Experimental Agriculture (2022), vol. 58, e53, 1–17
doi:10.1017/S0014479722000503

RESEARCH ARTICLE

Trait-based description of the agronomic and usage potential of a range of plantain varieties from Cameroon

Sylvain Dépigny[1,2,*] and Gaëlle Damour[1,2]

[1]CIRAD, UPR GECO, F-34398 Montpellier, France and [2]GECO, Univ Montpellier, CIRAD, Montpellier, France
*Corresponding author. Email: sylvain.depigny@cirad.fr

(Received 29 July 2022; revised 10 October 2022; accepted 21 October 2022)

Summary
A highly diverse range of plantain varieties are cropped in West and Central Africa, and it is essential to enhance knowledge on this diversity to support farmers in their varietal choices. This study aims at proposing a new way to describe a panel of plantain varieties, based on their agronomic and usage potential. The agronomic trait values of nine plantain varieties, including five traditional varieties (Batard, Big Ebanga, Essong, French Clair and Mbouroukou n°3) representative of the diversity of the plantain group, and four plantain-like hybrids (CRBP39, D248, D535 and FHIA21) were recorded at flowering and harvest. The findings revealed very marked inter-varietal variations, in line with the features of plantain morphotaxonomic subgroups, as well as very high intra-varietal variations, especially for the Essong variety. This extent of intra-varietal variation suggests that traditional plantain multiplication methods could favour the emergence of mutations in plantain varieties and hence of high intra-varietal variability. Finally, the monitored agronomic traits were integrated as agronomic and usage potential indicators per variety and morphotaxonomic subgroup, which could support decision-making on plantain varieties.

Keywords: Agronomic potential; Agronomic traits; Usage potential; Varietal diversity

Introduction

Plantain (*Musa accuminata x Musa balbisiana*) is an essential staple food in West and Central African households (Adheka *et al.*, 2018). Fruits of many plantain varieties produced, harvested and marketed under highly variable conditions and are used in many traditional dishes (Dury *et al.*, 1998). The variety is a major factor in plantain consumption patterns, particularly because it impacts the cropping, harvesting, transport, marketing and fruit processing conditions (Dury *et al.*, 2002).

A highly diverse range of plantain varieties are cropped in West and Central Africa (Adheka Giria, 2014). At least three different plantain varieties generally grow on the same field (Hauser and Amougou, 2010; Devos and Wilson, 1979; Yao, 1988; Achard and Sama Lang, 1998; Selatsa *et al.*, 2009). At the national territorial scale, several dozen varieties have been identified in assessment surveys (Odah *et al.*, 2013; Oppong *et al.*, 2004; Banful, 1998; Adheka *et al.*, 2013; Hauser and Amougou, 2010), which suggests that more than 150 plantain varieties are grown in West and Central Africa (Adheka Giria, 2014). This varietal diversity has been morphologically characterised according to botanical features and agronomic traits (IPGRI-INIBAP/CIRAD, 1996). The catalogue of *Musa* germplasm, West and Central African plantains (Ibobondji Kapu *et al.*, 2018) compiles morphological descriptions of 130 plantain varieties preserved *in vivo* in the African Center for Banana and Plantain Research (CARBAP) collection. The plantain group includes many morphological variations (inflorescence structure, pseudostem height and circumference, leaf shape, pseudostem colour, bunch structure, pulp colour and fruit apex shape, etc.), probably resulting from successive plant mutations (Tezenas du Montcel, 1983; De Langhe, 1961). The main variation concerns inflorescence degeneration (Swennen *et al.*, 1995), which affects the bunch structure (hand number, fruit number and size). This is the basis of the conventional morphotaxonomic classification of plantains (De Langhe *et al.*, 2005), which distinguishes four subgroups (or so-called 'types') of varieties (Tezenas du Montcel *et al.*, 1983; De Langhe, 1961): French, French Horn, False Horn and True Horn, respectively, in order of the most marked inflorescence degeneration, alongside a gradual decrease in the number of fruits per bunch. Pseudostem size, as defined by the number of leaves emitted before flowering, is another morphological variation used in the classification of all banana plants: it distinguishes giant varieties (> 40 leaves emitted), medium varieties (32 to < 38 leaves emitted) and small varieties (< 30 leaves emitted) (Tezenas du Montcel, 1983).

This morphotaxonomic classification helps rank varieties within the existing morphological diversity. It provides some information on yield potential (weight of bunches, cycle length, etc.), but only within the framework of a collection of plantains (specific design with low density, specific cultural practices, no repetition, etc.). Furthermore, it does not provide enough information on the response of a given variety to the various stresses linked to cropping conditions and/or pests. We define agronomic potential as the ability of a plant to produce fruit and respond to biotic and abiotic constraints and the usage potential as the market suitability of the fruits and their ability to be transformed by different processes. A farmer needs to know the agronomic and usage potential of existing varieties so as to be able to choose the most suitable varieties for his/her production system. Could the morphotaxonomic subgroup of a plantain variety be a good indicator to its agronomic and usage potential? Tezenas du Montcel *et al.* (1983) claimed that giant and medium French and False Horn varieties were favoured for their plant morphology and productivity features, as further supported by many field observations (Banful, 1998; Hauser and Amougou, 2010; Schill *et al.*, 2000). Yet the factors underlying these varietal choices, which are hypothesised as being linked with the relationship between the morphology of the different plantain varieties and their agronomic and usage potential, have to be explored. Some authors have compared traditional plantain varieties of different morphotaxonomic subgroups (usually French vs. False Horn) to assess differences in yield potential (Lama *et al.*, 1993; Melin *et al.*, 1976), responses to cropping conditions (Sibide *et al.*, 2006) or susceptibility to diseases and/or pests (Kosma *et al.*, 2012; Fouré *et al.*, 1990), whereas they have not explicitly compared the morphotaxonomic subgroups. Other authors have also focused on plantain varietal diversity with the aim of classifying varieties and gaining insight into the underlying mutations, yet without specifically linking them to the agronomic and usage potential (Agoreyo *et al.*, 2008; De Langhe *et al.*, 2005; Noyer *et al.*, 2005; Ude *et al.*, 2003).

The aim of this study was to propose a new way to describe a panel of plantain varieties, based on their agronomic and usage potential. We assume that the agronomic and usage potential could be described on the basis on few traits, that is, so-called 'agronomic traits' (Litrico and Violle, 2015) regarding the plantain morphology at flowering, leaf area at flowering and harvesting, and bunch features, measured in non-limiting growth conditions. We also assume that i) the agronomic potential could be reflected by the potential production and the response to biotic and abiotic stress, and ii) the usage potential could be reflected by plantain market value indicators extrapolated from the literature. Such a description would enable to compare varieties and choose the most appropriated ones. We sought answers to the following questions: (1) How do agronomic traits vary within and between plantain varieties? (2) Can groups of plantain varieties be identified on the basis of their agronomic traits? If so, are these groups identical to the morphotaxonomic subgroups? and (3) How could the agronomic and usage potential of a range of plantain varieties be compared to support farmers in making varietal choices? We described a panel of nine plantain varieties cultivated in Cameroon and belonging to different subgroups from plantain morphotaxonomic classification, including plantain-like hybrids. We measured and analysed agronomic traits descriptive of plantain morphology at flowering, leaf area at flowering and harvest, and bunches of a panel of nine plantain varieties belonging to different subgroups from the plantain morphotaxonomic classification, including plantain-like hybrids. Finally, we propose indicators of the agronomic and usage potential – calculated on the basis of these agronomic traits – to compare the studied varieties.

Materials & Methods

Plant material and experimental design

An experiment was carried out to describe nine plantain varieties (Table 1). Five traditional triploid plantain varieties commonly grown in Cameroon (Daniels *et al.*, 2001) were selected: one giant and one medium variety of the French subgroup (Essong and French Clair, respectively), one medium variety of the French Horn subgroup (Batard), and two medium varieties of the False Horn subgroup (Big Ebanga and Mbouroukou n°3). Four tetraploid plantain-like hybrid varieties were added to the panel: (i) CRBP39, D248 and D535 hybrids from the CARBAP-CIRAD collaborative varietal improvement programme, and (ii) the FHIA21 hybrid from the *Fundación Hondureña de Investigación Agrícola* (FHIA) improvement programme (Shaibu *et al.*, 2012; Hauser, 2010; Baiyeri *et al.*, 2000) which was chosen because of its high prevalence in plantain-based cropping systems in Africa (Angbo-Kouakou *et al.*, 2016). These varieties provided a representative panel of the morphological diversity that prevails within plantain varieties, with the exception of the True Horn subgroup, which was not studied because of the low prevalence of cultivated varieties of this subgroup in plantain-based cropping systems, explained particularly by their very low number of fruits per bunch (Tezenas du Montcel, 1983).

