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Original article

Morphological characterization of pineapple (*Ananas comosus*) genetic resources from Benin

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Summary

Introduction – **The narrow knowledge of the genetic variability in cultivated pineapple in the Republic of Benin and in other West African countries limits its efficient use and its expansion in the international market; it also hinders the efficient development of pineapple while the crop is listed among the top three priority fruit species to be promoted in Africa.** *Materials and methods* – **In this study, we assessed pineapple morphological diversity of 55 accessions collected in Benin. Ten qualitative and twenty quantitative traits were used to describe them. Stepwise discriminant analysis and hierarchical cluster analysis were performed to identify quantitative morphological traits which best differentiate accessions and group them into cultivars/morphotypes.** *Results and discussion* – **Five pineapple cultivars were identified and characterized for Benin, including 'Smooth Cayenne', 'Baronne de Rothschild', 'Pérola', 'Singapore Spanish', and 'Green Spanish'. We observed significant morphological variation among the cultivars. The collected materials were grouped in three clusters based on flowering date, fruit diameter, fruit shelf life, water content, leaf width, fruit weight and the crown height and weight. Correlation analyses between descriptors revealed positive relationships between fruits weight, peduncle diameter, and conicity index in 'Cayenne' and 'Spanish'.** *Conclusion* – **This study showed the existence of clear morphological variation among pineapple cultivars which could be used for fruit improvement through clonal selection and farmer training on propagule production and crop homogeneity. 'Singapore Spanish' and 'Green Spanish' could be promoted for their attractive shell color and long shelf life.**

Keywords
Benin, pineapple, *Ananas comosus*, cultivars, descriptors list, diversity

Significance of this study

What is already known on this subject?
- Untill recently, only two pineapple cultivars were reported in Benin: 'Smooth Cayenne' and 'Sugarloaf'.
- While fruit heterogeneity is said to decrease the product quality particularly for the international market, little is known about morphological variations in cultivated pineapple.

What are the new findings?
- Based on morphological traits, five pineapple cultivars were identified in the production systems of Benin, instead of two. These include: 'Pérola', 'Smooth Cayenne', 'Baronne de Rothschild', 'Green Spanish' and 'Singapore Spanish'.
- Most morphological variation was found between cultivars, however within-cultivar variation justifies clonal selection for quality and uniformity.
- Cultivars Singapore Spanish and Green Spanish presented a longer shelf life and could be promoted for their naturally colored shell trait as well.

What is the expected impact on horticulture?
- The recognition of the pineapple cultivars by farmers through capacity building should help reduce fruit heterogeneity.
- Arrangement of the dumpling at the beginning of production
- 'Singapore Spanish' and 'Green Spanish' should be promoted for their vivid natural shell color and their very long shelf life.

Introduction

Pineapple [*Ananas comosus* (L.) Merr.] is the third tropical fruit crop commercialized in the world. In 2016 its world production reached 25.8 Mt. In West Africa, pineapple is the second most important cultivated fruit after banana (Factfish, 2018). The fruit is rich in vitamins (*e.g.*, A and C), minerals, fibers, phytonutrients and proteins (Bartolomé *et al.*, 1995). It has medicinal properties as well (Okafor *et al.*, 2011) and represents cheap but quality nutrition for a large number of people and offers an opportunity for improving the nutritional status of many families (Hossain *et al.*, 2015). In Benin, pineapple is mostly cul-

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tivated in the South for its fresh fruit. It appears as one of the fruits that contribute to household income because of its high market demand (Picha, 2006). Over the past few decades, pineapple production has grown steadily from 37,600 t in 1995 to 215,000 t in 2015 in Benin (Factfish, 2018).

Ananas comosus encompasses five botanical varieties, of which *A. comosus* var. *comosus* is the edible pineapple. From the many cultivars observed in tropical America (Coppens d'Eeckenbrugge *et al.*, 1997b; Duval *et al.*, 1997), only five have taken economic importance in other tropical regions: 'Smooth Cayenne', 'Pérola', 'Singapore Spanish', 'Selangor Green', and 'Queen' (Coppens d'Eeckenbrugge *et al.,* 1997). 'Sugarloaf' (syn. 'Pérola') and 'Smooth Cayenne' have been the only two cultivars frequently reported in Benin.

In the pineapple production system of Benin, a major constraint that reduces the export potential is related to fruit heterogeneity, so that the produce does not meet quality requirements of international markets (Fassinou Hotegni *et al.*, 2014). Despite the efforts made to increase the export to Europe (the main international fresh pineapple market available), the share of Benin is still limited to less than 2% of its production (Fassinou Hotegni, 2014). The remaining pineapple, of lower quality, is delivered to local and regional markets resulting in a revenue shortfall for producers. The heterogeneity observed in fruit production can be caused by several reasons, including agronomic practices and planting material heterogeneity.

Indeed, previous studies by Fassinou Hotegni *et al.* (2014; 2015a, b) addressed fruit heterogeneity issues through agronomic practices including flowering and maturity synchronization. However, planting material heterogeneity can also be a source of fruit heterogeneity. Achigan-Dako *et al.* (2014) indicated that farmers had limited knowledge on pineapple cultivars. According to farmers, one or two cultivars only were available in their plots. These include 'Smooth Cayenne', a cultivar for export to regional and international markets, and 'Sugarloaf' ('Pérola'), the most used cultivar, well appreciated by local consumers for its flesh that is less acidic and sweeter, and with a thinner central core (Baafi *et al.*, 2015). These two cultivars are commonly recognized by the presence or absence of leaf spine and fruit shape, though those traits are not specific to them. Morphological characterization of 'Sugarloaf' in Côte d'Ivoire revealed important variability (Baafi *et al.*, 2015). Cultivar heterogeneity complicates the application of rigorous quality criteria and increases fruit elimination during sorting. Furthermore, collecting missions conducted by Agbangla *et al.* (2013) and Tossou *et al.* (2015) indicated that there are more than two pineapple cultivars in Benin. Such observations raised the question on (i) how the genetic diversity and variation in pineapple resources is organized, and (ii) how genetic variation can be managed to solve the problem of pineapple fruit heterogeneity, which is a real concern for researchers and farmers.

The present study aims at assessing the morphological diversity of pineapples cultivated in Benin. A better understanding of pineapple cultivar diversity will certainly contribute to address the issue of heterogeneity, thus improve our knowledge of the agro-morphological diversity of pineapple to set up an efficient pineapple improvement program.

Materials and methods

Study area

The experiment was carried out on the farm of the Faculty of Agronomic Sciences in Sekou (southern Benin). This site belongs to the Guinean phytogeographical region (White, 1986), between 6°25' and 7°30'N; 2° and 2°30'E, with a semi-deciduous rainforest. The soil is ferralitic (Azontondé, 1991). The area is characterized by a sub-equatorial climate with two rainy seasons and two dry seasons. The mean annual rainfall varies from 950 to 1,400 mm over 240 days. The mean annual temperature is 26 ± 2.5 °C. The local economy is based on agriculture with production systems dominated by maize, cassava, oil palm and pineapple (Agbangba *et al.*, 2010).

Plant material and field experiments

Two exploration missions were carried out, from August to September 2013 and from April to May 2014, in municipalities of southern and central Benin, to collect pineapple planting materials: suckers and slips. At the end of the exploration missions, 55 accessions were collected from farmers with at least ten propagules for each accession (Table 1). These planting materials were grown in Sekou for the morphological characterization of the genotypes.

The set of ten planting materials of each genotype collected from the farmers' fields were installed on an experimental plot. The plot dimension was 2.0 × 1.2 m. Planting materials were arranged in double planting rows with 80 cm between rows and 40 cm between plants. Dimethoate 40% and Thiophanate methyl 70% were applied on the plots to control soil insects and nematodes, respectively.

Common agronomic practices included weeding at three, six and nine months after planting. Mineral fertilization consisted of 10 g of a mixture of urea (46 N) and NPK (10-20-20) for each plant at 4 and 10 months after planting. Flowering was induced 13 months after planting. The experiment was conducted between September 2013 and May 2016.

Data collection

We used 20 quantitative and 10 qualitative traits selected among the pineapple descriptors (IBPGR, 1991) to describe accessions (Table 2). Data were collected on 55 individuals (ten plants in each plot) at flowering time (14 months after planting) and during harvest time (18 to 20 months after planting).

