Journal of Food Composition and Analysis 94 (2020) 103636

Contents lists available at ScienceDirect

Journal of Food Composition and Analysis

journal homepage: www.elsevier.com/locate/jfca

Original Research article

Variability of provitamin A carotenoids in plantain: Influence of cultivar, bunch type, maturation stage, and location

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ARTICLE INFO

Keywords:
Carotenoids
Central and West Africa
Plantain
Ripening
Daily intake

ABSTRACT

In this study, the effect of ripening stage (R), cultivar (C), bunch type (T), and location (L) on the variability of provitamin A carotenoids (pVACs) in 16 plantain cultivars grown in Cameroon and Gabon was investigated. For the sixteen plantain cultivars, fruits were collected at stages 1 (unripe), 5 (ripe), and 7 (overripe) from three different bunch types (French, False Horn, and True Horn) across 13 locations in Cameroon and Gabon. For all cultivars, the highest concentration of carotenoids was found in ripe pulp ($p < 0.05$). For bunch type, a higher level of pVACs was observed in the French type compared with the False Horn and True Horn types at all ripening stages. In addition, the concentration of pVACs at each ripening stage varied greatly across locations. In both countries, the interaction between the four factors, particularly between R × C, R × T, R × L, R × C × L, and R × T × L, contributed significantly ($p < 0.05$) to the variability of pVACs in plantain. Daily consumption of 100 g of ripe plantain could meet 36.2–101.7 % of the dietary reference intakes (DRIs) for children 1–5 years old, 20.7–58.1 % for adult women, and 16.1–45.2 % for adult men. These findings can serve as a guide to reducing vitamin A deficiency (VAD) in Africa.

1. Introduction

Carotenoids, the main bioactive constituents in fruit and vegetables, play a vital role in the prevention of many diseases (Singh et al., 2016). Some carotenoids are precursors of vitamin A biosynthesis. Many epidemiological studies report that the consumption of diets rich in carotenoids can improve immunity and reduce the risk of cancer, cardiovascular diseases, diabetes, age-related macular degeneration, and cataracts (Meyers et al., 2014; Müller et al., 2016). However, a deficiency of carotenoids, particularly provitamin A carotenoids, leads to vision disability in humans, especially in young children and pregnant women, and causes mortality owing to a weakened innate and adaptive immunity (Stephensen, 2001). In 2013, the World Health Organization (WHO) classified vitamin A deficiency (VAD) as a public health problem affecting one-third of children aged 6–59 months. The highest VAD rate was reported in countries with low per capita income, particularly sub-Saharan Africa (48 %) and South Asia (44 %) (Black et al., 2013). In Cameroon, the number of people facing food insecurity is estimated at 3.9 million, including 211,000, who are severely food insecure. Stunting remains a major public health issue, with levels reaching 38.4 % in the East Region; acute malnutrition is estimated at around 4.8 %. High malnutrition rates are primarily a result of limited consumption of nutritious food resulting in micronutrient deficiency. About 39 % of pre-school aged children and 18 % of pregnant women are deficient in vitamin A (World Food Program (WFP, 2018). Aguayo et al. (2005) reported that an estimated 937,600 children below 5 years of age are vitamin A deficient. Because of the lack of an appropriate policy and program action, VAD would annually cause about 12,000 deaths among

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https://doi.org/10.1016/j.jfca.2020.103636
Received 9 March 2020; Received in revised form 3 August 2020; Accepted 27 August 2020
Available online 1 September 2020
0889-1575/

children between 6 and 59 months old, representing 23.1 % of all causes of mortality in this age group. Likewise, a study by Abessolo et al. (2009) showed that more than 45 % of Gabonese children aged from 0 to13 years old experienced delayed growth, and this is positively correlated with low retinol concentrations.

Generally, the leading causes of VAD are linked to insufficient intake of vitamin A-rich foods, poor absorption of vitamins, and/or significant loss due to illness (Low et al., 2017). Many preventive strategies such as supplementation with high-dose vitamin A, fortification of foods during processing, dietary diversification and modification, and public health and disease-control measures have been proposed to counteract such problems (Wedner and Ross, 2017). Gibson et al. (2000) indicated that dietary diversification and modification by changing food production practices, food intake patterns, and traditional cooking methods were the most sustainable, economically feasible, equitable, and culturally acceptable strategies to combat VAD.

In countries with low per capita income, vitamin A intake is mainly acquired from fruits with yellow, orange, and red colors as well as from dark green leafy vegetables in the form of provitamin A carotenoids (pVACs) before conversion into retinol in the body (Ekesa et al., 2015). Among those fruits, plantain (*Musa* spp. AAB) is one of the major, cheap staples in African countries, especially in Cameroon and Gabon (Okolle et al., 2009), and is rich sources of carotenoids (Ekesa et al., 2015; Singh et al., 2016). Amah et al. (2019) reported that approximately 80 % of the carotenoids in plantain are α- and β-carotene. In addition, total carotenoids in tested cultivars varied from 5.1–16.0 $\mu g\ g^{-1}$ fresh weight (FW). Ngoh Newilah et al. (2009) also exhibited that the plantain genotype Mbouroukou 1 and *Musa* hybrid CRBP 755 in Cameroon contained the highest levels of retinol activity equivalents (RAE) compared with dessert banana. Borges et al. (2019a) stated that many factors such as cultivar, ripening stage, and location could contribute to the differentiation and variation of carotenoids and other biochemical compounds in plantain.

Plantain is a staple food in Cameroon and Gabon, but its contribution to pVACs in the diet is unknown. Therefore, the objectives of this study were to (i) evaluate the influence of ripening stage (R), cultivar (C), bunch type (T), and location (L) on the content of pVACs and (ii) investigate the influence of their interaction on pVAC content.