The experiment (see complete description in Dépigny *et al.* (2018)) was carried out at the CARBAP agricultural research station in Njombé (Littoral province, Cameroon) (4°34'N, 9° 38'E, 79 m a.s.l.) from June 2009 to December 2010. A brown andosol derived from a volcanic plateau prevailed under humid-topical climatic conditions with an 8-month rainy season. A 3000 m^2 experimental field that had been followed for 1 year prior to the study was used. Nine plants of each variety were planted in five elementary plots of 48 m^2 (i.e. 45 plants/variety) randomly located in the experimental field at a planting density of 1667 plants/ha. The plantain seedlings used in the experiment were produced by the macropropagation technique which is a pathogen-free *in vivo* multiplication method (Kwa, 2003). All plants were grown in non-limiting cropping conditions to enable them to express their production potential. These non-limiting cropping conditions were achieved by supplying mineral nutrients (twice a month to reach 270 g nitrogen (450 kg/ha), 140 g phosphorus (233 kg/ha), 900 g potassium (1500 kg/ha), 400 g calcium (666 kg/ha), 300 g magnesium (500 kg/ha) and 100 g sulphur (167 kg/ha) per plant and per crop cycle) and irrigation (every 2 days during the dry season), while also controlling weeds (both manual weeding and herbicide (glyphosate) applications), pests and diseases (nematicide (ethoprophos) treatments, both pheromone traps and insecticide (imidacloprid) treatments to monitor and control black weevils) to avoid any biotic and abiotic stress. Early sucker selection (upon emission) and desuckering by gouge every 15 days helped maintain the population density and avoid mother–plant competition from new useless suckers.

Trait measurement

A set of 14 agronomic traits (Table 2) were assessed on all individual plants (45 plants/variety x 9 varieties = 405 plants) at flowering and harvest during the first production cycle. The pseudostem height (Ht) was measured between the ground and the bottom of the V formed by the last two emitted leaves. The pseudostem circumference (G50) was measured at an aboveground height of

https://doi.org/10.1017/S0014479722000503 Published online by Cambridge University Press

Table 1. Description of the studied varieties and name abbreviations

Name	Abbreviation	Genome	Group	Size	Details
Batard	BA	AAB	French Horn	Medium	Traditional plantain variety in Cameroon
Big Ebanga	BE	AAB	False Horn	Medium	Traditional plantain variety in Cameroon
CRBP39	CR	AAAB	Hybrid	–	Plantain-like hybrid from CARBAP-CIRAD collaborative breeding programme
D248	DD	AAAB	Hybrid	–	Plantain-like hybrid from CARBAP-CIRAD collaborative breeding programme
D535	DC	AAAB	Hybrid	–	Plantain-like hybrid from CARBAP-CIRAD collaborative breeding programme
Essong	ES	AAB	French	Giant	Traditional plantain variety in Cameroon
French Clair	FC	AAB	French	Medium	Traditional plantain variety in Cameroon
FHIA21	FH	AAAB	Hybrid	–	Plantain-like hybrid from FHIA breeding programme
Mbouroukou n°3	MB	AAB	False Horn	Medium	Traditional plantain variety in Cameroon

Table 2. List of the agronomic traits measured

Name	Code	Unit	Source
Pseudostem height	Ht	cm	Measured
Pseudostem girth at 50 cm aboveground	G50	cm	Measured
Number of emitted leaves	NEL	leaf	Measured
Number of living leaves at flowering	NLLf	leaf	Measured
Number of living leaves at harvest	NLLh	leaf	Measured
Emitted leaf area	EFA	m^2	Calculated
Green leaf area at flowering	GAf	m^2	Calculated
Green leaf area at harvest	GAh	m^2	Calculated
Bunch weight	BW	kg	Measured
Number of bunch hands	BH	hand	Measured
Number of bunch fingers	BF	finger	Measured
Finger weight	FW	g	Measured
Flowering-harvest period	FHP	days	Calculated
Planting-harvest period	PHP	days	Calculated

50 cm. The number of emitted leaves (NEL) was measured at flowering. The number of living leaves was measured at flowering and harvest (NLLf and NLLh, respectively). The width and length of each emitted leaf were measured to calculate its leaf area according to Murray's formula (Murray, 1960) (length x width x 0.8). The total leaf area emitted at flowering (EFA) by the plantain plant, as well as the functional leaf area at time t, that is, the cumulative area of photosynthetically active leaves at that time t, flowering and harvest (GAf and GAh, respectively), were then calculated by summing the unit leaf areas. Bunches were harvested at the first ripened finger, including about half of the peduncle, as practiced by farmers. Each bunch was weighed (BW), and its structure was characterised by the number of fruit-bearing hands (BH) and the total number of fruits, or so-called fingers (BF). The mean finger weight (FW) was calculated by the BW/BF ratio. The planting, full flowering (last fertile open hand) and harvesting dates were recorded to calculate planting–harvesting intervals (PHP) and flowering–harvesting intervals (FHP).

Table 3. List of indicators of calculated production abilities

Name	Code	Description	Calculation
Robustness	iRob	Ability to resist fall	G50/Ht
Fruit filling ability	iFill	Ability to fill fruits completely even in limiting climatic and cropping conditions	FHP/(NLLf - NLLh)
Harvest frequency	iHr	Ability to have a short period between harvests	365/PHP
Bunch size	iBS	Ability to produce heavy bunches with many hands and fruits	BW
Hand size	iHS	Ability to produce large-sized hands	BW/BH
Fruit size	iFS	Ability to produce heavy large-sized fruits	FW

Calculation of agronomic and usage potential indicators

Six agronomic and usage potential indicators were calculated on the basis of the measured agronomic traits for each sampled plantain plant per variety (Table 3).

The production potential was represented by the plant ability to produce heavy bunches, that is, with high weights and many hands and fruits, with a short period between harvests. The plant ability to produce heavy bunches was assessed by the bunch size indicator (iBS), which corresponded to the measured bunch weight (BW). The period between harvests was assessed by the harvest frequency indicator (iHr), which corresponded to the number of harvested bunches in a year. Here, this indicator was calculated for the first harvested bunch.

The plant response to biotic and abiotic stress was represented by its ability to resist falling and to fill fruits completely even under limiting climatic and cropping conditions. The plant ability to resist fall reflects its response to biotic stress. Indeed, damage by banana black weevils (particularly *Cosmopolites sordidus*) and root endoparasitic nematodes (particularly *Radopholus similis*; *Pratylenchus spp.*) led to high fall rates, thereby hampering the ability of the plant to bring bunches to maturity. We assumed that plant robustness (Dorel *et al.*, 2016), calculated as the ratio between the plant girth and height, was a good indicator of its ability to resist falling (robustness indicator, iRob). The plant ability to fill fruits completely even under foliar fungi pressure (particularly *Pseudocercospora fijiensis*) and limiting climatic and cropping conditions reflects the plant response to biotic and abiotic stress. We assumed that the plant ability to maintain a substantial leaf area until harvest contributed to its tolerance to these stresses (Mobambo *et al.*, 1993). Hence, the fruit filling ability indicator (iFill) was calculated as a function of the number of living leaves at flowering (NLLf) and harvest (NLLh) and the flowering to harvest period (FHP). Two observations where the number of living leaves at flowering and harvest were identical (and thus the iFill indicator calculation became impossible) were deleted from the dataset.

Finally, the usage potential was represented by the plant ability to produce heavy bunches (iBS indicator), hands with numerous fruits (hand size indicator, iHS) and fruits with high weight and sizes (fruit size indicator, iFS) because of the importance of these criteria in West and Central African markets. Indeed, a high bunch weight, a high number of hands and fruits with high weights and sizes enhance the value of the bunches for field-side marketing (Baiyeri *et al.*, 2000), and then for retail sale per hand or finger for direct consumption (Osseni *et al.*, 1998; N'Da Adopo *et al.*, 1998; Dury *et al.*, 1998). These three indicators partly reflect the capacity of a plantain plant to generate marketable bunches.

Data analysis

For each trait, differences between varieties in mean trait values were tested with a one-way analysis of variance (ANOVA) followed by Tukey's *post hoc* tests. Agronomic trait variability was assessed with coefficients of variation (CV) within varieties (intra-varietal variability) and among

https://doi.org/10.1017/S0014479722000503 Published online by Cambridge University Press

varieties (inter-varietal variability) according to Garcia et al. (2020). CVs were calculated for each trait and variety as follows:

$$CV = \sigma/\mu, \text{ where } \mu \text{ is the mean trait value for the variety and } \sigma \text{ is the standard deviation around } \mu.$$

The intra-varietal variability of traits (mCV_{intra}) was calculated for each trait as the mean CV calculated for all varieties. The inter-varietal variability (CV_{inter}) was calculated as the mean of the mean variety trait values. We also calculated the mean variety intra-varietal variability ($mCV_{intra,var}$) as the mean CV calculated for all traits of a variety, in order to assess whether varieties differed in their trait intra-varietal variability.

Relationships between traits were assessed with a principal component analysis (PCA) using the *factomineR* package (Lê *et al.*, 2008). Studied varieties and morphotaxonomic subgroups were included as supplementary qualitative variables to study their projections on the PCA axis. Differences in principal component axe 1 (PC1) and principal component axe 2 (PC2) scores between morphotaxonomic groups were tested via one-way ANOVA followed by Tukey's honestly significant difference (HSD) tests. Hierarchical clustering on principal components (HCPC) was then performed to highlight clusters of observations. Differences between clusters in PC1 and PC2 scores were assessed by ANOVA followed by Tukey's HSD tests. Clusters were described according to trait values and proportions of individuals belonging to each morphotaxonomic subgroup. For traits, ANOVAs were performed to compare clusters. For each morphotaxonomic subgroup (supplementary qualitative variable), a v-test was performed to assess the relationship between this variable and the clusters and to compare with the whole dataset to determine significant differences (Husson *et al.*, 2017).

Differences in agronomic and usage potential indicator values between varieties and between morphotaxonomic subgroups were tested by one-way ANOVA followed by Tukey's HSD tests.