Recorded plant traits include plant height, leaf number, peduncle length and diameter, and flowering time (number of days from floral induction); recorded leaf traits include length, width, and color, observed on the longest leaf; fruit traits include weight, height, color; basal, middle and upper diameter; shape, shell color, texture, firmness, flesh color, aroma, total soluble solids (TSS), dry matter, water content, fruit shell thickness; fruitlet width, crown height and weight, fruit shelf life. The TSS were measured using a digital refractometer (HI 96801, Hanna Instruments, UK). The juice was collected at the top, middle and bottom of each fruit. The samples were measured after a simple calibration with distilled water. The refractive index of the sample was recorded as °Brix. Each experimental value is the mean of the three samples made of the different parts of the fruit.

The dry matter was measured by cutting 100 g of upper, middle and lower slices fresh fruit with skin and drying it in a 100% stainless steel incubator for 24 h at less than 100 °C, then weighed every hour to check that there is no variation.

Shelf life was estimated by storing after harvest a batch of three healthy fruits per cultivar at room temperature until they started to lose juice and firmness. Data were collected on each fruit and the average was calculated. Metric characters were measured using a Vernier caliper (± 0.02 mm) and

Table 1. List and provenance of 55 pineapple accessions collected in Benin and used for morphological characterization.

Acc. No.	Common local name	Cultivar	Village	Municipality	Climatic zone
EAD1687	Pain de Sucre	Pérola	Agamey	Dogbo	Guinean
EAD1644	Cayenne Lisse	Smooth Cayenne	Allada	Allada	Guinean
EAD1734	Pain de Sucre	Pérola	Allada Donou	Allada	Guinean
EAD1751	Cayenne Hoho	Baronne de Rothschild	Allada Donou	Allada	Guinean
EAD1784	Cayenne Hoho	Baronne de Rothschild	Dedomey	Kpomasse	Guinean
EAD1698	Pain de Sucre	Pérola	Djakotomey	Djakotomey	Guinean
EAD1708	Adjago	Smooth Cayenne	Djanglamey	Toffo	Guinean
EAD1719	Pain de Sucre	Pérola	Gbewedji Toffo	Toffo	Guinean
EAD1724	Cayenne Lisse	Smooth Cayenne	Gbewedji Toffo	Toffo	Guinean
EAD1730	Adjago	Smooth Cayenne	Gbewedji Toffo	Toffo	Guinean
EAD1580	Adjago	Smooth Cayenne	Colli Toffo	Toffo	Guinean
EAD1593	Pain de Sucre	Pérola	Colli Toffo	Toffo	Guinean
EAD1606	Adjago	Smooth Cayenne	Dame Toffo	Toffo	Guinean
EAD1623	Pain de Sucre	Pérola	Dame Toffo	Toffo	Guinean
EAD176	Pain de Sucre	Pérola	Tori	Tori	Guinean
EAD1679	Pain de Sucre	Pérola	Lokossa	Lokossa	Guinean
EAD1821	Pain de Sucre	Pérola	Ketou	Ketou	Guinean
EAD1678	Pain de Sucre	Pérola	Sakete	Sakete	Guinean
EAD1757	Pain de Sucre	Pérola	Yokpo Ze	Ze	Guinean
EAD1774	Cayenne Lisse	Smooth Cayenne	Yokpo Ze	Ze	Guinean
EAD1840	Adjago	Smooth Cayenne	Setto Djidja	Djidja	Sudano-Guinean
EAD1845	Pain de Sucre	Pérola	Setto Djidja	Djidja	Sudano-Guinean
EAD1850	Ognimon	Singapore Spanish	Setto Djidja	Djidja	Sudano-Guinean
EAD1855	Ognimon Ognibo	Green Spanish	Setto Djidja	Djidja	Sudano-Guinean
EAD1859	Cayenne Lisse	Smooth Cayenne	Setto Djidja	Djidja	Sudano-Guinean
EAD1445	Cayenne Lisse	Smooth Cayenne	Ouoghi 1	Save	Sudano-Guinean
EAD1456	Ognimon Ognibo	Green Spanish	Ouoghi 1	Save	Sudano-Guinean
EAD1463	Ognimon	Singapore Spanish	Ouoghi 1	Save	Sudano-Guinean
EAD1474	Pain de Sucre	Pérola	Ouoghi 2	Save	Sudano-Guinean
EAD1481	Ognimon Ognibo	Green Spanish	Ouoghi 2	Save	Sudano-Guinean
EAD1494	Cayenne Lisse	Smooth Cayenne	Ouoghi 3	Save	Sudano-Guinean
EAD1648	Adjago	Smooth Cayenne	Ouinhi	Ouinhi	Sudano-Guinean
EAD1862	Pain de Sucre	Pérola	Ouinhi Zoungo	Ouinhi	Sudano-Guinean
EAD1871	Ognimon Ognibo	Green Spanish	Ouinhi Zoungo	Ouinhi	Sudano-Guinean
EAD1831	Ognimon Ognibo	Green Spanish	Zapota	Zapota	Sudano-Guinean
EAD1834	Adjago	Smooth Cayenne	Zapota	Zapota	Sudano-Guinean
EAD1837	Ognimon	Singapore Spanish	Zapota	Zapota	Sudano-Guinean
EAD1667	Ognimon Ognibo	Green Spanish	Zangnanado	Zangnanado	Sudano-Guinean
EAD1673	Adjago	Smooth Cayenne	Zangnanado	Zangnanado	Sudano-Guinean
EAD1502	Adjago	Smooth Cayenne	Massi	Zogbodomey	Sudano-Guinean
EAD1525	Ognimon Ognibo	Green Spanish	Massi	Zogbodomey	Sudano-Guinean
EAD1550	Adjago	Smooth Cayenne	Tanwehessou	Zogbodomey	Sudano-Guinean
EAD1562	Pain de Sucre	Pérola	Tanwehessou	Zogbodomey	Sudano-Guinean
EAD1571	Ognimon	Singapore Spanish	Tanwehessou	Zogbodomey	Sudano-Guinean
EAD1330	Pain de Sucre	Pérola	Bante Cerpa	Bante	Sudano-Guinean
EAD1340	Pain de Sucre	Pérola	Bante Gouka	Bante	Sudano-Guinean
EAD1351	Pain de Sucre	Pérola	Bante Gouka	Bante	Sudano-Guinean
EAD1358	Cayenne Lisse	Smooth Cayenne	Bante Gouka	Bante	Sudano-Guinean
EAD1369	Ognimon	Singapore Spanish	Bante Gouka	Bante	Sudano-Guinean
EAD1383	Ognimon Ognibo	Green Spanish	Bante Gouka	Bante	Sudano-Guinean
EAD1402	Ognimon	Singapore Spanish	Dassa Soclogbo	Dassa	Sudano-Guinean
EAD1411	Pain de Sucre	Pérola	Dassa Soclogbo	Dassa	Sudano-Guinean
EAD1430	Pain de Sucre	Pérola	Glazoue Zaffe	Glazoue	Sudano-Guinean
EAD1436	Ognimon Ognibo	Green Spanish	Glazoue Zaffe	Glazoue	Sudano-Guinean
EAD1441	Adjago	Smooth Cayenne	Glazoue Zaffe	Glazoue	Sudano-Guinean

Table 2. Quantitative and qualitative traits, data collection time, and measurement methods of 55 pineapple accessions collected in Benin.