2. Materials and methods

2.1. Sample collection and preparation

Sixteen plantain cultivars from three different bunch types (French, False Horn, and True Horn) (Table 1) were collected in March 2019 (the beginning of the rainy season) from five locations in Cameroon (Bandounga, Njombe, Ntui, Bafia, and Batchenga) and eight locations in Gabon (Oyem, Ntoum, Bitam, Mitzic, Komi, Medakoe, Remboue, and Tsouka) (Fig. 1). The average temperature and rainfall, and soil classification at each sampling location are presented (Table 2). Fully developed bunches were harvested from farms cultivated either with or without fertilizer applications and grown in backyards, fields, or forests. Plantain was cultivated in monoculture or polyculture but also as a shade crop for cocoa production. Three bunches per cultivar were collected from each farm. Then deep green undamaged fruits were randomly sampled from the second and third hands of each bunch. The samples were packed in an aerated carton, labeled, and transported by road to the laboratory at the International Institute for Tropical Agriculture (IITA), Yaoundé, Cameroon. Three stages of ripening were considered according to the external color of the peel: 1 = mature green (unripe); 5 = all yellow with green ends (ripe); and 7 = yellow with black spots (fully ripe). The fruits were allowed to ripen naturally in a well-aerated room to reach each stage. At each ripening stage, three fingers from different bunches were randomly picked, and the fruits were cleaned, hand peeled, cut, kept in labeled zip-lock bags, and frozen at –25 °C before freeze-drying.

All samples were freeze-dried using a laboratory freeze-dryer (model Mudulyo, Edwards, England, UK) at a working pressure of 0.1 kPa and condenser chamber temperature of −45 °C for 72 h. The freeze-dried samples were then packaged, sealed in aluminum film bags, and stored in dark conditions at −20 °C for 2 weeks before transport to the Food and Nutrition Science Laboratory in IITA, Ibadan, Nigeria, for carotenoid analysis.

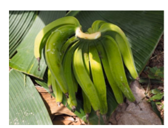
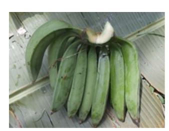
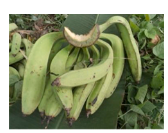
2.2. Extraction, analysis, and validation of carotenoids

Freeze-dried plantain samples were extracted according to the procedure described by Amah et al. (2019) with some modifications. Briefly, 5 g of each homogenized sample was weighed and thoroughly macerated in a mortar with 3 g of Celite in 50 mL of cold acetone. The solution was filtered with suction through filter paper in a Büchner funnel. This extraction procedure was repeated 3–4 times until the final residue appeared colorless. The acetone extract was then partitioned to 20 mL of petroleum ether in a separatory funnel. Distilled water was slowly added along the surface of the funnel allowing the two phases to separate without emulsion formation. Following this, the lower aqueous-acetone phase was discarded by washing four times with distilled water and, finally, with 150–200 mL of brine solution (NaCl) to break the emulsions formed. The upper organic (petroleum ether) phase was then filtered through anhydrous sodium sulfate into a 50 mL volumetric flask, and the volume was adjusted to 50 mL with petroleum ether. All the necessary precautions were taken as recommended by Rodriguez-Amaya (1999) to prevent errors during the carotenoid analysis.

The carotenoid analysis was carried out on a High-Performance Liquid Chromatography (HPLC) separation module (model Waters Alliance e2695, Waters Corporation, Milford, MA, USA) equipped with a polymeric YMC_{TM} C30 5 μm column (4.6 × 250 mm) and a photodiode array detector (PDA). The system was operated by Empower software (Waters Corporation, Milford, MA, USA). Fifteen mL of the petroleum ether extracted sample was concentrated and dried under nitrogen gas and reconstituted in 1 mL dichloromethane: methanol (50:50 $v\ v^{-1}$). The solution was filtered through a 0.22 mm polytetrafluoroethylene (PTFE) syringe filter (Millipore) into 2 mL vials (Waters PTFE/silicone septum) for HPLC. Sample injection volumes were 20 μL, and the flow rate was set at 1.0 mL min^{-1} at a temperature of 25 °C. Isocratic elution was performed for 10 min on extracts with 50: 50 $v\ v^{-1}$ methanol: methyl tert-butyl ether. The UV spectra were observed at 200–600 nm, and carotenoids were detected at 450 nm. Lutein, α-carotene, *trans*-β-carotene (*trans*-BC), 13-*cis*-β-carotene (13-*cis*-BC), and 9-*cis*-β-carotene (9-*cis*-BC) were identified using a standard external method based on the calibration curve established from pure standards. Identification of individual carotenoids in samples was possible by comparing their chromatograms with the retention times and absorption spectrum of pure commercial standards on the photodiode array detector library. Results were expressed as μg per g FW of the sample. Following the difference in fresh and freeze-dried weights, the moisture content of each sample was established, and the carotenoid values of fresh matter were determined [value of dry matter/(100/100−moisture%)].

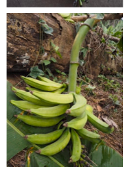
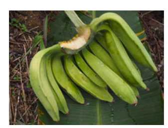
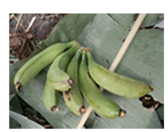
To validate the method, the selectivity, linearity, limit of detection (LOD), limit of quantification (LOQ), accuracy (recovery), and repeatability were analyzed. The selectivity of the LC system was evaluated by analyzing carotenoid isomers (all *trans*-lutein, all *trans*-α-carotene, all *trans*-BC, 13-*cis*-BC, and 9-*cis*-BC). Peak identification of each carotenoid standard was obtained from the chromatography by comparison of the diode array detector spectra with published data. Linearity was assessed by checking the detector response in the area units of duplicate injections of carotenoid standard as different concentrations through a linear regression using at least five-point analytical curves of all *trans*-lutein, α-carotene, and all *trans*-BC. The LODs were estimated applying the IUPAC Harmonised Guidelines for single-laboratory validation of methods of analysis (Thompson et al., 2002). It was calculated based on

Table 1
Plantain cultivars collected in Cameroon and Gabon for carotenoid analysis.