Results

Inter-varietal and intra-varietal variability in agronomic traits

The plantain varieties studied were differentiated according to the measured agronomic trait values (Table 4, Supplementary Material Fig. S1). Varietal effects were highly significant ($p < 0.0001$) for each measured agronomic trait. The traditional Essong, Batard, French Clair, Mbouroukou n°3 and Big Ebanga varieties differed from the hybrid CRBP39, D248, D535 and FHIA21 varieties, that is, the NLLf, NLLh, GAh and FHP agronomic trait values of the traditional varieties were higher, while the Ht, NEL and EFA agronomic trait values of the traditional varieties were lower. The Essong variety differed significantly from all other varieties with regard to nine agronomic traits, with much higher (Ht, G50, NEL, EFA, BH, BF and PHP) or much lower (NLLf, NLLh and GAh) values. The Big Ebanga variety had significantly lower G50, NLLf and BW agronomic trait values than the other varieties, which was also the case regarding the Mbouroukou n°3 variety for the BF, FHP and PHP agronomic traits, and the D353 variety for the Ht, NEL, GAf and FW agronomic traits. Within the traditional varieties, a decreasing gradient of Ht, G50, NEL, EFA, BW, BH, BF and PHP agronomic trait values and an increasing gradient of FW agronomic trait values was noted between French and French Horn subgroup varieties and False Horn subgroup varieties.

Intra-varietal variability in the measured agronomic traits also differed markedly among the varieties and studied traits (Table 4, Supplementary Material Fig. S1). The highest mean intra-varietal variability in agronomic traits per variety ($mCVintra_{,var}$) was 26% (Essong). This latter variety was found to have the highest intra-varietal variability in the GAh, NLLh, GAf, EFA, PHP, NEL, BH and G50 agronomic traits (ranked in decreasing order of variability). The mean intra-varietal variability in agronomic traits of the other varieties ranged from 10% (French Clair) to 15% (Batard). The Mbouroukou n°3 variety had the lowest intra-varietal variability in the

https://doi.org/10.1017/S0014479722000503 Published online by Cambridge University Press

https://doi.org/10.1017/S0014479722000503 Published online by Cambridge University Press

Table 4. Mean agronomic trait values of the varieties ± coeficients of variation (CV). For each trait, different letters indicate a significant difference between variety means (Tukey's HSD test). For each trait, the intra-varietal variability of traits (mCVintra) was calculated as the mean CV calculated for all varieties. For each variety, the mean variety intra-varietal variability (mCVintra,var) was calculated as the mean CV calculated for all variety traits. See Tables 1 and 2 for variety and trait abbreviations

	Ht	G50	NEL	NLLf	NLLh	EFA	GAf	GAh	BW	BH	BF	FW	FHP	PHP	$mCV_{intra,var}$
BA	*(b)* **437.2** ± 5%	*(b)* **84.0** ± 5%	*(b)* **43.5** ± 4%	*(bcd)* **12.6** ± 14%	*(e)* **5.0** ± 36%	*(b)* **38.5** ±10 %	*(a)* **19.7** ± 19 %	*(d)* **7.60** ± 40%	*(ab)* **29.6** ± 17%	*(b)* **9.6** ± 10%	*(c)* **92.6** ± 13%	*(c)* **317** ± 13%	*(e)* **82.6** ± 19%	*(b)* **378.6** ± 7%	± 15%
BE	*(b)* **387.2** ± 8%	*(g)* **37.1** ± 4%	*(c)* **37.1** ± 4%	*(d)* **11.8** ± 7%	*(d)* **5.9** ± 21%	*(c)* **28.3** ± 9%	*(cd)* **15.8** ± 11%	*(d)* **8.41** ± 24%	*(d)* **16.8** ± 20%	*(cd)* **7.3** ± 9%	*(e)* **46.0** ± 47%	*(b)* **477** ± 18%	*(e)* **81.0** ± 9%	*(e)* **322.0** ± 3%	± 14%
CR	*(d)* **353.7** ± 7%	*(cd)* **74.5** ± 9%	*(de)* **33.0** ± 4%	*(b)* **13.3** ± 11%	*(ab)* **8.3** ± 19%	*(d)* **23.2** ± 9%	*(d)* **15.7** ± 14%	*(bc)* **10.84** ± 20%	*(c)* **23.6** ± 17%	*(c)* **7.6** ± 8%	*(b)* **104.2** ± 9%	*(f)* **226** ± 15%	*(a)* **98.7** ± 5%	*(de)* **324.8** ± 2%	± 11%
DC	*(bc)* **381.4** ± 7%	*(c)* **77.5** ± 8%	*(d)* **33.1** ± 2%	*(a)* **14.4** ± 10%	*(a)* **9.1** ± 21%	*(c)* **28.3** ± 12%	*(ab)* **19.0** ± 13%	*(a)* **13.53** ± 20%	*(c)* **23.0** ± 23%	*(e)* **6.4** ± 12%	*(d)* **82.5** ± 14%	*(de)* **277** ± 21%	*(bc)* **92.1** ± 10%	*(d)* **335.5** ± 4%	± 13%
DD	*(f)* **306.4** ± 5%	*(f)* **68.9** ± 4%	*(e)* **31.6** ± 4%	*(bc)* **12.8** ± 11%	*(cd)* **6.5** ± 20%	*(d)* **24.4** ± 11%	*(d)* **15.1** ± 16%	*(d)* **8.54** ± 24%	*(c)* **21.3** ± 13%	*(e)* **6.8** ± 9%	*(b)* **113.1** ± 12%	*(g)* **190** ± 17%	*(bc)* **93.0** ± 6%	*(e)* **319.3** ± 4%	± 12%
ES	*(a)* **478.7** ± 7%	*(a)* **97.9** ± 11%	*(a)* **49.6** ± 12%	*(cd)* **11.8** ± 10%	*(f)* **1.5** ± 79%	*(a)* **55.1** ± 19%	*(d)* **14.9** ± 37%	*(e)* **1.76** ± 108%	*(b)* **30.0** ± 12%	*(a)* **10.3** ± 12%	*(a)* **165.9** ± 18%	*(f)* **0** ± 18%	*(cd)* **90.4** ± 10%	*(a)* **452.1** ± 15%	± 26%
FC	*(cd)* **364.0** ± 6%	*(ef)* **69.7** ± 7%	*(c)* **37.3** ± 4%	*(cd)* **12.0** ± 9%	*(de)* **5.6** ± 22%	*(c)* **27.8** ± 8%	*(cd)* **16.2** ± 12%	*(d)* **7.97** ± 25%	*(c)* **22.0** ± 11%	*(de)* **6.9** ± 7%	*(cd)* **84.8** ± 8%	*(e)* **261** ± 13%	*(de)* **84.2** ± 11%	*(de)* **327.8** ± 4%	± 10%
FH	*(e)* **331.4** ± 7%	*(cde)* **73.4** ± 7%	*(c)* **36.3** ± 4%	*(a)* **14.9** ± 7%	*(a)* **8.9** ± 20%	*(d)* **24.5** ± 11%	*(bc)* **17.7** ± 12%	*(ab)* **12.13** ± 22%	*(a)* **32.1** ± 19%	*(c)* **7.7** ± 8%	*(b)* **106.8** ± 11%	*(cd)* **299** ± 14%	*(ab)* **96.2** ± 6%	*(c)* **352.9** ± 4%	± 11%
MB	*(b)* **395.6** ± 6%	*(def)* **73.6** ± 7%	*(c)* **38.2** ± 2%	*(cd)* **12.3** ± 11%	*(bc)* **6.9** ± 17%	*(c)* **27.8** ± 7%	*(cd)* **15.9** ± 14%	*(c)* **9.29** ± 24%	*(c)* **23.9** ± 11%	*(c)* **7.9** ± 7%	*(e)* **45.4** ± 20%	*(a)* **550** ± 11%	*(f)* **69.0** ± 9%	*(f)* **312.8** ± 4%	± 11%
mCV_{intra}	± 6%	± 7%	± 4%	± 10%	± 28%	± 11%	± 17%	± 34%	± 16%	± 9%	± 17%	± 15%	± 9%	± 5%	
CV_{inter}	± 14%	± 21%	± 14%	± 13%	± 38%	± 34%	± 19%	± 37%	± 25%	± 18%	± 40%	± 41%	± 14%	± 12%	

