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Morphological characterization of amaranth (*Amaranthus hybridus* L.) accessions from urban and peri-urban market gardening in two locations of Côte d'Ivoire

Jean-Claude N'zi, PhD
Unit of Training and Research of Biosciences, University Felix Houphouët-Boigny, Côte d'Ivoire / ICRAF-World Agroforestry, Côte d'Ivoire
Christophe Kouame, PhD
ICRAF-World Agroforestry, Côte d'Ivoire
Kabre Vonogo Nikodeme, PhD
Université Joseph Ki-Zerbo, Burkina Faso
Fondio Lassina, PhD
Centre National de Recherche Agronomique, Côte d'Ivoire
Agbo Edith, PhD
UFR Nutrition, Université Abobo-Adjamé, Côte d'Ivoire
Mahyao Adolphe, PhD
Centre National de Recherche Agronomique, Côte d'Ivoire

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Abstract

This work focuses on the morphological characterization of eighteen amaranth accessions (*Amaranthus hybridus*) collected in urban and peri-urban market gardening in Abidjan and Yamoussoukro in Côte d'Ivoire. The accessions have been regenerated and multiplied at the experimental and production station of the National Center for Agronomic Research in Anguédédou. The study was conducted using a Fisher block design with three replicates. Quantitative and qualitative variables were observed and measured for each of these accessions. The results showed a high variability for each of the nine (09) quantitative variables and for some of the fifteen (15) qualitative variables studied. The green morphotype showed the strongest performance in terms of leaf biomass (29 leaves per plant), stem strength (5.9 cm diameter), plant height (137 cm) and panicle length (48.7 cm). These data confirm morphological variability within the population of *A. hybridus* studied that could be used in a program for the improvement and sustainable cultivation of this foodstuff in Côte d'Ivoire.

Keywords: *Amaranthus hybridus*, diversity, accessions, variables, urban and peri-urban market gardening

Introduction

Market gardening is a growing activity that generates income for the populations in large cities and their surroundings due to the increase in food needs. Among these dietary needs are leafy vegetables including amaranth (*Amaranthus spp.*), a leafy vegetable rich in vitamins and essential minerals. Indeed, according to Fondio et al. (2011), amaranth leaves are rich in vitamins A, C and B9, iron, calcium and sulphur amino acids such as methionine, lysine and cysteine. Amaranth is a popular vegetable plant on many global vegetable farms whose leaves and seeds are consumed in various forms (Písaříková et al., 2005; Fondio et al., 2012; Mburu et al., 2012) thus constituting a good food supplement to starchy foods such as cereals and tubers.

The cultivation of this species provides considerable income to farmers through the marketing of its leaves and seeds (National Research Council, 2006; Fondio et al., 2012). However, very little agronomic data exist on this species of traditional leafy vegetable in Côte d'Ivoire. The only information available is the work of Terrible (1983) on the census of vegetable plants grown in Côte d'Ivoire, Ondo (1992) who reported on the inventory of cultivated plants in the botanical garden of the University of Cocody and Fondio et al. (2011; 2012) on the technical itinerary of this species in Côte d'Ivoire and good agricultural practices for the production of underutilized vegetables in sub-Saharan Africa. To help mitigate this situation, a study was undertaken to determine the morphological variability of some accessions in urban and peri-urban market gardening in Abidjan and Yamoussoukro for a better knowledge of *A. hybridus* L. The specific objectives were (i) to collect the accessions grown by the producers, (ii) to evaluate the agronomic performance of the accessions through morphological markers and (iii) to establish the link between the different traits expressed by the individuals of *Amaranthus hybridus* studied.

Material & Methods
Plant material

The plant material consists of eighteen (18) accessions of *Amaranthus hybridus* collected in Abidjan and Yamoussoukro. The choice is made for these cities, in view of their high supply of production and consumption of *A. hybridus*. The exhaustive collection technique was used by surveying all the producers in each city surveyed, so that the number varies greatly from one city to another. Each accession is represented by seeds and is accompanied by a collection sheet containing information on the geographical origin of the accession, the farmer descriptors, the cultivation practices and the accession code.