Bunch type	Cultivar	Visual appearances		Mean finger weight: edible portion (g)[a,b]	Mean finger length (cm)[c]	Mean finger girth (cm)[d]	Location	Country
		Bunch	Hands					
	Essong			163.4 (37.8)	28.1 (3.0)	4.0 (0.3)	Bafia, Ntui Bitam, Mitzic	Cameroon Gabon
	Red Essong			130.7 (37.7)	26.9 (1.5)	4.1 (0.4)	Batchenga	Cameroon
	Batard			194.0 (41.7)	29.2 (2.5)	3.7 (0.2)	Njombe Medakoe, Oyem, Komi	Cameroon Gabon
French	Njock Kon			243.8 (12.5)	33.4 (2.7)	4.3 (0.4)	Bandounga	Cameroon
	Elat			109.8 (20.3)	27.5 (2.2)	3.3 (0.4)	Batchenga, Ntui	Cameroon
	French Sombre			128.4 (12.4)	26.3 (1.8)	3.2 (0.1)	Tsouka	Gabon
	French Clair			254.9 (16.3)	35.9 (1.3)	4.0 (0.3)	Mitzic	Gabon

(*continued on next page*)

Table 1 (*continued*)

Bunch type	Cultivar	Visual appearances		Mean finger weight: edible portion (g)[a,b]	Mean finger length (cm)[c]	Mean finger girth (cm)[d]	Location	Country
		Bunch	Hands					
	Mbouroukou 1			548.2 (114.6)	41.2 (2.2)	5.3 (0.5)	Oyem	Gabon
	Mbouroukou 2			215.9 (25.3)	29.4 (1.6)	4.1 (0.2)	Ntoum	Gabon
	Mbouroukou 3			338.8 (45.7)	33.9 (2.0)	5.0 (0.3)	Bandounga, Njombe, Ntui	Cameroon
False Horn	Ebang			276.1 (75.0)	32.9 (4.1)	4.5 (0.4)	Bafia, Ntui	Cameroon
							Mitzic, Ntoum	Gabon
	Big Ebanga			273.4 (66.1)	32.4 (3.4)	4.3 (0.5)	Bandounga, Njombe	Cameroon
							Komi, Remboue	Gabon
	Red Ebang			295.3 (46.9)	33.6 (2.7)	4.4 (0.4)	Oyem, Bitam	Gabon
	Egnongui (Gorilla finger)			273.6 (15.9)	30.3 (1.9)	4.5 (0.2)	Bitam	Gabon

(*continued on next page*)

Table 1 (*continued*)

Bunch type	Cultivar	Visual appearances		Mean finger weight: edible portion (g)[a,b]	Mean finger length (cm)[c]	Mean finger girth (cm)[d]	Location	Country
		Bunch	Hands					
True Horn	Assugmbele			338.9 (46.7)	40.7 (4.0)	4.4 (0.4)	Bafia, Ntui Komi, Mitzic Bafia, Ntui	Cameroon Gabon Cameroon
	Assangda (one hand)		–	528.2 (77.0)	4.8 (0.5)	47.8 (2.7)	Oyem, Mitzic	Gabon

[a] Means (± standard deviation).
[b] Mean weight of edible portion calculated weighing 6–12 fingers, depending on cultivar, without peel.
[c] Mean finger length calculated from stem to tip of 6–12 well-formed fingers, depending on cultivar.
[d] Means finger girth calculated from three different positions of 6–12 well-formed fingers, depending on cultivar.
Source: Authors

the standard deviation of the response of the analytical curve (Sy) and the slope (S) of the calibration curve according to the formula: LOD = 3.3(Sy/S). The LOQs was computed according to the formula: LOQ = 10 (Sy/S). The standard deviation of the response was determined from the standard deviation of y-intercepts of regression lines. Recovery was determined by spiking samples of plantain with known amounts of carotenoid standards prior to extraction in three additional levels for each carotenoid. The within-day test for repeatability of the chromatographic systems was analyzed using all *trans*-BC of known concentrations using the HPLC, and the result was expressed as percentage of relative standard deviation (%RSD).

The validation results showed that the linear regression was significant ($p < 0.05$) in the evaluated concentration ranges, which was also corroborated by the high values of the determination of coefficient ($R^2 \geq 0.9994$). The residual plots of all the analytical curves followed a Gaussian distribution. The calculated LODs and LOQs for all carotenoids were in the range of 0.005–0.020 μg mL^{-1} and 0.014–0.050 μg mL^{-1}, respectively. The recovery values varied from 90 to 95 % for all carotenoid standards, which could imply approximately 5–10 % of carotenoid losses during the analytical procedure. The RSD for retention time was 0.11, peak height 0.26, and peak area 0.37 %, which were within an acceptable limit of 5%.

2.3. Vitamin A calculation and its dietary reference intakes

Total carotenoids (TC) with provitamin A activity were computed as pVACs (μg g^{-1} FW) = α-carotene+13-*cis*-BC+9-*cis*-BC+*trans*-BC; TC were computed as TC (μg g^{-1} FW) = total pVACs + lutein. Provitamin A content expressed in terms of β-carotene equivalents (BCEs) was calculated as BCE (μg g^{-1} FW) = 0.5 *trans*-α-carotene+*trans*-BC+0.53*cis*-BC, where *cis*-BC is the sum of 13-*cis*-BC and 13-*cis*-AC. These values were then converted into retinol activity equivalents (RAEs), assuming that 1/12th of the total all-*trans*-BCEs ingested is taken up into the body (Yeum and Russell, 2002). The RAEs in μg per 100 g FW were compared with the vitamin A DRI for children 1–5 years old at 400 RAE μg day^{-1}, for adult and pregnant women at 700 RAE μg day^{-1}, and for adult men at 900 RAE μg day^{-1} (FAO/WHO, 2002).

2.4. Statistical analysis

The analysis of variance (ANOVA) and least significant difference (LSD) was used to examine the presence of statistically significant mean differences in carotenoid content by R, C, T, and L at a 5 % significance level using the SAS program (Ver. 9.4, SAS Inst., Cary, NC, USA). The influence of the key factors: R, C, T, and L on pVACs content was analyzed. In addition to the mean difference in pVACs across R, C, T, and L, their interaction effects were also examined using ANOVA.

3. Results and discussion

3.1. Bunch type vs ripening stage on carotenoid content

Considering the effect of T and R (without C and L effects), the results showed a higher level of pVACs was found in the French type at all maturity stages when compared with corresponding values in False Horn and True Horn types (Fig. 2). For example, the level of pVACs in unripe pulp (stage 1) of the French type was higher by 60.1 % than the False Horn type and by 57.1 % than the True Horn type (Table 3). In the ripe pulp (stage 5) of the French type, the pVACs were about 13.2 % higher than in the False Horn type and 32.6 % higher than in the True Horn type. In overripe pulp (stage 7), pVACs were 24.8 % higher than in the False Horn type and 33.7 % higher than in the True Horn type. Slightly higher values of individual carotenoids such as lutein, α-carotene, 13-*cis*-BC, and 9-*cis*-BC in plantain have also been reported by Amah et al. (2019) who assessed the variability of *Musa acuminata* cultivars and hybrids.