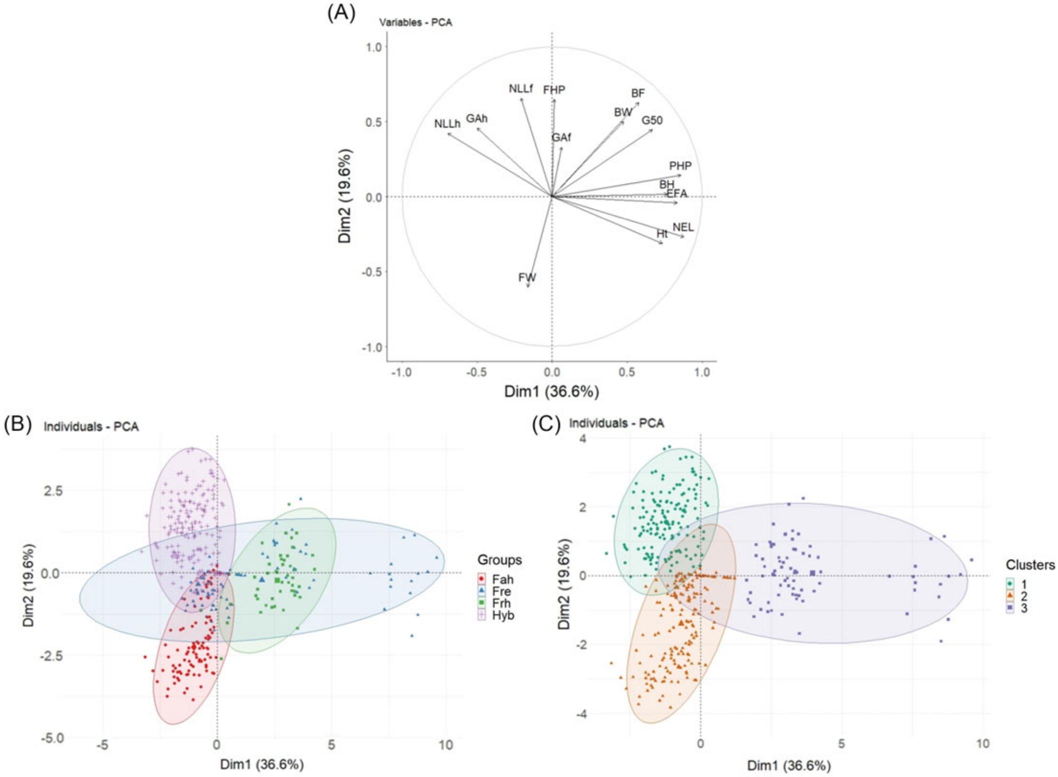

Figure 1. Principal component analysis (PCA) performed on agronomic traits measured at flowering and harvest: (A) correlation circle between traits on the first two axes; (B) observations on the first two axes with the morphotaxonomic subgroups represented; (C) observations on the first two axes with the HCPC clusters represented. See Table 2 for trait abbreviations. 'Fah': False Horn; 'Fre': French; 'Frh': French Horn; and 'Hyb': Hybrids.

agronomic NLLh, BW, FW, EFA, BH and NEL traits (ranked in decreasing order of variability, i.e. from 37% to 12%). The mean intra-varietal variability in each agronomic trait (mCV $_{intra}$) ranged from 4% (NEL) to 34% (GAh). NLLh, GAf, BW and FW agronomic trait variability values were above 15%, while NEL, PHP, Ht, G50, BH, FHP and NLLf agronomic trait variability was below 10%. For all measured agronomic traits, this intra-varietal variability was lower than the inter-varietal variability (CV $_{inter}$), especially for the NEL, EFA and G50 agronomic traits.

Relationships between morphotaxonomic subgroups and agronomic traits

The morphotaxonomic classification revealed a substantial part of the agronomic trait variation across varieties but was not sufficient. The PCA focused on agronomic traits explained 56.2% of the total variance on the first two axes (Figure 1A). The first axis explained 36.6% of this variance and was positively correlated with NEL, PHP, EFA, BH, Ht and G50 (with contributions of 15.0%, 14.4%, 13.5%, 11.4%, 10.5% and 8.7%, respectively) and negatively correlated with NLLh (with a 9.4% contribution). The second axis explained 19.6% of the total variance and was positively correlated with NLLf, FHP, BF, BW and GAf (with contributions of 15.7%, 15.3%, 14.3%, 9.1% and 4.0%, respectively) and negatively correlated with FW (with a 13.3% contribution). While observations of varieties belonging to the French Horn, False Horn and Hybrids subgroups were dispersed within groups mainly along axis 2, the French subgroup was very broadly dispersed along axis 1, with moderate dispersion along axis 2 (Figure 1B). On axis 1, the French Horn and French

https://doi.org/10.1017/S0014479722000503 Published online by Cambridge University Press

Table 5. Differences between clusters defined by the HCPC: agronomic traits (mean ± SD) and results of the v-test performed in HCPC for the variable morphotaxonomic subgroup. For each trait, different letters indicate a significant difference between subgroup means (Tukey's HSD test). Bold values indicate the best value of the agronomic trait

	Cluster1	Cluster2	Cluster3
Agronomic traits			
Ht	341 ± 34 *(c)*	379 ± 29 *(b)*	**445 ± 41 *(a)***
G50	73.3 ± 6.3 *(b)*	64.9 ± 14.8 *(c)*	**87.5 ± 10.9 *(a)***
NEL	33.6 ± 2.2 *(c)*	37.2 ± 1.8 *(b)*	**44.9 ± 5.4 *(a)***
EFA	24.9 ± 2.6 *(c)*	29.2 ± 7.1 *(b)*	**46.5 ± 11.4 *(a)***
NLLf	**14.0 ± 1.4 *(a)***	12.1 ± 1.2 *(b)*	12.5 ± 1.5 *(b)*
GAf	17.1 ± 2.5 *(b)*	15.9 ± 2.1 *(c)*	**18.1 ± 4.5 *(a)***
NLLh	**8.2 ± 1.9 *(a)***	6.3 ± 1.3 *(b)*	3.8 ± 2.2 *(c)*
GAh	**11.4 ± 2.8 *(a)***	8.7 ± 2.1 *(b)*	6.6 ± 3.3 *(c)*
BW	25.4 ± 6.3 *(b)*	21.7 ± 3.8 *(c)*	**29.3 ± 4.4 *(a)***
BH	7.2 ± 0.9 *(b)*	7.4 ± 0.7 *(b)*	**9.7 ± 1.3 *(a)***
BF	102.7 ± 15.8 *(b)*	66.6 ± 26.0 *(c)*	**126.1 ± 42.5 *(a)***
FW	250.7 ± 59.5 *(b)*	**381.9 ± 138.7 *(a)***	278.4 ± 65.5 *(b)*
PHP	333.2 ± 17.3 *(b)*	324.2 ± 14.6 *(c)*	**401.2 ± 56.7 *(a)***
FHP	35.5 ± 6.7 *(c)*	79.6 ± 11.1 *(b)*	**87.2 ± 10.4 *(a)***
Morphotaxonomic groups			
Fah	0% (−)	51.4% (+)	0% (−)
Fre	1.3% (−)	29.7% (+)	46.8% (+)
Frh	0% (−)	2.3% (−)	53.25% (+)
Hyb	98.7% (+)	16.6% (−)	0% (−)

subgroups were significantly different from the False Horn and Hybrids subgroups. On axis 2, the French Horn and French subgroups did not significantly differ but were significantly different from False Horn and Hybrids subgroups, which were also significantly different with respect to each other.

The HCPC highlighted three groups of significantly different plantain plants ($P < 0.0001$) (Table 5, Figure 1C). Group 1 included 98.7% hybrid plantain plants, Group 2 was a mixture of plantain plants of the False Horn (51.4%), French (29.7%) and Hybrids (16.6%) subgroups, while Group 3 was a mixture of plantain plants of the French Horn (53.25%) and French (46.8%) subgroups. Group 1 corresponded to plantain plants whose NLLf, NLLh and GAh agronomic trait values were significantly higher than the others, Group 2 corresponded to plantain plants whose FW agronomic trait values were significantly higher than the others, and Group 3 included plantain plants whose Ht, G50, NEL, EFA, GAf, BW, BH, BF, FHP and PHP agronomic trait values were higher than the others.

Agronomic and usage potential indicators

Significant differences ($P < 0.0001$) were noted in the agronomic and usage potential indicator values between the morphotaxonomic subgroups (Table 6) and varieties studied (Figure 2). The most favourable (i.e. highest) indicator values were obtained by False Horn varieties for the harvest frequency (iHR) and fruit size (iFS) indicators, by the French Horn varieties for the bunch size (iBS) indicator and by the hybrid varieties for the robustness (iRob), hand size (iHS) and fruit filling ability (iFill) indicators. The analysis of between variety differences in indicators values highlighted the abilities of some varieties. The Big Ebanga and Mbouroukou n°3 varieties obtained favourable values for the fruit size (iFS) and harvest frequency (iHR) indicators, but unfavourable values for the bunch size (iBS), hand size (iHS) and robustness (iRob) indicators. The Essong variety obtained the most unfavourable values for the fruit filling ability (iFill), fruit size (iFS) and harvest frequency (iHR) indicators, while it was among the varieties with the most favourable bunch size (iBS) indicator values. Finally, several hybrid varieties obtained very

https://doi.org/10.1017/S0014479722000503 Published online by Cambridge University Press

Table 6. Mean values of indicators of agronomic and usage potentials (± SD) for each morphotaxonomic subgroup. For each indicator, different letters indicate a significant difference between subgroup means (Tukey's HSD test). Bold values indicate the best value of the indicator

Indicators	False Horn	French	French Horn	Hybrids
iRob	0.146 ± 0.047 (a)	0.196 ± 0.160 (b)	0.193 ± 0.007 (b)	**0.216 ± 0.016 (c)**
iHr	**1.15 ± 0.04 (c)**	1.01 ± 0.16 (a)	0.97 ± 0.07 (a)	1.10 ± 0.06 (b)
iBS	20.7 ± 4.7 (a)	25.0 ± 4.8 (b)	**29.6 ± 5.1 (c)**	25.0 ± 6.3 (b)
iHS	2.70 ± 0,54 (a)	3.17 ± 0,40 (b)	3.047 ± 0,50 (b)	**3.49 ± 0,76 (c)**
iFS	**517 ± 82 (c)**	238 ± 46 (a)	317 ± 42 (b)	247 ± 60 (a)
iFill	14.5 ± 5.5 (a)	12.0 ± 4.6 (a)	13.3 ± 11.5 (a)	**19.7 ± 11.7 (b)**

