téhivigboto	Dannou	SE	68	Mosso	Ouassa	NW
28	Wan akpavi	DamèWogon	SE	69	Kplobè rouge	Dani	C
29	Atama	Save	C	70	Djètoko	Glazoué	C
30	Malanville gros grain	Save	C	71	Kwx	Dani	C
32	Boto	Ouèdèmè	C	72	Egni-awo	Glazoué	C
33	Yawari gros grain	Dani	C	73	Kplobè wéwé	Dani	C
34	Sèhèkou original	Ouèdèmè	C	74	Ewa Nigeria	Diho	C
35	Sindjinnansin	Dannou	SE	75	Tchawa koubanguè/ Grand Tchawa	Alédjo-Kpataba	NW
36	Tonton	Dani	C	76	Toura	Ouassa	NW
37	Tchadilè djofè	Diho	C	77	Nanwi	Dannou	SE
38	Tawa gros grain	Dani	C	78	Tola	Glazoué	C
39	Azangban	Dani	C	79	Ewa Zaffé	Glazoué	C
40	Atchawe Dangbo	Dannou	SE				
41	Matamaéko	Ouoghi	C				

C : Center, NE : North Eastern, NW : North Western, SE : South Eastern / C : Centre, NE : Nord-Est, NW : Nord-Ouest, SE : Sud-Est.

plant and seed morphology included growth habit, pod pigmentation, flower colour, stem colour, seed shape, eye pattern, seed coat colour, skin texture. Quantitative traits of plant and seed comprised : plant height at five different development stages, days to first flower, days to first pod ; days to 50 % maturity, pod length, number of seeds per pod, number of pods per plant per variety, and number of seeds per plant, and 1000-seed weight.

The characterization, based on the knowledge of farmers and researchers, was carried out in the framework of a local learning group, and took place during different sessions covering the period from crop growth to post harvest.

DATA ANALYSIS

Qualitative characters of seed and plant morphology

The qualitative data were encoded into 3 to 7 classes. Frequency distributions were performed according to the following nine qualitative variables dealing with plant and seed morphology : growth habit, young pod pigmentation, flower colour, stem colour, grain shape, eye pattern, eye colour, seed coat colour, and seed coat texture. The frequency distributions were used to calculate the Shannon-Weaver diversity index (H') for each characteristic (Grenier *et al.*, 2004) :

$$H' = -\sum_{i=1}^{n} p_i \ln(p_i) \quad (1)$$

where n is the number of phenotypic classes, and p_i the frequency of the observation in the ithclass. Due to their additive property, the indices of each character could be extended to characteristics and the global phenotypic diversity was estimated by calculating the mean index value using SAS 8^e program.

Quantitative traits of plant and seed

Descriptive statistics were computed for each quantitative agro-morphological trait. Principal component analyses were performed on the 10 quantitative traits (see above). Principal component analysis reveals the importance of different quantitative traits in explaining multivariate polymorphism (Mallkarjurna *et al.*, 2003 ; Naghavi and Jahansouz, 2005). Data were standardized to a mean of zero and a variance of one. According to Kaiser's rule on standardized data, components or factors to be retained were those whose eigen-values were greater than one (Sharma, 1996). Data on quantitative traits for plant and seed were analysed for 51 early-maturing varieties and 16 late-maturing varieties. Data related to the other three varieties were not presented due to the lack of records.

Genotype by environment interaction

An integrated full interaction analysis of variance was carried out. Such an analysis describes the phenotypic responses and allows a quantification by regression on the mean model of differences in environmental sensitivity between varieties (Finlay and Wilkinson, 1963 ; van Eeuwijk *et al.*, 2005). In the absence of explicit physical or meteorological characterizations of an environment, a good approximation of the general biological quality of the environment is given by the mean phenotypic performance across the genotypes (van Eeuwijk *et al.*, 2005). The phenotypic responses of individual genotypes are then regressed on the average performance, and the genotype by environment interaction expresses itself by differences in the slopes between the genotypes.The model for the regression on the mean can be written as follows :

$$\mu_{ij} = \mu + G_i + E_j + \beta_i E_j \; ; \quad (2)$$

where the genotype by environment interaction is modelled as differential genotypic sensitivity and represented by the parameters β_i to environmental characterization Ej, with the average sensitivity being zero.

Generalized Linear Model of Analysis of Variance (GLM ANOVA) under SAS was performed to analyze the variation of yield components in response to change in date of planting, season and in the year effects.The GLM ANOVA is appropriate especially for unbalanced data, where there are unequal numbers of records for different combinations of class variables specified in the model structure. With this ANOVA, the number of pods per plant, the number of seeds per pod and the number of seeds per plant were analysed. The following effects were considered :

- Genotype (farmer-named variety) ;
- Variety-type (early- or late-maturing) ;
- Year (2003-2005 for early-maturing, and 2004-2005 for late-maturing varieties) ;

- Date (Year) : Date or planting period nested within year effect. The season effect was considered for early-maturing as they were planted during different cropping seasons and the date effect for the late-maturing varieties, as for the late ones two dates of planting were distinguished during a same cropping season. The late-maturing varieties can only be planted once a year.

Three interaction effects were defined :

- Genotype x Year ;
- Genotype x Date (Year) ;
- Genotype x Variety-type x Date (Year) ;

Data were analysed with 35 early-maturing varieties over 2003-2005 and 15 late-maturing varieties over 2004-2005 for the genotype by environment interaction. These varieties are those for which the yields are consistently available over three or two years for a comparison across years. In the first year (2003), the late-maturing varieties did not perform well.

RESULTS

MORPHOLOGICAL AND AGRONOMIC DIVERSITY

Cowpea varieties greatly differed in their morphological and agronomic traits. Various classes of these characters were considered by farmers and used in this study. There were variations in growth habit and stem colour. Some varieties were spreading (prostrate and semi-prostrate), locally named late-maturing varieties, while others were erect or semi-erect. Different plant and seed morphology characteristics were reported. Some cowpea variety pods were entirely pigmented, while others were not, or just at the apex of the pod. There was a diversity in flower colour, white/whitish, white and purple-edge, purple, and yellowish. The stem was light green, green, or purple depending on the variety. The seed was either kidney, ovoid, globose or rhomboid. There was a diversity of the eye patterns : very small, small, narrow, and wide or in some cases absent. Where the eye was markedly present, its colour was blue, brown, black or red. The cowpea varieties were characterized by seed coat colour as white, cream/ivory, brown, red, black, and variegated (black and black-white, light-dark brown, red-black, brown-black, ivory-black, or beige-black). Texture of the seed coat was also different : smooth, rough, or wrinkled (Table 2).

The Shannon Weaver diversity index calculated from plant and seed morphology of the different cowpea varieties showed a high mean global index of diversity in the whole collection (H'= 1.23), and ranged from 1.02 for pod pigmentation to 1.61 for seed coat colour. Dealing with individual traits, seed coat colour showed the highest (1.61) total diversity in all regions. Within regions, this phenotypic diversity index varied from 0.33 to1.57, depending on considered area. It varied from 1.05 to 1.46 (with a mean of 1.26) in central region, from 0.65 to 1.57 in the north and from 0.30 to 1.46 in the south eastern. Mean value for each region was 1.26 (Center), 1.07 (North) and 0.79 (south-eastern).