Experimental site

This study was conducted in 2007 at the Experimentation and Production Station of the National Center for Agronomic Research (CNRA) in Anguédédou, a locality located thirty kilometers from Abidjan in the southwest of Côte d'Ivoire and has the geographical coordinates of 5°22 N, 4°8W and 95 m altitude. The climate of the study area is bimodal with two rainy seasons (March-June and September-November) and two dry seasons (July-August and December-February). During the period of the trial, the average monthly temperature varied between local. 27 and 31°C and the average monthly humidity was 73.6%. The soil of the experimental plot is ferralitic and sandy-textured and is highly acidic and has a well-decomposed organic matter content (pH = 4.5 and C/N = 10.5) according to Fondio et al. (2015).

Methods
Experimental set-up and cultural practices

The experimental device used is a Fisher block with 3 repetitions. The elementary plot is 2 x 5 m. Before transplanting, the soil was deeply disturbed and levelled, followed by organic fertilization with chicken droppings, maintenance and regular irrigation of the plots. The seeds were then placed in nurseries on boards set up for this purpose. Twenty-one days after sowing, the plants were transplanted on ridges. Each ridge constitutes an elementary plot which includes 7 plants arranged in a line with 20 cm between the rows and 20 cm between plants in the same line. Phytosanitary treatments were carried out on request.

Data collection

Data on fifteen (15) qualitative variables and nine (09) quantitative variables were respectively observed and measured on three plants per line of seven (07) plants, randomly marked. For this characterization, the IPGRI descriptor for amaranth was used for the choice of variables or characters

(Grubben, 1975; Grubben & van Sloten, 1981). Thus, the wingspan and height of the plant, the length of the petiole, the length of the blade, the width of the blade, the date of emergence, the number of leaves, the date of flowering, the length of the panicle, the spinosity of the stem, the color of the stem and branches, were observed, described and measured likewise the colour of the petiole, the shape of the tip of the blade, the shape of the base of the leaf blade, the spinosity of the blade, the colour of the veins, the type of inflorescence, the position of the inflorescence, the colour and position of the inflorescence. It should be noted that the variable emergence date is expressed in days after sowing and corresponds to the number of days that separate the sowing and emergence of 50% of the seeds, while that of the flowering date corresponds to the number of days from sowing to the appearance of the first flower and is also expressed in days after sowing. The seeds of the panicles are harvested when they are completely dry.

Data analysis

All data collected was analyzed using the SAS software. Analyses of variance were performed to determine the significance of the block and variety effects. The separation of the means was performed according to the Duncan test at the 5% threshold.

Results and Discussion

Results

Morphological diversity related to the qualitative variables of *Amaranthus hybridus* L.

The analysis of the qualitative variables showed the existence of morphological variability, especially in the colour of the organs within the *Amaranthus hybridus* L. accessions studied (Table 1). Based on the coloration of the stem and inflorescence, three (03) morphotypes stand out with a clear predominance of the green morphotype which represents 67% of the collection. This morphotype, in addition to the green colouration of the stem and inflorescence, also has a uniform green colour of the flower petals, leaf blades, and leaf veins (Figure 1). The green-purple (or purple-green) morphotype represents 28% of the collection. This morphotype retains the same colouration for the leaves and flowers in addition to that of the stem and inflorescence. The purple morphotype represents 5% of the collection. This morphotype also retains the same purple coloration for the leaves and flowers. At the level of the inflorescence, two forms were observed. These are the panicle (88%) and umbel (12%) inflorescences.