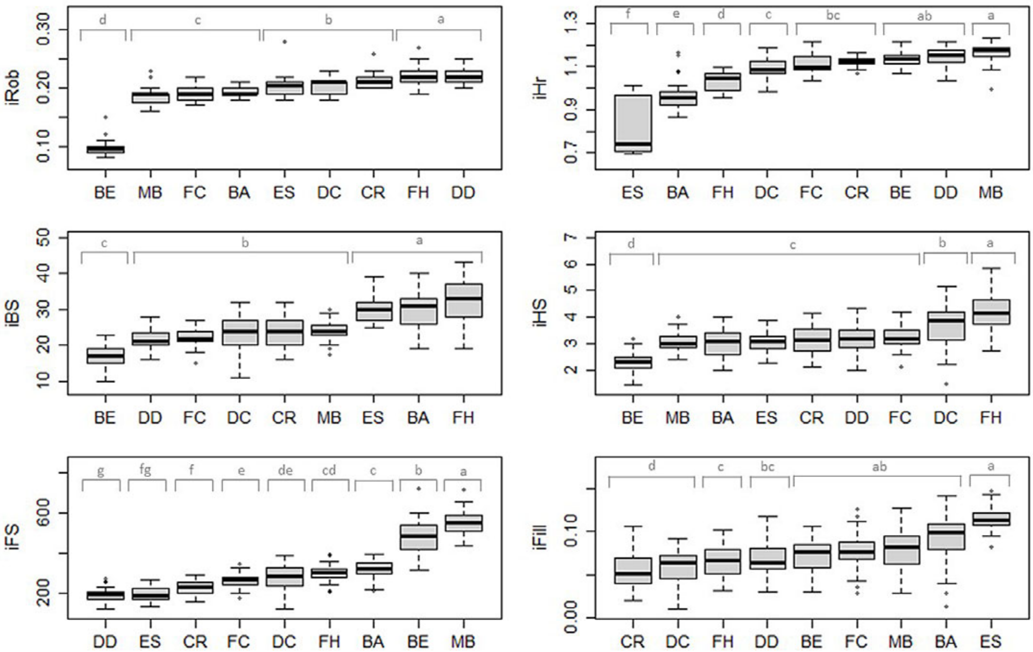

Figure 2. Boxplots of indicator values for agronomic and usage potentials of the studied varieties. iRob: robustness; iFill: fruit filling ability; iHr: harvest frequency; iBS: bunch size; iHS: hand size; and iFS: fruit size. For each indicator, different letters indicate a significant difference between varieties, with higher indicator values representing greater variety abilities. See Table 1 for variety name abbreviations.

favourable values for the fruit filling ability (iFill) (CRBP39 and D535) and hand size (iHS) indicators (FHIA21 and D535).

Discussion

A high inter-varietal variability

The monitored agronomic trait were highly variable among varieties and morphotaxonomic subgroups. While measurement of these traits during successive crop cycles and at different locations would ensure a more comprehensive description of the varieties, we assume that a description of the first cycle in one location with non-limiting conditions, as done in this study, already gives reliable information on comparison between varieties (see similar approaches for species

https://doi.org/10.1017/S0014479722000503 Published online by Cambridge University Press

comparisons in Kazakou *et al.*, 2014 and Garcia *et al.*, 2020). The observed inter-varietal variations in agronomic traits were in line with variations reported in other plantain variety panels (Selatsa *et al.*, 2009; Odah *et al.*, 2013; Adheka *et al.*, 2013; Ortiz and Vuylesteke, 1998; Swennen *et al.*, 1995). They again illustrate many mutations that prevail within plantain varieties, resulting in different extents of reproductive system degeneration and impacts on all plantain plant organs.

Essong was the most outstanding variety: the size and number of its organs (pseudostem, leaves, hands and fruits in the bunch) and its cycle length were much higher than noted in the other varieties. The plant morphology, bunch structure and cycle lengths of this plantain variety were typical of the French giant variety subgroup (De Langhe *et al.*, 2005; Ortiz *et al.*, 1998). Ortiz *et al.* (1998) suggested that mutations expressed in French giant varieties may have been gradually selected by growers so as to obtain a reduced plantain plant morphology in order to enhance wind resistance and a shorter cycle to boost yields. The French Clair medium variety could be a result of this selection process: the proportions of traits of plants of this variety were found to be in similar to those of the Essong variety, especially regarding the bunch structure, but the organs were smaller and the cycle lengths shorter. The Batard variety could be a further result of this selection process with regard to both the plantain morphology and bunch structure, which resembled those of French medium varieties, but it also had a higher mean fruit weight that was closer to that of False Horn varieties. This variety belongs to the French Horn subgroup which, according to various molecular analysis results, presents with inflorescence degeneration like that of False Horn varieties but with less of an impact on the plant morphology (Crouch *et al.*, 2000; De Langhe *et al.*, 2005).

The marked differences noted between traditional plantain varieties and hybrid varieties concerned the persistence of the leaf area (number of living leaves and functional leaf areas at flowering and harvest), which was much higher for hybrid varieties. These findings, which are in line with other reported performance evaluation data for plantain-like hybrid varieties (Irish *et al.*, 2013; Dzomeku *et al.*, 2007; Lemchi *et al.*, 2005; Cohan *et al.*, 2003), suggest that plantain hybrids have better tolerance to banana black leaf streak (*Pseudocercospora fijiensis*), which was a major varietal improvement criterion for plantain in major international programmes (Craenen and Ortiz, 1998; Cohan *et al.*, 2003). Note also that the hybrid varieties had a more stocky and robust morphology compared to traditional varieties. These results are consistent with the plantain ideotype sought in most plantain breeding programmes, that is, a small- to medium-sized, short-cycle plantain plants with a leaf area that is tolerant or resistant to banana black spot, while producing heavy bunches with many hands and fruits (Jenny *et al.*, 1994; Vuylsteke and Swennen, 1993; Tezenas du Montcel, 1993; Ortiz and Langie, 1997). Hybrid plantain varieties were also found to have the highest fruit filling periods (flowering-harvest interval), which has been previously observed and explained by their higher ploidy levels (Vuylsteke *et al.*, 1993; Shaibu *et al.*, 2003).

A high intra-varietal variability

The monitored agronomic trait values were also sometimes highly variable within plantain plants of the same variety. Few published studies have investigated this issue; most studies have been focused on assessing inter-varietal variations in the plantain group (see 4.1.). Yet variations in agronomic traits within the same variety of the *Musa* genus have already been documented, assessed and used – especially within the Cavendish group (*Musa accuminata*, AAA) – to distinguish different clones within the same cropped variety (Rodrigues *et al.*, 2012), or to compare the production performance of different existing clones in a specific pedoclimatic context (Robinson *et al.*, 1993; Pinar *et al.*, 2020). The absence of similar studies on plantain could be explained by the fact that conventional planting material propagation techniques are still generally implemented in the main plantain production areas (Kone *et al.*, 2011; Kouakou *et al.*, 2019; Lescot and Ganry, 2008). This range of techniques and probably of technical expertise levels, propagation sites and mother plant physiological and sanitary states could have been conducive to highly varied selection and the emergence of multiple mutations (Vuylesteke and Swennen, 1990; Ortiz *et al.*, 1998), thereby increasing the possibility of intra-varietal variability, process that would not be limited by the lack of mass selection.

The Essong variety showed the highest mean intra-varietal variability in agronomic traits, as well as the highest intra-varietal variability in several agronomic traits. This trend might be explained first by its long cycle duration in comparison with shorter-cycle plantain plants, and this could increase the chance of undergoing stress during the growth period, which could impact the functioning of each banana plant to different extents and be conducive to dispersion of the agronomic trait values at the end of the cycle. This hypothesis is supported by the high mean intra-varietal variability in the agronomic traits of the Batard variety, which also had a longer cycle than the other studied varieties. A second explanation could be the existence of different relatively stable mutations within the Essong variety grown in Cameroon. The PCA graph projection findings for the varieties (see Supplementary Material Fig. S2) supports this hypothesis by highlighting two groups of plantain plants discriminated in the Essong variety on axis 1. One group of plantain plants of this variety thus showed significantly higher cycle length, emitted leaf number and pseudostem circumference at flowering values. This difference should be further investigated using tailored molecular marker methods (Lamare and Rao, 2015; Marimuthu Somasundaram *et al.*, 2019).

Finally, three of intra-varietal variability levels emerged at the monitored agronomic trait scale. The least variable agronomic traits described the plantain morphology (pseudostem height and circumference and leaf area emitted at flowering) and cycle length. These traits are also reportedly not highly variable under environmental effects (IPGRI-INIBAP/CIRAD, 1996) as they are likely closely related to the banana plant development pattern, which could explain their lower variability in our study. The most variable agronomic traits involved changes in leaf area up to harvest, which could be explained by the many factors that can affect the leaves during a cycle (black leaf streak, wind, bird damage, etc.); these agronomic traits are more related to plantain plant growth. Finally, agronomic traits describing bunch components (number of hands and fingers in the bunch, bunch weight) showed intermediate variability – these traits could be the result of the plantain plant development and growth pattern. This trend, which has been further highlighted by the analysis of correlations between agronomic traits (Arantes *et al.*, 2010; Orluchukwu and Ogburia, 2014), could be of interest with regard to the choice of agronomic traits to be monitored and measured in varietal assessments and in designing tools for predicting the functioning of varieties (Dépigny *et al.*, 2016).