At 70 % of similarity on the Gower General Similarity coefficient, nine clusters can be distinguished. The first six clusters were assembled in one large group comprising only white seed coat of late- and early-maturing varieties, while the second cluster was composed of mixtures of seed colour and early-maturing varieties (Figure 1).

One particular trait farmers recognized as being important in the late-maturing varieties was the growth habit (i.e. the trend to be prostrate). Based on this characteristic, some varieties (such as Mata, Djetoko, Atama, Moussa and Egniawo) could be easily identified in the field and were considered to be a distinctive group. Within this group, plant pigmentation, flower colour, and morphological seed traits could be used to further distinguish the different types. Some results were reported on the interactive sessions to characterize the different varieties with the local learning group. The leaf or the plant colour alone was not sufficient, sometimes, to make a clear distinction between varieties, but was useful to indicate a genotypic relation. Distinction was mainly made on the basis of pod and seed characteristics (Box 1 and Box 2).

Box 1. Plant pigmentation and seed traits

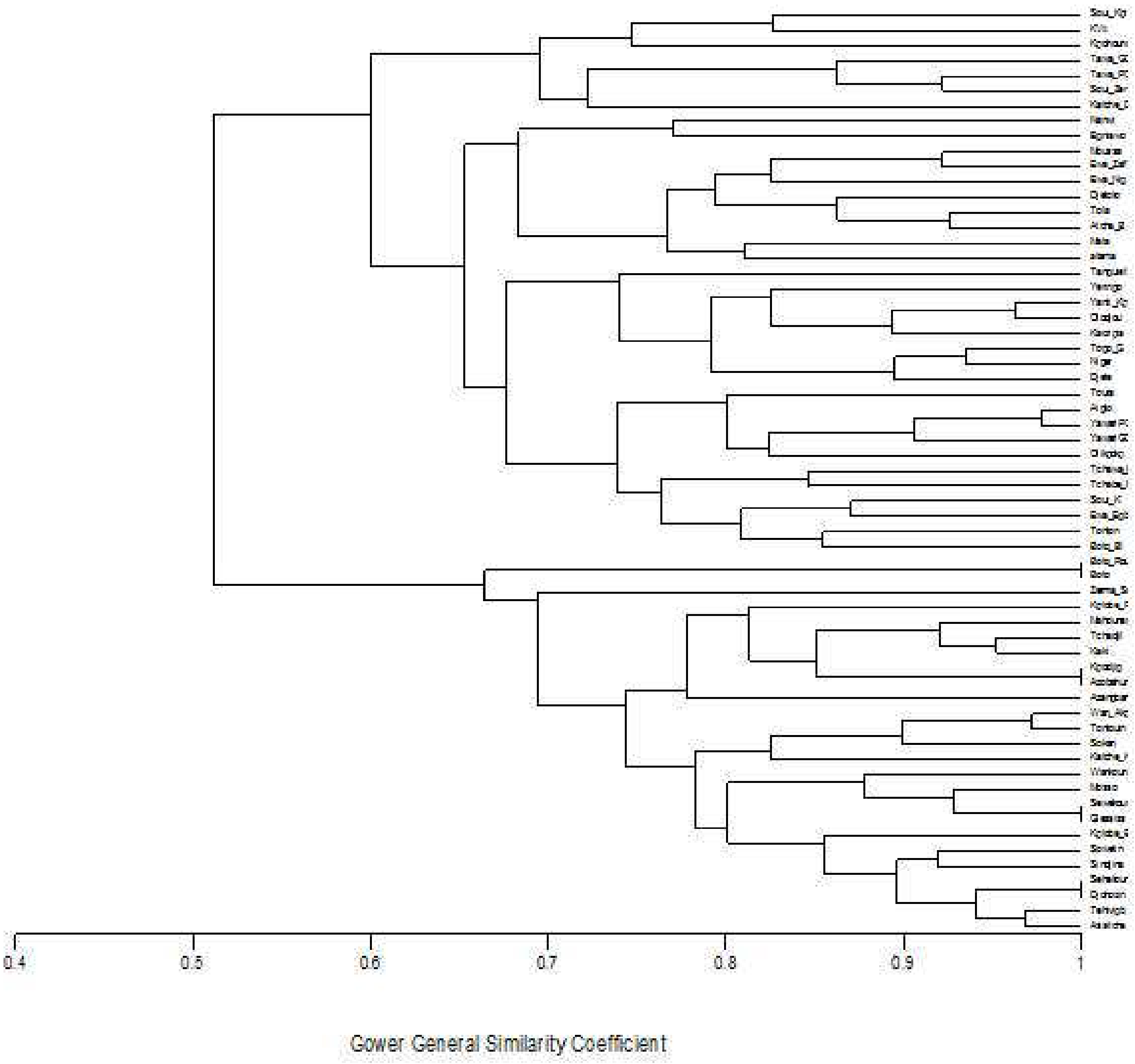
Djètoko and Atama. The leaves of Djètoko were smaller and darker than those of Atama. Djètoko is semi-prostrate (the main stem reaches some height before spreading while Atama is prostate (branches quickly flat on ground).The stems of Djètoko were taller and more red-purple

Table 2 : Frequency distribution and Shannon-Weaver diversity index (H') for qualitative characters.

Distribution de fréquence et indice de diversité (H') de Shannon-Weaver pour les caractères qualitatifs

