Vol. 23(10), pp.298-309, October 2024
DOI: 10.5897/AJB2024.17693
Article Number: 09D430F72688
ISSN: 1684-5315

http://www.academicjournals.org/AJB

ACADEMIC JOURNALS
expand your knowledge

African Journal of Biotechnology

Full Length Research Paper

Morphological, biochemical and sensory characterization of some cocoa genotypes (*Theobroma cacao* L.) grown in Cameroon

Maboune Tetmoun Suzanne Abeline[1,2]*, Ives Bruno M. Efombagn[1], Eddy Léonard Mangaptché Ngonkeu[1,2] and Emmanuel Youmbi[2]

[1]Institute of Agricultural Research for Development (IRAD) P. O. Box 2067 Messa Yaoundée, Cameroon.
[2]Department of Plant Biology, Faculty of Science, University of Yaounde I, P. O. Box 812, Yaounde, Cameroon.

Received 31 July, 2024; Accepted 11 October, 2024

Cameroon's cocoa is derived from a wide variety of genetic material. These genotypes are not adequately classified in terms of the quality of cocoa produced. The aim of this study was to help improve cocoa quality by selecting genotypes with organoleptic properties. An assessment was conducted on the agro-morphological, biochemical and sensory characteristics of traditional 'German cacao' genotypes (GR and GJ) and other cultivated hybrids. The results showed variability in terms of agro-morphological, biochemical and sensory characteristics. ICS40, ICS43 and GR developed large pods; PA7, BBK726 and PA150 had smaller pods. BBK726, UPA337, PA7 and MA12 had approximately the same biochemical properties as the traditional "German cocoa" genotypes. ICS40, UPA150 and ICS95 had the highest levels of flavonoids, anthocyanins and polyphenols. A correlation was established between growth morphology and the biochemical properties of the genotypes. Sepal and pod size were good indicators of flavonoid, anthocyanin and polyphenol content. GJ, GR, ICS43 and MA12 presented cocoa of better organoleptic quality. The reddish colour of this cocoa is determined by both biotic and abiotic factors.

Key words: Anthocyanin, cocoa, flavour, flavonoids, polyphenols.

INTRODUCTION

Cocoa trees were first grown in Latin America and are now widely grown in the tropical belt that covers Central America, the Caribbean, South America, Africa, India, Indonesia and Asia. Cameroon is the fifth largest cocoa producer in the world, and accounted for more than 280,000 tons of cocoa beans in 2021 (ICCO, 2022). In Cameroon, cocoa is the second-largest export crop, second only to timber, excluding petroleum product(Akoa et al., 2021). It is grown by about 260,000 small-scale farmers and provides a livelihood for over a million people living in the forest zone. According to data from the National Cocoa and Coffee Board of Cameroon (ONCC), cocoa has generated revenues of about 491.3 million dollars, accounting for roughly 4.5% of the national

*Corresponding author. E-mail: mabounetetmoun@gmail.com. Tel: +237 677357248.

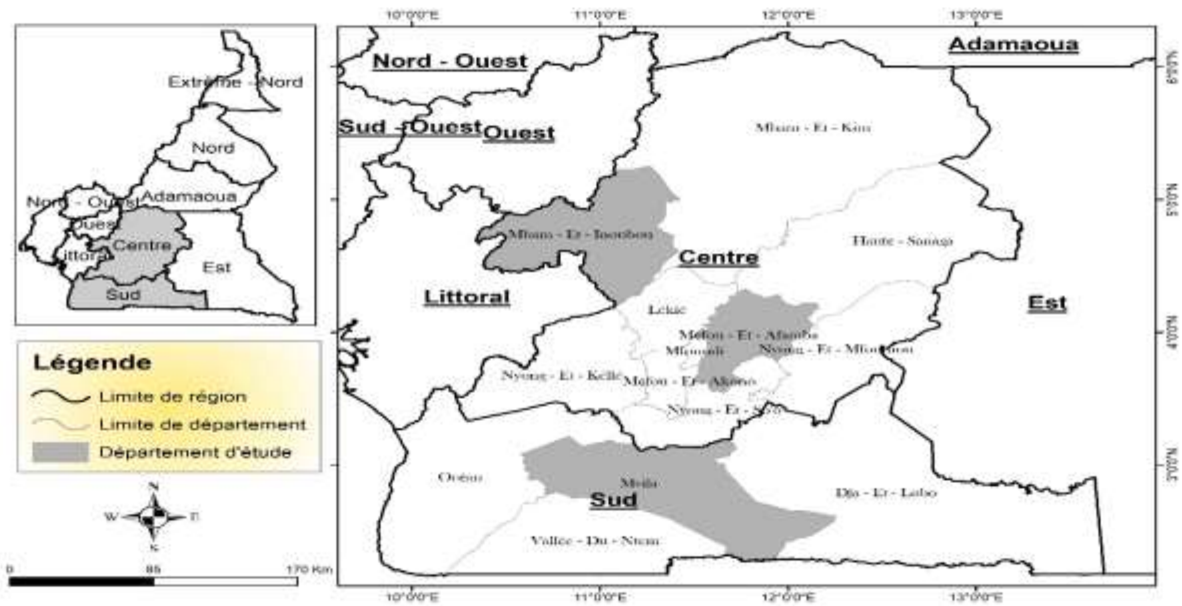

Figure 1. Geographical location of the study area and pod source divisions.

budget and contributing to about 4% of Cameroon's Gross Domestic Product (GDP) (ICCO, 2022). The chocolate industry needs a sustainable and constant supply of good quality cocoa beans in order to meet its increasing demands. Among quality criteria, the biochemical, organoleptic and color characteristics of cocoa are the most sought-after. The reddish color, typical of Cameroon's cocoa is in high demand on the international market (Fontaine and Huetz-Adams, 2020). Unfortunately, it is difficult to meet the demand for cocoa in Cameroon as a result of supply shortages, despite its increased cocoa production. Scientific and genetic studies related to the reddish color, considered to be the best quality factors, are limited to older cocoas commonly known as "German cacao" (Stoll et al., 2017). Furthermore, cocoa research has focused more on agronomic characteristics such as the selection of high-yielding genotypes, and their resistance or tolerance to common diseases (Efombagn et al., 2008, 2009; Ndoumbè-Nkeng et al., 2009). This research paid little attention to the biochemical and sensory criteria which are crucial in determining the quality of marketable cocoa as well as the requirements for the chocolate industry. Pioneering work on the quality of Cameroon's genotypes focused on analysing amino acids and reducing sugars profiles of cocoa beans from the SNK (Trinitario) and TIKO (Forastero) genotypes after in vitro incubation in lactic and acetic acid solutions (Niemenak et al., 2020). In addition, Akoa et al. (2023) analysed the sensory and aromatic profiles of highly appreciated hybrid genotypes obtained from manual pollinations between Trinitario × Forastero. Their work illustrated positive correlations between biochemical and sensory profiles, responsible for the high quality chocolates highly sought after due to their health benefits.

The aim of this research was to broaden the scientific work carried out on the reddish colour to cover other widely adopted genotypes, in order to explore possibilities for improving the key factor that determine cocoa quality in Cameroon. This required a more comprehensive characterization of the various Cameroonian cocoa genotypes, incorporating the biochemical and sensory aspects in relation to the plant's morphological characteristics. The study further sought to improve the quality of Cameroon's cocoa, based on the analysis of genotypes with reddish colour potential. More specifically, the study set out to identify factors that determine the reddish colour potential by evaluating the agro-morphological, biochemical and sensory characteristics of the various locally selected genotypes.

