Agromorphological and Phenological Variability of 10 Bambara Groundnut [*Vigna subterranea* (L.) Verdc. (Fabaceae)] landraces cultivated in the Ivory Coast

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Summary

The objective of this study was to investigate the agro-morphological and phenological characteristics of ten Bambara groundnut landraces that originated in the Ivory Coast. The study was conducted on an experimental plot at the University of Abobo-Adjame. The trial was set up according to a randomized complete block design with five replications. Twenty variables were used to identify the landraces. Landraces Ci1, Ci3, Ci10 and Ci12 exhibited high emergence percentages, early maturity within 90 DAS (days after sowing) and low vegetative/floral development. A high seed yield (388 to 495 kg/ha) was also obtained from these landraces. In contrast, a low seedling emergence rate, high vegetative development and yield (80 kg/ha) could be observed with landrace Ci9. This landrace reached maturity within 180 DAS. Landraces Ci2, Ci4, Ci5, and Ci8, on the other hand, reached maturity between 120-150 DAS. The principal component analysis conducted on the data obtained showed that the landraces with a high seed yield were early in terms of flowering and maturity, but presented low vegetative development, with limited foliage, secondary roots, leaf area and biomass. The physiological and agronomical traits presented by landraces that originated in the Ivory Coast could be exploited in Bambara groundnut varietal improvement programmes.

Résumé

Variabilités agromorphologique et phénologique de 10 écotypes de voandzou [*Vigna subterranea* (L.) Verdc. (Fabaceae)] cultivés en Côte d'Ivoire

Une étude a été réalisée sur la parcelle expérimentale de l'Université d'Abobo-Adjamé afin d'estimer les caractéristiques agromorphologique et phénologique de dix écotypes ivoiriens de voandzou. Le dispositif en blocs de Fisher complètement aléatoire avec cinq répétitions a été adopté. Les résultats ont montré que vingt variables sont liées entre elles et permettent de discriminer les écotypes de voandzou. Avec les écotypes Ci1, Ci3, Ci7, Ci10 et Ci12, le taux d'émergence a été élevé, le cycle de culture réduit (90 jours), la croissance et la floraison ont été limitées. Un rendement élevé en graines (388 à 495 kg/ha) a aussi été obtenu avec ces écotypes. L'écotype Ci9 a exprimé un faible taux d'émergence des plantules, un développement végétatif important et une faible productivité en graines (80 kg/ha). Cet écotype a atteint la maturité 180 jours après semis. Les écotypes Ci2, Ci4 et Ci5 d'une part et Ci8 d'autre part, ont respectivement atteint leur maturité, 120 et 150 jours après semis. L'analyse en composantes principales a montré que les écotypes ayant un rendement élevé sont précoces. Mais, le nombre de feuilles et racines secondaires, la surface foliaire et la biomasse restent faibles. La variabilité exprimée entre les écotypes ivoiriens peut être exploitée dans les programmes d'amélioration variétale du voandzou.

Introduction

Agricultural policy in developing countries focuses mainly on cash crops. This choice has not significantly improved the population's food situation. However, it has encouraged growers to abandon many local crops, which have declined as a result. Because of their nutritional quality, these crops could have played a major role in providing a balanced diet for an ever-increasing human population, but have been under-exploited. Their yields have therefore remained low and unstable.

In West Africa, Bambara groundnut is mainly cultivated by women, together with maize, millet or groundnut (1, 7). The proteins found in its seeds have high lysine content and combining them with cereals as part of the diet represents a beneficial nutritional supplement for many local populations (14). The flour obtained from its seeds could provide a viable substitute for "conventional" flours in the composition of various manufactured products (2). The popularisation of Bambara groundnut cultivation and increasing its

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production could provide farmers with a substantial income and contribute to food safety in Africa (15).
Over the last few decades, the scientific community has shown renewed interest in this neglected and under-used crop. From 1992 - 2006, three major research projects funded by the European Union were implemented by the Universities of Nottingham and Wageningen, in cooperation with various countries, including Botswana, Namibia, Malawi, Tanzania and Sierra Leone.
Despite the increasing number of scientific reports on Bambara groundnut in Africa (3, 15, 17) very little bibliographical data is currently available on the distribution, genetic diversity, cultivation method and uses of this plant in the Ivory Coast. A number of preliminary studies (4, 5, 11) have been conducted in this country. However, the collection analysed was limited to four landraces. Morphological characterisation represents the first stage of the investigation of a collection of genetic resources (16). For many species, this approach remains the most frequently used. In addition, the objective of this study is to evaluate the growth, development, duration of phonological stages and factors in the yield produced by Bambara groundnut landraces cultivated in the Ivory Coast.