Character	Class	Centre Freq	Centre H'	North Freq	North H'	South-Eastern Freq	South-Eastern H'	Total Freq	Total H'
Growth habit	1=Rrect	0.39		0.64		0.10		0.40	
	2=semi-erect	0.37		0.36		0.50		0.38	
	3=prost. + semi-prost.	0.24	1.08	0.00	0.65	0.40	0.94	0.22	1.07
Pod pigmentation	0=absent	0.49		0.64		0.50		0.52	
	1=present at the apex	0.24		0.22		0.20		0.23	
	2= entirely coloured	0.27	1.05	0.14	0.89	0.30	1.03	0.25	1.02
Flower colour	1=white/whitish	0.41		0.43		0.00		0.36	
	2=white & purple-edge	0.10		0.14		0.00		0.09	
	3=purple	0.34		0.36		0.90		0.43	
	4=yellowish	0.15	1.25	0.07	1.19	0.10	0.33	0.12	1.20
Stem colour	1= light green	0.27		0.14		0.60		0.29	
	2=Green	0.10		0.07		0.40		0.14	
	3= green-purple	0.41		0.57		0.00		0.38	
	4= purple	0.22	1.28	0.22	1.11	0.00	0.67	0.19	1.04
Seed shape	1=Kidney	0.43		0.36		0.37		0.41	
	2=Ovoid	0.25		0.36		0.45		0.30	
	4=Globose	0.11		0.14		0.09		0.12	
	5=Rhomboid+Crowder	0.21	1.28	0.14	1.29	0.09	1.16	0.17	1.28
Eye pattern	0=absent	0.36		0.21		0.82		0.41	
	1=very small	0.07		0.14		0.09		0.08	
	2=Eye filling the narrow grove	0.05		0.00		0.00		0.03	
	3=Narrow eye	0.22		0.22		0.00		0.19	
	4=Small eye	0.07		0.29		0.09		0.12	
	5=wide eye	0.23	1.56	0.14	1.57	0.00	0.60	0.17	1.54
Eye Colour	0= absent	0.36		0.21		0.82		0.41	
	1=Blue	0.04		0.00		0.09		0.04	
	2=Brown	0.41		0.43		0.09		0.36	
	3=Black	0.17		0.36		0.00		0.17	
	4=red	0.02	1.24	0.00	1.06	0.00	0.60	0.02	1.24
Seed coat co	1=White	0.48		0.64		0.09		0.45	
	2=Cream + Ivory	0.18		0.07		0.00		0.13	
	4=Brown	0.16		0.07		0.00		0.11	
	5=Red	0.07		0.00		0.18		0.07	
	6=Black; Black-White	0.00		0.00		0.09		0.13	
	7=light-dark brown	0.04		0.07		0.37		0.09	
	8=Red-black; Brown-black, Ivory-black; Beige-black	0.07	1.46	0.15	1.13	0.27	1.46	0.02	1.61
Skin texture	1= smooth	0.43		0.72		0.91		0.56	
	3= smooth to rough	0.36		0.07		0.09		0.26	
	5= Rough	0.18		0.21		0.00		0.16	
	7= Rough to wrinkled	0.03	1.14	0.00	0.75	0.00	0.30	0.02	1.05
Average			1.26		1.07		0.79		1.23
S.E.*			0.056		0.093		0.129		0.072

* S. E.: Standard Error / * S. E : Erreur-type



Clusters basés sur les caractéristiques morphologiques des variétés de niébé.

pigmented than those of Atama. The pods of Djètoko were bigger than the ones of Atama. The seed eye of Djètoko was red-purple while the eye of Atama was black. Djètoko was easier to shell while the pod was difficult to shatter. However, Djètoko and Atama have similar seed coat colour (white), growth habit (spreading) and flowering period.

Box 2. Earliness, plant vigour and photoperiodism

During field observations and data analysis with the farmers, it was noticed that some varieties that were supposed to be early-maturing and hence planted in the first rainy season, had not flowered till to 11-12 weeks after sowing.These varieties were Aïglo, Tchawa Koubanguè, Toura, Moro, Soui Kerri, and Ewa Egbessi. The leaves of one of them (Soui Kerri) began turning yellow, indicating that senescence had started. It appeared that when cowpea spends its normal growth duration without flowering, the leaves dry out and drop, but the stem remains alive. Farmers noted that all varieties so called late- maturing flower in early October.The photoperiodic response appeared as the basis of classification by farmers as so called late-maturing varieties.

QUANTITATIVE AGRONOMIC TRAITS ANALYSIS

Diversity of agronomic traits

Farmers suggested that the number of seeds per pod, number of pods per plant, and number of seeds per plant were very important characteristics. Basically, early-maturing varieties flowered within 40 days (Table 3). Coefficients of variation of parameters as days to first flowering, days to first pod, and days to 50 % maturity were almost the same. Days to 50 % maturity was, globally, reached 59 days after emergence. These early-maturing varieties ended their growth cycle at meanly 68 days, after emergence. The mean value of pods per plant was 19, whereas the number of seeds per pod was 14. The average number of seeds per plant was relatively high (267). The coefficients of variation showed that variance magnitude/ amplitude in number of seeds per plant, in number of pods per plant, and in 1000-seed weight, was higher than in the variance magnitude in other parameters.

When planted at the appropriate date (based on local knowledge), first flowering in late-maturing varieties (locally recognized as having a particular period of flowering) occurred globally at 53 days, 55 days for first pods, and 76 days to reach 50 % maturity Table 3. Average duration of their cycle was 83 days.Thus, productive period of late-maturing varieties appeared to be longer (Table 3). Figures 2a and 2b show the dendrogram built based on Euclidean distance of quantitative traits using the NTSYS-pc package after data standardisation. At 0.55 point of distance, nine groups of early-maturing varieties can be distinguished (Figure 2a). At 0.55 point of distance, the late-maturing varieties can be separated into six groups (Figure 2b).

Correlations between agronomic traits

For both early- and late-maturing varieties « (left and right parts of Table 4), » there were positive and highly significant associations between days to first flowering, days to first pods, days to 50 % maturity, and the duration of the growth cycle. Within each of the two variety groups these characteristics are probably governed by the same genes. These characteristics, however, were not correlated with pod length, number of pods per plant, number of seeds per pod and number of seeds per plant, for either early or late-maturing varieties. Length per pod and number of seeds per pod, pods per plant and seeds per plant, seeds per pod

Table 3 : Descriptive statistics of yield components and agro-morphological and phenological characters

Statistique descriptive des composantes du rendement des caractéristiques agro-morphologiques et phénologiques

	Early-maturing					Late-maturing				
Characteristics	Mean	Min	Max	SD	CV	Mean	Min	Max	SD	CV
DaFlow*	39.7	32.0	44.5	2.9	7.4	53.0	42.9	66.1	5.9	11.1
DaPod	41.9	34	48.1	2.9	7.0	55.2	45.4	68.1	5.7	10.3
DPodma50	58.7	51.7	71	4.5	7.6	76.3	63.7	88.7	6.3	8.2
Durcycle	68.0	56.8	88	8.2	12.1	83.2	70.4	95.3	6.7	8.1
Leng_pod	15.9	11.7	19.7	2.1	13.1	13.8	12.2	15.4	0.9	6.7
Seed_pod	14.1	9.5	18.9	2.2	15.6	12.2	10.4	13.9	1.7	8.7
Pod_plt	18.8	10.1	34	4.5	23.8	23.9	8.9	35.9	6.7	28.2
Seed_plt	267.1	156.9	480.2	71.3	26.7	298.9	117.7	505.2	94.2	31.5
1000-seed weight	129.3	64	219	28.7	22.2	128.6	91	239	34.8	27.1

* DaFlow= days to first flower, DaPod= days to first pod; DPodma50= days to 50% maturity, Durcycle= cycle duration, Leng_pod= pod length, seed_pod= number of seeds per pod, Pod_plt = number of pods per plant, Seed_plt= number of seeds per plant. / * DaFlow= Nombre de jours à la première floraison, DaPod= Nombre de jours à l'apparition de la première gousse; D50Podma= Nombre de jours à 50 % de maturité, Durcycle= durée du cycle; Leng_pod= longueur de la gousse; seed_pod= nombre de grains par gousse; Pod_plt = nombre de gousses par plante; Seed_plt= nombre de grains par plante.