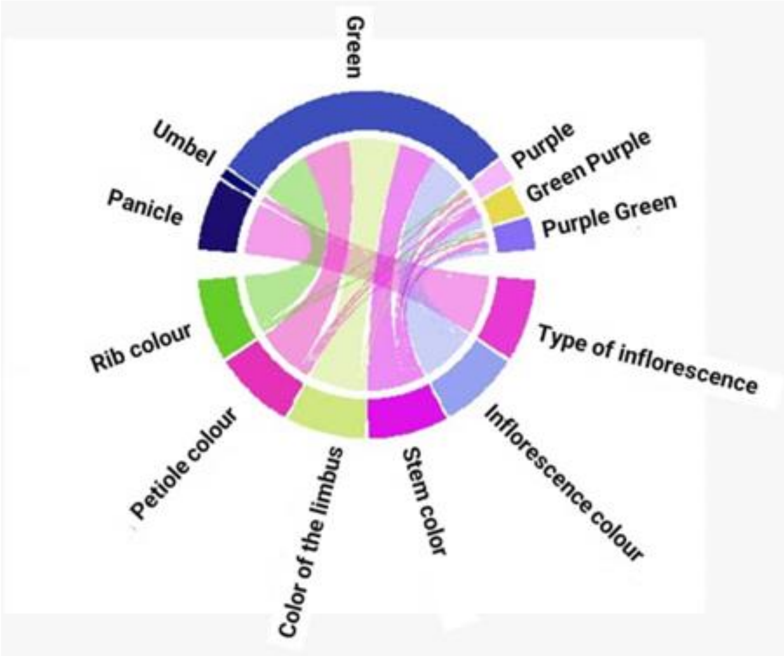


Figure 1. Pie diagram linking the different qualitative variables discriminating between *Amaranthus hybridus accessions*

Table 1: Qualitative variables of the different accessions of Amaranthus hybridus observed in the experimental station

ACCESSIONS	SPINOS	PHYTAX	BOSLIM	BASLIM	FORLIM	BFEUIL	PROENER	TYPINF	COULINF	COULTIG	COULLIM	COULPET	COULNER	POSINF	TYPRACI
TATROK	0 thorns	Couplet	Sharp	Sharp	Lanceolate	Whole	Few	Panicle	Green	Green	Green	Green	Green	Terminal	Pivot
AMPT08	0 thorns	Couplet	Sharp	Sharp	Lanceolate	Whole	Few	Panicle	Green	Green	Green	Green	Green	Terminal	Pivot
YQB06	0 thorns	Couplet	Sharp	Sharp	Lanceolate	Whole	Few	Panicle	Purple	Purple	Purple	Purple	Purple	Terminal	Pivot
ABAN04	0 thorns	Couplet	Sharp	Sharp	Lanceolate	Whole	Few	Panicle	Green	Green	Green	Green	Green	Terminal	Pivot
YKO07	0 thorns	Couplet	Sharp	Sharp	Lanceolate	Whole	Few	Panicle	Green	Green	Green	Green	Green	Terminal	Pivot
AKSSI07	0 thorns	Couplet	Sharp	Sharp	Lanceolate	Whole	Few	Panicle	Green	Green	Green	Green	Green	Terminal	Pivot
YQB06	0 thorns	Couplet	Sharp	Sharp	Lanceolate	Whole	Few	Panicle	Green	Green	Green	Green	Green	Terminal	Pivot
YFON01	0 thorns	Couplet	Sharp	Sharp	Lanceolate	Whole	Few	Panicle	Green	Green	Green	Green	Green	Terminal	Pivot
APB09	0 thorns	Couplet	Sharp	Sharp	Lanceolate	Whole	Few	Panicle	Prp-green	Prp-green	Green	Prp-green	Green	Terminal	Pivot
KNYA	0 thorns	Couplet	Sharp	Sharp	Lanceolate	Whole	Few	Panicle	Prp-green	Prp-green	Green	Green	Green	Terminal	Pivot
YQB05	0 thorns	Couplet	Sharp	Sharp	Lanceolate	Whole	Few	Panicle	Green-prp	Green-prp	Green	Green	Green	Terminal	Pivot
YMIL02	0 thorns	Couplet	Sharp	Sharp	Lanceolate	Whole	Few	Panicle	Prp-green	Prp-green	Green	Green	Green	Terminal	Pivot
AMPT02	0 thorns	Couplet	Sharp	Sharp	Lanceolate	Whole	Few	Panicle	Green-prp	Green-prp	Green-prp	Green-prp	Green-prp	Terminal	Pivot
YFON04	0 thorns	Couplet	Sharp	Sharp	Lanceolate	Whole	Few	Panicle	Green	Green	Green	Green	Green	Terminal	Pivot
YQR04	0 thorns	Couplet	Sharp	Sharp	Lanceolate	Whole	Few	Panicle	Green	Green	Green	Green	Green	Terminal	Pivot
YGK05	0 thorns	Couplet	Sharp	Sharp	Lanceolate	Whole	Few	Panicle	Green	Green	Green	Green	Green	Terminal	Pivot
YQB08	0 thorns	Couplet	Sharp	Sharp	Lanceolate	Whole	Few	Panicle	Green	Green	Green	Green	Green	Terminal	Pivot
ABAN17	0 thorns	Couplet	Sharp	Sharp	Lanceolate	Whole	Few	Panicle	Green	Green	Green	Green	Green	Terminal	Pivot