MATERIALS AND METHODS

Study area and biological material

The different cocoa genotypes were collected in seed fields located in the Mefou and Afamba, Mbam and Inoubou Divisions in the Centre Region and the Mvila Division in the South Region of Cameroon (Figure 1 and Table 1) from October 2022 up to December 2022 and their morphological traits were measured. These two regions fall within the bimodal rainfall forest agro-ecological zone (zone v), characterised by two dry seasons and two rainy seasons. The traditional "German cocoa" and hybrid cocoa genotypes were selected based on the petals and sepals colour.

Morphological data collection

Agromorphological data from thirteen genotypes were collected in three seed fields, and thirty cocoa plants per genotype were sampled in each plantation. Morphological characteristics included

Table 1. Agronomic characteristics of the thirteen selected genotypes.

Genotype	Origin	Locality source of cacao pods	Characteristics
UPA143	Upper Amazon	Awae (3°53'244'' N and 11°50'199''E°) -	Disease resistance High productivity
IMC60 and IMC67	Upper Amazon	Awae, Ebolowa (2.4°95'4.1'' N and 11°08'12.4''E°) -	Larger stem diameter Disease resistance
MA12	Upper Amazon Amazonia	Awae -	Disease resistance High productivity
PA7	Amazonia	Awae	High susceptibility to disease
BBK726	Hybrid clone	Awae -	Resistance to black pot disease High productivity
GJ et GR	German cacao with yellow (GJ) and red (GR) pods at maturity	Mfou (3°49'0'' N and 11°36'0''E°), Yaoundé - -	Longer growing period Disease and pest resistance Small-sized beans
ICS40, ICS43, UPA337, ICS 95	Venezuela	Awae, Ebolowa -	Resistance to black pot disease High productivity
UPA150	Venezuela	Awae, Yaoundé (3°51'54'' N and 11°27'39''E°)	Moderate resistance to black pod disease

Table 2. Selected liqueur flavour descriptors, score and rating scale.

Taste descriptors	Cacao note, acidity, bitterness, astringency, fruity, floral, spice, nutty, sweetness, over fermented, pungent, roast, woody				
Score	**[0-2]**	**[2-4]**	**[4-6]**	**[6-8]**	**[8-10]**
Rating scale	Null	Low	Medium	High	Very high

Source: End and Dand (2015).

leaf, flower and pod growth. The variables measured were the length and width of leaves, sepals and petals, and the length and diameter of pods. Data were collected via visual observations, using rulers and callipers, and recorded on a data collection sheet.

Biochemical analysis

Biochemical attributes were obtained from cocoa beans after fermentation and drying. The biochemical parameters measured were: pH, brix, temperature (°C), soluble sugar (using the method described by Aschwell (1957)), anthocyanins (Guisti and Wrolstad, 2001), flavonoids and phenolic compounds (Singleton et al., 1999), and fermentation index. The wooden box fermentation system was adopted, using gravity to turn the cocoa beans, resulting in good-quality cocoa (Wood and Lass, 1985; Lehrian et al., 1980; Pedro et al., 2016).

Sensory characterization

Sensory analysis of the cocoa liqueurs was carried out following the method described by End and Dand (2015) and Alexandre et al. (2016). For this purpose, 13 aroma descriptors were selected and scores were presented on a scale from 0 to 10. Experiments were repeated three times at two-week intervals (Table 2). The flavours tested were: cocoa note, acidity, bitterness, astringency, fruitiness, florality, spiciness, nuttiness, sweetness, fermentation, unpleasantness of flavor, and roasting.

Statistical analysis of data

Excel spreadsheets were used to enter the data collected and to plot curves and figures. Statistical analyses were carried out using XLSTAT software version 16.5.03. Variance analysis (ANOVA) was conducted to compare the growth performance, biochemical and sensory properties of the different genotypes. Duncan's test was used to distinguish the analyses when there was a significant difference at a 5% probability threshold. The Principal Component Analysis (PCA) was used to explore relationships between variables.

RESULTS AND DISCUSSION

Morphological characteristics of genotypes

The variance analysis (ANOVA) revealed that

Table 3. Morphological characteristics of different cocoa genotypes (mean values ± SD).

Genotype	Leaf width (cm)	Leaf length (cm)	Sepal width (mm)	Sepal length (mm)	Petal width (mm)	Petal length (mm)	Pods length (cm)	Pods diameter (cm)
BBK726	10.28±2.25[b]	32.60±0.84[abc]	0.1±0.00[b]	0.44±0.11[b]	0.1±0.00[a]	0.30±0.10[b]	12.65±0.58[f]	10.00±1.00[fghi]
GJ	13.08±2.73[a]	34.63±6.49[a]	0.1±0.00[b]	0.44±0.11[b]	0.1±0.00[a]	0.30±0.10[b]	15.67±0.57[de]	8.00±1.00[i]
GR	10.33±2.73[b]	32.90±7.04[ab]	0.1±0.00[b]	0.42±0.13[b]	0.1±0.00[a]	0.28±0.84[b]	17.30±1.53[cd]	11.87±1.21[def]
ICS43	6.52±0.74[d]	24.87±2.89[cd]	0.1±0.00[b]	0.53±0.25[ab]	0.1±0.00[a]	0.50±0.18[a]	23.33±0.57[ab]	12.20±1.06[cde]
IMC60	7.62±3.41[cd]	23.14±11.29[cd]	0.1±0.00[b]	0.58±0.23[ab]	0.1±0.00[a]	0.20±0.12[a]	25.67±1.53[a]	16.00±1.00[a]
IMC67	7.36±2.76[cd]	22.98±9.40[d]	0.1±0.00[b]	0.60±0.16[b]	0.1±0.00[a]	0.54±0.18[b]	18.33±1.52[cd]	10.31±1.53[efgh]
ICS40	6.65±3.64[d]	22.20±10.23[d]	0.1±0.00[b]	0.42±0.13[ab]	0.1±0.00[a]	0.28±0.08[b]	18.68±1.53[c]	11.33±0.58[defg]
MA12	9.62±1.44[bc]	27.53±4.06[bcde]	0.1±0.00[b]	0.52±0.08[b]	0.1±0.00[a]	0.32±0.08[b]	24.00±1.00[ab]	14.00±1.00[abc]
UPA150	10.47±2.19[b]	33.90±2.56[a]	0.1±0.00[b]	0.42±0.13[a]	0.1±0.00[a]	0.28±0.08[a]	12.00±1.73[f]	9.00±1.00[hi]
PA7	8.39±1.69[bcd]	27.55±4.39[bcde]	0.1±0.00[b]	0.68±0.15[ab]	0.1±0.00[a]	0.60±0.14[b]	14.00±1.00[ef]	8.23±0.93[hi]
UPA337	9.20±1.60[bc]	28.60±3.66[bcd]	0.1±0.00[b]	0.52±0.08[ab]	0.1±0.00[a]	0.32±0.08[a]	13.75±3.07[ef]	9.60±0.58[ghi]
ICS95	8.73±3.14[bcd]	27.23±7.72[cde]	0.14±0.05[a]	0.58±0.23[ab]	0.1±0.00[a]	0.20±0.12[b]	22.00±1.00[b]	14.62±1.53[ab]
UPA143	9.06±1.70[bc]	27.54±4.45[bcde]	0.14±0.55[a]	0.60±0.16[ab]	0.1±0.00[a]	0.54±0.18[b]	18.00±2.00[cd]	12.64±1.53[bcd]

*Different letters in a column denote statistically significant differences at $p < 0.05$.

morphological growth characteristics measured on aerial organs (leaves, flowers, fruit) varied significantly (p <5%) according to genotype. Leaf growth was greater with the GR, GJ, UPA150 and BBK726 genotypes, when measured on leaf length and width. The values obtained for leaf length were 13.80, 10.47, 10.33, and 10.28 cm, respectively; the shortest leaf length was observed on genotype ICS43 (6.52 cm). Genotypes UPA150 (0.60 cm), IMC60 (0.54 cm), and UPA337 (0.54 cm) tended to have more developed floral organs (sepal length). IMC60, MA12 and ICS43 develop larger pods, while BBK726, UPA150 and PA7 had smaller pod sizes (Table 3). Morphological traits determined the phenotype in a given environment and justified the genotypic variability of individuals in phenotype expression. This behavioural variability was responsible for properties that had an impact on cocoa quality and organoleptic properties. These results reflect the work of Tchouatcheu et al. (2019), who also observed variations in morphological traits across different cocoa varieties in terms of the length, diameter and mass of fresh pod beans harvested in the same region. These morphological variations in the different genotypes used could influence fermentation and the chemical and sensory properties of the cocoa obtained.