No.	Quantitative traits					Qualitative traits		
	Plant part	Trait	Code	Data collection time	Measurement method	Trait	Code	Modalities
1	Whole plant	Number of leaves	Phy	At flowering	Counted from the base of the root to the last in the plant center	Plant posture	Lsh	Erect; Semi erect
2		Plant height (cm)	Plh		Measured vertically from the soil to the top of the highest leaf	Leaf color	Lvc	Green white; Light green; Red purple; Yellow green
3	Leaf	Leaf length (cm)	Lel		Length of the D-leaf measured from its base to its apex	Distribution of leaf thorns	Dep	Whole (all); Partial (Top)
4		Leaf base width (cm)	Lbw		Measured at the leaf base	Fruit shape	Frf	Oval; Ovoid; Pyramidal
5	Inflorescence	Flowering time (days)	Flt		Number of days between induction and flowering	Flesh aroma	Ari	Rich; Medium
6	Fruit	Peduncle length (cm)	Pel	At harvest	Measured from the soil to the fruit base	Flesh firmness	Fir	Firm; Medium
7		Peduncle diameter (cm)	Ped		Measured at the fruit base	Texture	Tex	Fibrous; Less fibrous
8		Fruit height (cm)	Frh		Measured from the fruit base to the crown base	Fruit color	Frc	Yellow; Orange; Greyed orange; Light green
9		Basal diameter (mm)	Fbd		Measured at the fruit base	Flesh color	Flc	Yellow; Yellow white; Yellow pale; Orange
10		Middle diameter (mm)	Fmd		Measured at fruit midheight	Calyx color	Cab	Yellow; Red
11		Upper diameter (mm)	Fud		Measured below the crown			
12		Fruit weight (kg)	Frw					
13		Total soluble solids (°Brix)	Sug		Measured with a refractometer			
14		Fruit skin thickness (mm)	Fst		Measured with a Vernier calliper (0.02 default)			
15		Fruitlet width (mm)	Scw		Measured with a Vernier calliper (0.02 default)			
16		Water content (%)	Wac		Using an incubator			
17		Dry matter (g 100 g^{-1})	Drw					
18		Crown length (cm)	Crl					
19		Crown weight (g)	Crw					
20		Fruit shelf life (days)	Lil		Measured between harvesting and rotting			

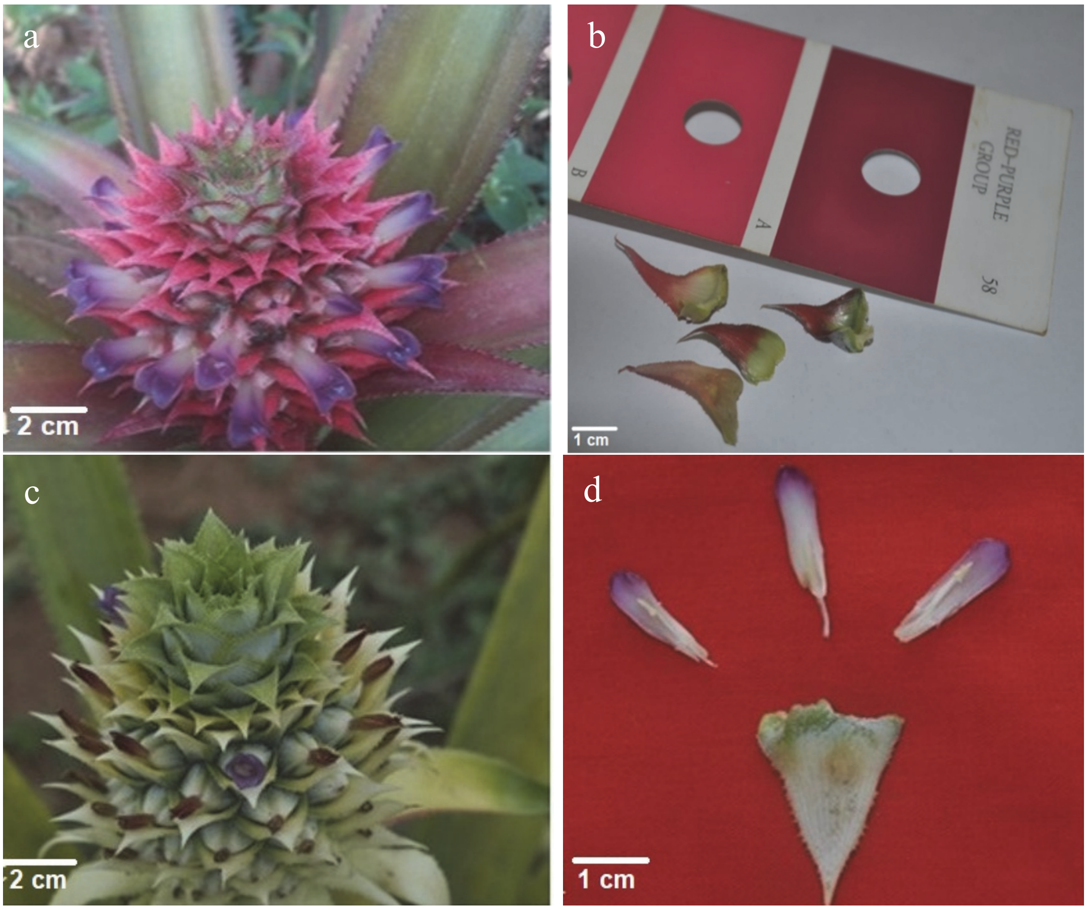

FIGURE 1. Inflorescence types in pineapple germplasm collected in Benin. a), b): Flowers with red sepals ('Singapore Spanish'); c), d): Flowers with green white sepals ('Green Spanish').

weights were obtained using an electronic scale (±0.2 g). Color identification was based on the color chart of the Royal Horticultural Society (RHS, 1995) (Figure 1). Herbarium specimens were deposited at the National Herbarium of Benin at the University of Abomey-Calavi, Benin.

Data analysis

All quantitative variables were tested for normality. Descriptive statistics such as maximum and minimum values, means, standard deviation, and coefficient of variation were computed. Linear mixed effect models were used to investigate variations of quantitative traits of pineapple using cultivar as a fixed factor and origin as a random factor. The ratio of fruit basal diameter over fruit upper diameter was calculated as an index of fruit conicity. A hierarchical cluster analysis was performed using all the 30 morphological traits (both quantitative and qualitative) to define groups of relatively similar individuals with Gower algorithm. Correlation matrices were computed for the whole sample as well as for groups of accessions sharing a same ancestry. A stepwise discriminant analysis was used to identify the morphological traits which best differentiate the fore defined pineapple clusters. Clusters were then described based on the selected traits through a canonical discriminant analysis. All analyses were done using the R version 3.2.3 (Husson *et al.*, 2013).

Results and discussion

Varietal identification of accessions

Accessions were identified after fruit production using altogether farmers' description of materials, botanical data from the live collection, and previous descriptions by Py *et al.* (1987), and Chan *et al.* (2003). The identification was based on leaf traits and number of leaves, flowers, fruits traits, and plant growth. Based on the initial description, all 55 genotypes were gathered into four morphological classes corresponding to five cultivars (Figure 2).

A first group included 18 accessions of 'Smooth Cayenne', with local names such as 'Adjago', and 'Cayenne Lisse', and two accessions of its spiny derivative, *i.e.*, 'Baronne de Rothschild', locally named 'Cayenne Hoho'. 'Smooth Cayenne' accessions were characterized by smooth or partially spiny leaf, medium-sized fruits (1–2 kg) to large-sized fruits (up to 4 kg), cylindrical to oval shape, with large flat eyes and light-yellow flesh that was sweet and fibrous. TSS was high (12–16 °Brix). The fruit ripened steadily, turning yellow from the base.

Twenty accessions of 'Pérola' were also collected, commonly called 'Sugarloaf' or its French equivalent 'Pain de Sucre'; the plant was erect and medium-sized with spiny green leaves, and basal slips surrounding the medium-sized fruit. The latter, borne on a long peduncle, was dark green and

FIGURE 2. Fruit shapes and colors in pineapple germplasm collected in Benin. a): Cylindrical ('Singapore Spanish'); b), c): Ovoid fruits turning orange, grey and yellow, ('Singapore Spanish' and 'Green Spanish', respectively); d), e): Conical or pyramidal yellow and green fruits ('Pérola'); f): Oval green unripe fruit turning yellow at maturity ('Smooth Cayenne').

turned to yellow when ripe, with an irregular conical or pyramidal shape; the flesh was white to pale yellow, firm, juicy and sweet, ranging from 10 to 16 °Brix. The slips were many, from four to more than twelve.

We found six accessions of 'Singapore Spanish', locally called 'Ognimon'. The flesh was firm, pale, aromatic and sweet, with moderate TSS (around 12 °Brix). The plant was medium-sized, with spiny dark green leaves, tinged with anthocyanins. Floral bracts showed an intense bright red color (Figure 1a). The plant produced a small cylindrical fruit (0.5–1.0 kg), slips (about four to seven for four typical 'Singapore Spanish' accessions and one to three for the two others) and suckers.

Finally, there were nine accessions of 'Green Spanish' (syn. 'Selangor Green' and 'Green Pine'), locally called 'Ognimon Ognibo'. This cultivar is very closely similar to 'Singapore Spanish', from which it appears to differ by a mutation suppressing anthocyanins in all organs, except for the petals. Indeed, the leaves and inflorescences were uniformly green, the sepals pale yellow and the fruit yellow at maturity (Figure 2c).