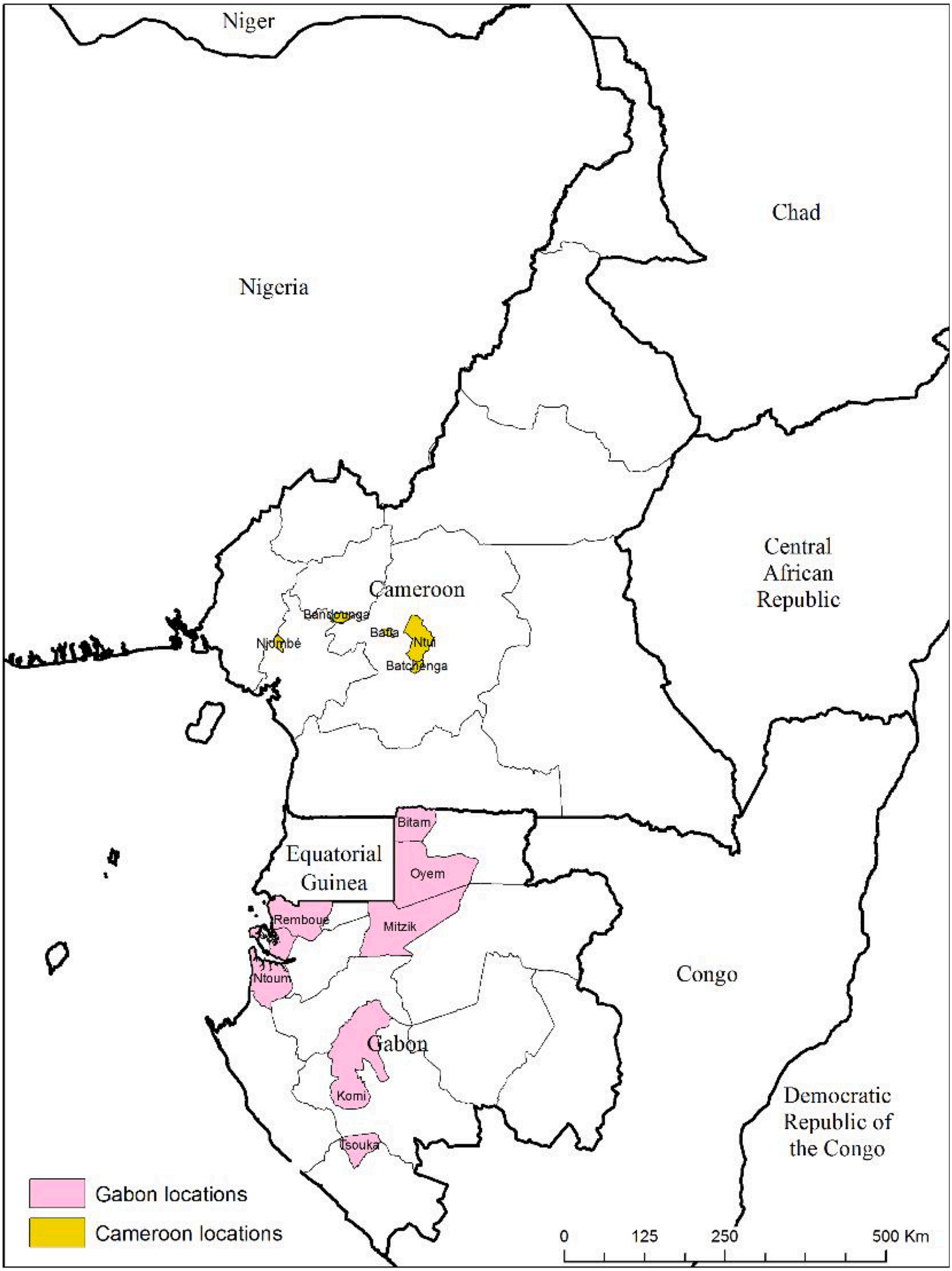


Fig. 1. Sampling locations in Cameroon and Gabon.

When the proportion of relative carotenoids across the different bunch types at each ripening stage is considered, a significant increase of *trans*-BC was observed from stage 1 to stage 5 while levels of lutein, 13-*cis*-BC, and 9-*cis*-BC decreased during ripening before slightly increasing at stage 7 (Fig. 3). An increase of the *cis* proportion in overripe pulp might be due to enzymatic or non-enzymatic isomerization of *trans*-carotenes to *cis*-isomers (Ekesa et al., 2015). In addition, lutein and 13-*cis*-BC greatly decreased by 60.3 and 52.0 % in False Horn and by

Table 2
Average temperature, rainfall, and soil classification of studied locations in Cameroon and Gabon.

Country	Location	Average temperature (°C)	Average rainfall (mm year^{-1})	Soil classification
Cameroon	Bandounga	23.1	2160	Ferralitic and hydromorphic soils
	Njombe	26.6	3002	Little evolved eutrophic brown soils and typical ferralitic soils
	Ntui	24.8	1573	Ferralitic and hydromorphic soils (sandy-clay, clay)
	Bafia	25.2	1548	Yellow ferralitic soil (sandy-clay)
	Batchenga	24.8	1611	Ferralitic and hydromorphic soils
Gabon	Oyem	23.3	1793	Ferralitic and hydromorphic soils (sandy-clay)
	Ntoum	26.2	2716	Ferralitic and hydromorphic soils (sandy-clay)
	Bitam	24.1	1737	Ferralitic and hydromorphic soils (clay)
	Mitzic	23.6	1653	Ferralitic and hydromorphic soils (sandy- clay)
	Komi	26.1	1999	Ferralitic and hydromorphic soils (sandy)
	Medakoe	26.2	2005	Ferralitic and hydromorphic soils (sandy)
	Remboue	25.5	3039	Ferralitic and hydromorphic soils (sandy-clay)
	Tsouka	28.0	2011	Ferralitic and hydromorphic soils (sandy)

Source: Authors

36.5 and 55.1 %, respectively, in True Horn when the fruits were ripened to stage 5; α-carotene and *trans*-BC increased by 13.5 and 56.5 %, respectively, in False Horn and by 16.9 and 62.4 % in True Horn. In the French type, no variation was clearly observed when compared with those of False Horn and True Horn. It is interesting that more than 90 % of the carotenoids isolated in the French type at all ripening stages contributed to pVACs, while less than 10 % was made up of the non-pVACs lutein. Although about 90 % of carotenoids in ripe and overripe pulp of False Horn and True Horn was pVACs, the contribution of carotenoids to pVACs in unripe pulp was less than 80 % in False Horn and 85 % in True Horn. Amah et al. (2019) also showed that the highest proportion of pVACs (88 %) is in plantain when compared to *Musa acuminata* cultivars (78 %) and hybrids (67 %) sampled at the fresh ripe stage.