Biochemical profile of genotypes

Laboratory tests assessed the biochemical quality of traditional "German cocoa" and other hybrid genotypes. The analysis of variance (ANOVA) revealed significant differences (p<5%) in the biochemical parameters measured. Genotypes ICS95 and IMC67 had more acidic cocoa measured on pulp and cotyledons. Genotypes BBK726, GJ and GR revealed a significantly reduced cocoa acidity tending towards neutrality. Brix levels were also measured on pulp and cotyledons. Genotypes ICS40 and IMC60 had a lower Brix on the pulp, while ICS95 and IMC67 had higher values on the cotyledons (Figures 2 and 3).

Flavonoids, anthocyanins and polyphenols displayed an higher content in the ICS95, UPA150 and ICS40 genotypes followed by genotypes UPA143, PA7, UPA337, GR, BBK726, GJ and IMC67. The IMC60 genotypes showed the lowest values. Genotypes ICS40 and PA150 had higher soluble sugar contents. BK726, GJ, GR, MA12, PA7, UPA143, UPA337 and IMC60 showed low soluble sugar content between 6.87 and 16.44 (Figures 4 and 5).

The fermentation process measured using the fermentation index was intensified with ICS40 (0.86), ICS43 (0.89), PA150 (0.88) and UPA143 (0.91).
Temperatures measured during the fermentation process ranged from 25 to 28°C (Figure 6). These fermentation factors are genotype dependent and this tallies with Hegmann (2015).

The Principal Component Analysis (PCA) with 60.55% of total variability explained the relationships between variables. Flavonoids and anthocyanins were positively correlated. The correlation circle revealed that flavonoids and anthocyanins were positively correlated with each other as were phenolic compounds and soluble sugars.

The fermentation index was negatively correlated with the temperature. Anthocyanins and cotyledon Brix were also negatively correlated with pulp and cotyledon pH. A graphic representation of the findings showed that the genotypes could be classified into three categories depending on the biochemical nature of the cocoa: the first group included ICS40, UPA150 and ICS95 which

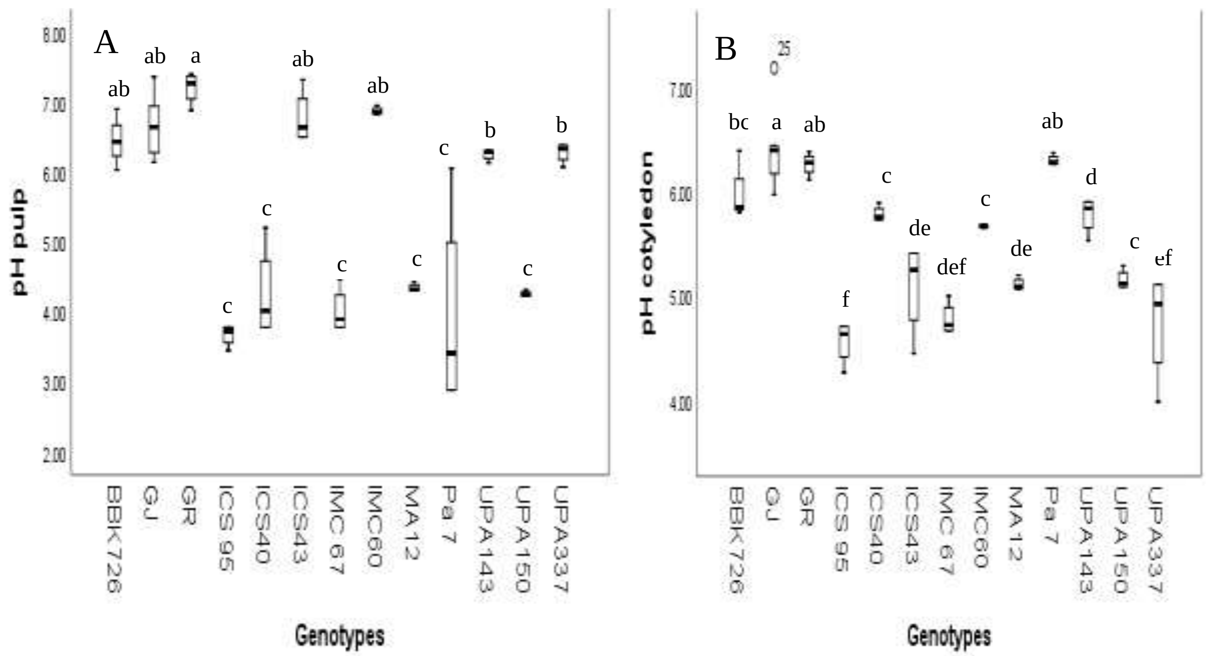

Figure 2. Variation in pulp pH (A) and cotyledon pH (B) of traditional "German cocoa" genotypes (GJ and GR) and hybrid cocoa genotypes after fermentation, different letters indicate significant differences between genotypes according to Duncan's test.

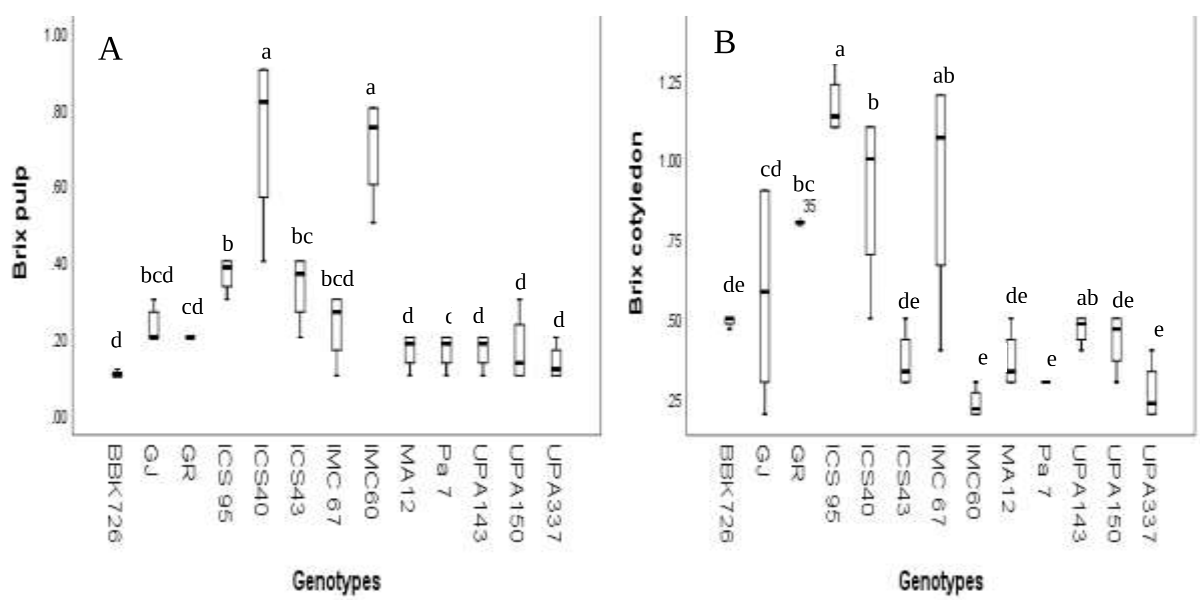

Figure 3. Variation in Brix pulp (A) and Brix cotyledons (B) of the traditional "German cocoa" genotypes (GJ and GR) and hybrid genotypes of cocoa trees after fermentation, different letters indicate significant differences between genotypes according to Duncan's test.

displayed higher levels of flavonoids, anthocyanins, polyphenols and soluble sugars. The second group encompassed traditional "German cocoa" genotypes (GJ and GR), BBK726, UPA337, PA7 and MA12 characterized by average levels of flavonoids, anthocyanins, polyphenols and soluble sugars. The third group was made up of IMC60 displaying relatively lower contents of biochemical determinants (Figure 7).