Agronomic potential and morphotaxonomic subgroups

Our study of the measured agronomic traits revealed three significantly different groups of plantain plants very close to the plantain morphotaxonomic subgroups. The measured agronomic traits thus revealed a large part of the morphotaxonomic subgroup classification, as also observed in other studies (Osuji *et al.*, 1997; Swennen *et al.*, 1995). French-type plantains were hard to position between groups 2 and 3, which could be explained by the marked morphology gradient in the studied plantains, but also by the existence of more or less expressed reversions from the False Horn type to the French type (Crouch *et al.*, 2000; Ramcharan and Gonzalez, 1984; De Langhe *et al.*, 2005; Youmbi *et al.*, 2005). This correspondence between agronomic traits descriptive of the agronomic potential and morphotaxonomic subgroups led us to put forward a hypothesis on the existence of a banana functioning model (development rules, biomass allocation rules, source–sink relations, etc.) specific to each morphotaxonomic subgroup. This would be an interesting avenue to explore in view of the development of tools for predicting varietal potentials under different cropping conditions (pedoclimatic, intensification level, etc.) (Dépigny *et al.*, 2016).

https://doi.org/10.1017/S0014479722000503 Published online by Cambridge University Press

	Agronomic potential				Potential usage		
	Potential production ability		Response to biotic and abiotic stresses		Market criteria adequation		
	Harvest frequency	Bunch size	Robustness	Filling ability	Bunch size	Hand size	Fruit weight
Batard	4	10	7	3	8	4	3
Big Ebanga	9	0	0	4	0	0	8
CRBP39	9	10	9	9	4	4	1
D535	8	8	8	10	4	7	2
D248	9	3	10	5	3	5	0
Essong	0	9	8	0	9	4	0
French clair	8	3	7	3	3	5	2
FHIA21	6	10	10	6	10	10	3
Mbouroukou n°3	10	5	7	4	5	4	10

Figure 3. Scoreboard of agronomic and usage potential indicators of the studied varieties. Scores correspond to indicator values rescaled on a scale of 0 (lowest value of the indicator) to 10 (highest value of the indicator).

Agronomic and usage potential indicators

It is essential to formalise knowledge acquired on plantain varietal diversity to support farmers in making varietal choices. The agronomic and usage potential indicators proposed in this study were developed with the aim of encapsulating the production potential and the market suitability of the studied varieties. They were developed to compare varieties and to support decision-making on varietal choices. Further evaluation of a subset of selected species, in different environment conditions or during successive cycles, could be conducted depending on the objectives. The production potential was described by the harvest frequency (iHR) and bunch size (IBS) indicators, both of which were complementary regarding their description of the production potential, while revealing a trade-off also reported for dessert banana (Dorel *et al.*, 2016), that is, varieties that had the longest cycles, such as FHIA21, Essong and Batard, also produced the largest bunches probably because of a longer carbohydrate accumulation time. Conversely, varieties with the shortest cycles, such as Mbouroukou n°3, Big Ebanga and certain hybrid varieties, produced smaller bunches. The potential response to biotic and abiotic stress, as described by the robustness (iRob) and fruit filling ability (iFill) indicators, supplemented the description of the agronomic potential. The two proposed indicators highlighted the superiority of the different hybrid varieties tested over traditional plantain varieties. This could be explained by the fact that plantain breeders strive to achieve greater plantain robustness and better tolerance to black Sigatoka disease. Finally, the usage potential was described by the bunch size (iBS), hand size (iHS) and fruit size (iFS) indicators, which were complementary and opposing, that is, a bunch consisting of many hands and fruits (e.g. FHIA21, Essong and Batard) will have smaller and lighter fruits than a bunch with fewer hands and fruits (e.g. Mbouroukou n°3 and Big Ebanga).

Figure 3 summarises the abilities of the nine studied varieties and highlights that all of the sought-after abilities were not pooled in any single variety. This means that farmers have to make trade-offs between the abilities of the different available plantain varieties to address their production constraints and meet their marketing objectives (Norgrove and Hauser, 2014). In Cameroon, French giant varieties, such as Essong, are grown because of their ability to produce heavy bunches (Hauser and Amougou, 2010), then offering high market profitability (Ndemba, 2003), a substantial household food supply (Nyoneng, 2003) and fruits that are appreciated for staple meal-making (Ngoh Newilah *et al.*, 2005). False Horn varieties, such as Big Ebanga and Mbouroukou n°3, are cropped because of their short cycles and fruit, which is highly esteemed for local dishes (Ngoh Newilah *et al.*, 2005) and whose size is particularly suitable for certain uses, such as the preparation of chips (Fonfang Fouepe *et al.*, 2016). Including varieties with different abilities in the production system, either in the form of plots dedicated to different varieties, or in the form of a varietal mixture plot, is another way for farmers to manage their trade-offs, that is, enhance responses to agronomic constraints (Quénéhervé *et al.*, 2011) and the marketing potential (Dépigny *et al.*, 2016). This could partly explain the high proportion of plantain crop plots in Cameroon where French and False Horn varieties are jointly cropped (Hauser and Amougou, 2010; Achard, 1998).

Conclusion

This study revealed marked differences in measured agronomic trait values among the studied plantain varieties, while also highlighting high intra-varietal variations in some varieties, such as Essong. Links between the monitored agronomic traits and the morphotaxonomic classification were found, suggesting the existence of functioning laws specific to each plantain morphotaxonomic subgroup. Finally, the findings of this study enabled us to propose an initial formalisation of agronomic and usage potential indicators per variety. This characterisation of plantain varietal diversity should be a real asset for plantain growers. Other indicators would now need to be developed that integrate traits from several disciplines. This also calls into question the methods and tools used to assess and characterise the very broad-ranging varietal diversity spanning many countries, as well as to identify and formalise the needs of plantain farmers, consumers and processors.

Supplementary material. For supplementary material accompanying this paper visit https://doi.org/10.1017/S0014479722000503

Acknowledgements. The authors wish to thank the CARBAP team for their rigorous observations, including Médard Talla Djomessi, Frédéric Tchotang, David Essome Ngando, Gabriel Fansi, Jean-Pierre Ebongue and many other CARBAP staff who contributed to the trials. This study was conducted in the framework of the CARBAP-CIRAD collaborative agricultural research programme and funded by CIRAD and CARBAP core budgets.

Declaration of Competing Interest. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the research reported in this paper.

Author Contributions. Study design: SD; Methodology: SD and GD; Data curation: SD; Data presentation: SD and GD; Writing: SD and GD; Project administration: SD.

Data Availability. Data production, measurement and curation were described in a data paper (Dépigny *et al.*, 2018), and data are available on the CIRAD Dataverse website: https://doi.org/10.18167/DVN1/CBUVWU

References

Achard R. (1998). Place du bananier dans les associations agroforestières. In *Symposium sur la recherche et développement dans les zones tropicales humides d'Afrique Centrale et de l'Ouest*, 75–179 Yaoundé, Cameroun.

Achard R. and Sama Lang P. (1998). Description des systèmes de production du sud-ouest du Cameroun : quels enseignements pour l'intervention de la recherche? In Picq C., Fouré E. and Frison E.A. (eds), *Bananas and Food security. Les productions bananières : un enjeu économique majeur pour la sécurité alimentaire*. Douala (Cameroun): INIBAP, pp. 649–666.

Adheka J. G., Dhed'a D. B., Karamura D., Blomme G., Swennen R. and De Langhe E. (2018). The morphological diversity of plantain in the Democratic Republic of Congo. *Scientia Horticulturae* **234**, 126–133.

Adheka J.G., Dhed'a D.B., Sivirihauma C., Karamura D., Langhe E.d., Swennen R. and Blomme G. (2013). Plantain collection and morphological characterization in Democratic Republic of Congo: past and present activities and prospects. In Blomme, G., van Asten, P. and Vanlauwe, B. (eds), *Banana systems in the humid highlands of sub-Saharan Africa: enhancing resilience and productivity*. Wallingford (UK): CABI, pp. 1–7.

Adheka Giria J. (2014). Contribution to the characterization and classification of the Congo basin African plantains (Musa AAB) in the Democratic Republic of Congo. In *Department of Biotechnological Sceinces*, Vol. PhD thesis: University of Kisangani.

Agoreyo B.O., Golden K.D. and Brown S.E. (2008). Analysis of genetic variability among plantain cultivars (Musa paradisiaca L.) using arbitrarily primed PCR technique. *African Journal of Biotechnology* **7**, 1041–1045.

Angbo-Kouakou E., Temple L., Mathé S. and Assemien A. (2016). Plateformes d'innovation comme dispositif d'orientation des trajectoires technologiques des filières agricoles. Cas de la filière banane plantain en Côte d'Ivoire. *OpenScience* **18**, 1–18.

Arantes A., Donato S. and Silva S. (2010). Relationship between morphological characters and yield components in plantains. *Pesquisa agropecuaria brasileira* **45**, 224–227.

Baiyeri K.P., Mbah B.N. and Tenkouano A. (2000). Yield components of triploid and tetraploid Musa genotypes in Nigeria. *HortScience* **35**, 1338–1343.

Banful B. (1998). Production of plantain, an economic prospect for food security in Ghana. In Picq C., Fouré E. and Frison E.A. (eds), *Bananas and Food security. Les productions bananières : un enjeu économique majeur pour la sécurité alimentaire*. Douala (Cameroun): INIBAP, pp. 151–160.