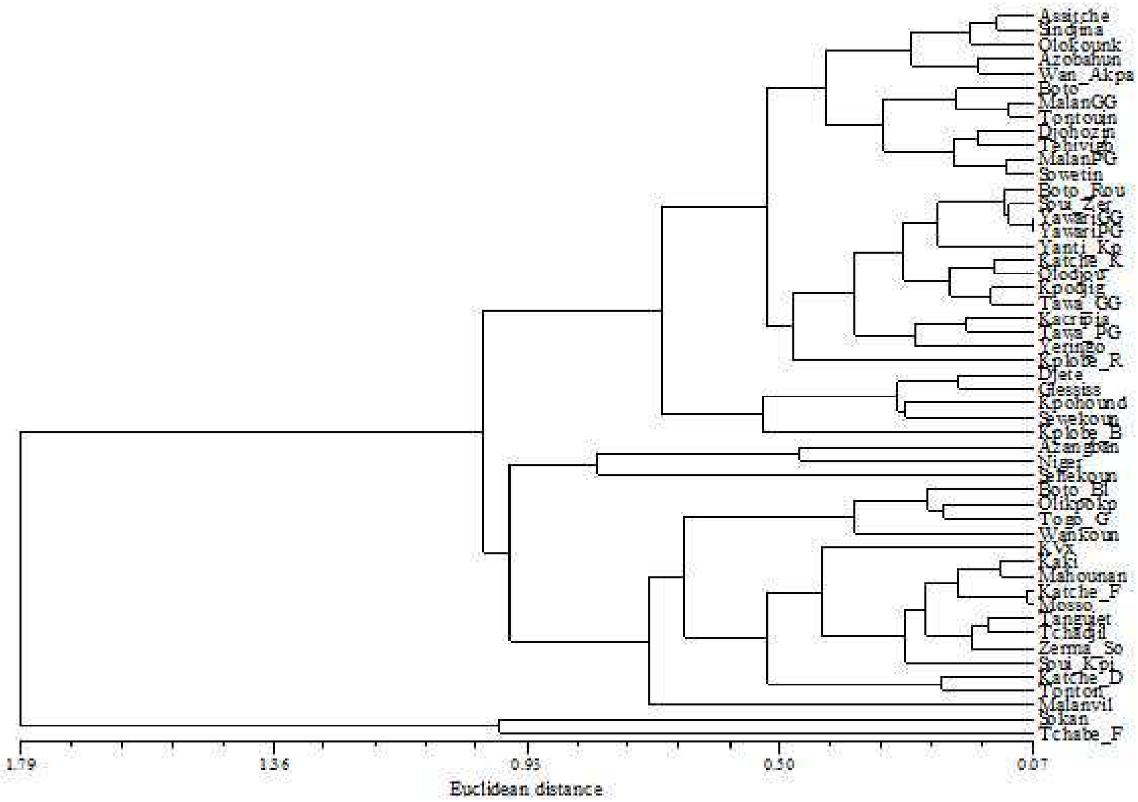


Figure 2a : Clustering based on agronomic performance for early-maturing varieties.

Clusters basés sur la performance agronomique des variétés précoces.

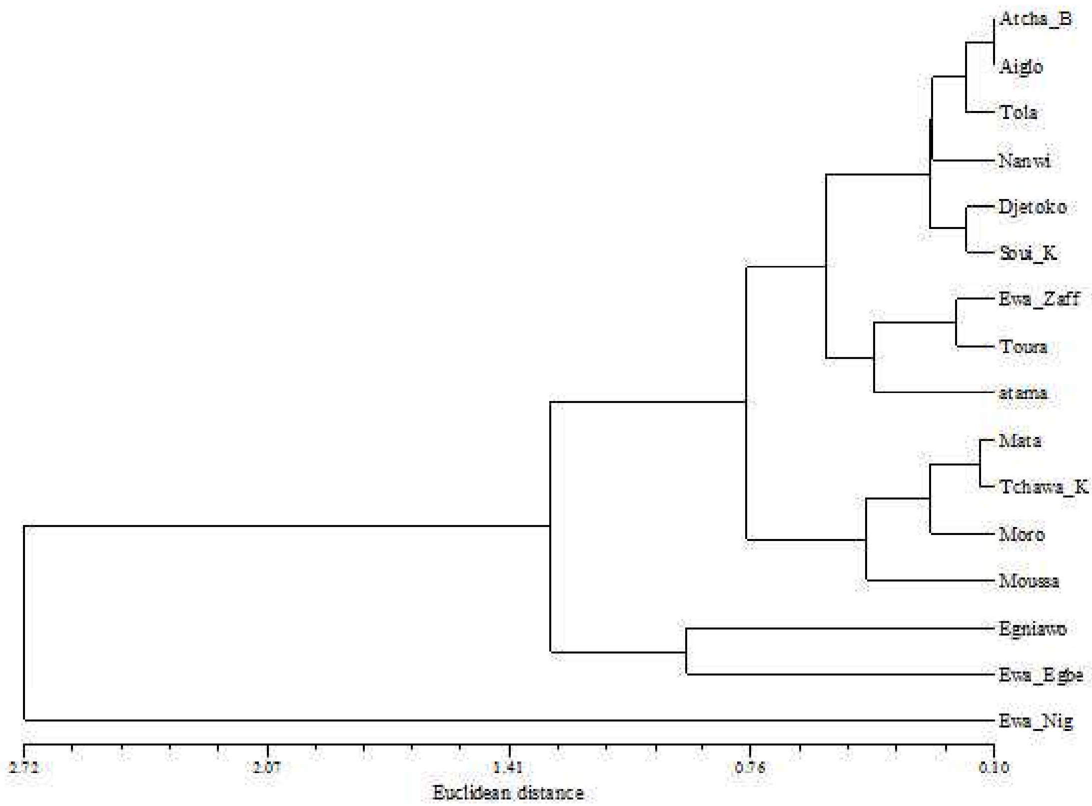


Figure 2b : Clustering based on agronomic performance for late-maturing varieties

Clusters basés sur la performance agronomique des variétés tardives.

Table 4 : *Phenotypic correlations between yield components and agro-morphological and phenological characters (Correlation matrix from 51 early-maturing (bottom left), 16 late-maturing (upper right))*

Corrélations phénotypiques entre les composantes du rendement et les caractères agro-morphologiques et phénologiques (matrice de correlation pour 51 variétés précoces (bas gauche), 16 variétés tardives (haut droit)

	Late-maturing varieties								
Early-maturing varieties	DaFlow	DaPod	DPodma50	Durcycle	Leng_pod	Pod_plt	Seed_plt	Seed_pod	1000-seed weight
DaFlow	-	0.994***	0.922***	0.905***	-0.054	-0.029	0.058	0.125	0.299
DaPod	0.973***	-	0.910***	0.894***	-0.053	-0.038	0.049	0.123	0.307
DPodma50	0.622***	0.674***	-	0.973***	-0.092	-0.054	-0.026	-0.046	0.466*
Durcycle	0.278**	0.369***	0.814***	-	-0.137	0.033	0.047	-0.097	0.420
Leng_pod	0.164	0.193	0.351***	0.242*	-	0.187	0.287	0.551**	-0.074
Pod_plt	0.034	0.047	0.115	0.126	-0.114	-	0.962***	0.345	-0.160
Seed_plt	-0.082	-0.056	0.152	0.164	0.349**	0.824***	-	0.573**	-0.294
Seed_pod	-0.167	-0.140	0.140	0.164	0.811***	-0.121	0.447***	-	-0.500*
1000-seed weight	0.370***	0.377***	0.224	0.060	0.208	-0.036	-0.101	-0.099	-
	DaFlow	DaPod	DPodma50	Durcycle	Leng_pod	Pod_plt	Seed_plt	Seed_pod	1000-seed weight