The flavonoid, anthocyanin and polyphenol content of cocoa beans are determinants of their reddish color.

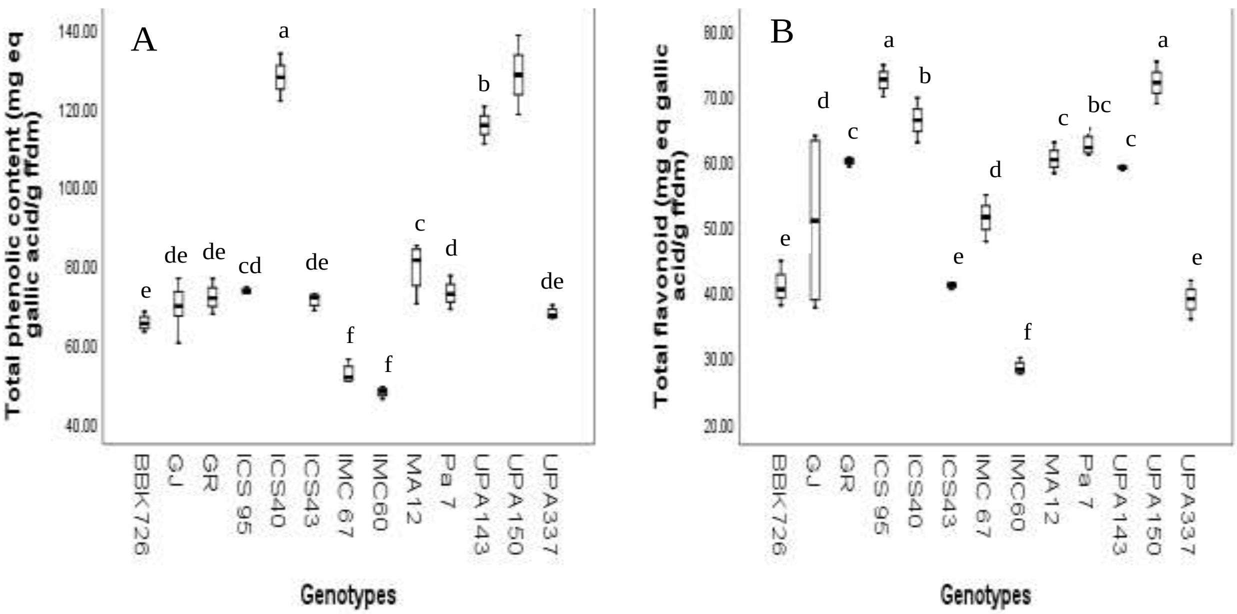

Figure 4. Variation in polyphenols (A) and flavonoids (B) of traditional "German cocoa" genotypes (GJ and GR) and hybrid cocoa genotypes after fermentation, different letters indicate significant differences between genotypes according to Duncan's test. Results are expressed as mg eq gallic acid/g of fat free dried material (ffdm).

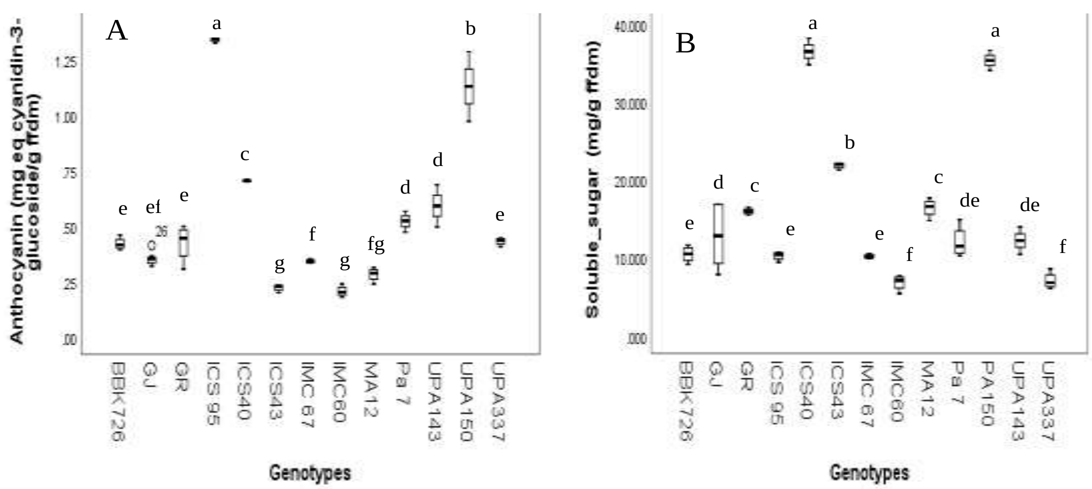

Figure 5. Variation in anthocyanins (A) and soluble sugars (B) of traditional "German cocoa" genotypes (GJ and GR) and hybrid cocoa genotypes after fermentation, different letters indicate significant differences between genotypes according to Duncan's test.

Indeed, Stoll et al. (2017) showed that a high concentration of anthocyanins in cotyledons was linked to an enhanced reddish colour of cocoa. Several biotic and abiotic factors may have worked synergistically to influence the reddish colour of cocoa beans. They include the biotic and abiotic factors. Biotic factors are linked to the genetic background (internal factors) of cacao seeds that influence the size of the beans, the chemical and free forms of flavonoids, anthocyanins, polyphenols and other chemical compounds, all of which influence their appearance in the cotyledons of cocoa beans. Abiotic factors refer to the natural environmental and climatic factors, farming techniques and post-harvest practices(external factors). These factors have a modulating effect on the presence/abundance of biochemical attributes in the cotyledons. Therefore, Niemenak et al. (2006) and Oracz et al. (2015) found that the cocoa polyphenol content is linked to several factors

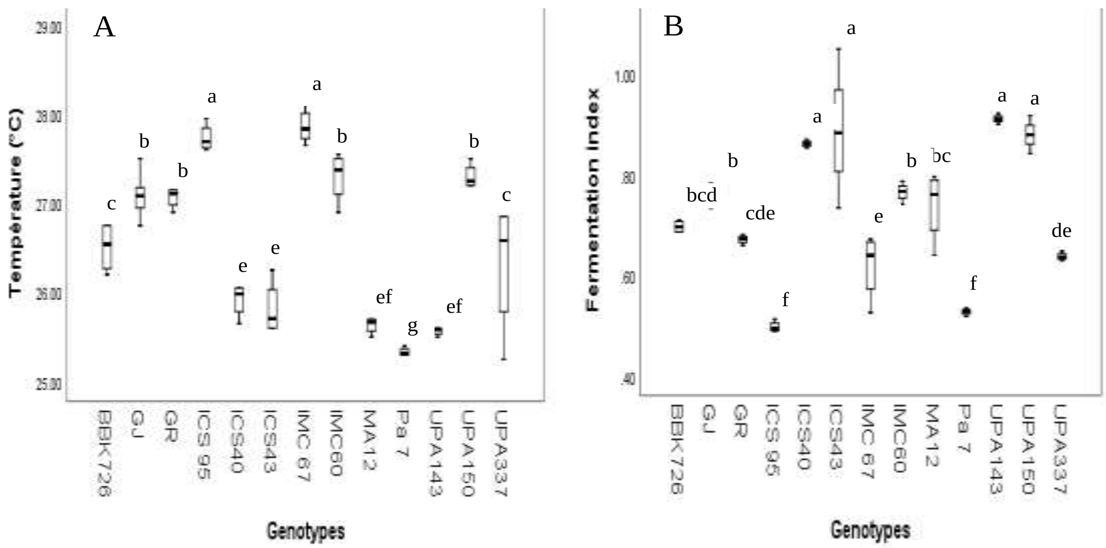

Figure 6. Variation in temperature (A) and fermentation index (B) of traditional "German coca" genotypes (GJ and GR) and hybrid cocoa genotypes, different letters indicate significant differences between genotypes according to Duncan's test.