3.2. Cultivar vs ripening stage on carotenoid content

The major carotenoid isolated at all maturity stages was α-carotene (45.5 %), followed by *trans*-BC (25.3 %), 13-*cis*-BC (14.1 %), lutein (12.5 %), and 9-*cis*-BC (2.6 %) (Table 3).There was a wide variation in carotenoid content in all plantain cultivars analyzed. It ranged from 0.3–22.1 μg g^{-1} FW at maturity stage 1, 29.9 to 106.0 μg g^{-1} FW at stage 5, and 19.7 to 93.6 μg g^{-1} FW at stage 7. The average TC varied from 0.7–24.5 μg g^{-1} FW at stage 1; from 32.9–119.3 μg g^{-1} FW at stage 5; and from 23.9–99.1 μg g^{-1} FW at stage 7. These concentrations are within the range of values for banana and plantain reported by Ngoh Newilah et al. (2009); Englberger et al. (2010); Ekesa et al. (2015); Amah et al. (2019), and Borges et al. (2019b). Likewise, the concentration of α-carotene, *trans*-BC, 13-*cis*-BC, lutein, and 9-*cis*-BC in all cultivars significantly increased ($p < 0.05$) from stage 1 (unripe) to stage 5 (ripe) and then decreased at stage 7 (overripe).

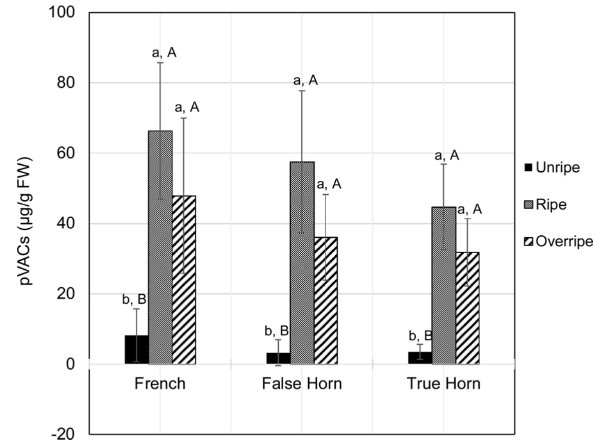


Fig. 2. Variation of provitamin A carotenoids (pVACs) of plantain cultivars at ripening stage 1, 5, and 7 as affected by the different bunch types of plantain (French, False Horn, and True Horn).
Means (± standard deviation) within a bar followed by different lower-case letters (ripening stages) and different upper-case letters (bunch types), differ by LSD test ($p < 0.05$).

Considering the effect of C and R (without T and L effects), it could be seen that unripe French Sombre (22.09 μg g^{-1} FW), Red Essong (15.0 μg g^{-1} FW), and Batard (9.6 μg g^{-1} FW) exhibited the highest value of pVACs (Table 4). The value was very low in Mbouroukou 3 (1.4 μg g^{-1} FW), Njock Kon (1.4 μg g^{-1} FW), and Egnongui (1.4 μg g^{-1} FW). At the ripe stage, French Sombre (104.6 μg g^{-1} FW), French Clair (83.6 μg g^{-1} FW), and Egnongui (80.7 μg g^{-1} FW) showed the highest value of pVACs among all cultivars. The overripe pulp of French Sombre (66.5 μg g^{-1} FW) still contained the highest value of pVACs, followed by Mbouroukou 2 (59.0 μg g^{-1} FW) and Elat (54.6 μg g^{-1} FW). Overall, the level of pVACs in all cultivars decreased by an average of 31.9 % when the fruits continued to ripen from stage 5–7. The highest loss of pVACs during ripening was observed in Big Ebanga (59.2 %), followed by Mbouroukou 1 (48.9 %), Batard (48.6 %), and French Clair (45.3 %).

An increase of carotenoids in ripe pulp indicates the degradation of chlorophylls with a concomitant rise of carotenoids (Singh et al., 2016; Alos et al., 2019). Likewise, the level of difference in carotenoid accumulation during ripening in each cultivar might be caused by the different expression and regulation of carotenogenesis gene transcripts as well as the structure and function of diverse metabolic enzymes (Zhang et al., 2012; Ma et al., 2018) caused by the different growing conditions at the various sampling sites. Indeed, Ngoh Newilah et al. (2009) made a causal link between increases of α- and β-carotene as well as of lutein in the ripe pulp during the fruit production cycle and fertilizer application. The reduction in carotenoids during the overripe stage could probably be explained by oxidation and/or the isomerization process of carotenoids (Schieber and Carle, 2005; Borges et al., 2019c). In contrast, Ngoh Newilah et al. (2009) exemplified the reduction in carotenoid levels to the carotenoid degradation during ripening. This mechanism occurs via enzymatic cleavage and may stimulate the synthesis of other carotenoid isomers, such as volatile compounds (Borges et al., 2019b).

3.3. Location vs ripening stage on carotenoid content

The result showed that carotenoid concentrations in plantain at each stage of ripening varied greatly among locations (Table 3). At stage 1,

Table 3
Carotenoid content at ripening stages 1, 5, and 7 in plantain cultivars grown in Cameroon and Gabon.