Significance level: *<10 %; **; 5 %; ***<1 % / Seuil de signification: *<10 %; **; 5 %; ***<1 %.
* DaFlow= days to first flower, DaPod = days to first pod ; DPodma50 = days to 50 % maturity, Durcycle = cycle duration, Leng_pod = pod length, seed_pod = number of seeds per pod, Pod_plt = number of pods per plant, Seed_plt = number of seeds per plant. / * DaFlow = Nombre de jours à la première floraison, DaPod = Nombre de jours à l'apparition de la première gousse ; D50Podma = Nombre de jours à 50 % de maturité, Durcycle = durée du cycle ; Leng_pod = longueur de la gousse ; seed_pod = nombre de grains par gousse ; Pod_plt = nombre de gousses par plante ; Seed_plt = nombre de grains par plante.

and seeds per plant were highly and positively correlated. At the opposite, 1000-seed weight and the number of seeds per pod, number of seeds per plant and number of pods per plant were negatively correlated.

Principal component analysis of quantitative agronomic traits

The principal component analysis showed four significant components for early-maturing varieties and three main components for late-maturing varieties, following Kaiser's rule (Table 5). The first four components contributed to 89.4 % (Table 6). Each of them contributed to 40.2 % (first component), 22.5 % (second component), 16.3 % (third component) and 10.3 % (fourth component) of the total variance of the original variables. Days to first flowering, days to first pod and days to 50 % maturity predominantly explained first component ; that was the case of number of seeds per pod and number of seeds per plant in second component. In late-maturing varieties, three main components expressed 86.4 % of total variation with 48.2 % (first component), 26.7 % (second component) and 11.4 % (third component) for each component. As for early-maturing varieties, first component was mainly explained by days to first flowering, days to first pod and days to 50 % maturity in late-maturing varieties. The number of pods per plant, number of seeds per pod, and number of seeds per plant determined second component.

Table 5 : Principal components for 10 quantitative characters for early- and late-maturing varieties

Composantes principales pour 10 caractères quantitatifs relatifs aux variétés précoces et Tardives.

	Early-maturing group (n=51)				Late-maturing group (n=16)			
	PC1	PC2	PC3	PC4	PC1	PC2	PC3	PC4
Eigen values	4.02	2.25	1.62	1.03	4.82	2.68	1.14	0.90
Percentage variation	40.23	22.54	16.25	10.34	48.21	26.77	11.38	8.98
Cumulative variation	40.23	62.77	79.02	89.36	48.21	74.98	86.36	95.34
	Loadings (eigen-vectors)				Loadings (eigen-vectors)			
DaFlow*	0.43	-0.23	0.05	0.17	0.45	0.06	0.09	-0.08
DaPod	0.45	-0.20	0.05	0.12	0.44	0.06	0.10	-0.07
D50Podma	0.44	0.08	0.01	-0.33	0.44	-0.02	-0.03	0.06
Durcycle	0.32	0.15	0.03	-0.59	0.44	0.00	-0.13	0.01
Leng_pod	0.21	0.42	-0.43	0.23	-0.05	0.32	0.46	0.69
Pod_plt	0.06	0.28	0.69	0.17	-0.02	0.49	-0.56	0.07
Seed_plt	0.07	0.56	0.38	0.19	-0.00	0.56	-0.37	-0.01
Seed_pod	0.06	0.53	-0.42	0.04	-0.01	0.50	0.44	-0.06
1000-seed weight	0.21	-0.15	-0.10	0.62	0.20	-0.28	-0.31	0.69

Records in bold are loading values with most significant impact / Les chiffres en gras se réfèrent aux facteurs prépondérants qui ont l'impact le plus significatif.

* DaFlow = days to first flower, DaPod = days to first pod ; D50Podma = days to 50 % maturity, Durcycle = cycle duration, Leng_pod = pod length, seed_pod = number of seeds per pod, Pod_plt = number of pods per plant, Seed_plt= number of seeds per plant. / * DaFlow = Nombre de jours à la première floraison,DaPod = Nombre de jours à l'apparition de la première gousse; D50Podma = Nombre de jours à 50 % de maturité, Durcycle= durée du cycle ; Leng_pod = longueur de la gousse ; seed_pod = nombre de grains par gousse ; Pod_plt = nombre de gousses par plante ; Seed_plt = nombre de grains par plante.

Table 6 : Average values of yield components of cowpea varieties grown at different cropping seasons and planting dates over 2003-2005

Valeurs moyennes des composantes du rendement des variétés de niébé cultivées à différentes saisons et dates de cultures sur la période 2003-2005.

Variety-type	Factors	Factor levels	Total number of plants	Number of seeds per pod	Number of pods per plant	Number of seeds per plant
Early-maturing	Season	Season-1	1207	15.2 a*	18.9 a	292 a
		Season-2	3000	12.9 b	18.8 b	244 b
	Year	2003	1057	11.8 c	22.4 a	271 a
		2004	2300	13.9 b	17.1 c	244 b
		2005	850	14.9 a	19.1 b	281 a
Late -maturing	Date	Date-1	800	12.2 b	27.0 a	337 a
		Date-2	1010	12.5 a	23.5 b	297 b
	Year	2004	920	12.4 a	26.2 a	333 a
		2005	890	12.4 a	23.8 b	296 b

* For each factor, means followed with the same letters are significantly different at the level of 5 % with the test of Student-Newman-Keuls./ * Pour chaque facteur, les moyennes suivies des mêmes lettres ne sont pas significativement différentes au seuil de 5 % avec le test of Student-Newman-Keuls.

Genotype by environment interaction: effects of planting date, season, and year on yield components

Yield components (number of seeds per pod, number of pods per plant and number of seeds per plant) in both variety groups were significantly different from one year to another, except number of seeds per pod in late-maturing varieties (Table 7). In early-maturing ones, first planting season revealed significantly more seeds per pod, pods per plant and seeds per plant than the second one. In late-maturing varieties, the two planting dates expressed significantly different values for yield components ; second date showing more seeds per pod, but fewer pods per plant and fewer seeds per plant than the first date.

Combined analysis of yield components over three-year experiments indicated that all sources of variance were highly significant ($p < 0.001$) for all parameters, except number of seeds per pod in late-maturing varieties. Significant Seasonx Variety and Yearx Variety interactions suggested differences among varieties in response to varying season conditions and years. The magnitude of these responses varied from one season to another, one year to another and from one variety to another. These results indicated that the yield components of cowpea are highly dependent on genotypes, season and year, and on the genotype by environment interactions.

The effect of year was larger than the effect of season and the effect of season was larger than the effect of variety for the early-maturing varieties, whereas for late-maturing varieties the effect of variety was higher than the effect of year, and the effect of year was larger than the effect of planting date for the three yield components. The effect of year was the highest for number of pods per plant and number of seeds per plant, whereas the effect of variety was largest for number of seeds per pods for the late-maturing varieties.