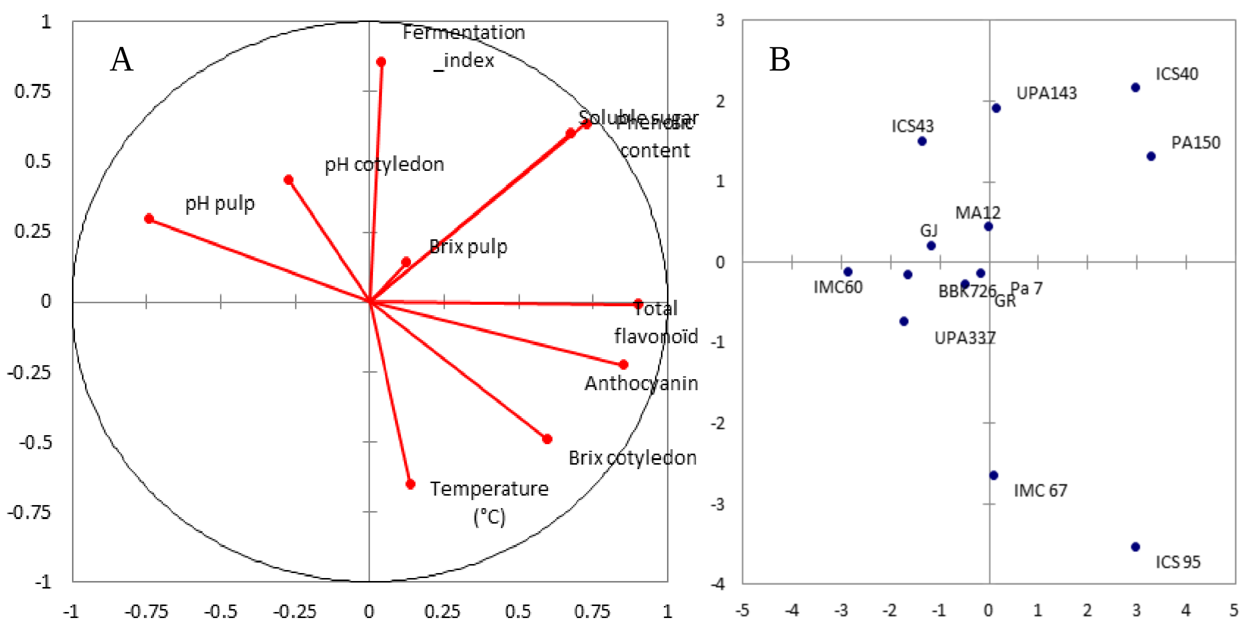

Figure 7. Principal component analysis (PCA) showing the correlation between biochemical attributes (A) and genotype (B).

such as the ecological environment, pod ripeness, harvest time and storage duration. In addition to these factors, agricultural practices were also considered.

It was found that there is a correlation between agromorphological traits and the biochemical properties of cocoa from different genotypes. The size of the pods and floral organs (sepal width) are indicators of the biochemical attributes and quality of the cocoa. Sepal width and cocoa pod size are correlated with the flavonoids anthocyanins, polyphenols and soluble sugars content of the cocoa beans. Indeed, these compounds played a role in the physiological processes of plant development notably by influencing the metabolic processes responsible for the growth of reproductive organs or by regulating the synthesis of growth regulators that contribute to developmental processes. Stoll et al.

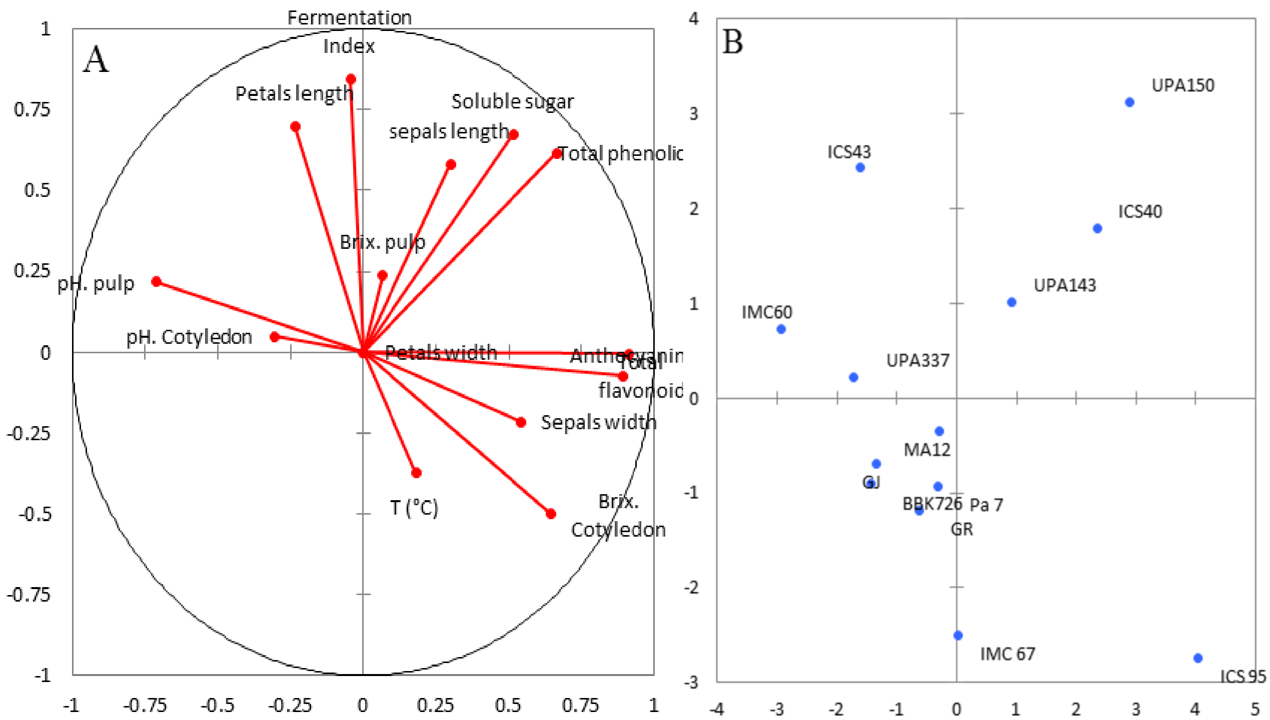

Figure 8. Principal component analysis (PCA) showing the correlation between biochemical attributes and agromorphological characteristics of cocoa flowering (A) and genotype (B).