SPINOS: Spinosity, **PHYTAX:** Phyllotaxis, **BOSLIM:** Shape of the tip of the blade, **BASLIM:** Shape of the base of the blade, **FORLIM:** Shape of the blade, **BFEUIL:** Margin of leaves, **PROENER:** Prominence of veins, **TYPINF:** Type of inflorescence, **COULINF:** Inflorescence colour, **COULLIM:** Colour of the blade, **COULTIG:** Stem colour, **COULPET:** Petiole colour, **COULNER:** Veins colour, **POSINF:** Inflorescence position, **TYPRACI:** Root type, **Prp:** Greenish purple, **Spr-green:** Purple green, **Pivot:** Pivotal, **0 spine:** Spineless.

Morphological diversity related to quantitative variables of *Amaranthus hybridus*

Analysis of the variability of quantitative variables of Amaranthus hybridus

The analysis of the comparative average performance of *Amaranthus hybridus* accessions showed low values of the coefficients of variation (CV<30%) for all the variables studied, thus reflecting a low heterogeneity of the plant material for these different traits. Indeed, the values of the coefficient of variation varied from 4.98% to 41.4%. Accessions of *A. hybridus* flower between 38 and 60 days after sowing at an average height of 108.4 cm with stems of 4.1 cm in diameter. The majority of accessions had leaves with long petioles (10.1 cm) and a long, wide blade of 14.9 cm and 6.7 cm, respectively. All accessions of *A. hybridus* have panicles ranging from 36 cm to 48.7 cm long. In summary, the results of the analysis of variance showed that the characteristic features discriminating the different accessions of *A. hybridus* are, among others, the height of the plant, the diameter of the stem, the length of the petiole and the number of leaves whose values of the coefficient of variation vary between approximately 20 and 25% (Table 2). The analysis of the probability levels of the quantitative variables studied shows significant differences observed at the 1 and 5% thresholds for some of the quantitative variables studied. Thus, variables such as emergence corresponding to the number of days after sowing, flowering date and number of leaves showed a very significant difference at the 1% threshold. Variables such as plant height and leaf blade width showed a significant difference at the 5% threshold. The other four (04) variables, stem diameter, petiole length, blade length and panicle length, showed no significant differences at the 1% and 5% levels (Table 3).

Analysis of the relationships between quantitative variables of Amaranthus hybridus

The study of the relationships between the quantitative and qualitative variables measured revealed several correlations at the 5% threshold (Table 4). Positive and significant correlations are observed between the height of the plant and each of the variables, number of leaves (0.746); width of the blade (0.688); stem diameter (r = 0.681) and petiole length (r = 0.583). Positive and significant correlations were also observed between inflorescence colour and each of the variables, stem colour (r = 1); petiole colour (r = 0.739); blade colour and vein (r = 0.620); between the date of emergence and each of the variables blade width (r = 0.567) and vein prominence (r = 0.998). A positive and significant correlation was observed between petiole length and each of the variables blade length (r = 0.611) and blade width (r = 0.541). On the other hand, the most important negative and significant correlations are observed between the emergence date and the flowering date (r = -0.668); between the date of flowering and each of the variables blade width (r = - 0.507) and vein prominence (r = - 0.676).

Organization of the variability of *Amaranthus hybridus*

The results of the principal component analysis (PCA) of the quantitative descriptors showed that the first 3 components with eigenvalues of 5.31, 3.58, and 3.08 respectively expressed 70.49% of the total variability observed. The analysis of eigenvalues shows that the variables studied have different performances (Table 5). The variables plant height, leaf blade width, leaf number, leaf blade color, stem color, inflorescence color, petiole color, and vein color are correlated with axis 1 and explain 31.28% of the total variance. These variables define this axis, which thus represents the productivity and color axis. The variables stem width, petiole length and blade length are correlated with axis 2 and express 21.08% of the total variance. This is the axis of biometric diversity. The variables, vein prominence, flowering date, panicle length and root type, are strongly correlated with axis 3 and express 18.13% of the total variance. This is the axis of flowering. In total, of the 16 variables analyzed, the descriptors plant height, leaf blade width, leaf number, leaf blade colour, stem colour, inflorescence colour, petiole colour, vein colour, stem diameter, petiole length and leaf blade length contributed to more than 52% of the total variability.