Within the early-maturing group, the varieties Sewekoun, Glessissoafoado, Djete, and Assitchenon had the highest number of seeds per plant, ranging from 311 to 470 seeds/plant, while Azangban and Olikpokpodoudou had the lowest value (162 and 172 respectively) (Table 8). The means of the other varieties ranged from 200 to 300 seeds per plant.

For the late-maturing varieties, the varieties Mata and Tchawa Kougbangue had the highest number of seeds per plant (505 and 439, respectively), whereas Ewa Nigeria, Atama and Ewa Egbessi had the lowest values (117.7 to 209.7) (Table 9). The mean yield of the other varieties ranged from 248 to 371 seeds per plant. The number of pods per plant appeared to be the most important yield component determining total number of seeds per plant.

Table 7 : Genotype by environment : effects of planting date, season, and year on yield components

Interaction Génotype x milieu : effets des dates de semis, de la saison et de l'année sur les composantes du rendement.

GLM-ANOVA		Number of seeds per pod		Number of pods per plant		Number of seeds per plant	
Source of variation	Degree of Freedom	Mean Square	F_value	Mean Square.	F_value	Mean Square	F_value
Early-maturing							
Season	1	931.5	239.69***	403.2	9.78***	702474.1	53.27***
Variety	34	215.8	55.52***	1814.7	22.95***	368365.7	19.78***
Year	2	1199.5	309.60***	1916.1	29.45***	456857.4	27.57***
Season × Variety	27	36.2	9.30***	725.1	13.17***	173411.2	12.76***
Year × Variety	45	118.6	30.51***	858.5	14.09***	230931.6	16.12***
Year × Season × Variety	4	31.3	8.06***	378.6	6.25***	85388.8	5.87***
Model	119	229.4	58.58***	1423.7	23.11***	343725.3	23.35***
Error	4067	3.9		61.6		14718.2	
R-Square		0.63		0.40		0.41	
Mean		13.6		18.8		258.5	
Late-maturing							
Date	1	11.9	5.63**	11765.8	116.69***	1703273.5	92.84***
Variety	14	146.0	69.4***	5528.8	54.84***	1042799.1	56.84***
Year	1	22.5	10.71***	17126.9	169.87***	2600990.0	141.77***
Date × Variety	11	25.9	12.33***	1554.8	15.42***	309516.4	16.87***
Year × Variety	12	68.6	32.61***	2502.0	24.81***	545085.9	29.71***
Year × Date × Variety	3	31.4	14.9***	2474.2	24.54***	571053.2	31.13***
Model	45	81.8	38.87***	3988.9	39.56***	784681.8	42.77***
Pooled error	1764	2.1		100.8		18347.0	
R-Square		0.50		0.50		0.52	
Mean		12.4		25.0		314.8	

Significance level : * 10 %; ** 5 %; *** 1 % / Seuil de signification: * 10 %; ** 5 %; *** 1 %

Table 8 : Genotype by environment (period of planting, season and year) interaction with GLM ANOVA : Tests of multiple range comparison (35 early-maturing varieties, 2003-2005)

Interaction Génotype x milieu (période de semis, saison et année) avec GLM ANOVA : Tests de comparaison multiple (35 variétés précoces, 2003-2005).

Variety	Total number of plants	Number of pods_per plant		Number of seeds per_pod		Number of seeds_per plant	
		Mean	SD	Mean	SD	Mean*	SD
Sewekoun	160	34.0 a	13.89	13.8 gh	2.06	471 a	203.0
Glessiss	160	24.9 bc	11.12	14.2 gf	1.65	354 b	164.1
Djete	102	25.7 b	12.31	13.3 hji	2.44	353 b	204.2
Assitche	52	18.6 efghijk	8.90	16.3 ab	1.77	311 c	171.5
Kpodjig	120	18.2 efghijk	10.90	15.6 bcd	2.98	295 cd	209.3
Djohozin	52	18.9 efghij	9.69	14.8 def	2.03	287 cde	164.4
Kacripia	130	17.6 efghijkl	7.10	16.0 abc	2.71	286 cde	133.3
Tonton	160	20.3 def	13.43	13.5 ghi	2.52	285 cde	207.3
Katche_K	120	22.7 cd	12.02	11.6 mn	3.23	282 cde	196.6
Tawa_GG	172	18.9 efghij	7.45	14.6 ef	2.50	280 cde	127.4
Tawa_PG	172	19.7 defgh	9.92	13.8 gh	3.37	274 cde	152.2
Boto_Rou	120	17.7 efghijkl	7.69	15.2 cde	3.21	273 cde	143.0
Mosso	90	21.6 de	10.64	12.1 klm	1.84	265 cdef	144.1
Katche_D	80	15.8 hijklmn	6.47	16.6 a	2.58	264 cdef	119.7
Soui_Zer	90	17.4 fhijkl	7.86	14.8 def	1.78	261 cdef	132.3
Mahounan	120	17.1 fhijkl	6.87	15.0 def	2.39	258 cdefg	116.3
YawariGG	200	20.5 def	9.12	12.5 jkl	2.18	258 cdefg	136.9
Tanguiet	130	19.2 defghi	7.26	13.2 hij	2.09	255 cdefg	109.6
Yeringo	90	19.4 defgh	7.37	12.9 ijk	1.54	250 defhg	95.2
Kaki	172	15.3 ijklmn	6.80	15.9 abc	2.02	245 defhg	114.7
Kplobe_B	90	19.2 defghi	10.49	12.0 ml	2.14	237 defhg	149.9
Yanti_Kp	130	15.3 ijklmn	6.93	15.6 bcd	2.30	237 defhg	113.0
Niger	132	20.8 def	12.09	11.1 no	2.67	231 efhg	139.6
Tchadjil	130	14.2 lmn	5.67	16.1 ab	1.77	229 efhgi	93.8
Katche_F	50	17.6 fghijl	8.76	12.5 jkl	1.98	228 efhgi	134.1
Zerma_So	120	14.6 klmn	6.56	15.1 de	3.12	227 efhgi	121.9
Soui_Kpi	120	13.2 mn	6.50	15.6 cd	1.65	206 fghij	107.7
Wankoun	160	16.1 ghijklm	6.79	12.1 klm	3.08	204 fghij	114.9
Togo_G	120	17.9 efghijk	9.52	11.3 mno	2.14	201 ghij	111.3
Kplobe_R	110	17.8 efghijk	10.50	10.2 p	3.52	200 ghij	176.8
Boto_Bl	160	16.8 fghijklm	7.83	12.5 jkl	6.02	197 ghij	141.4
KVx	120	16.8 fghijklm	7.86	11.6 mn	2.18	197 ghij	105.8
Tchabe_F	60	20.0 defg	8.55	9.5 q	2.55	192 hij	115.0
Olikpokp	142	15.3 ijklmn	6.83	11.4 mno	2.47	172 ij	85.5
Azangban	52	12.4 n	5.57	13.1 hij	1.65	162 j	76.1
Global	4207	18.8	10.01	13.6	3.21	258	155.1

* Means with the same letters are not significantly different at the level of 5 % with the test of Student-Newman-Keuls under GLM ANOVA / * Les moyennes avec les lettres ne sont pas statistiquement différentes à 5 % avec le test de Student-Newman-Keuls sous GLM ANOVA.