(2017) also characterize traditional "German cocoa" genotypes by the morphology of seed germination observed in the red colour of the radicle stemming from the cotyledons, which is a phenotypic trait that is different from other local cocoa clones. Negi et al. (2010) have also demonstrated the role of flavonoids in regulating various developmental processes such as the initiation of rhizogenesis. Paulin et al. (2003) attribute a functional role to polyphenol-rich genotypes in improving resistance to black pod rot in cocoa thanks to their contribution both in forming a rigid wall that acts as a barrier against pathogens, as well as in reducing the nutritional value of tissues and thus inhibiting predation on the plant organ.

The correlation circle and PCA displayed a total variability of 51.95 and 55.62% of pod and floral characteristics, respectively. Genotypes MA12, PA7, GR, GJ, BBK726, UPA337 and IMC60 developed narrower sepal width in relation to lower flavonoid and anthocyanin contents. The ICS95 genotype with wider sepals is characterized by higher flavonoid and anthocyanin contents in the cotyledons. There is a positive correlation between sepal length and high polyphenol and sugar concentration with the genotype (Figure 8). Genotypes ICS40, UPA150, MA12, UPA143 and ICS43 had larger pods and higher cocoa content in terms of polyphenols and soluble sugars, while genotypes PA7, GJ, GR, BBK726, IMC60, IMC67 and UPA337 had smaller pods and produced cocoa with low levels of polyphenols and soluble sugars (Figure 9).

Sensory properties of genotypes

The analysis of the organoleptic properties of the cocoa liquor prepared from the different cocoa genotype revealed significant sensory differences in the gustatory quality ($p<5\%$). The average scores obtained by the tastemakers ranged from 0 to 6 on a scale of 10. Scores were lowest for spiciness, nuttiness, sweetness notes and unpleasantness flavours; and highest for cocoa note and bitterness. The flavours cocoa, bitterness, astringency, nuttiness, sweetness, fermentation, roasting and unpleasantness notes revealed a sensitivity of tested intensities to genotype.

The Principal Component Analysis (PCA) accounting for 45.74% of total variability enabled the genotypes to be associated with the characteristics of organoleptic variables. It revealed that genotypes MA12, GJ, GR and ICS43 have a stronger woody, floral, fruity and earthy flavour. BBK726, ICM67 and ICM60 had a spicy aroma while UPA337 and ICS40 had a high cocoa content in their aroma. Genotypes UPA143 and ICS95 had an aroma characterized by a strong acidity, nutty presence and a strong unpleasant and slightly sweet flavour (Figure 10).

The result showed that cocoa from Cameroon is

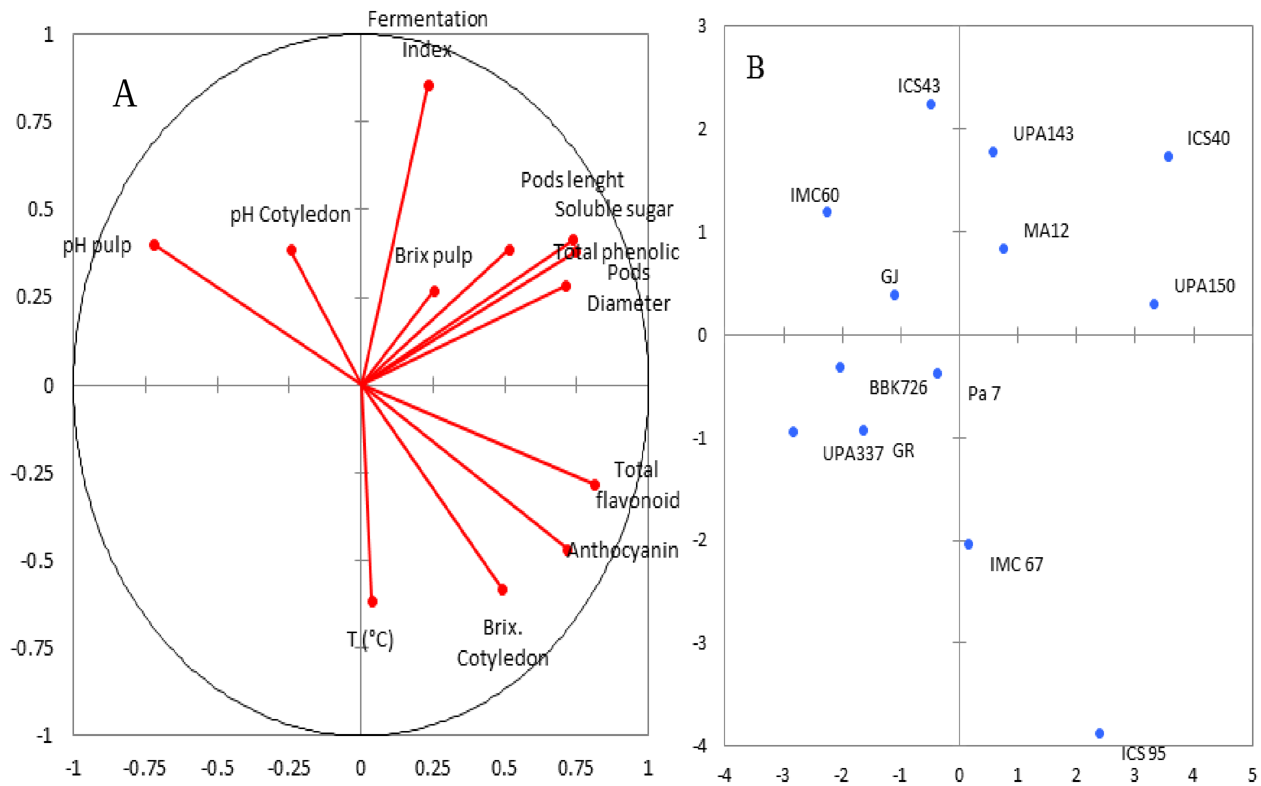

Figure 9. Principal component analysis (PCA) showing the correlation between biochemical attributes and agromorphological characters of cocoa fruiting (A) and genotype (B).

characterized by a fruity, floral, woody, acidic, bitter, astringent and earthy notes with a high cocoa content. The bitterness and astringency are thought to be caused by the caffeine, theobromine and polyphenol content of the cocoa genotypes as well as the level of post-harvest fermentation of the beans. Alexandre et al. (2016) attribute the bitter taste and astringency of cocoa to the presence of biochemical compounds, mainly polyphenols. According to these authors, polyphenols diminish during fermentation which may explain the decrease in bitterness and astringency for well-fermented cocoa. The acidity of cocoa aroma is associated with the breakdown of soluble sugars and proteins into lactic and acetic acids due to the metabolic activity of acetic bacteria and a decrease in pH.

The GJ, GR, ICS43 and MA12 genotypes produced quality cocoa with most of the positive aroma attributes as follows: fruitiness, bitterness, florality and cocoa notes. As a result, the biochemical nature of cocoa has an impact on the gustatory qualities of cocoa aroma. The content of cocoa beans, mainly flavonoids, anthocyanins, polyphenols and soluble sugars are key to metabolic processes involved in forming numerous structural and functional chemical compounds, the outcomes of which have consequences for changes in the physical state, such as the colour and sensory properties of the beans, as well as the organoleptic qualities. The correlations between sensory properties and biochemical characteristics show that polyphenols, flavonoids, anthocyanins and soluble sugars are strongly positively correlated with the spicy and fruity cocoa aroma flavours. However, the content of those compounds is negatively correlated with the bitter, earthy and floral notes. In addition, sweet, woody and cocoa flavours seemed to be slightly influenced by the biochemical nature of cocoa (Figure 11).