Table 2: Quantitative variables of the different accessions of Amaranthus hybridus measured in experimental stations

Accessions	DLEV (das)	DFLO (das)	LONGTIG (cm)	LARTIG (cm)	LONGPET (cm)	LONGLIM (cm)	LARGLIM (cm)	NFEUIL	LONGPAN (cm)
ABAN04	3 a	45 efgh	78.3 d	2.9 b	6.9 b	13.3 b	5.4 cd	19 cdef	38.5 abc
ABAN17	3 a	42 ghij	137 a	5.9 a	13.8 a	18.3 d	8.8 a	29 ab	41.2 abc
AKSSI07	3 a	48 bcde	99 abcd	3.1 b	10.2 ab	14.2 ab	6.4 bc	16 ef	35.9 c
AMPT02	3 a	41 hij	92.8 bcd	4.4 ab	9.8 ab	13.9 ab	6.5 bc	22 abdef	39.3 abc
YMIL02	3 a	38 k	126 abc	4.5 ab	12.3 a	15.8 ab	7.5 abc	28 abc	48 ab
APB09	3 a	38 jk	117.5 abcd	4.1 ab	9.8 ab	14.4 ab	7.2 abc	31 a	39 abc
YQB06	3 a	45 defgh	127,2 abc	4 ab	9.3 ab	15.5 ab	7.5 abc	28 abc	40.8 abc
YQB06	3 a	46 cdefg	101 abcd	2.9 b	7 b	6.1 bc	6.1 bc	20 bcdef	42.8 abc
YFON01	3 a	40 ijk	104 abcd	4.3 ab	9.7 ab	14.7 ab	6.7 abc	15 f	42.8 abc
YFON04	3 a	44 fghi	96.8 abcd	3.7 b	9.1 ab	14.5 ab	6.4 bc	18 ef	39.3 abc
YGK05	3 a	46 cdefg	106.3 abcd	4 ab	12.5 a	16.5 ab	7 abc	19 cdef	44.8 ab
YKO07	3 a	49 bc	134.2 ab	4.4 ab	10.3 ab	15.7 ab	8.1 ab	25 abcdef	44 abc
YQB08	3 a	47 cdef	114.8 abcd	4.3 ab	11.2 ab	14 ab	6.7 abc	21 bcdef	36 bc
YQB05	3 a	46 cdefg	132.5 ab	4.8 ab	10.6 ab	12.9 ab	6.2 bc	27 abc	44.5 abc
YQR04	3 a	44 fghi	93.2 bcd	3.9 b	10.4 ab	15.4 ab	6.8 abc	18 def	37 abc
AMPT08	3 a	49 bcd	105.8 abcd	4 ab	9 ab	16.8 ab	6.7 abc	26 abcd	39.2 abc
TATRO	2,3 b	52 b	97.7 abcd	4.1 ab	10.2 a	15.9 ab	4.1 d	22 abcdef	48.7 a
KNYA	2 c	60 a	87.5 cd	4.1 ab	9.5 ab	12;9 b	6.3 bc	17 def	43 abc
Averages	**3**	**45**	**108.4**	**4.1**	**10.1**	**14.9**	**6.7**	**22**	**41.4**
C.V.	**6.85**	**4.98**	**19.59**	**24.84**	**23.95**	**16.3**	**16.99**	**21.6**	**14.5**

DLEV: Date at emergence, **DFLO:** Date of flowering, **LONGTIG:** Plant height, **LARTIG:** Stem diameter, **LONGPET:** Petiole length, **LONGLIM:** Blade length, **LARGLIM:** Leaf blade width, **NFEUIL:** Number of leaves, **LONGPAN:** Panicle length.
* Numbers followed by the same letter are not significantly different at the 5% threshold. C.V: Coefficient of variation.