Materials and methods

This study was conducted on an experimental plot at the University of Abobo-Adjame (5°23 N and 4°11 W) in the south of the Ivory Coast. Ten landraces of Bambara groundnut, which originated in the Ivory Coast, were used for the study (Table 1). These landraces were collected between January-March 2006. A randomized complete block design with five replications was adopted for this study. The surface area of each elementary plot was 9.375 m^2, divided into 5 ridges separated by a gap of 50 cm.
Fourteen seeds were sown per ridge at a depth of 5 cm. The distance between the sowing spots was 30 cm. Various agro-morphological parameters were evaluated, based on the list of Bambara groundnut descriptors (8), at the emergence, growth, flowering, fructification and harvest stages.
All the values obtained were subjected to a variance analysis. This analysis was followed by the Newman-Keuls Test, if the value for statistic F was significant with a threshold of 5%. Finally, a principal component analysis was conducted. All the data was analysed using XL STAT-Pro 7.1. software.

Results and discussion

The germination capacity and vigour of seedlings of the different landraces were evaluated by estimating the emergence percentage (EP) and mean emergence time (MET). During this study, the first day of seedling's emergence of was observed between 6 – 15 days after sowing (DAS). The appearance of seedlings was observed at 6 DAS in landraces Ci1, Ci2, Ci3, Ci4, Ci10 and Ci12 and at 7 DAS in landraces Ci5, Ci7, Ci8 and Ci9. The difference in emergence times may indicate intra-landrace variability. This same difference in seedling emergence times has already been highlighted by various authors (4, 12). Contrary to these results, the emergence of Bambara groundnut seedlings was observed at 14-24 DAS by Karikari (9). Within the same line, means followed by the same letters are not significantly different according to

Table 1
Areas of origin and main characteristics of ten native Bambara groundnut landraces from the Ivory Coast

Landrace	Area of origin	Characteristics	
		Colour	Shape
Ci1	Salamvogo (Ouangolodougou)	Cream testa	Small
Ci2	Korhogo	Cream testa with red spots	Medium-sized
Ci3	Salamvogo (Ouangolodougou)	Black and grey mottles on cream background	Big
Ci4	Korhogo	Black	Small
Ci5	Odienne	Dark red testa	Big
Ci7	Ouangolodougou	Purple testa with dark purple spots	Big and Elongated
Ci8	Bouake	Cream testa with black spots	Small
Ci9	Manfla	Black rhomboid spots on cream background	Big
Ci10	Sinematialie	Black rhomboid spots on cream background	Small
Ci12	Sinematialie	Red and grey mottles on cream background	Small

Table 2
Evaluation of emergence, growth, flowering and fructification parameters for ten Bambara groundnut landraces