A higher cultivar diversity was observed in the central region of Benin, where pineapple cultivation is not intensive. On the whole, five pineapple cultivars were found and characterized, contrary to the widespread information that there were only two cultivars in the country (Achigan-Dako *et al.*, 2014; Arinloye *et al.*, 2015; Fassinou Hotegni *et al.*, 2012). Those cultivars included 'Smooth Cayenne', the most common cultivar in the world, 'Pérola', the most important cultivar in Brazil, also present in western Africa, as well as 'Singapore Spanish' and its anthocyan-less form 'Green Spanish'. In itself, this roster reflects and complements the history of pineapple diffusion throughout the Old-World tropics.

The most ancient cultivars are 'Singapore Spanish' and 'Green Spanish'. The former was also collected from feral populations in Côte d'Ivoire and Cameroon (Coppens d'Eeckenbrugge *et al.*, 1997a), while both cultivars have been reported in South Asia and South-East Asia (India, Thailand, Vietnam, Indonesia, Philippines, southern China), where they had been introduced by the Portuguese from eastern Brazil in the early 16th century, in a process initiated before 1505 in relation to their trade travels to the Indian Ocean (Coppens d'Eeckenbrugge *et al.*, 2018).

The Portuguese had also disseminated 'Pérola', but later and only along the Gulf of Guinea. After they had explored the Brazilian coasts further south, they discovered this excellent pineapple, and introduced it in West Africa when they engaged in systematic travels promoted by the slave trade across the southern Atlantic Ocean. This explains why 'Pérola' has not diffused around the Indian Ocean.

'Smooth Cayenne' was discovered in 1819 in French Guiana by Perrottet, from Paris; the five plants he had collected were multiplied and sent to several European and tropical countries. In the late 19th century, this cultivar arrived in Hawaii, where commercial processing of the fruit started. From then, it was closely associated to the industrial development of the pineapple, soon accounting for more than 90% of the international trade. At the end of the 20th century, 'Smooth

Cayenne' had achieved an impressive economic domination over other cultivars, in all production areas, including in West Africa.

The hegemony of 'Smooth Cayenne' has only been disputed by 'MD-2' on the international fresh fruit market. However, we have not observed this new hybrid in Benin. It has recently been introduced by the National Institute of Agricultural Research.

Variation for qualitative traits in the pineapple germplasm

Ten qualitative traits were recorded and evaluated to analyze the variation in the germplasm. These traits showed distinctive features among accessions. The leaves were arranged in a rosette around the stem. They were erect or semi-erect. Smooth or partly smooth leaves were only observed in 'Smooth Cayenne'. All other cultivars were fully spiny, including 'Singapore Spanish' and 'Green Spanish' whose spininess is highly variable in other countries, according to Chan *et al.* (2003). Thorns were distributed on the whole leaf border for 'Pérola', 'Red Spanish', and 'Green Spanish'. In 'Smooth Cayenne', a few thorns were distributed at the base and at the tip of the leaf. Leaf color varied from uniform green to purple and green yellow. We observed four main types of leaf color. The dominant colors were light green and yellow green (43.65% of the total sample), observed in 'Smooth Cayenne' and 'Green Spanish'. Other colors such as whitish green (45.45%) were found in 'Pérola', and red purple (10.90%) in 'Singapore Spanish' accessions. The flowers were small. Their corolla was purple or red, subtended by a red or purple bract (Figure 1). Red corollas were observed in 'Smooth Cayenne', 'Pérola' and 'Singapore Spanish', while purple corollas were observed in 'Green Spanish' only.

Much variation was observed in fruit shape and color (Figure 2). Fruit shape was oval, ovoid, conical or pyramidal. Oval or cylindrical fruits were recorded in 'Smooth Cayenne', 'Singapore Spanish' and 'Green Spanish'; pyramidal or conical fruits were found in 'Pérola'. Shape and size variation were observed within cultivars; conical fruits dominate in 'Pérola', but other shapes (long conical, pyriform and "cylindrical sharp taper"; see IBPGR, 1991) were found too. The same trends were noticed in 'Smooth Cayenne' and 'Baronne de Rothschild' where "reniform" and "cylindrical slight taper" shapes were found, too. Fruit color included greyish green, light green, orange, and yellow. Generally, cultivated pineapple ripen from the base to the top of the fruit. When this maturation gradient is strong, it may be expressed externally by a gradient of colors (Chan *et al.*, 2003). This was the case for 'Smooth Cayenne', 'Baronne de Rothschild' and 'Pérola'. For 'Singapore Spanish' and 'Green Spanish', there was no such gradient and their external colors were respectively uniform orange and yellow. Flesh color varied among cultivars from white, golden white for 'Pérola, yellow for 'Smooth Cayenne', 'Baronne de Rothschild' and 'Green Spanish' to orange for 'Singapore Spanish'. It did not vary appreciably among accessions from a same cultivar. The flesh was juicy and fibrous with medium firmness for 'Smooth Cayenne', 'Baronne de Rothschild' and 'Pérola' while firm and fiberless for 'Green Spanish' and 'Singapore Spanish'. Pineapple cultivars could be distinguished using leaf color and spininess, fruits color and shape, and flesh color, as established by Bartolomé *et al.* (1995).

The knowledge in shape diversity and fruit shape management could facilitate pineapple fruit sorting for international export. Tossou *et al.* (2015) reported ten shape types in 'Pérola' and four shape types in 'Smooth Cayenne'. Differences within cultivars are sometimes caused by environment, *e.g.*, nutrient deficit (Friend, 1981; Malézieux *et al.*, 2003), or cultivation practices (Cunha, 1998; González Suárez *et al.*, 1976; Lacoeuilhe *et al.*, 1978). Clonal selection of each morphological type to assess if shape and size are heritable would be a first step. Leal and Coppens d'Eeckenbrugge (1996) reported that clonal selection in pineapple allows the identification of mutants, and thence their elimination from planting materials.

Variation for quantitative traits in the pineapple cultivars

Twelve quantitative traits in (i) 'Smooth Cayenne' and its spiny variant 'Baronne de Rothschild', (ii) 'Pérola', and (iii) 'Singapore Spanish' and its anthocyan-less variant 'Green Spanish' are presented in bar charts (Table 3). Pineapple inflorescence, borne at the apex of the stem, developed about 129.67 ± 3.20 and 130.45 ± 4.24 days after induction respectively for 'Green Spanish' and 'Singapore Spanish'; 133.50 ± 5.50 days after induction for 'Pérola' and 144.30 ± 3.25 days after induction for 'Smooth Cayenne'. The lowest average values of leaf basal width were observed in 'Singapore Spanish' (4.50 ± 1.58 cm); medium values were observed in 'Cayenne' (5.19 ± 0.58 cm); and higher values in 'Pérola' (5.92 ± 0.65 cm). The heaviest fruit were observed in 'Smooth Cayenne' (mean value of 1.82 ± 0.88 kg), as also reported by Chan *et al.* (2003) and Coppens d'Eeckenbrugge *et al.* (2011). The smallest average fruits were those of 'Singapore Spanish' and 'Green Spanish' (0.70 ± 0.18 kg, 0.77 ± 0.18 kg respectively), which contrasts with the impressive development of their crown. The highest average values of fruit basal diameter were observed in 'Smooth Cayenne' (86.56 ± 13.34 mm), then come 'Pérola' (80.92 ± 13.52 mm) and 'Singapore Spanish' (72.62 ± 7.65 mm) and 'Green Spanish' (79.91 ± 8.27 mm); for the mean upper diameter, the order is different, with the lowest values observed in 'Pérola' (64.51 ± 13.97), in relation to its high conicity index (1.28 ± 0.25). Average fruit weight and length in 'Smooth Cayenne' and 'Pérola' aligned with the values reported by Singleton (1965). 'Singapore Spanish' and 'Green Spanish' showed particular fruit flesh quality, with lower soluble solids and much higher dry matter percentage. They also benefited from the longest fruit shelf life (27.13 ± 1.73 days), contrasting with 'Pérola', which showed the shortest one (13.05 ± 2.52 days).

SNK test analyses showed that traits such as fruit weight (Frw), water content (Wac), fruit dry matter (Drw), crown height (Crh), crown weight (Crw), flowering time (Flt), fruit upper diameter (Fud), fruit middle diameter (Fmd), fruit basal diameter (Fbd), fruitlet width (Scw), number of leaves (Phy), leaf basal width (Lbw) and fruit shelf life (Lif), varied significantly among cultivars ($P < 0.05$).