Cohan J.P., Abadie C., Tomekpe K. and Tchango Tchango J. (2003). Evaluation des performances agronomiques et de résistance à la maladie des raies noires de l'hybride «CRBP 39» : résultat du 1er cycle de culture. *InfoMusa* **1**, 29–32.

Craenen K. and Ortiz R. (1998). Influence of black Sigatoka disease on the growth and yield of diploid and tetraploid hybrid plantains. *Crop Protection* **17**, 13–18.

Crouch J.H., Crouch H.K., Madsen S., Vuylesteke D. and Ortiz R. (2000). Comparative analysis of phenotypic and genotypic diversity among plantain landraces (Musa spp., AAB group). *Theoretical and Applied Genetics* **101**, 1056–1065.

Daniels J., Jenny C., Karamura D. and Tomekpe K. (Eds) (2001). *Musalogue, a catalogue of Musa germplasm. Diversity in the genus Musa.* Montpellier: INIBAP.

De Langhe E. (1961). La taxonomie du bananier plantain en Afrique équatoriale. *Journal d'Agriculture Tropicale et de Botanique Appliquée* **8**, 417–449.

De Langhe E., Pillay M., Tenkouano A. and Swennen R. (2005). Integrating morphological and molecular taxonomy in Musa: the African plantains (Musa spp. AAB group). *Plant Systematics and Evolution* **255**, 225–236.

Dépigny S., Lescot T., Achard R., Diouf O., Cote F.X., Fonbah C., Sadom L. and Tixier P. (2016). Model-based benchmarking of the production potential of plantains (Musa spp., AAB): application to five real plantain and four plantain-like hybrid varieties in Cameroon. *The Journal of Agricultural Science* **155**, 1–14.

Dépigny S., Tchotang F., Talla M., Fofack D., Essomé D., Ebongué J.-P., Kengni B. and Lescot T. (2018). The 'Plantain-Optim' dataset: agronomic traits of 405 plantains every 15 days from planting to harvest. *Data in Brief* **17**, 671–680.

Devos P. and Wilson G. (1979). Intercropping of plantain with food crops: maize, cassava and cocoyams. *Fruits* **34**, 169–174.

Dorel M., Damour G., Leclerc N., Lakhia S., Ricci S., Vingadassalon F. and Salmon F. (2016). Parent plant vs sucker – how can competition for photoassimilate allocation and light acquisition be managed in new banana hybrids? *Field Crops Research* **198**, 70–79.

Dury S., Bricas N., Tchango Tchango J. and Bikoï A. (1998). La consommation et les critères de qualité du plantain à Douala et Yaoundé. In Picq C., Fouré E. and Frison E.A. (eds), *Bananas and Food security. Les productions bananières : un enjeu économique majeur pour la sécurité alimentaire*. Douala (Cameroun): INIBAP, pp. 507–523.

Dury S., Bricas N., Tchango Tchango J., Temple L. and Bikoï A. (2002). The determinants of urban plantain consumption in Cameroon. *Food Quality and Preference* **13**, 81–88.

Dzomeku B.M., Bam R.K., Adu-Kwarteng E., Darkey S.K. and Ankomah A.A. (2007). Agronomic and physio-chemical evaluation of FHIA-21 in Ghana. *International Journal of Agricultural Research* **5**, 1215–1219.

Fonfang Fouepe G.H., Folefack D.P., Pane Pagui Z., Bikoi A. and Noupadja P. (2016). Transformation et commercialisation des chips de banane plantain au Cameroun : une activité artisanale à forte valeur ajoutée. *International Journal of Biological and Chemical Sciences* **10**, 1183–1198.

Fouré E., Mouliom Péfoura A. and Mourichon X. (1990). Etude de la sensibilité variétale des bananiers et des plantains à Mycosphaerella fijensis MORELET au Cameroun. Caractérisation de la résistance au champ de bananiers appartenant à divers groupes génétiques. *Fruits* **4**, 339–345.

Garcia L., Damour G., Kazakou E., Fried G., Bopp M.C. and Metay A. (2020). Seasonal and interannual variations in functional traits of sown and spontaneous species in vineyard inter-rows. *Ecosphere* **11**, 1–15.

Hauser S. (2010). Growth and yield response of the plantain (Musa spp.) hybrid "FHIA 21" to shading and rooting by Inga edulis on a southern cameroonian ultisol. In Dubois T., Hauser S., Staver C. and Coyne D. (eds), *International Conference on Banana and Plantain in Africa: Harnessing international partnerships to increase research impact, Vol. 879–2*. Mombasa (Kenya): Acta Horticulturae, pp. 487–494.

Hauser S. and Amougou D. (2010). Plantain (Musa spp.) cropping systems of southern cameroon. In Dubois T., Hauser S., Staver C. and Coyne D. (eds), *International Conference on Banana and Plantain in Africa: Harnessing international partnerships to increase research impact, Vol. 879–2*. Mombasa (Kenya): Acta Horticulturae, pp. 495–508.

Husson F., Lê S. and Pagès J. (2017). *Exploratory multivariate analysis by example using R*. New York: Chapman and Hall/CRC.

Ibobondji Kapu L., Newilah Ngoh G., Tomekpe K., Ruas M., Chase R. and Roux N. (2018). *Musalogue : Catalogue de germoplasme de Musa. Plantains d'Afrique occidentale et centrale*. Bioversity International, Montpellier, France: Picq, Claudine.

IPGRI-INIBAP/CIRAD (1996). *Descripteurs pour le bananier (Musa spp.)*. Institut international des ressources phytogénétiques, Rome, Italie; Réseau international pour l'amélioration de la banane et la banane plantain; Montpellier, France; Centre de coopération internationale en recherche agronomique pour le développement, Montpellier, France.

Irish B.M., Goenaga R., Rios C., Chavarria-Carvajal J. and Ploetz R. (2013). Evaluation of banana hybrids for tolerance to black leaf streak (Mycosphaerella fijiensis Morelet) in Puerto Rico. *Crop Protection* **54**, 229–238.

Jenny C., Auboiron E. and Beveraggi A. (1994). Breeding plantain-type hybrids at CRBP. In Jones D. (ed) *First conference of the international Musa testing program: the improvement and testing of Musa: a global partnership*. Honduras: Inibap, pp. 176–187.

Kazakou, E., Violle, C., Roumet, C., Navas, M.-L., Vile, D., Kattge, J. & Garnier, E. 2014. Are trait-based species rankings consistent across data sets and spatial scales? *Journal of Vegetation Science* **25**: 235–247.

Kone T.M., Kone M., Traore S. and Kouadio J.Y. (2011). Multiplication Rapide du Bananier Plantain (Musa Spp. Aab) In Situ: une Alternative Pour la Production En Masse de Rejets. *Agronomie africaine* **23**, 21–31.

Kosma P., Zachee A., Begoude D., Hoopen M.t., Kuate J. and Akoa A. (2012). Evaluation of the sensitivity of two plantain varieties essong and big ebanga to the nematode Radopholus similis. *African Journal of Biotechnology* **11**, 14755–14760.

Kouakou K.R., Kone T., Aby N., Traore S., Dogbo D.O. and Kone M. (2019). Performances comparees de vivo plants issus de deux techniques de multiplication chez trois cultivars de bananier plantain [Musa paradisiacal, (musaceae)] a azaguie. *Agronomie africaine* **8**, 115–126.

Kwa M. (2003). Activation de bourgeons latents et utilisation de fragments de tige du bananier pour la propagation en masse de plants en conditions horticoles in vivo. *Fruit* **58**, 315–328.

Lama M., Sidibe N. and Barry M.L. (1993). Étude de comportement de deux variétés de bananier plantain en milieu paysan en Guinée Maritime (Guinée Conakry). *InfoMusa* **1**, 11–12.

Lamare A. and Rao S. (2015). Efficacy of RAPD, ISSR and DAMD markers in assessment of genetic variability and population structure of wild Musa acuminata colla. *Physiology and Molecular Biology of Plants* **21**, 349–358.

Lê S., Josse J., Husson F. and Mazet J. (2008). FactoMineR: an R package for multivariate analysis. *Journal of Statistical Software* **25**(1), 1–18.

Lemchi J.I., Ezedinma C.I., Tshiunza M., Tenkouano M. and Faturoti B.O. (2005). Agroeconomic evaluation of black Sigatoka resistant hybrid plantains under smallholder management systems. *African Journal of Biotechnology* **4**, 1045–1053.

Lescot T. and Ganry J. (2008). Plantain (Musa spp.) cultivation in Africa: a brief summary of developments over the previous two decades. In Dubois T., Hauser S., Staver C. and Coyne D. (eds), *International Conference on Banana and Plantain in Africa: Harnessing international partnerships to increase research impact, Vol. 879–2*. Mombassa (Kenya): Acta Horticulturae, pp. 445–455.

Litrico I. and Violle C. (2015). Diversity in plant breeding a new conceptual framework. *Trends in Plant Science* **20**(10), 604–613.

Marimuthu Somasundaram S., Subbaraya U., Durairajan S. G., Rajendran S., Gopalakrishnan J., Shahul Hameed B., Palani D. and Suthanthiram B. (2019). Comparison of two different electrophoretic methods in studying the genetic diversity among plantains (Musa spp.) using ISSR markers. *Electrophoresis* **40**(9), 1–8.