PCA showed the correlation between sensory descriptors and the genotype. The positive correlation established between polyphenols, flavonoids, anthocyanins and soluble sugars with woody and fruity flavors reveals that increasing the concentration of these biochemical elements in cocoa beans would result in more pronounced woody and fruity flavours. Cocoa aroma results from the enzymatic transformations of metabolite during fermentation. The sweetness, woodiness and cocoa flavours were only slightly influenced by biochemical compounds analyses. They are probably from other substrates resulting from multiple transformations controlled by the biological agents of fermentation, that is, yeast and bacteria. The same trend is applicable for cocoa flavour, which is not dependent on polyphenols, flavonoids and anthocyanins. These

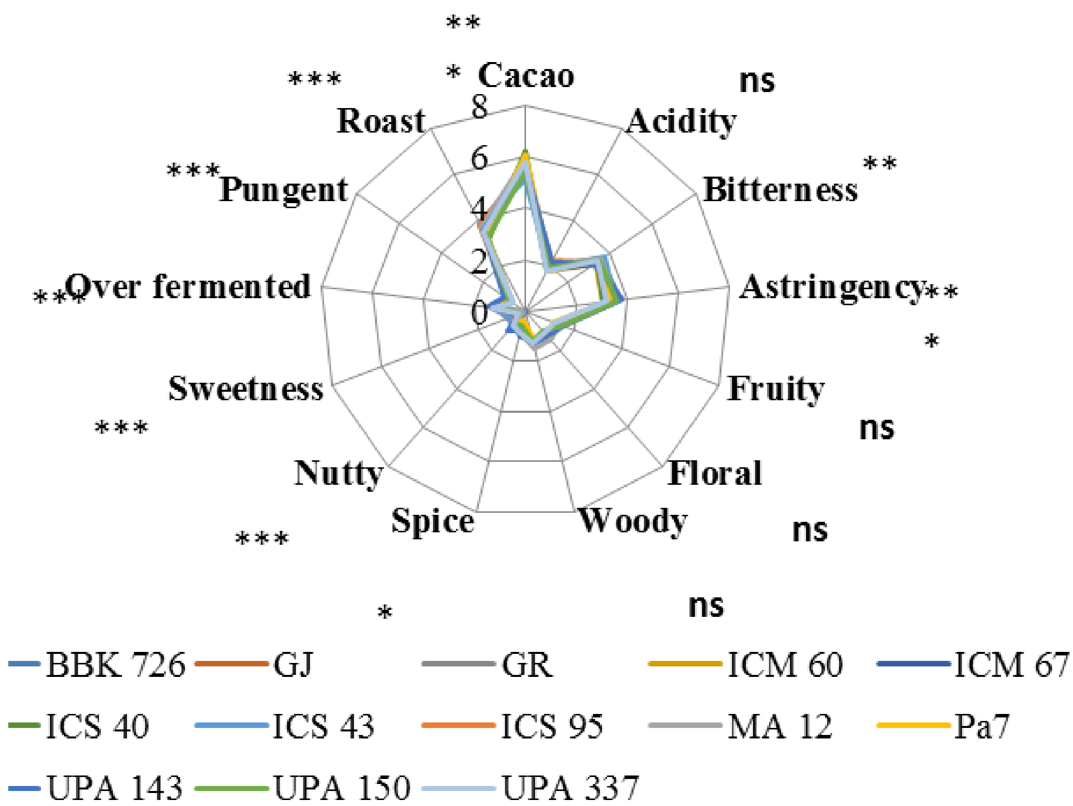

Figure 10. Sensory properties for 13 cocoa genotypes grown in Cameroon, *p < 0.5; ** p < 0.1; *** p < 0.01; different asterix numbers indicate significant differences between genotypes according to Duncan's test, ns= not significant.

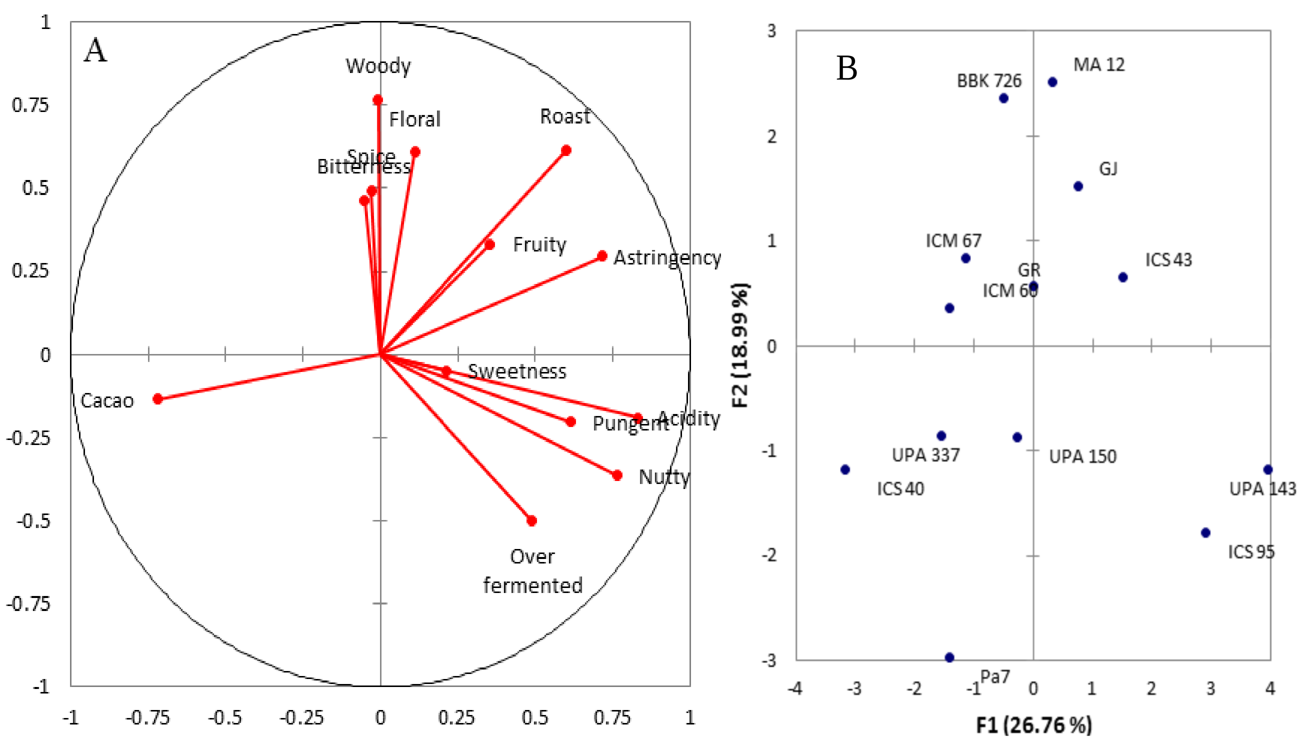

Figure 11. Principal component analysis (PCA) showing the correlation between sensory descriptors (A) and genotype (B).

observations are supported by the works of many other authors. Kadow et al. (2015) assert that cocoa flavour precursors are essentially made up of small peptides, free amino acids and reducing sugars. Bastos et al. (2019) showed that bitter flavour is associated with high levels of polyphenols, methylxanthines and organic acids. Moreover, Mohamed et al. (2019) associated spicy and vanilla flavours with high concentrations of ß-myrcene and 2.3-butanedione, respectively. Akoa et al. (2023), analysing the sensory and biochemical characterization of chocolate from hybrids grown in Cameroon showed that a low concentration of lactic acid in chocolate is positively correlated with chocolate flavor quality.