The distribution of the conicity index confirms fruit shape observations, as it varies strongly among cultivars. Overall, this ratio of the fruit basal diameter over fruit upper diameter is higher than 1.5 in more than 75% of 'Pérola', 56% of 'Smooth Cayenne' and 'Baronne de Rothschild', and 18% of 'Singapore Spanish' and 'Green Spanish', with respective mean values of 1.28 ± 0.24, 1.21 ± 0.2 and 1.10 ± 0.19 for these three groups of accessions. In three accessions of 'Singapore Spanish' and three of 'Green Spanish', the mean upper fruit diameter even exceeds the mean fruit basal diameter. The largest diameter of the peduncle was found in 'Smooth Cayenne'. This is consistent with information collected from

TABLE 3. Minimum, maximum, mean value and standard deviation (SD) values of quantitative traits in pineapple cultivars collected in Benin. For units, see Table 2. Codes for characters (in alphabetic order): Crh: Crown height; Crw: Crown weight; Drw: Dry matter, Fbd: Fruit basal diameter; Flt: Flowering time; Fmd: Fruit middle diameter; Fud: Fruit upper diameter; Frh: Fruit length; Fst: Fruit skin thickness; Frw: Fruit weight; Lel: Leaf length; Lbw: Leaf base width; Lil: Fruit shelf life; Ped: Peduncle diameter; Pel: Peduncle length; Phy: Number of leaves; Plh: Plant height; Scw: Fruitlet width; Sug: Total soluble solids; Wac: Water content.

Cultivars	Lel	Lmw	Phy	Plh	Flt	Frh	Fbd	Fmd	Fud	Frw	Sug	Fst	Scw	Wac	Drw	Crh	Crw	Pel	Ped	Lif
Green Spanish																				
Minimum	72.47	4.00	28.00	44.00	125.00	10.50	63.39	79.24	56.70	423.45	9.00	8.33	19.12	68.20	21.20	18.00	216.55	32.00	1.30	25.00
Maximum	112.50	6.70	66.00	96.00	132.00	23.70	90.03	100.82	96.30	1,004.73	11.00	14.07	25.20	78.80	31.80	32.14	299.60	48.80	2.20	29.00
Mean	85.92	5.26	42.03	77.24	129.67	14.95	79.91	93.92	72.47	774.01	9.44	11.09	22.60	75.08	24.92	25.77	268.21	41.10	1.82	27.00
SD	14.34	1.01	11.30	16.21	3.20	3.93	8.27	8.29	12.77	199.84	0.73	1.92	1.75	4.08	4.08	4.67	27.93	5.50	0.28	1.32
Singapore Spanish																				
Minimum	62.00	3.30	20.00	46.00	123.00	10.00	65.66	86.40	61.62	451.60	8.50	8.70	20.60	69.40	21.50	19.50	155.50	31.00	1.30	25.00
Maximum	86.65	5.40	45.20	82.50	135.00	16.70	84.44	102.82	76.57	993.08	12.00	13.34	22.92	78.50	30.60	31.50	314.85	44.00	1.95	30.00
Mean	73.50	4.50	32.81	63.67	130.45	13.48	72.65	94.64	69.96	706.81	9.92	11.40	21.60	73.98	26.02	26.86	264.85	38.38	1.71	27.33
SD	10.92	0.78	10.22	16.03	4.24	2.40	7.63	6.04	5.30	181.59	1.20	1.72	0.94	3.75	3.75	4.54	57.06	4.89	0.24	2.34
Pérola																				
Minimum	40.00	4.00	24.00	42.00	120.00	13.10	58.62	75.76	48.17	697.85	10.00	8.70	18.01	82.60	11.30	10.50	130.92	29.60	1.35	10.00
Maximum	94.00	6.50	66.00	94.50	142.00	32.00	115.24	116.62	98.45	2,513.10	16.00	15.45	28.75	88.70	17.40	26.50	373.00	49.00	3.00	20.00
Mean	79.10	5.19	39.56	73.79	133.50	18.91	80.92	96.85	64.51	1,373.80	12.03	10.98	21.76	85.60	14.40	20.18	184.20	41.45	1.94	13.05
SD	13.04	0.66	10.96	15.23	5.50	6.62	13.53	10.53	13.97	486.48	1.78	1.95	2.29	1.92	1.92	3.93	62.70	5.28	0.48	2.52
Cayenne																				
Minimum	56.50	4.00	27.00	44.00	138.00	13.50	67.13	77.80	52.07	602.80	10.00	7.14	16.97	75.57	12.06	3.50	93.05	31.00	1.30	15.00
Maximum	111.00	6.00	62.50	102.00	146.00	25.00	113.56	125.66	99.00	4,156.95	16.00	15.81	24.87	87.94	24.43	30.00	360.10	50.50	4.30	25.00
Mean	79.48	4.95	43.01	74.17	144.30	18.36	86.56	103.17	72.96	1,826.12	13.30	11.89	22.10	85.42	14.58	20.52	222.38	40.95	2.19	19.15
SD	11.75	0.58	11.64	13.59	3.25	3.87	13.43	12.93	15.30	888.46	1.34	2.37	1.93	2.82	2.82	5.98	80.56	6.04	0.73	2.56

pineapple producers in southern Benin (Achigan-Dako *et al.*, 2014).

Relationships among quantitative traits

To compute correlation matrices for accessions derived from a common clonal ancestry, three subsamples were considered: (i) the 18 'Smooth Cayenne' accessions and two 'Baronne de Rothschild' accessions (hereafter designated as the "Cayenne accession group"; (ii) the 20 accessions of 'Pérola'(hereafter referred to simply as 'Pérola'); and (iii) the six accessions of 'Singapore Spanish' and the nine accessions of 'Green Spanish' (hereafter designated as the "Spanish accession group").

On the global sample, the correlation analysis showed relatively few associations among quantitative traits (Table 4). Logically, vegetative characters (plant height and leaf traits) are positively correlated, with values around 0.50 for leaf traits and a 0.81 correlation between leaf length and plant height. These vegetative traits show no particular correlations with any fruit traits. Fruit traits show logical correlations among fruit diameters and fruitlet dimensions (from 0.45 to 0.73) as well as crown height and weight (0.47). The clear correlation between fruit weight and peduncle diameter (0.63) was also expected (Adjé, 2013).

Less expected are the very weak correlations between fruit height, basal and median diameters, and weight (between 0.20 and 0.26). Several relatively strong correlations are even more surprising, as those between fruit weight and TSS (0.57), between TSS and dry matter (-0.53), between conicity and peduncle length (0.61), between conicity and crown weight (-0.44), and between fruit weight and crown height (-0.50). Shelf life appears correlated positively with dry matter (0.73) and crown weight (0.41) and negatively with TSS (-0.41). In fact, these correlations, positive for traits associated to the Cayenne accession group, and 'Pérola', and negative for traits associated to the Spanish accession group mostly reflect the contrast between the larger and heavier fruits, often conical, with higher soluble solids, lower dry matter, and wider peduncle in the two former groups versus the smaller and more cylindrical fruits, with larger crowns, higher dry matter and longer fruit shelf life of the last one. In other words, these correlations are conditioned by the particular cultivar composition of our sample.

This interpretation is reinforced by the analysis of correlation matrices obtained within cultivars of common origins (Tables 4 and 5). In fact, the six correlations above mentioned are not confirmed within the three groups of accessions. The correlation of 0.57 between fruit weight and TSS is weaker among Cayenne accessions (0.32) and 'Pérola' (0.40) and negative for Spanish accessions (-0.50). The negative correlation (-0.53) observed for TSS and dry matter is contradicted in all three subsamples (respectively -0.15, 0.28 and 0.45). The correlation between fruit weight and crown height is only confirmed in the Cayenne accession group (-0.50), while negligible in both other groups. The high correlation between shelf life and dry matter (0.73) is confirmed in none of the three groups. The same holds true for the correlation between shelf life and crown weight, as well as for the negative correlation between shelf life and TSS. Finally, the correlation of -0.49 observed between fruit weight and dry matter is also contradicted by the low value found within the three subsamples.