	Landraces									
Parameters	Ci1	Ci2	Ci3	Ci4	Ci5	Ci7	Ci8	Ci9	Ci10	Ci12
Emergence										
EP (%)	91.14 a	87.71 ab	77.71 c	91.14 a	79.71 bc	82.28 abc	83.71abc	61.45 d	88.85 ab	88.00 ab
MET (d)	7.22 d	7.82 c	7.98 c	7.99 c	8.21 bc	8.51 b	7.87 c	9.88 a	7.31 d	7.28 d
Growth										
HP (cm)	15.58 cd	19.29 b	14.41 d	24.03 a	20 b	18.59 b	19.87 b	16.73 c	15.75 cd	15.86 cd
NF	44.64 e	91.28 d	37.64 e	130.22 b	111.06 c	47.22 e	99.19 cd	172.28 a	40.20 e	34.20 e
ADB (g)	10.21 d	21.79 c	9.23 d	30.23 b	21.14 c	18.30 c	26.81 b	43.79 a	9.66 d	8.17 d
LA (cm^2)	11.24 e	11.33 e	11.62 e	15.50 d	17.02 c	24.52 a	21.34 b	20.63 b	10.13 ef	9.49 f
RL (cm)	32.99 b	35.66 b	33.55 ab	37.40 ab	34.94 ab	35.10 ab	36.34 ab	38.96 a	32.62 b	36.03 ab
NSR	25.56 b	28.14 b	24.97 b	27.40 b	29.10 b	33.77 a	34.8 a	35.18 a	22.56 b	26.64 b
NN	4.74 a	5.51 a	6.52 a	3.32 a	3.44 a	3.49 a	3.61 a	5.43 a	5.30 a	4.95 a
EDB (g)	0.45 e	0.68 cd	0.40 e	0.64 d	0.75 c	0.62 d	0.90 b	1.13 a	0.38 e	0.37 e
PFE	62.50 e	87.18 d	39.32 f	142.66 a	97.12 cd	51.32 ef	106.88 bc	112.48 b	43.3 f	50.32 ef
Phenology										
DFF (j)	28.58 a	30.34 a	28.98 a	28.28 a	29.54 a	28.82 a	29.26 a	40.46 b	28.02 a	28.02 a
D50%F (j)	38.88 f	52.05 d	39.34 f	54.43 cd	59.55 b	43.04 e	56.85 c	70.43 a	39.02 f	38.06 f
DPF (j)	44.86 c	52.94 b	44.38 c	47.04 c	51.55 b	47.58 c	51.06 b	67.75 a	44.36 c	43.58 c
DPM (j)	87.92 d	117.52 c	91.33 d	114.49 c	143.20 b	92.74 d	141.32 b	172.20 a	87.66 d	87.36 d

EP= emergence percentage; MET= mean emergence time; PH= plant height; NF= number of leaves; ADB: aerial dry biomass; LA= leaf area; RL= root length; NSR= number of secondary root; NN= number of nodules; UDB: underground dry biomass; PFE: pod formation efficiency; DFF= days to first flowering; D50%F = days to 50% flowering; DPF= days to pod formation; DPM= days to pod maturity.

Newman-Keuls test ($p< 0.05$).

The highest EP were observed for landraces Ci1, Ci2, Ci4, Ci7, Ci8, Ci10 and Ci12. Of these landraces, Ci1, le Ci10 and Ci12 presented the lowest mean emergence time (Table 2). The variability of response between the landraces in terms of emergence appears to indicate that the seeds are inconsistent when it comes to germination quality, which is probably due to their health, physiological condition and size. Growth evaluation (Table 2) has shown that plant height range from 14 – 25 cm. Landrace Ci4 was the largest in plant height. The highest values in terms of number of leaves, aerial/underground dry biomass, root length and number of secondary roots were observed in landraces Ci8 and Ci9. The lowest values were obtained from landraces Ci1, Ci3, Ci10 and Ci12. This difference in behaviour between the landraces could be linked to the efficiency of solar radiation interception and particularly the biological efficiency of the conversion of radiation to biomass. Contrary to this result, a study conducted in Botswana showed that a landrace with the same colour and approximately the same size seed as Ci1 presented very high vegetative development (10). These differences in behaviour observed in these two apparently identical landraces would confirm the influence of environmental conditions on the growth and development of Bambara groundnut landraces. The leaf area was high in landraces Ci7, Ci8 and Ci9 and low in landraces Ci1, Ci2, Ci3, Ci4, Ci5, Ci10 and Ci12. The number of nodules was low and statistically identical in all the landraces. This finding could be linked to the absence of rhizobium bacteria in the soil (14).

The transition from vegetative to reproductive phase is a key event in the plant development cycle, as it has a decisive effect on their adaptability to environmental conditions. The results relating to the phenology of Bambara groundnut are indicated in table 2. Days to first flowering ranged from 28 - 41 DAS. Except landrace Ci9, the flowers appeared approximately 28

DAS for all landraces. Days to 50% flowering were longer for this last landrace compared to the others. Variability between the landraces was observed in terms of average days to first flowering, days to 50 % flowering and days of pod formation and maturity. This variability made it possible to identify early landraces with short crop cycles (3 months): landraces Ci1, Ci3, Ci10, Ci12 and Ci7. The early maturation often makes it possible to harvest under favourable climatic conditions. Therefore, the timing of the flowering period is a decisive factor for the final yield. The pod formation efficiency (PFE) was low (less than 50%) for all the landraces studied. This result supposes that the development or evolution of a major proportion of flowers was halted. This failure may result from unfavourable environmental conditions, which cause many flowers to fall, thus confirming the importance of the timing of the flowering period. The low PFE may also be explained by the fact that, with Bambara groundnut, flowering does not take place simultaneously but over a period of time (Figure 1). Bearing this in mind, the pods do not mature over a short period, resulting in pods of different types and ages. Figure 1 shows that flowering and leaf production develop exponentially. These two phenomena take place at a stage when height growth slows down considerably. The plant reaches a certain height and grows a certain number of leaves before preparing for reproduction at approx. 28 DAS.