Table 3: Probability levels of quantitative variables studied for Amaranthus hybridus

Accessions	**DLEV**	**DFLO**	**LONGTIG**	**LARTIG**	**LONGPET**	**LONGLIM**	**LARGLIM**	**NFEUIL**	**LONGPAN**
Repetition	-	0.8548	0.3748	0.1893	0.0167	0.0060	0.0321	0.2545	0.0663
Accessions	0.0001	0.0001	0.0431	0.1734	0.1654	0.4048	0.0156	0.0015	0.3531
Averages	**3**	**45**	**108.4**	**4.1**	**10.1**	**14.9**	**6.7**	**22**	**14.5**
C.V.	**6.85**	**4.98**	**19.59**	**24.84**	**23.95**	**16.3**	**16.99**	**21.6**	**41.4**

DLEV: Date at emergence, **DFLO:** Date of flowering, **LONGTIG:** Plant height, **LARTIG:** Stem diameter, **LONGPET:** Petiole length, **LONGLIM:** Blade length, **LARGLIM:** Leaf blade width, **NFEUIL:** Number of leaves, **LONGPAN:** Panicle length.

Table 4: Correlation matrix of quantitative and qualitative variables

VAR.	**DLEV**	**DFLO**	**LONGTIG**	**LARTIG**	**LONGPET**	**LONGLIM**	**LARGLIM**	**NFEUIL**	**LONGPAN**	**PROENER**	**TYPINF**	**COULINF**	**COULTIG**	**COULLIM**	**COULPET**	**COULNER**	**TYPRACI**
DLEV	-																
DFLO	**-0.668**	-															
LONGTIG	0.157	-0.355	-														
LARTIG	0.007	-0.271	**0.681**	-													
LONGPET	0.067	-0.192	**0.583**	**0.781**	-												
LONGLIM	-0.318	0.080	0.439	**0.507**	**0.611**	-											
LARGLIM	**0.567**	**-0.507**	**0.688**	**0.557**	**0.541**	**0.493**	-										
NFEUIL	-0.097	-0.316	**0.746**	**0.537**	0.313	0.378	0.457	-									
LONGPAN	-0.362	0.109	0.293	0.291	0.251	0.205	-0.127	0.227	-								
PROENER	**0.998**	**-0.676**	0.159	0.005	0.058	-0.306	**0.584**	-0.086	-0.382	-							
TYPINF	0.082	0.303	-0.301	0.008	-0.086	-0.343	-0.096	-0.242	0.108	0.081	-						
COULINF	0.218	-0.311	0.265	0.151	0.018	-0.182	0.215	**0.482**	0.176	0.214	0.354	-					
COULTIG	0.218	-0.311	0.265	0.151	0.018	-0.182	0.215	**0.482**	0.176	0.214	0.354	**1,.00**	-				
COULLIM	0.106	-0.059	0.189	0.010	-0.125	0.044	0.178	0.263	-0.084	0.104	-0.076	**0.620**	**0.620**	-			
COULPET	0.139	-0.224	0.238	0.013	-0.133	-0.010	0.226	**0.475**	-0.163	0.136	-0.099	**0.739**	**0.739**	**0.829**	-		
COULNER	0.106	-0.059	0.189	0.010	-0.125	0.044	0.178	0.263	-0.084	0.104	-0.076	**0.620**	**0.620**	**1.000**	**0.829**	-	
TYPRACI	-0.273	0.124	0.170	-0.041	-0.201	0.312	0.148	0.350	-0.136	-0.236	-0.086	0.330	0.330	**0.635**	**0.505**	**0.635**	-

DLEV: Date of emergence, **DFLO:** Date of flowering, **LONGTIG:** Height of plant, **LARTIG:** Diameter of stem, **LONGPET:** Length of petiole, **LONGLIM:** Length of blade, **LARGLIM:** Width of blade, **NFEUIL:** Number of leaves, **LONGPAN:** Length of panicle, **PROENER:** Prominence of veins, **TYPINF:** Inflorescence type, **COULINF:** Inflorescence colour, **COULTIG:** Stem colour, **COULLIM:** Leaf blade colour, **COULPET:** Petiole colour, **COULNER:** Vein colour, **TYPRACI:** Root type.
In bold, the significant correlation coefficient threshold at the 5% threshold.