All other correlations observed in the global sample appear consistent with their equivalents in the three

TABLE 4. Correlation matrices based on quantitative traits for the whole sample (normal font, below diagonal) and for accessions of cultivar Pérola (bold font, above diagonal). Codes for characters (in alphabetic order): Crh: Crown height; Crw: Crown weight; Drw: Dry matter; Fbd: Fruit basal diameter; Flt: Flowering time; Fmd: Fruit middle diameter; Fud: Fruit upper diameter; Frh: Fruit length; Fst: Fruit skin thickness; Frw: Fruit weight; Lel: Leaf length; Lbw: Leaf base width; Lil: Fruit shelf life; Ped: Peduncle diameter; Pel: Peduncle length; Phy: Number of leaves; Plh: Plant height; Scw: Fruitlet width; Sug: Total soluble solids; Wac: Water content.

	Lel	Lmw	Phy	Plh	Flt	Frh	Fdb	Fmd	Fud	Frw	Sug	Fst	Scw	Wac	Drw	Crh	Crw	Pel	Ped	Lil
Lel		**0.49**	**0.56**	**0.86**	**0.10**	**-0.14**	**0.29**	**-0.12**	**0.04**	**-0.01**	**0.15**	**0.32**	**0.26**	**0.10**	**-0.10**	**0.25**	**-0.46**	**0.30**	**0.41**	**0.04**
Lbw	0.58		**0.12**	**0.37**	**-0.20**	**-0.46**	**0.08**	**-0.04**	**0.24**	**0.16**	**0.21**	**-0.33**	**0.44**	**0.02**	**-0.02**	**0.16**	**-0.24**	**0.26**	**-0.05**	**0.06**
Phy	0.45	0.26		**0.75**	**-0.14**	**0.36**	**0.24**	**0.16**	**0.10**	**-0.17**	**0.33**	**-0.07**	**0.44**	**0.02**	**-0.02**	**0.08**	**0.17**	**0.18**	**0.03**	**-0.06**
Plh	0.81	0.50	0.50		**0.12**	**0.10**	**0.09**	**-0.09**	**-0.02**	**0.14**	**0.21**	**-0.29**	**0.21**	**0.04**	**-0.04**	**0.16**	**0.08**	**0.26**	**0.05**	**0.06**
Flt	0.06	-0.30	-0.1	0.03		**-0.22**	**-0.16**	**0.18**	**-0.15**	**0.01**	**0.14**	**0.26**	**0.15**	**-0.22**	**0.22**	**0.05**	**0.09**	**-0.03**	**0.10**	**-0.06**
Frh	0.32	0.00	0.27	0.19	-0.20		**0.13**	**0.41**	**-0.26**	**-0.23**	**0.06**	**0.37**	**0.43**	**0.41**	**-0.41**	**-0.17**	**0.42**	**0.31**	**0.13**	**-0.28**
Fbd	0.07	0.13	0.36	0.23	-0.21	0.26		**0.71**	**0.60**	**0.20**	**0.09**	**-0.21**	**0.88**	**0.34**	**-0.34**	**-0.25**	**0.02**	**0.55**	**0.57**	**0.07**
Fmd	0.07	0.10	0.31	0.09	0.19	0.25	0.73		**0.59**	**0.11**	**0.17**	**0.06**	**0.70**	**0.30**	**-0.30**	**-0.43**	**0.42**	**0.42**	**0.24**	**0.09**
Fud	0.14	0.09	0.16	0.04	-0.10	-0.15	0.57	0.64		**0.32**	**0.32**	**-0.40**	**0.53**	**-0.15**	**0.15**	**-0.15**	**0.25**	**0.02**	**0.12**	**-0.30**
Frw	0.00	0.09	0.03	0.15	0.00	0.20	0.37	0.31	0.09		**0.40**	**-0.16**	**0.01**	**-0.01**	**0.01**	**-0.17**	**-0.11**	**-0.12**	**0.28**	**-0.16**
Sug	-0.04	0.09	0.25	0.12	0.19	0.26	0.23	0.31	0.14	0.57		**0.08**	**0.18**	**-0.28**	**0.28**	**-0.10**	**0.09**	**0.13**	**0.07**	**0.18**
Fst	-0.06	-0.23	0.14	-0.07	0.34	-0.02	-0.07	-0.00	-0.26	-0.00	0.10		**-0.09**	**0.18**	**-0.18**	**-0.01**	**0.35**	**0.14**	**0.14**	**0.33**
Scw	0.27	0.10	0.35	0.09	0.16	0.30	0.71	0.60	0.45	0.01	0.02	-0.06		**0.33**	**-0.33**	**-0.14**	**0.28**	**0.52**	**0.47**	**0.12**
Wac	0.00	0.01	0.13	0.08	-0.06	0.33	0.29	0.30	-0.04	0.49	0.02	0.06	-0.03		**-1**	**0.15**	**0.16**	**0.09**	**0.42**	**0.21**
Drw	0.05	-0.01	-0.13	-0.08	0.32	-0.33	-0.29	-0.30	0.04	-0.49	-0.53	-0.06	0.03	-1		**-0.15**	**-0.16**	**-0.09**	**-0.42**	**-0.21**
Crh	0.04	-0.06	0.08	-0.19	0.15	-0.37	-0.30	-0.27	0.00	-0.50	-0.39	0.18	0.07	-0.42	0.42		**0.14**	**-0.25**	**-0.16**	**-0.18**
Crw	0.04	-0.13	0.17	-0.16	0.18	-0.12	0.02	0.33	0.38	-0.33	-0.14	0.39	0.30	-0.34	0.34	0.47		**0.02**	**-0.15**	**0.05**
Pel	0.12	0.08	0.18	0.32	-0.08	0.28	0.36	0.06	-0.23	0.14	0.10	0.14	0.15	0.09	-0.09	-0.38	-0.24		**0.36**	**0.43**
Ped	0.22	0.12	0.03	0.13	0.09	0.12	0.44	0.43	0.13	0.63	0.24	0.04	0.32	0.28	-0.28	-0.32	-0.08	0.16		**0.20**
Lil	0.09	-0.08	-0.06	-0.03	-0.05	-0.27	-0.09	-0.06	0.14	-0.26	-0.41	0.08	0.07	-0.73	0.73	0.35	0.41	-0.01	0.00	

Table 5. Correlation matrices based on quantitative traits for accessions of cultivars Smooth Cayenne and Baronne de Rothschild (normal font, below diagonal) and for accessions of cultivars Singapore Spanish and Green Spanish (bold font, above diagonal). Codes for characters as for Table 4.