The evaluation of yield components (Table 3) made it possible to determine the production capacities of the plants studied. The number of mature pods in landraces Ci3 and Ci8 was statistically equal and greater than those for other landraces. There was no formation of pods with 2 seeds in landraces Ci4 and Ci5. However, number of pods with 2 seeds was low in Ci9 and high in landraces Ci1, Ci10 and Ci12. A major capacity to use assimilates for reserve structures may therefore exist in the latter landraces.

The 100 seed weight (W100S) and seed weight (SW), which is greater in landraces Ci3, Ci5, Ci7 and Ci9, suggests that the latter produced large seed. These seeds would therefore represent a major reserve of nutrients for people and animals. Shelling percentage was higher in landraces Ci7, Ci8 and Ci9. Landrace Ci7 showed the greatest seed length and smallest seed width. The smallest seed lengths were observed in landraces Ci4, Ci8, Ci10 and Ci12. Finally, the highest seed widths were observed in landraces Ci3 and Ci5. Seed yields ranged from 79 - 495 kg/ha. The highest yields were obtained from landraces Ci3, Ci10 and Ci12, while the lowest yield was obtained from

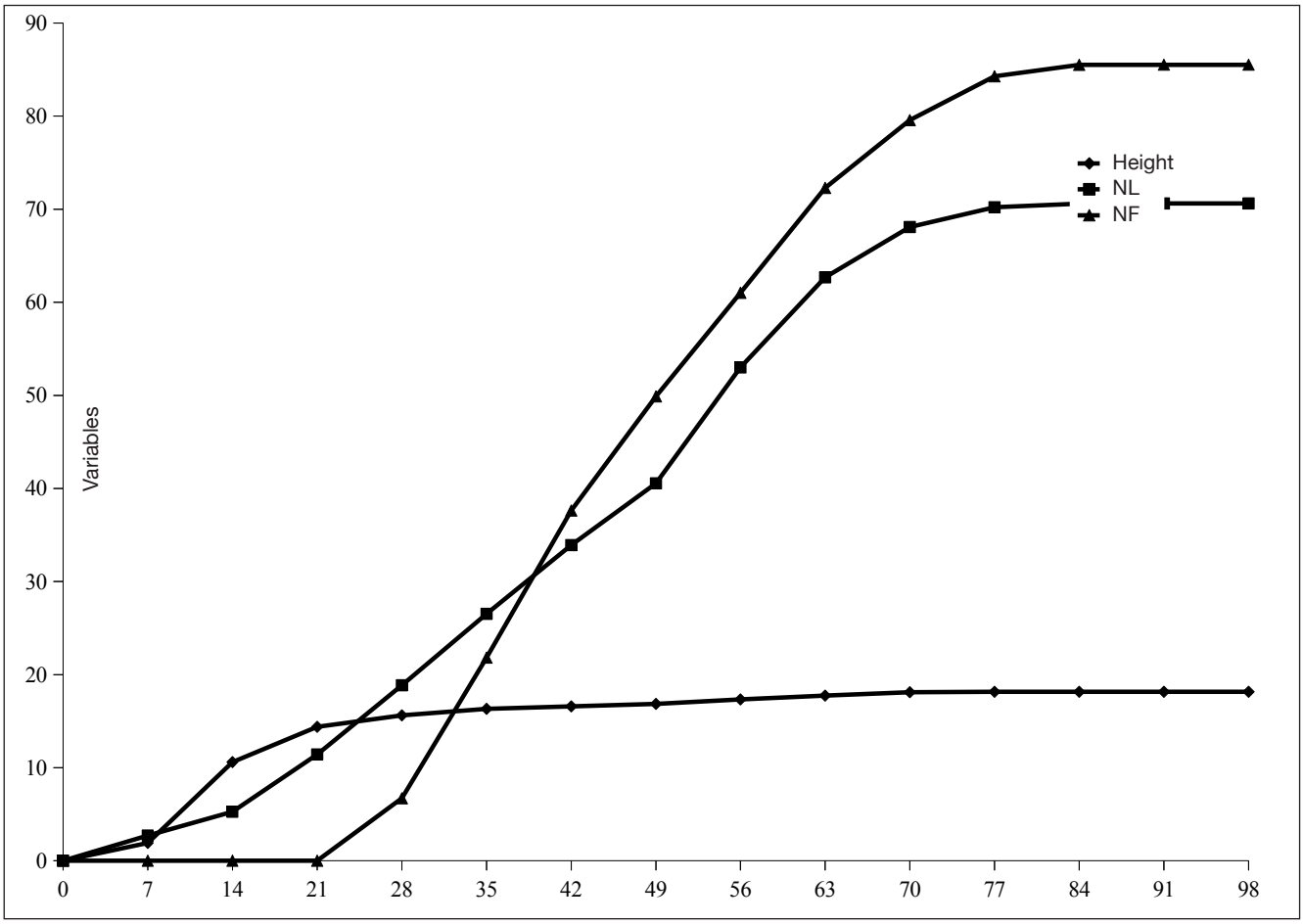

Figure 1: Evolution of plant height, number of leaves and flowers in Bambara groundnut landraces, according to the number of days after sowing (DAS).

Table 3
Evaluation of yield components and yield in ten Bambara groundnut landraces

	Landraces									
Parameters	Ci1	Ci2	Ci3	Ci4	Ci5	Ci7	Ci8	Ci9	Ci10	Ci12
NMP	20.06 b	30.11 a	16.95 bc	22.77 b	22.09 b	21.98 b	34.13 a	12.33 c	20.36 b	22.02 b
P2P (%)	17.84 a	7.33 b	14.20 b	0.00 d	0.00 d	12.26 b	12.37 b	4.17 c	23.00 a	17.83 a