Bunch type	Cultivar	Location	Country	Maturity stage	Lutein (μg g^{-1} FW)	α-carotene (μg g^{-1} FW)	13-*cis*-BC (μg g^{-1} FW)	9-*cis*-BC (μg g^{-1} FW)	*trans*-BC (μg g^{-1} FW)	pVACs (μg g^{-1} FW)	TC (μg g^{-1} FW)	BCE (μg g^{-1} FW)
French	Essong			1	0.86 (0.07)^{bC}	0.92 (0.14)^{bE}	0.65 (0.05)^{bD}	0.10 (0.00)^{bD}	0.29 (0.02)^{cE}	1.97 (0.21)^{cE}	2.83 (0.15)^{cE}	0.97 (0.11)^{cF}
		Bafia	Cameroon	5	4.34 (0.00)^{aB}	25.45 (0.15)^{aC}	5.96 (0.25)^{aB}	1.07 (0.02)^{aC}	12.42 (0.07)^{aC}	44.89 (0.20)^{aC}	49.24 (0.20)^{aC}	21.28 (0.10)^{aC}
				7	4.19 (0.43)^{aB}	16.65 (1.06)^{bD}	4.42 (0.73)^{aB}	1.00 (0.07)^{aC}	9.38 (0.52)^{bC}	31.46 (2.24)^{bC}	35.65 (1.81)^{bC}	14.75 (1.08)^{bD}
				1	0.35 (0.00)^{bC}	0.25 (0.00)^{cE}	0.08 (0.03)^{cD}	0.04 (0.01)^{bD}	0.16 (0.05)^{cE}	0.53 (0.10)^{cE}	0.88 (0.10)^{cE}	0.25 (0.05)^{cF}
		Ntui	Cameroon	5	4.98 (0.17)^{aAB}	38.86 (2.33)^{aB}	5.73 (0.23)^{aB}	0.84 (0.02)^{aC}	25.57 (0.06)^{aB}	71.00 (2.64)^{aB}	75.97 (2.81)^{aB}	32.23 (1.32)^{aB}
				7	5.88 (0.68)^{aA}	11.52 (1.04)^{bD}	2.89 (0.02)^{bC}	0.58 (0.04)^{aC}	5.52 (0.14)^{bD}	20.50 (1.19)^{bD}	26.38 (0.51)^{bD}	9.59 (0.58)^{bE}
				1	0.69 (0.30)^{bC}	1.16 (0.01)^{cE}	1.30 (0.03)^{bCD}	0.63 (0.32)^{bC}	0.51 (0.05)^{cE}	3.60 (0.40)^{cE}	4.29 (0.69)^{cE}	1.82 (0.20)^{cF}
		Bitam	Gabon	5	4.43 (0.03)^{aB}	51.83 (0.75)^{aA}	5.08 (0.07)^{aB}	1.73 (0.12)^{aB}	33.65 (5.13)^{aA}	92.29 (5.70)^{aA}	96.72 (5.73)^{aA}	43.44 (2.40)^{aA}
				7	4.95 (0.25)^{aAB}	39.67 (1.65)^{bB}	6.69 (0.21)^{aAB}	0.73 (0.05)^{bC}	21.33 (2.02)^{bB}	68.42 (0.53)^{bB}	73.36 (0.77)^{bB}	32.34 (0.07)^{bB}
				1	0.67 (0.13)^{bC}	2.82 (0.48)^{bE}	1.40 (0.05)^{bCD}	0.15 (0.04)^{cD}	0.67 (0.03)^{bE}	5.03 (0.46)^{bE}	5.71 (0.59)^{bE}	2.51 (0.23)^{bF}
		Mitzic	Gabon	5	4.16 (0.00)^{aB}	53.95 (0.50)^{aA}	8.92 (0.10)^{aA}	1.93 (0.09)^{bB}	36.39 (1.01)^{aA}	101.20 (0.50)^{aA}	105.36 (0.50)^{aA}	47.69 (0.16)^{aA}
				7	5.48 (0.51)^{aA}	51.11 (1.22)^{aA}	7.98 (0.84)^{aA}	3.83 (0.71)^{aA}	30.65 (3.57)^{aA}	93.57 (2.47)^{aA}	99.05 (1.97)^{aA}	44.26 (0.90)^{aA}
	Red Essong			1	0.62 (0.18)^{bC}	4.32 (0.94)^{bD}	1.86 (0.30)^{bC}	0.46 (0.01)^{bB}	1.66 (0.25)^{bC}	8.30 (1.49)^{bD}	8.93 (1.31)^{bD}	4.08 (0.73)^{bC}
		Batchenga	Cameroon	5	7.19 (1.06)^{aA}	16.35 (1.31)^{aC}	7.15 (0.12)^{aA}	0.62 (0.00)^{aA}	14.48 (0.07)^{aA}	38.60 (1.11)^{aB}	45.79 (2.17)^{aB}	18.10 (0.56)^{aAB}
				7	6.49 (0.07)^{aAB}	13.66 (0.64)^{aC}	6.43 (0.54)^{aA}	0.60 (0.05)^{aA}	10.88 (1.20)^{aA}	31.57 (1.36)^{aB}	38.05 (1.29)^{aB}	14.85 (0.54)^{aB}
				1	2.83 (0.06)^{cB}	12.81 (0.75)^{bC}	2.67 (0.04)^{bBC}	0.64 (0.09)^{bA}	5.56 (0.04)^{bB}	21.68 (0.77)^{cC}	24.51 (0.71)^{cC}	10.39 (0.39)^{bB}
		Ntui	Cameroon	5	8.20 (0.16)^{aA}	39.89 (1.72)^{aA}	4.96 (0.25)^{aB}	0.86 (0.05)^{aA}	13.14 (0.20)^{aA}	58.85 (1.61)^{aA}	67.05 (1.45)^{aA}	28.17 (0.77)^{aA}
				7	5.94 (0.11)^{bAB}	31.83 (1.65)^{aB}	3.61 (0.40)^{aB}	0.86 (0.29)^{aA}	10.79 (0.33)^{aA}	47.09 (0.62)^{bA}	53.03 (0.73)^{bA}	22.44 (0.33)^{aA}
	Batard			1	1.07 (0.04)^{cCD}	10.64 (0.04)^{cD}	2.36 (0.19)^{bBC}	0.35 (0.09)^{bC}	7.43 (0.06)^{cC}	20.79 (0.01)^{cC}	21.86 (0.03)^{cC}	9.83 (0.01)^{cBC}
		Njombe	Cameroon	5	6.24 (0.00)^{aA}	34.98 (1.78)^{aA}	8.93 (0.23)^{aA}	1.45 (0.11)^{aA}	19.32 (0.41)^{aB}	64.67 (2.53)^{aA}	70.92 (2.53)^{aA}	30.72 (1.23)^{aA}
				7	2.28 (0.21)^{bC}	16.22 (0.09)^{bC}	2.93 (0.04)^{bBC}	0.73 (0.04)^{bB}	10.33 (0.02)^{bC}	30.20 (0.04)^{bB}	32.48 (0.25)^{bB}	14.17 (0.01)^{bB}
				1	0.88 (0.17)^{bD}	5.61 (0.48)^{cE}	2.58 (0.30)^{bBC}	0.57 (0.03)^{aBC}	1.78 (0.02)c	10.54 (0.79)^{cCD}	11.42 (0.96)^{cCD}	5.23 (0.41)^{cC}
		Medakoe	Gabon	5	5.76 (0.26)^{aAB}	25.17 (0.41)^{aB}	4.28 (0.26)^{aB}	0.86 (0.02)^{aB}	16.56 (0.07)^{aB}	46.88 (0.05)^{aB}	52.64 (0.32)^{aB}	21.94 (0.03)^{aAB}
				7	5.20 (0.57)^{aAB}	13.59 (0.05)^{bC}	3.54 (0.99)^{abB}	0.62 (0.09)^{aB}	7.12 (0.16)^{bC}	24.88 (1.18)^{bC}	30.08 (0.61)^{bC}	11.81 (0.61)^{bB}
				1	0.61 (0.01)^{cD}	1.03 (0.03)^{cF}	0.66 (0.12)^{cC}	0.17 (0.01)^{cC}	0.40 (0.00)^{cD}	2.26 (0.14)^{cD}	2.87 (0.15)^{cD}	1.12 (0.07)^{cC}