Conclusion

Agromorphological observation displayed that genotypes UPA143 and ICS95 had more developed sepals; IMC60, MA12 and ICS43 had large fruit pods; while BBK726, UPA150 and PA7, and had smaller pods. Biochemical properties reveal that BBK726, UPA337, PA7, and MA12 had similar characteristics with the traditional 'German cocoa' genotypes (GJ and GR). ICS40, UPA150 and ICS95 had higher levels of flavonoids, anthocyanins, polyphenols and soluble sugars. IMC60 had a lower content of flavonoids, anthocyanins, polyphenols and soluble sugars. Sepal width and length, fruit length and diameter were correlated with biochemical properties and cocoa quality, enabling genotypes to be identified in the field on the basis of their agromorphological characteristics. Several factors acting in synergy determine the reddish colour of the cocoa. Organoleptic properties varied greatly depending on the genotype. This research has elaborated factors that are very useful in screening cocoa variety from which red powder could be obtained. Such factors could be very useful to breeder who can do their selection on young seedling using the morphplogical traits. Biochemical factors could be very useful as key factors in the certification of cocoa beans for market.

ACKNOWLEDGEMENTS

This work benefited from the contributions of the Cocoa Research Team at IRAD-Cameroon. Conversely, the contributions of Prof. Dr Nicolas Niemenak, Dr TAGNE Appolinaire, M. Wilfried Dogmo and M. Romuald Nsouga are also very highly appreciated.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Akoa SP, Boulanger R, Effa Onomo P, Lebrun M, Ondobo ML, Lahon MC, Ntyam Mendo SM, Niemenak N, Djocgoue PF (2023). Sugar profile and volatile aroma composition in fermented dried beans and roasted nibs from six controlled pollinated Cameroonian fine-flavor cocoa (*Theobroma cacao* L.) hybrids. Food Bioscience 53:102603

Akoa SP, Effa Onomo P, Manga Ndjaga J, Ondobo ML, Djocgoue PF (2021). Impact of pollen genetic origin on compatibility, agronomic traits and physicochemical quality of cocoa (*Theobroma cacao* L.) beans. Scientia Horticulturae 287:110278. https://doi.org/10.1016/j.scienta.2021.110278

Alexandre C, Sophie A, Fabrice D, Frédéric D, Jean-Christophe M, Thomas P, Alain S (2016). L'analyse sensorielle: un outil de mesure de la qualité du cacao de l'Océan Indien, Actualités de la Recherche en Sciences de l'Education dans l'Océan Indien, Travaux & documents 50:48-56, ffhal-02267902f

Aschwell G (1957). Colorimetric analysis of sugar. Methods in Enzymology 3:73-105.

Bastos VS, Uekane TM, Bello NA, de Rezende CM, Flosi Paschoalin VM, Del Aguila EM (2019). Dynamics of volatile compounds in TSH 565 cocoa clone fermentation and their role on chocolate flavor in Southeast Brazil. Journal of Food Science and Technology 56(6):2874-2887.

End MJ, Dand R (2015). CAOBISCO/ECA/FCC Cocoa Beans: Quality Requirements of the Chocolate and Cocoa Industry. http://www.cocoaquality.eu

Efombagn MIB, Sounigo O, Eskes AB, Motamayor JC, Manzanares-Dauleux M, Schnell R, Nyassé S (2009). Parentage analysis and outcrossing patterns in cacao (*Theobroma cacao* L,) farms in Cameroon. Heredity 103:46-53.

Efombagn MIB, Motamayor JC, Sounigo O, Eskes AB, Nyassé S, Cilas C, Schnell R, Manzanares-Dauleux MJ, Kolesnikova Allen M (2008). Genetic diversity and structure of farm and GenBank accessions of cacao (*Theobroma cacao* L,) in Cameroon revealed by microsatellite markers. Tree Genetics and Genomes 4:821-831.

Fontaine CA, Huetz-Adams F (2020). Cocoa Barometer. International Cocoa Initiative.

Guisti MM, Wrolstad RE (2001) Anthocyanins characterization and measurement with UV visible spectroscopy. Current Protocols in Food Analytical Chemistry 6:103-112.

Hegmann E (2015). Quality-determining characteristics of new cocoa clones selected at CATIE and their behaviour during post-harvest. PhD Thesis University of Hamburg 222 p.

ICCO (2022). Quaterly Bulletin of Cocoa Statistics, International Cocoa Organisation.

Kadow D, Niemenak N, Rohn S, Lieberei R (2015). Fermentation-like incubation of cocoa seeds (*Theobroma cacao* L,), Reconstruction and guidance of the fermentation process. LWT- Food Science and Technology 62:357-361

Lehrian DW, Keeney PG, Butler DR (1980). Triglyceride characteristics of cocoa butter from cacao fruit matured in a microclimate of elevated temperature. Journal of the American Oil Chemists´ Society 57:66-69. https://doi.org/10.1007/BF02674362

Mohamed R, Abdullah A, Yap KC, Mustapha WAW (2019). Comparative study of flavour precursors, volatile compounds and sensory between Malaysian and Ghanaian Cocoa beans. Sains Malaysiana 48(3):487-598.

Ndoumbè-Nkeng M, Efombagn MIB, Nyassé S, Nyemb E, Sache I, Cilas C (2009). Relationships between cocoa *Phytophthora* pod rot disease and climatic variables in Cameroon. Canadian Journal of Plant Pathology 31(3):309-320. DOI: 10,1080/07060660909507605

Negi S, Sukumar P, Liu X, Cohen JD, Muday GK (2010). Genetic dissection of the role of ethylene in regulating auxin dependent lateral and adventitious root formation in tomato. Plant Journal 61:3-15

Niemenak N, Evina Eyamo JV, Mouafi Djabou SA, Ngouambe Tchouatcheu AG, Bernhardt C, Lieberei R, Bisping B (2020). Assessment of the profile of free amino acids and reducing sugars of cacao beans from local Cameroonian Trinitario (SNK varieties) and Forastero (TIKO varieties) using fermentation-like incubation. Journal of Applied Botany and Food Quality 93:321-329.

Niemenak N, Rohsius C, Elwers S, Omokolo ND, Lieberei R (2006). Comparative study of different cocoa (*Theobroma cacao* L) clones in terms of their phenolics and anthocyanins contents. Journal of Food Composition and Analysis 19(6-7):612-619.

Oracz J, Zyzelewicz D, Nebesny E (2015). The content of polyphenolic compounds in cocoa beans (*Theobroma cacao* L.), depending on variety, growing region, and processing operations: a review. Critical Reviews in Food Science and Nutrition 55(9):1176-1192. https://doi.org/10.1080/10408398.2012.686934

Paulin D, Snoeck L, Nyasse S (2003). Survey on the growing practices and planting material used for cacao growing in the central Region of Cameroon, Ingenic Newsletter 8:5-8,

Pedro PP, Guera S, Contreras D (2016). Changes in physical and chemical characteristics of fermented cocoa (*Theobroma cacao* L.) beans with manual and semi mechanized transfer between fermented boxes. Scientia Agropecuaria 7(2)11-119 DOI: 117268/sci,agropecu,2026,02,04

Singleton VL, Orthofer R, Lamela-Raventós RM (1999). Analysis of total phenols and other oxidation substrates and antioxidant means of Folin–Ciocalteau reagent. Methods in Enzymology 299:152-178.

Stoll L, Niemenak N, Bisping B, Reinhard L (2017). German cacao of Cameroon-New facts on a traditional variety fallen in to oblivion, Journal of Applied Botany and Food Quality 90:274-279. DOI:10,5073/JABFQ,2017,090,034 1

Tchouatcheu NG, Niemenak N, Noah MA, Lieberei R (2019). Effect of cocao quality grade on cocao evaluation by cut test and correlation with free amino acids and polyphenols profiles; Journal of Food Science and Technology 56(5):2621-2627. doi: 10,1007/s13197-019-03749-y

Wood GAR, Lass RA (1985). Cocoa, Longman Group Ltd, Blackwell Science Ltd, Fourth Edition 620 p.