SW (g)	0.60 c	0.59 c	0.81 a	0.56 c	0.72 b	0.71 b	0.43 d	0.62 c	0.61 c	0.62 c
W100S (g)	55.33 d	47.89 e	76.54 a	53.45 d	72.67 b	67.09 c	40.71 f	67.33 c	52.76 d	53.22 d
SP (%)	33.31c	35.79 b	29.97c	36.35 b	35.40 b	38.97 a	39.82 a	40.37 a	30.01c	32.57 c
SL (cm)	12.28 d	12.24 d	12.84 c	11.50 e	13.92 b	15.79 a	11.09 e	11.64 e	11.69 e	11.49 e
SWi (cm)	9.98 bc	9.84 bcd	10.12 b	9.51±0 d	10.46 a	8.63 f	8.94 e	9.92 bcd	9.71 cd	9.63 cd
Y(kg/ha)	388.06 b	105.33 c	408.56 ab	263.81 bc	105.1 c	250.94 bc	289.02 bc	79.68 c	392.5 ab	495.11a

NMP= number of mature pods; P2P= pods with 2 seeds percentage; W100S= 100 seed weight; SW= seed weight; SP= shelling percentage; SL= seed length; SWi= seed width; Y= yield
Within the same line, means followed by the same letters are not significantly different according to Newman-Keuls test (0.05).

landrace Ci9. These yields are lower than those quoted in the literature. In fact, Bambara groundnut production ranges from 650 - 850 kg/ha in many semi-arid countries. For example, the following yields have been reported: 940 kg/ha in Burkina Faso, 672 kg/ha in Mali and 574 kg/ha in Ghana (13). The low yield obtained in the course of this study could be explained by high humidity following the heavy rainfall that occurred during the cultivation period.

Principal component analysis

A principal component analysis (PCA) was conducted, in order to include the most inter-correlated variables in a reduced number of independent synthetic variables.

According to the PCA (Figure 2), 84.01% of the total variability was expressed by the first three axes. Axis F1 explains 54.11% of this variability, while axis F2 and axis F3 account for 19.40% and 10.49%, respectively.