Melin P., Plaud G.T.D.M. and Hugues H.T. (1976). Potentiel de productivité de deux cultivars de French plantain. *Fruits* **31**, 655–657.

Mobambo K.N., Gauhl F., Vuylesteke D., Ortiz R., Pasberg-Gauhl C. and Swennen R. (1993). Yield loss in plantain from black sigatoka leaf spot and field performance of resistant hybrids. *Field Crops Research* **35**, 35–42.

Murray D. B. (1960). The effect of deficiences of the major nutrients on growth and leaf analysis of the banana. *Tropical Agriculture, Trinidad and Tobago* **37**, 97–106.

N'Da Adopo A., Amafon Aguie G., Kehe M., Kamara F. and Fofana V. (1998). Les perspectives d'évolution du circuit de distribution de la banane plantain en Côte d'Ivoire. In Picq C., Fouré E. and Frison E.A. (eds), *Bananas and Food security. Les productions bananières : un enjeu économique majeur pour la sécurité alimentaire*. Douala (Cameroun): INIBAP, pp. 537–553.

Ndemba B.A. (2003). Biodiversité et savoirs paysans sur les plantains dans la province du sud Cameroun. Université de Dschang, Faculté d'Agronomie et des Sciences sociales. CARBAP, Centre Africain de Recherche sur Bananier et Plantains, p. 114.

Ngoh Newilah G., Tchango Tchango J., Fokou E. and Etoa F.-X. (2005). Processing and food uses of bananas and plantains in Cameroon. *Fruits* **60**, 245–253.

Norgrove L. and Hauser S. (2014). Improving plantain (Musa spp. AAB) yields on smallholder farms in West and Central Africa. *Food Security* **6**, 501–514.

Noyer J.L., Causse S., Tomekpe K., Bouet A. and Baurens F.C. (2005). A new image of plantain diversity assessed by SSR, AFLP and MSAP markers. *Genetica* **124**, 61–69.

Nyoneng A.N. (2003). Biodiversité et ethnobotanique des plantains et bananiers d'altitude en écosystème cultivé dans l'ouest du Cameroun. In *CARBAP*, Vol. Ingénieur Agronome: FASA Dschang.

Odah K., Aziadekey M., Tozo K., Akpavi S., Koukouma R., Guelly A., Kokou K., Assignon K., Akogo Y., Aidam A., Akpagana K., Kenny L., Ait-Oubahou A., Zinsou C. and Gbeassor M. (2013). The genetic diversity of plantain grown in the western area of ??the Plateaux Region, Togo.[French]. *International Journal of Biological and Chemical Sciences* **7**, 1910–1918.

Oppong K.E.Y., Banful B., Anno N.F.O. and Moses E. (2004).Characterization and preliminary evaluation of local plantain (Musa spp. ABB group) landraces in Ghana. 81–84: MUSACO Report of the fourth Annual Steering Committee meeting held in East Legon, Accra, Ghana, 2–4 April, 2001. 2004; 81–84.

Orluchukwu J.A. and Ogburia M.N. (2014). The relationship of growth and yield components of different plantain (Musa spp.) cultivars in a humid area of southern Nigeria. *Advances in Life Sciences* **4**, 37–43.

Ortiz R. and Langie H. (1997). Path analysis and ideotypes for plantain breeding. *Agronomy Journal* **89**, 988–994.

Ortiz R., Madsen S. and Vuylsteke D. (1998). Classification of African plantain landraces and banana cultivars using a phenotypic distance index of quantitative descriptors. *Theoretical and Applied Genetics* **96**, 904–911.

Ortiz R. and Vuylesteke D. (1998). Quantitative variation and phenotypic correlations in banana and plantain. *Scientia Horticulturae* **72**,239–253.

Osseni B., Séry Z., N'Guessan A. and Yao N.T. (1998). Evolution des circuits de commercialisation de la banane plantain à l'échelle d'une petite localité du sud forestier de la Côte d'Ivoire. In Picq C., Fouré E. and Frison E.A. (eds), *Bananas and Food security. Les productions bananières : un enjeu économique majeur pour la sécurité alimentaire*. Douala (Cameroun): INIBAP, pp. 555–564.

Osuji J.O., Okoli B.E., Vuylsteke D. and Ortiz R. (1997). Multivariate pattern of quantitative trait variation in triploid banana and plantain cultivars. *Scientia Horticulturae* **71**, 197–202.

Pinar H., Bircan M., Unlu M., Turkay C., Uzun A., Ercisli S. and Hanci F. (2020). Selection and identification of superior banana phenotypes from Turkey. *Genetic Resources and Crop Evolution* **68**, 667–677.

Quénéhervé P., Barrière V., Salmon F., Houdin F., Achard R., Gertrude J.-C., Marie-Luce S., Chabrier C., Duyck P.-F. o. and Tixier P. (2011). Effect of banana crop mixtures on the plant-feeding nematode community. *Applied Soil Ecology* **49**, 40–45.

Ramcharan C. and Gonzalez A. (1984).Yield, Agronomic Characteristics and Variability of 'Regular Maricongo' and 'Dwarf Plaintains' (Musa AAB) Using Tissue-Cultured Plantlets in St. Croix, USVI. In *Small farm systems in the caribbean*, Vol. 20, 21–26 ST. CROIX, U.S. VIRGIN ISLANDS: Caribbean food crops society.

Robinson J.C., Nel D.J. and Eckstein K. (1993). A field comparison of ten Cavendish sub-group banana cultivars and selections (Musa AAA) over four crop cycles in the subtroDics. *Journal of Horticultural Science* **68**, 511–521.

Rodrigues F.E., Librelon S.S., Nietsche S., Costa M.R. and Pereira M.C.T. (2012). Genetic variability in clones of 'Prata Anã' bananas based on phenotypic and molecular markers. *Bragantia* **71**, 182–189.

Schill P.F., Afreh Nuamah K., Gold C.S. and Green K.R. (2000). Farmers' perceptions of constraints to plantain production in Ghana. *International Journal of Sustainable Development and World Ecology* **7**, 12–24.

Selatsa A A., Tenkouano A., Njukwe E., Iroume R.N. and Bramel P.J. (2009). Morphological diversity of plantain (Musa sp. L. AAB Group) in Cameroon: Relationships to farmer's cultural practices. *The African Journal of Plant Science and Biotechnology* **1**, 51–58.

Shaibu A.A., Maji E.A. and Ogburia M.N. (2012). Yield evaluation of plantain and banana landraces and hybrids in humid agro ecological zone of Nigeria. *Journal of Agricultural Research and Development* **2**, 74–79.

Shaibu A.A., Nwonuala A.I., Tenkouano A. and Ogburia M.N. (2003). Agronomic performance of 4n x 2n derived plantain (Musa sp. AAB group) hybrids in humid agro-ecological zone of Nigeria. *International Journal of Agriculture and Rural Development*, **4**, 1–8.

Sibide A., Ontsougou F., Traore B., Keita S. and Sanogo N.P. (2006). Adaptabilité du bananier plantain (Musa paradisiaca) aux conditions pédoclimatiques de Katibougou. In *ACORBAT, Vol. 2* Joinville (Brésil), pp. 113–119.

Swennen R., Vuylsteke D. and Ortiz R. (1995). Phenotypic diversity and patterns of variation in West and Central African Plantains (Musa Spp, Aab Group Musaceae). *Economic Botany* **49**, 320–327.

Tezenas du Montcel H. (1983). Variabilité dans l'ensemble des cultivars de plantains de la collection d'Ekona au Cameroun. *Fruits* **38**, 246–255.

Tezenas du Montcel H. (1993). Amélioration génétique des bananiers pour la résistance aux maladies et ravageurs : stratégie d'amélioration. Fruits **48**, 11–14.

Tezenas du Montcel H., De Langhe E. and Swennen R. (1983). Essai de classification des bananiers plantains (Musa AAB). *Fruits* **38**, 461–474.

Ude G., Pillay M., Ogundiwin E. and Tenkouano A. (2003). Genetic diversity in an African plantain core collection using AFLP and RAPD markers. *Theoretical and Applied Genetics* **107**, 248–255.

Vuylesteke D. and Swennen R. (1990). Somaclonal variation en African plantains. *IITA Research* **1**, 4–10.

Vuylsteke D. and Swennen R. (1993).Genetic improvement of plantains: the potential of conventional approaches and the interface with in-vitro culture and biotechnology. 169–176: Proceedings of the workshop on biotechnology applications for banana and plantain improvement held in San Jose, Costa Rica, 27–31 January 1992. 1993. 169–176. 25 ref.

Vuylsteke D., Swennen R. and Ortiz R. (1993). Registration of 14 improved tropical Musa plantain hybrids with Black Sogatoka resistance. *HortScience* **28**, 957–959.

Yao N. (1988). Enquête sur les systèmes de culture intégrant le bananier plantain en milieu paysan de Côte d'Ivoire. *Fruits* **43**, 149–159.

Youmbi E., Fonkam N.J.P., Ngaha D., Nkeng M.N. and Kwa M. (2005). Comportement de vitroplants de bananiers plantains issus de bourgeons axillaires et apicaux au cours de l'acclimation et en champs. *Fruit* **60**, 91–100.

Cite this article: Dépigny S and Damour G. Trait-based description of the agronomic and usage potential of a range of plantain varieties from Cameroon. *Experimental Agriculture*. https://doi.org/10.1017/S0014479722000503