	Lel	Lmw	Phy	Plh	Flt	Frh	Fbd	Fmd	Fud	Frw	Sug	Fst	Scw	Wac	Drw	Crh	Crw	Pel	Ped	Lil
Lel		**0.86**	**0.55**	**0.84**	**0.05**	**0.59**	**0.51**	**0.27**	**-0.04**	**0.44**	**-0.14**	**0.17**	**0.44**	**-0.10**	**0.10**	**-0.03**	**0.28**	**0.24**	**0.16**	**0.17**
Lbw	0.38		**0.33**	**0.69**	**-0.19**	**0.67**	**0.57**	**0.47**	**0.25**	**0.56**	**-0.18**	**-0.20**	**0.47**	**-0.12**	**0.12**	**-0.26**	**0.12**	**0.24**	**0.42**	**0.21**
Phy	0.29	0.39		**0.36**	**-0.18**	**0.32**	**0.39**	**0.18**	**-0.25**	**0.41**	**-0.29**	**0.33**	**0.48**	**-0.07**	**0.07**	**0.26**	**0.19**	**0.02**	**0.24**	**-0.41**
Plh	0.75	0.40	0.38		**0.20**	**0.49**	**0.26**	**0.19**	**-0.01**	**0.20**	**0.03**	**0.04**	**-0.16**	**-0.18**	**0.18**	**-0.23**	**0.02**	**0.39**	**0.45**	**0.45**
Flt	0.06	-0.27	-0.20	0.24		**-0.02**	**-0.13**	**0.14**	**-0.04**	**0.06**	**0.04**	**0.10**	**0.08**	**0.04**	**-0.04**	**0.07**	**0.10**	**-0.09**	**0.10**	**-0.02**
Frh	0.15	0.03	0.07	0.14	-0.01		**0.74**	**0.36**	**0.06**	**0.61**	**-0.26**	**-0.25**	**0.46**	**-0.28**	**0.28**	**-0.63**	**-0.12**	**0.39**	**0.36**	**0.24**
Fbd	0.35	-0.08	0.40	0.38	-0.12	0.12		**0.37**	**0.12**	**0.85**	**-0.51**	**-0.23**	**0.75**	**0.08**	**-0.08**	**0.20**	**-0.10**	**0.51**	**0.58**	**-0.14**
Fmd	0.19	0.09	0.40	0.17	0.22	-0.13	0.78		**0.69**	**0.67**	**-0.53**	**-0.44**	**0.55**	**0.05**	**-0.05**	**0.03**	**0.22**	**-0.20**	**0.67**	**-0.33**
Fud	0.34	-0.03	0.37	0.15	-0.05	0.05	0.73	0.71		**0.34**	**-0.28**	**-0.54**	**0.30**	**0.32**	**-0.32**	**0.07**	**0.20**	**-0.32**	**0.55**	**-0.31**
Frw	-0.00	0.03	-0.13	0.34	0.03	0.21	0.25	0.15	-0.05		**-0.50**	**-0.21**	**-0.79**	**0.10**	**-0.10**	**-0.02**	**0.11**	**0.25**	**0.64**	**0.27**
Sug	-0.16	0.27	0.31	0.04	0.08	0.15	0.14	0.31	0.22	0.32		**0.35**	**-0.33**	**-0.45**	**0.45**	**-0.12**	**-0.01**	**0.08**	**-0.43**	**0.43**
Fst	0.01	-0.15	0.13	0.04	0.12	-0.49	-0.03	0.05	-0.19	-0.06	-0.18		**-0.21**	**0.15**	**-0.15**	**0.42**	**0.36**	**-0.18**	**-0.50**	**0.05**
Scw	0.15	-0.14	0.21	-0.10	0.09	0.15	0.60	0.55	0.40	-0.04	0.04	0.01		**-0.23**	**0.23**	**0.15**	**0.28**	**0.08**	**0.68**	**-0.51**
Wac	0.33	-0.00	0.21	0.36	-0.10	-0.10	0.21	0.33	0.10	0.19	0.15	-0.12	0.04		**-1**	**-0.31**	**0.12**	**-0.19**	**0.06**	**-0.20**
Drw	-0.33	0.00	-0.21	-0.36	0.10	0.10	-0.21	-0.33	-0.10	-0.19	-0.15	0.12	-0.04	-1		**0.31**	**-0.12**	**0.19**	**-0.06**	**0.20**
Crh	-0.14	0.05	0.10	-0.52	0.05	-0.17	-0.25	-0.16	-0.05	-0.50	-0.16	0.29	0.15	-0.35	0.35		**0.51**	**-0.75**	**-0.01**	**-0.64**
Crw	0.10	-0.02	0.33	-0.17	0.09	-0.40	0.18	0.49	0.44	-0.35	0.16	0.49	0.32	0.10	-0.10	0.44		**-0.48**	**0.10**	**-0.46**
Pel	-0.11	-0.12	0.21	0.33	-0.03	0.01	0.15	-0.12	-0.37	0.23	-0.03	0.31	-0.17	0.13	-0.13	-0.28	-0.29		**-0.03**	**-0.53**
Ped	0.19	0.23	-0.07	0.27	0.12	-0.11	0.24	0.36	0.04	0.70	0.13	0.01	0.20	0.15	-0.15	-0.36	0.01	0.08		**-0.55**
Lil	0.12	0.14	-0.01	0.06	-0.06	-0.12	0.15	0.19	-0.12	0.36	0.14	-0.07	-0.00	-0.28	0.28	0.02	-0.02	-0.10	0.54	

subsamples, except for the weak association between fruit size and dimensions. The positive association among vegetative traits is confirmed, with values around 0.40–0.70 for leaf traits and above 0.80 between leaf length and plant height. Their correlations with fruit traits are again low or negligible, except for the Spanish accession group, where correlation values between 0.41 and 0.56 are observed for leaf traits with fruit weight, and, secondarily, five values between 0.44 and 0.48 with fruitlet width. The positive associations between fruit diameters and fruitlet dimensions, observed on the whole sample, are confirmed in the three subsamples (values from 0.30 to 0.75). The association between fruit weight and peduncle diameter is also confirmed, although it appears much weaker in 'Pérola' (0.28) than in the Cayenne accession group (0.70) and in the Spanish accession group (0.64). The positive association between conicity and peduncle length and the negative one between conicity and crown weight are surprisingly confirmed in the three subsamples, with values from 0.53 to 0.69 for the former, and from -0.24 to -0.46 for the latter.

The poor associations detected between fruit weight and dimensions (height and diameters) in the whole sample, appear related to shape diversity, among subsamples as well as within two of them, as shown by contrasted correlations. Thus, while fruit size (as measured by weight) is clearly correlated with height (0.61) and basal or median (0.85 and 0.67) diameters in the Spanish accessions, probably in relation to the more regular shape of their cylindrical fruit, this is not the case in the other subsamples, with low values between -0.23 and 0.25. Shape irregularity seems particularly problematic in 'Pérola', where fruit height not only shows a weak negative correlation with weight (-0.23), but also a positive association with conicity (0.45).

The dependence of many correlations on the varietal composition of our sample hampers any extrapolation to other cultivars, even for those associations that look consistent across all correlation matrices. In any case, this study must be considered preliminar, as the plant materials were grown directly from propagules collected on farms, which implied limitations in plant numbers and homogeneity. Nonetheless, some associations that seem consistent across the three subsamples should be further explored in the next stages of the research, particularly those surprising correlations relating fruit conicity to peduncle length and crown development. The exploration of associations that diverge among the three subsamples can be important too in the design and follow up of clonal selection efforts. For example, the simple and consistent correlations between fruit weight and dimensions in 'Singapore Spanish' and 'Green Spanish' should facilitate selection for fruit size (without negative effects on fruit shape), whereas the more complex situation in 'Pérola' and, to a lesser extent, in 'Smooth Cayenne', imposes to consider fruit size, shape and heterogeneity simultaneously at each stage of the process.

Relationships among accessions

The hierarchical cluster analysis, based on the 30 quantitative and qualitative traits, separated the accessions in two main clusters, as shown in Figure 3. The first one grouped 73% of the accessions (40) containing cv. Pérola in one subgroup (cluster 1a) and cvs. Smooth Cayenne and Baronne de Rothschild in a second subgroup (cluster 1b). This subdivision is not strongly supported, with one accession of 'Pérola' falling in the Cayenne subcluster and one accession of 'Smooth Cayenne' falling in the 'Pérola' subcluster. The two representatives of 'Baronne de Rothschild' are consistently included in the Cayenne subcluster. However, they do not show particular affinity, being placed in different branches of subcluster 1b, which suggests that they originated from independent spiny mutations in different strains of the culti-