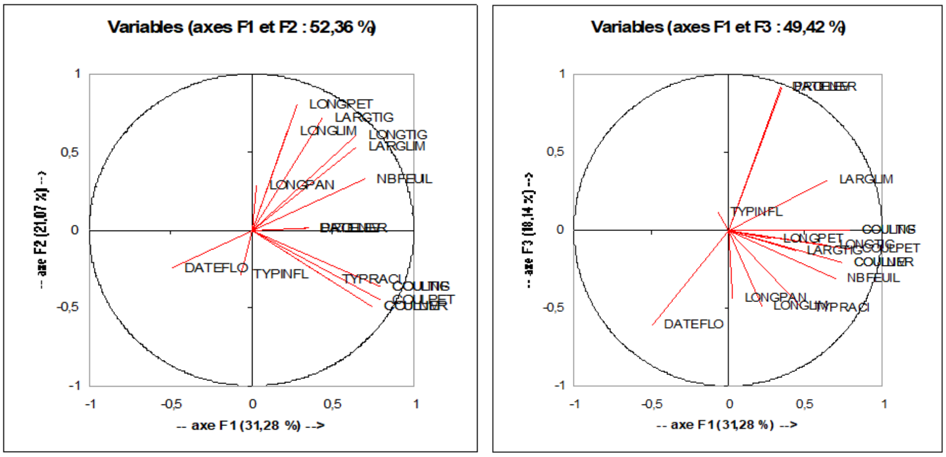
Table 5: Performance of discriminating qualifying variables on the 3 main axes of the PCA

Components	**Axe 1**	**Axe 2**	**Axe 3**
Eigenvalues	5.318	3.583	3.084
Variances explained	31.280	21.075	18.138
Cumulative eigenvalues	5.318	8.901	11.985
Cumulative variances (%)	31.280	52.355	70.494
Variables defining axes and their eigenvalues	LONGTIG (0.649) LARGLIM (0.642) NFEUIL (0.693) COULLIM (0.737) COULTIG (0.790) COULINF (0.790) COULPET (0.795) COULNER (0.737)	LONGPET (0.802) LARTIG (0.722) LONGLIM (0.631)	DLEV (0.917) PROENER (0.915) DFLO (-0.61) TYPRACI (-0.5) LONGPAN (-0.436)

LONGTIG: Plant height ; **LARGLIM:** Width of the blade ; **NFEUIL:** Number of leaves ; **COULLIM:** Colour of the blade ; **COULTIG:** Stem color ; **COULINF:** Colour of the inflorescence ; **COULPET:** Petiole colour ; **COULNER:** Colour of the veins ; **DFLO:** Flowering date ; **LONGPET:** Petiole length ; **LARTIG:** Width of the shank ; **LONGLIM:** Length of the blade ; **DLEV:** Date of emergence ; **PROENER:** Prominence of the veins ; **TYPRACI:** Root type ; **LONGPAN:** Length of the panicle.

However, the quality of the representation of each variable on the correlation circles (Figure 1) confirms the result obtained with eigenvalues. These two results suggest that the 11 descriptors mentioned above are discriminating and can be used to select amaranth accessions.

Figure 2. Quality of the representation of the variables studied on the correlation circles of the 1&2 and 1&3 planes of the PCA



LONGTIG: Plant height ; **LARGLIM:** Width of the blade ; **NFEUIL:** Number of leaves ; **COULLIM:** Colour of the blade ; **COULTIG:** Stem color ; **COULINF:** Colour of the inflorescence ; **COULPET:** Petiole colour ; **COULNER:** Colour of the veins ; **DFLO**: Flowering date ; **LONGPET:** Petiole length ; **LARTIG:** Width of the shank ; **LONGLIM:** Length of the blade ; **DLEV:** Date of emergence ; **PROENER:** Prominence of the veins ; **TYPRACI:** Root type ; **LONGPAN:** Length of the panicle.

Discussion

The domestication of a species is justified by its adaptation to pedoclimatic conditions, its food, economic and medicinal role. The production of *Amaranthus hybridus* L. as an urban and peri-urban market garden crop in Abidjan and Yamoussoukro could be justified by its socio-economic value for the local population (Fondio et al., 2012). Indeed, amaranth, characterized by intra- and interspecific variability, is domesticated and produced in market gardening as a leafy vegetable.

The selection criteria for a species or morphotype are generally based on agronomic and/or nutritional potential, demand, and market value (Fondio et al., 2012; Missihoun et al., 2012; Adjatin et al., 2017). The strong presence of the green morphotype among the accessions of *A. hybridus* in the present collection is justified by a selection oriented towards this morphotype in particular, because of its preferential characteristics. Indeed, from an agronomic point of view, the green morphotype showed the strongest performance in terms of leaf biomass (29 leaves per plant), stem strength (5.9 cm in diameter), plant height (137 cm) and panicle length (48.7 cm). This suggests that the green color seems to be a selection criterion used by producers in Abidjan and Yamoussoukro in the production of this leafy vegetable. The green morphotype has also been identified as the most cultivated and consumed in Benin, Niger, Nigeria and Gabon (Soro et al., 2018; Iboune & Assouman, 2023). According to Assogba Komlan et al.