Axis F1 was formed by the following variables, which express growth and phenology: MET, NF, LA, ADB, UDB, DFF, D50%F, DPF, DPM, le RL, NSR, P2P, PFE, SP and yield. This axis can be described as a vegetative and floral development axis. Similar results have been reported for *Vigna mungo* (L.) Hepper (6). In fact, it has been shown that the variables, which characterise the vegetative and reproductive phase in *V. mungo*, contribute to the formation of a single axis. Axis F1 compares two groups. The group consists of Ci1, Ci3, Ci10 and Ci12. This group is characterised by a short crop cycle and a low number of leaves and secondary roots, with few flowers forming. In addition, leaf area and aerial/underground dry biomasses were reduced. However, pod formation efficiency, number of pods with 2 seeds and seed yield were high for these landraces. The second group consists only of Ci9. The F2 axis is formed by the variables that define yield components: number of pods, 100 seeds weight,

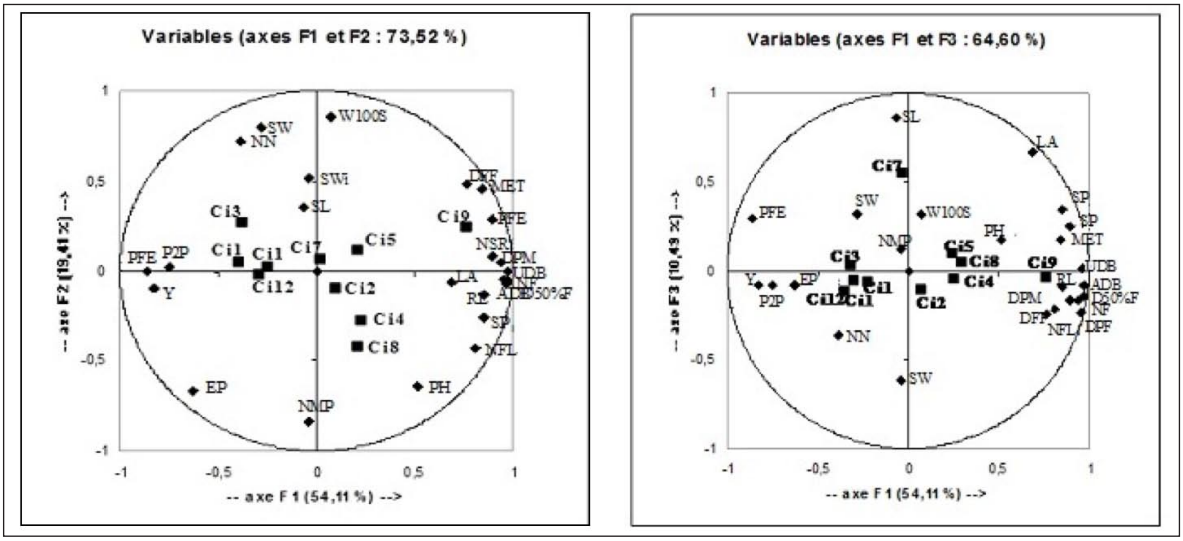

Figure 2: Correlation circles obtained from the PCA, expressing the representativity of the variables and landraces, according to axes F1 et F2 (A) and axes F1 and F3 (B).

seed weight, seed length and seed width. This axis can be considered to describe the seed size. It makes it possible to characterise the third group, which consists of landraces Ci2, Ci4, Ci5, Ci7 and Ci8. The projection of variables and landraces in axes F1 and F3 has shown a change to the structure of axis F2. In fact, the group is more consistent when axis F3 is considered. This axis made it possible to separate seed length and width from the other variables and landrace Ci7 from other landraces. This landrace is characterised by particularly long seeds.

Conclusion

At the end of this study, the characterisation of Bambara groundnut landraces has shown that significant differences exist, in terms of morphological, phonological and agronomic factors. Of the parameters used for characterisation, only the number of nodules was identical for all landraces. In terms of flowering and fructification parameters, the phonological observations made it possible to show that landraces Ci1, Ci3, Ci10, Ci12 and Ci7 were early with a 90-day cycle. Out of the 24 variables used, 20 can be used to distinguish between Bambara groundnut landraces. Landrace Ci7 was identified by means of seed length and width. Landraces Ci1, Ci3, Ci9, Ci10 and Ci12 were identified by their phenological characteristics. Finally, landraces Ci2, Ci4, Ci5 and Ci8 were identified by their agronomic characteristics. The results also showed that landraces with a low number of mature pods produced high 100 seed weights.

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