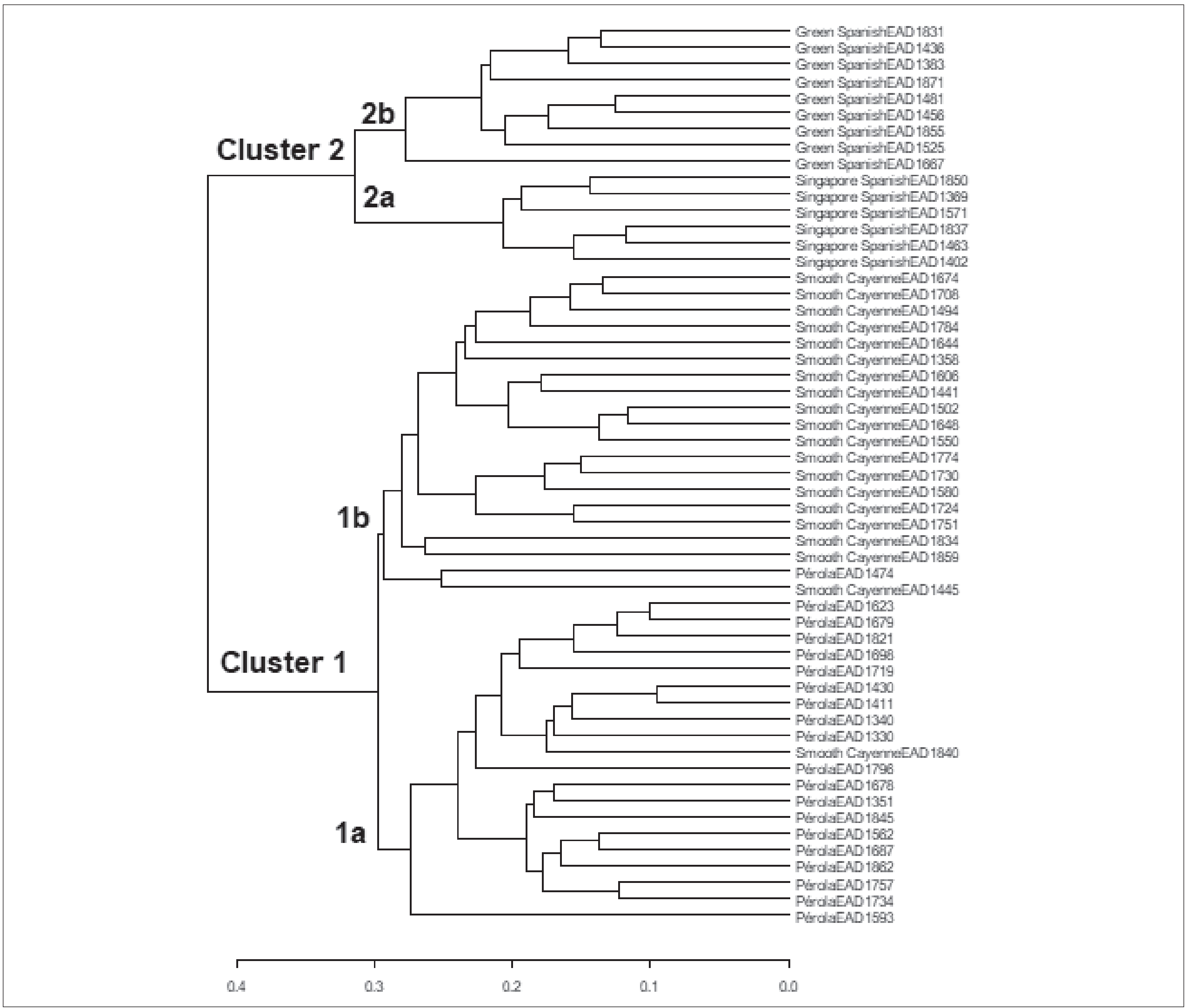

FIGURE 3. Dendrogram obtained from hierarchical clustering analysis of 55 pineapple genotypes based on 30 quantitative and qualitative morphological traits using the Gower's metric.

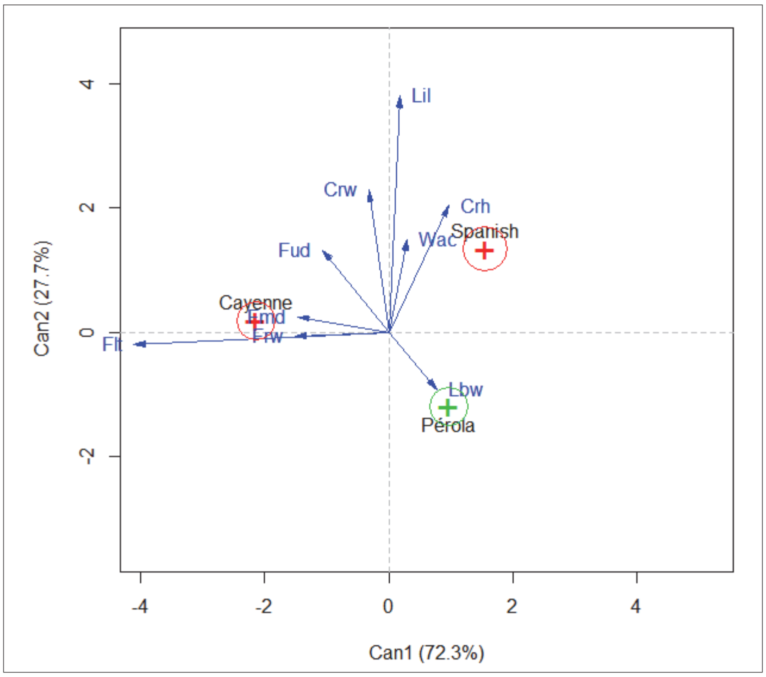

FIGURE 4. Map of morphological traits and pineapple somaclonal groups based on scores from canonical discriminant analysis. Morphological traits: Fmd: Fruit middle diameter; Flt: Flowering time; Frw: Fruit weight; Lbw: Leaf base width; Fud: Fruit upper diameter, Crh: Crown height; Crw: Crown weight; Lil: Fruit shelf life; Wac: Water content.

var. Such hypothesis is plausible, given the high reverse mutation rate of the S gene (Collins, 1960).

The second cluster grouped 27% of the accessions (15), subdivided into two subgroups, constituted respectively by the accessions of 'Singapore Spanish' and by those of 'Green Spanish', separating these somaclonal variants even more clearly than 'Pérola' and 'Smooth Cayenne'. This relatively clear divergence is very probably related to their ancient separation, as their coexistence in many countries dates back to their introduction in the early 16th century.

Stepwise discriminant analysis revealed thirteen quantitative morphological traits as significantly discriminating pineapple cultivars with a classification rate of 74%. Discriminant traits included fruit shelf life (Lil), crown height (Crh), crown weight (Crw), flowering time (Flt), water content (Wac), dry matter (Drw), fruit upper diameter (Fud), fruit basal diameter (Fbd), fruit middle diameter (Fmd), fruit weight (Frw), number of leaves (Phy), leaf basal diameter (Lbw), and fruitlet width (Scw). Canonical discriminant analysis showed that the first ten identified pineapple cultivars traits were significantly different (Wilks' $\lambda = 0.21$, $P < 0.001$). Two significant canonical axes were obtained accounting for 100% of the variation (Figure 4). 'Singapore Spanish' and 'Green Spanish' were characterized by high values for traits such as shelf life (Lil), dry matter (Drw), crown height (Crh), crown weight (Crw) and fruitlet width (Scw); 'Pérola' accessions were characterized by high values for leaf basal width (Lbw). The Cayenne group was characterized by large fruits, long flowering time, high fruit middle and upper diameters, as well as high juice content. Those accessions could be used by the processors who need to optimize their juice production. In order to optimize the production, it will be important to apply best agronomic practices including the use of adequate planting material within appropriate planting calendar, since the planting period has an effect on fruit production. Malézieux *et al.* (2003) showed that pineapples planted during the rainy season produce larger fruits than pineapples planted in the dry season, because the duration of the vegetative phase determines fruit yield. 'Pérola' was characterized by average fruit weight, low fruit dry matter, low leaf basal width and short fruit shell life. The group made up of 'Singapore Spanish' and 'Green Spanish', was characterized by individuals that show natural yellow or orange coloration and long fruit shelf life. Large fruits were mostly found in 'Smooth Cayenne' and 'Pérola'. Fruit shape is related with fruit size, as large fruits tend to be conical whereas small fruits are cylindrical or ovoid. Thus, considering this trend, fruit shape should characterize each cultivar. For their cultivation, it is important to use homogeneous propagules of each cultivar when planting, selecting propagules of uniform size and weight, and manage induction time so as to get a homogeneous fruit production. A better management of planting materials, in each cultivar, is an important step towards avoiding heterogeneity in shape and size.

Conclusion

This study is the first one revealing the simultaneous presence of the cultivars 'Pérola', 'Smooth Cayenne', 'Baronne de Rothschild', 'Green Spanish' and 'Singapore Spanish' in pineapple fields in Benin. 'Singapore Spanish' and 'Green Spanish', identified for their natural golden or yellow color, can be stored for about three or four weeks after harvesting. These cultivars should be promoted in Benin in order to reduce the use of ethephon (calcium carbide) for skin coloring, which is banned in the export market and poses a problem of non-compliance with required residue standards for consumption. The promotion of these cultivars could be accompanied with important actions including the production of propagules of these cultivars through micropropagation to compensate for the lack of planting material as these cultivars are not widely cultivated.

The morphological characterization of *Ananas comosus* present in Benin contributes to better assess the phenotypes of the nationwide collected cultivars, and to identify the plants with desired characteristics for breeding. It shows three morphological groups of pineapple in Benin. It also shows the existence of variability within and among cultivars, where fruit shape depends on the cultivar and fruit size. According to the market needs, clonal selection can be applied to cultivars. It is important that farmers get trained to recognize their pineapple planting materials and to manage the diversity within their cultivars. Other farmers should be trained to produce good quality propagules to increase the dissemination of selected clones. There is an obvious need to establish sound seed systems to improve pineapple production and to mitigate heterogeneity and degenerescence issues.

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