(2016), Dinssa et al. (2016), the green morphotype is the most produced and valued by women in all urban, peri-urban and rural regions of tropical Africa.

In addition to amaranth, Kiébré (2016) and Kabré (2019) also observed selection oriented towards the green morphotype on *Cleome gynandra* and *Hibiscus cannabinus*, respectively. In addition, the very high intra- and interspecific variability (Ouédraogo et al., 2021) observed in the collection of *A. hybridus* could be justified by the production system on the one hand and by the mode of reproduction of the plant on the other. These two phenomena lead to the appearance of intermediate forms within the species due to the recombination of morphological traits through gene flow. Indeed, with an outcrossing rate of 25-35%, A. *hybridus* shows a high degree of inter-species hybridization, which would justify the morphological diversity observed (Lanta et al., 2003). Wu et al. (2000) also found wide diversity in stem and leaf colour when assessing China's genetic resource collection. Xiao et al. (2000) also classified 31 amaranth varieties on the basis of 17 biological traits, whose leaf shape and colour were considered to be more discriminating for the classification of amaranth varieties. Thus, the presence of intermediate forms in the collection of *A. hybridus* would be linked to the production of different morphotypes and/or species in the same plot or very close plots, thus leading to spontaneous hybridizations. In addition, certain factors such as pedoclimatic conditions or natural and artificial selection, which can lead to highly variable selective pressures on genotypes, thus leading to morphological variability or the appearance of new phenotypes (Nagarajan & Prasad, 1980; Palomino & Ruby, 1991).

The existence of genetic diversity being the basic condition required for a varietal creation program (Pandey & Singh, 2011), the accessions of this study, characterized by significant variability, offer possibilities for improvement of *A. hybridus* in Côte d'Ivoire with a view to meeting the food and economic needs of the population. In addition, the different correlations observed between traits can facilitate this genetic improvement insofar as, when traits are positively correlated, the improvement of one will lead to that of the others. Thus, the better agronomic performance of the green morphotype gives it a particular interest in a selection and improvement program for production as a leafy vegetable. The green morphotype TATROK, AMPT08, ABAN04, YKO07, AKSSI07, YQB06B, YFON01, YFON04, YQR04, YGK05, YQB08, and ABAN17 accessions could be used as potential sires in a breeding program. Indeed, in addition to its agronomic performance, the strongly coloured green morphotype is very rich in β-carotenes and lutein with antioxidant properties capable of preventing certain serious diseases such as cancer and cardiovascular diseases (McLaren & Frigg, 2002; Tiemtoré, 2004).

The different correlations provide information on the genetic association between various traits under specific environmental conditions. This can help in the formulation of selection methods in the context of varietal improvement. Thus, the strong positive correlation of plant height with leaf biomass, leaf blade width, stem diameter and petiole length suggest that large plants have robust stems capable of supporting significant leaf biomass. This means that a selection oriented towards one of these traits would generally imply that of the others. As a result, selection oriented towards large plants could contribute to the improvement of leaf yield. Akaneme et al. (2013) ; Sarker et al. (2014) ; Abe et al. (2015) also noted that leaf biomass is strongly influenced by vegetative growth parameters such as plant height, number of leaves per plant, and stem diameter. However, the most important negative and significant correlations observed between the emergence date and the flowering date on the one hand, and between the flowering date and each of the variables of leaf blade width and vein prominence on the other, show that long-cycled amaranth plants have a very short emergence time and produce small leaves. This is because these long-cycle plants have not been able to express their photosynthetic potential to the best of their ability, thus allowing them to accumulate enough reserve substances.

Conclusion

This study highlighted the existence of a significant morphological variability within the accessions of *Amaranthus hybridus* from Côte d'Ivoire. This variability was observed on some quantitative variables studied such as organ color, stem diameter, plant height, leaf biomass, blade length and width. Interesting correlations between traits of interest were also noted. Promising accessions of the species have also been identified on the basis of important biometric traits. This includes accessions with tall plants, more leaves, and longer leaf length that can be used as potential sires in an *A. hybridus* breeding program.

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