		Oyem	Gabon	5	6.69 (0.22)^{aA}	33.95 (2.10)^{aA}	7.95 (0.12)^{aA}	1.86 (0.02)^{aA}	17.15 (0.19)^{aB}	60.90 (2.33)^{aA}	67.59 (2.56)^{aA}	29.24 (1.15)^{aA}
				7	4.28 (0.25)^{bB}	6.86 (0.09)^{bE}	3.09 (0.09)^{bB}	0.87 (0.00)^{bB}	8.83 (0.07)^{bC}	19.65(0.07)^{bC}	23.94 (0.33)^{bC}	8.97 (0.03)^{bBC}
				1	0.78 (0.19)^{bD}	2.20 (0.33)^{cF}	1.50 (0.31)^{bC}	0.36 (0.06)^{bC}	0.54 (0.10)^{cD}	4.61 (0.48)^{cD}	5.38 (0.29)^{cD}	2.32 (0.26)^{cC}
		Komi	Gabon	5	6.78 (0.24)^{aA}	35.92 (1.13)^{aA}	8.52 (0.07)^{aA}	1.68 (0.02)^{aA}	27.08 (0.29)^{aA}	73.19 (1.33)^{aA}	79.97 (1.09)^{aA}	34.59 (0.64)^{aA}
				7	5.29 (0.25)^{aAB}	23.39 (2.18)^{bB}	7.35 (0.12)^{aA}	1.37 (0.16)^{aA}	19.48 (0.02)^{bB}	51.58 (2.23)^{bAB}	56.87 (2.48)^{bAB}	24.09 (1.12)^{bAB}
				1	0.70 (0.25)^{b}	0.68 (0.15)^{c}	0.31 (0.01)^{b}	0.09 (0.03)^{b}	0.29 (0.10)^{b}	1.36 (0.29)^{b}	2.06 (0.53)^{b}	0.68 (0.14)^{b}
	Njock Kon	Bandounga	Cameroon	5	4.22 (0.07)^{a}	33.48 (3.76)^{a}	5.91 (0.47)^{a}	0.85 (0.00)^{a}	17.78 (0.05)^{a}	58.02 (4.27)^{a}	62.24 (4.20)^{a}	27.62 (2.15)^{a}
				7	3.98 (0.93)^{a}	27.95 (0.05)^{b}	5.43 (0.03)^{a}	0.76 (0.03)^{a}	16.71 (1.64)^{a}	50.84 (1.69)^{a}	54.83 (2.63)^{a}	24.09 (0.70)^{a}
	Elat			1	0.52 (0.03)^{bC}	0.90 (0.17)^{bD}	0.64 (0.04)^{cD}	0.09 (0.03)^{bB}	0.15 (0.04)^{bC}	1.79 (0.28)^{bC}	2.31 (0.31)^{bD}	0.90 (0.14)^{bC}
		Batchenga	Cameroon	5	4.18 (0.92)^{aB}	30.39 (0.04)^{aB}	7.51 (0.11)^{aB}	0.94 (0.05)^{aA}	12.40 (1.79)^{aB}	51.24 (1.98)^{aB}	55.42 (2.90)^{aC}	24.63 (0.82)^{aB}
				7	3.22 (0.19)^{aB}	27.33 (2.07)^{aB}	5.94 (1.00)^{bC}	0.79 (0.02)^{aA}	13.22 (1.29)^{aB}	47.28 (1.76)^{aB}	50.49 (1.95)^{aC}	22.16 (1.07)^{aB}
				1	0.65 (0.00)^{bC}	5.58 (0.29)^{cC}	1.36 (0.31)^{cD}	0.08 (0.01)^{bB}	2.91 (0.09)^{bC}	9.92 (0.12)^{bC}	10.57 (0.12)^{cD}	4.76 (0.06)^{bC}
		Ntui	Cameroon	5	6.24 (0.07)^{aA}	43.99 (1.32)^{aA}	9.54 (0.02)^{aA}	1.23 (0.31)^{aA}	21.58 (2.66)^{aA}	76.34 (1.67)^{aA}	82.58 (1.60)^{aA}	36.49 (0.60)^{aA}
				7	5.93 (0.05)^{aA}	34.38 (0.65)^{bB}	6.49 (0.88)^{bBC}	1.12 (0.07)^{aA}	19.92 (1.46)^{aA}	61.91 (1.76)^{aA}	67.83 (1.70)^{bB}	29.24 (0.76)^{aA}
				1	1.09 (0.02)^{c}	10.57 (1.33)^{c}	3.23 (1.05)^{c}	0.55 (0.11)^{b}	7.73 (0.28)^{c}	22.09 (0.10)^{c}	23.18 (0.08)^{c}	10.52 (0.05)^{c}
	French Sombre	Tsouka	Gabon	5	14.70 (0.32)^{a}	51.88 (5.76)^{a}	11.39 (0.84)^{a}	1.45 (0.02)^{a}	39.83 (3.00)^{a}	104.5 (7.90)^{a}	119.26 (7.58)^{a}	48.80 (3.63)^{a}
				7	6.56 (0.20)^{b}	38.10 (1.10)^{b}	5.50 (0.47)^{b}	0.83 (0.05)^{b}	22.01 (1.74)^{b}	66.47 (1.16)^{b}	73.03 (1.36)^{b}	31.00 (0.40)^{b}
			Gabon	1	0.53 (0.04)^{b}	5.87 (0.30)^{c}	1.21 (0.11)^{b}	0.04 (0.02)^{c}	1.11 (0.14)^{c}	8.23 (0.53)^{c}	8.75 (0.57)^{c}	4.04 (0.25)^{c}
	French Clair	Mitzic		5	6.80 (0.93)^{a}	47.06 (0.67)^{a}	7.86 (0.13)^{a}	1.52 (0.22)^{a}	27.18 (1.80)^{a}	83.62 (0.78)^{a}	90.42 (1.70)^{a}	38.89 (0.17)^{a}
				7	6.49 (0.06)^{a}	28.57 (0.61)^{b}	7.31 (1.53)^{a}	0.61 (0.06)^{b}	9.23 (0.15)^{b}	45.72 (2.24)^{b}	52.21 (2.18)^{b}	21.89 (1.14)^{b}
False Horn	Mbouroukou 1			1	0.40 (0.02)^{b}	0.61 (0.15)^{c}	0.55 (0.07)^{b}	0.05 (0.03)^{b}	0.43 (0.11)^{c}	1.63 (0.13)^{c}	2.03 (0.15)^{c}	0.81 (0.07)^{c}
		Oyem	Gabon	5	4.38 (0.10)^{a}	40.15 (1.63)^{a}	7.43 (0.24)^{a}	1.51 (0.02)^{a}	17.51 (0.21)^{a}	66.60 (1.62)^{a}	70.98 (1.72)^{a}	31.93 (0.78)^{a}
				7	4.46 (0.25)^{a}	21.09 (0.21)^{b}	6.58 (0.27)^{a}	1.10 (0.00)^{a}	5.28 (0.09)^{b}	34.06 (0.57)^{b}	38.52 (0.32)^{b}	16.72 (0.28)^{b}
	Mbouroukou 2			1	0.68 (0.14)^{b}	0.88 (0.14)^{c}	0.74 (0.01)^{b}	0.12 (0.00)^{b}	0.20 (0.04)^{b}	1.95 (0.20)^{c}	2.63 (0.06)^{c}	0.98 (0.10)^{c}
		Ntoum	Gabon	5	4.62 (0.04)^{a}	35.29 (2.06)^{a}	6.95 (0.34)^{a}	2.00 (0.04)^{a}	29.08 (0.19)^{a}	73.32 (1.57)^{a}	77.93 (1.61)^{a}	34.04 (0.80)^{a}
				7	4.27 (0.25)^{a}	26.44 (0.22)^{b}	6.51 (0.00)^{a}	1.79 (0.04)^{a}	24.24 (0.54)^{a}	58.98 (0.36)^{b}	63.24 (0.61)^{b}	27.11 (0.12)^{b}
	Mbouroukou 3	Bandounga	Cameroon	1	2.94 (0.10)^{bC}	1.33 (0.18)^{cD}	0.95 (0.30)^{bC}	0.11 (0.02)^{bB}	0.37 (0.03)^{bC}	2.75 (0.42)^{bC}	5.70 (0.32)^{cD}	1.37 (0.22)^{bB}