Table 9 : Tests of multiple range comparison of Student-Newman-Keuls under GLM ANOVA (15 late-maturing varieties, 2004-2005)

Tests de comparaison multiple de Student-Newman-Keuls sous GLM ANOVA (15 variétés tardives, 2004-2005).

		Numbeof pods per plant		Numbeof seeds per pod		Number of seeds per plant	
Variety	No	Mean*	S.D.	Mean*	S.D.	Mean*	S.D.
Mata	160	35.9 a	21.89	13.9 a	1.02	505 a	321.6
Tchawa_K	120	35.3 a	16.44	12.4 c	1.27	439 b	213.8
Moro	80	28.9 bc	13.30	12.8 c	0.98	371 c	174.8
Aiglo	120	29.7 b	10.53	11.8 d	1.70	353 cd	135.2
Moussa	160	25.9 cde	11.42	13.3 b	1.40	345 cde	160.9
Djetoko	120	27.6 bcd	14.68	12.4 c	1.27	342 cde	193.9
AtchaweB	160	23.6 ef	8.66	13.3 b	1.85	321 def	136.6
Soui_Ker	120	24.2 def	13.87	12.5 c	1.40	302 efg	175.2
Tola	80	23.4 ef	9.19	12.7 c	1.59	299 efg	121.1
Egniawo	160	27.3 bcd	10.91	10.4 f	1.63	284 fgh	122.6
Nanwi	120	19.2 gh	6.44	13.8 a	1.86	266 gh	101.5
Toura	120	20.8 fg	8.06	11.9 d	1.32	249 h	104.4
Ewa_Egbe	80	18.3 gh	9.86	11.2 e	1.79	210 i	126.3
Atama	120	16.9 h	10.44	10.6 f	1.89	181 i	115.8
Ewa_Nig	90	8.9 i	5.67	11.7 d	3.74	118 j	116.5
Global	1810	25.0	14.06	12.4	2.02	315	193.4

* Means with the same letters are not significantly different at the level of 5 % with the test of Student-Newman-Keuls under GLM ANOVA. / *Les moyennes suivies des mêmes lettres ne sont pas statistiquement différentes au seuil de 5 % avec le test de Student-Newman-Keuls sous GLM ANOVA.

DISCUSSION

The cowpea varieties analysed with farmers were characterized via different, distinctive and diverse morphological and agronomic traits. The varieties varied in leaf, stem, flower, pod, and seed shape and colour, and in growth habit. While the white seed colour has dominant influence in the Guinea Sudan zone of Benin, the red seed coat colour, and a variegated seed coat colour characterize most of the varieties from the south-east of the country. Recently, the central role of cultural preferences for the colour of some varieties has been analysed (Zannou *et al.*, 2007). The white varieties are essential in rituals, and mostly preferred by consumers in the central part of Benin (Zannou *et al.*, 2007), whereas red types constitute the main element of rituals in the south and south-east of the country. Some white varieties have medicinal values in the central part of Benin (Zannou *et al.*, 2004) and other less common colours, e.g. black types, are used by local medical practitioners in the southeast. On barley in Ethiopia, Kebebew *et al.* (2001) note a local belief that the natural white colour increases the appetite of consumers, and black-grained types are mainly preferred for making beer, local distilled spirit, and for medicine.

The Shannon-Weaver index revealed a large morphological diversity within the cultivars, on average, 1.23. This value is greater than the overall mean value (0.77) found for sorghum (Abdi *et al.*, 2002), for tef (0.31-1.00) by Kefyalew *et al.* (2000), and for barley (0.51-0.72) by Kebebew *et al.* (2001) in Ethiopia. This study on cowpea shows variation in individual traits between regions. While the white seed coat types dominated the varieties from the north and central parts of the Guinea and Sudan zone of Benin, the red and variegated seed coat colours characterize cowpeas from the south-east of the country. For barley in Ethiopia, Kebebew *et al.* (2001) reveal variation in individual traits between regions. In this study on cowpea, as in studies on other crops such as sorghum and barley, the central role of farmers in selecting varieties with different traits and use values is recognized as a factor in shaping local germplasm, in addition to the play of natural selection.

As apparent from an early study (Zannou *et al.*, 2004), and confirmed here by the results of joint-experimentation, yield is an important criterion for farmers. Yield, along with other preferences and quality-related criteria, have been reported in other studies as criteria of farmer acceptability when breeding cowpea (Kitch *et al.*, 1998). The present study has shown that yield components (number of seeds per pod, number of pods per plant and number of seeds per plant) were highly dependent on the variety, its physiological characteristics and the environmental conditions. In the Guinea and Savanna zones of Ghana, Padi (2004) realized that with increased stress, the experimental coefficient of variation of the yield increased, indicating that under stress there was a decrease in the precision with which grain yields could be assessed for the genotypes. At lower levels of stress, the genotypic variation closely approached the phenotypic variation. It was suggested that knowledge on the key stress factors underlying the genotype by environment interaction can permit delineating homogenous production zones for purpose of recommending specific cowpea varieties. Egli (1998) and Vega *et al*. (2001) offered similar findings for cereals and oil-seed crops. Egli (1998) reported that the seed number, the main yield component of cereals and oil-seed, was strongly dependent on genotype, environmental and management factors. In soybean, sunflower, and maize, seed number depends on the sequential processes of flower morphogenesis and seed set (Vega *et al.*, 2001).

Photoperiod can have large effects on reproductive development, although some genotypes are insensitive (Ellis *et al.*, 1994 ; Craufurd *et al.*, 1997). This involves variation in earliness (i.e. minimum time to flower). The mechanism of timely flowering in a particular location is modulated in cowpea by responsiveness to temperature and photoperiod (Hadley *et al.*, 1983 ; Roberts and Summerfield, 1987) : Interaction Génotype x milieu : effets des dates de semis, de la saison et de l'année sur les composantes du rendement. Most cowpeas are quantitative short-day plants, wherein flowering is delayed in periods longer than the critical photoperiod, or are plants that are relatively insensitive to photoperiod (day-neutral types) (Hadley *et al.*, 1983 ; Lush and Evans, 1980). The initiation of floral buds and their subsequent development may require different numbers of inductive short days (Lush and Evans, 1980) or have different critical photoperiods. As photoperiods shorten towards the end of the rainy season in West Africa, these adaptive features ensure timely flowering (Wien and Summerfield, 1980). Warmer temperatures can hasten the appearance of flowers in both photosensitive and insensitive genotypes (Summerfield *et al.*, 1985). In our experiments most early-maturing varieties behaved as photo-insensitive cultivars, whereas other varieties considered by farmers as late-maturing were more photosensitive (short-day) types, flowering only in October. However, there can be an interaction between photoperiod and temperature in these late-maturing varieties. Wien and Summerfield (1980) revealed that local cowpeas in West Africa are well adapted, so that they can start to flower at the end of the rains at a particular location.The duration of the reproductive period appeared in this analysis also to be a crucial factor, differing between cowpea cultivars. In our field experimental conditions, 60 % of the late-maturing varieties yielded 300 to 505 seeds per plant while 11 % of the early-maturing varieties yielded 300 to 470 seeds per plant.

The study also revealed that there is a negative association between the 1000-seed weight and the number of seeds per pod, number of seeds per plant and number of pods per plant. Similar results were found for three cultivated and one weedy cowpea by Ilori *et al*. (1996), who report that the 100-seed weight was negatively correlated with the number of pods per plant, number of seeds per plant, and number of ovules per pod in Nigeria.

CONCLUSION

This study shows the presence of important genetic variability among the Benin cowpea germplasm which can be used to broaden the genetic bases of the crop for better use of its genetic potential. Several mechanisms, biophysical and physiological, interfere on the expression of different genes as visible traits. This diversity of mechanisms in place in different varieties determines the variation in yield and other preferred traits farmers often obtain. The study has shown that knowledge concerning these mechanisms helps understanding the choice farmers often make, and provides insights into local plant genetic material used by farmers.

ACKNOWLEDGMENTS

The assistance and cooperation of the farmers, the researchers of the National Agricultural Research Institute of Benin (INRAB) and the representatives of the extension service in the study area are gratefully acknowledged.

REFERENCES

Abdi A., Bekele E., Asfaw Z., Teshome A. 2002. Patterns of morphological variation of sorghum (Sorghum bicolor (L.) Moench) landraces in qualitative characters in North Shewa and South Welo, Ethiopia. Hereditas 137 : 161 - 172.

Craufurd P. Q., Summerfield R. J., Ellis R. H., Roberts E. H. 1997. Photoperiod, temperature, and the growth and the development of cowpea. In : Singh B. B., Mohan Raj D. R., Dashiell K. E., Jackai L. E. N. (Eds.), Advances in cowpea research, pp. 75 - 86. IITA and JIRCAS. Ibadan, Nigeria.

Egli D. B. 1998. Seed biology and the yield of grain crops. 1st ed. CAB International, Oxford, UK. 178 p.

Ellis R. H., Lawn R. J., Summerfield R. J., Qi A., Roberts E. H., Chay P. M., Brouwer J. B., Rose J. L., Yeates S. J. 1994. Towards the reliable prediction of time to flowering in six annual crops. III. Cowpea (Vigna unguiculata). Experimental Agriculture 30 : 17 - 29.

Finlay K. W., Wilkinson G. N. 1963. The analysis of adaptation in a plant breeding programme. Australian Journal of Agricultural Research 14 : 742 - 754.

Grenier C., Bramel P. J., Dahlberg J. A., El-Ahmadi A., Mahmoud M., Peterson G. C., Rosenow D.T., Ejeta G. 2004. Sorghums of the Sudan : analysis of regional diversity and distribution. Genetic Resources and Crop Evolution 51 : 489 - 500.

Hadley P., Roberts E. H., Summerfield R. J., Minchin F. R. 1983. A Quantitative Model of Reproductive Development in Cowpea [Vigna unguiculata (L) Walp.] in relation to Photoperiod and Temperature, and Implications for Screening Germplasm. Annals of Botany 51 : 531 - 543.

Ilori C. O., Togun A. O., Fawole I. 1996. Growth and development characteristics in reciprocal crosses between weedy and cultivated cowpea. African Crop Science Journal 5(2) : 139 - 144.

Kebebew F., Tsehaye Y., Mc Neilly T. 2001. Morphological and farmers cognitive diversity of barley (Horeum vulgare L. (Poaceae) at Bale and North Shewa of Ethiopia. Genetic Resources and Crop Evolution 00 : 1 - 15.

Kefyalew T., Tefera H., Assefa K., Ayele M. 2000. Phenotypic diversity for qualitative and phenologic characters in germplasm collections of tef (Eragrostis tef). Genetic Resources and Crop Evolution 47 : 73 - 80.

Kitch L. W., Boukari O., Endondo C., Murdock L. L. 1998. Farmer acceptability criteria in breeding cowpea. Experimental Agriculture 34 : 47 5 - 486.

Lush W. M., Evans L. T.1980. Photoperiodic Regulation of Flowering in Cowpeas (Vigna unguiculata (L.) Walp.). Annals of Botany 46 : 719 - 725.

Mallkarjurna S. B. P., Updhyaya H. D., Kenchana Goudar P. V., Kullaiswamy B. Y., Singh S. 2003. Phenotypic variation for agronomic characteristics in a groundnut core collection for Asia. Field Crops Research 84, 359 - 371.

Naghavi M. R., Jahansouz M. R. 2005. Variation in the agronomic and morphological traits of Iranian chickpea accessions. Journal of Integrative Plant Biology 47(3) : 375 - 379.

Padi F. K. 2004. Relationship between stress tolerance and grain yield stability in cowpea. Journal of Agricultural Science 142 : 431 - 443.

Pasquet R. S. 1999. Genetic relationships among subspecies of Vigna unguiculata (L.) Walp. based on allozyme variation. Theoretical and Applied Genetics 98 : 1104 - 1119.

Roberts E. H., Summerfield R. J. 1987. Measurement and prediction of flowering in annual crops, In : Atherton J. G. (ed.), Manipulation of flowering, Butterworth, London, pp. 17 - 50.

Sharma S. 1996. Applied Multivariate Techniques. John Wiley & Sons, Inc. 512 p.

Summerfield R. J., Pate J. S., Roberts E. H., Wien H. C.

1985. The physiology of cowpeas, In : Singh S. R. Rachie K. O. (*eds.*), Cowpea Research, Production and Utilization, Wiley, Chichester, UK, pp. 65 -100.

van Eeuwijk F. A., Malosetti M., Yin X., Struik P. C. Stam P. 2005. Statistical model for genotype by environmental data : from conventional ANOVA models to eco-physiological QTL models. Australian Journal of Agricultural Research 56 : 883 - 894.

Vega C. R. C., Andrade F. H., Sadras V. O., Uhart S. A., Valentinuz O. R. 2001. Seed Number as a Function of Growth. A Comparative Study in Soybean, Sunflower, and Maize. Crop Science 41 : 748 - 754.

Wien, H. C., Summerfield R. J. 1980. Adaptation to of cowpeas in West Africa : effects of photoperiod and temperature responses in cultivars of diverse origin. In : Summerfield R. J., Bunting (eds.), Advances in legume science, HUMSO, London, UK, pp. 405 - 417.

Zannou A., Ahanchédé A., Struik P. C., Richards P. C., Zoundjihékpon J., Tossou R, Vodouhè S. 2004. Yam and cowpea diversity management by farmers in the guinea-sudan transition zone of Benin. NJAS - Wageningen Journal of Life Sciences 52 (3 - 4) : 393 - 420.

Zannou A., Tossou R. C., Vodouhè S., Richards P., Struik P. C., Zoundjihékpon J., Ahanchédé A., Agbo V. 2007. Socio-cultural factors influencing and maintaining yam and cowpea diversity in Benin. International Journal of Agricultural Sustainability 5 (2 - 3) : 140 - 160.