(*continued on next page*)

Table 3 (*continued*)

Bunch type	Cultivar	Location	Country	Maturity stage	Lutein (μg g^{-1} FW)	α-carotene (μg g^{-1} FW)	13-*cis*-BC (μg g^{-1} FW)	9-*cis*-BC (μg g^{-1} FW)	*trans*-BC (μg g^{-1} FW)	pVACs (μg g^{-1} FW)	TC (μg g^{-1} FW)	BCE (μg g^{-1} FW)
				5	6.35 (0.11)^{aA}	30.39 (0.09)^{aA}	6.23 (0.09)^{aA}	1.04 (0.00)^{aA}	13.19 (0.08)^{aA}	54.70 (0.04)^{aA}	61.05 (0.15)^{aA}	25.62 (0.02)^{aA}
				7	5.15 (0.25)^{aAB}	23.96 (0.25)^{bB}	5.77 (0.02)^{aA}	0.69 (0.02)^{aA}	14.42 (0.44)^{aA}	44.83 (0.73)^{aA}	49.98 (0.97)^{bB}	20.74 (0.31)^{aA}
		Njombe	Cameroon	1	0.53 (0.14)^{cD}	0.36 (0.12)^{cD}	0.35 (0.04)^{bC}	0.07 (0.01)^{cB}	0.16 (0.05)^{cC}	0.95 (0.04)^{bC}	1.47 (0.10)^{cD}	0.47 (0.02)^{bB}
				5	6.03 (0.04)^{aA}	23.57 (2.19)^{aB}	5.04 (0.13)^{aAB}	1.01 (0.15)^{aA}	14.45 (0.10)^{aA}	44.07 (2.08)^{aA}	50.10 (2.11)^{aB}	20.31 (1.05)^{aA}
				7	4.86 (0.29)^{bB}	17.24 (0.95)^{bC}	4.48 (0.83)^{aB}	0.69 (0.06)^{bA}	7.87 (0.83)^{bB}	30.27 (2.55)^{aB}	35.13 (2.26)^{bC}	14.05 (1.16)^{aA}
		Ntui	Cameroon	1	0.34 (0.06)^{bD}	0.12 (0.08)^{bD}	0.15 (0.04)^{bC}	0.04 (0.01)^{bB}	0.05 (0.00)^{bC}	0.35 (0.15)^{bC}	0.69 (0.21)^{bD}	0.18 (0.07)^{bB}
				5	4.92 (0.06)^{aB}	20.54 (1.30)^{aBC}	5.04 (0.44)^{aAB}	1.19 (0.15)^{aA}	12.99 (0.02)^{aA}	39.77 (1.62)^{aB}	44.68 (1.67)^{aB}	18.58 (0.81)^{aA}
				7	4.02 (0.11)^{aBC}	18.00 (0.00)^{aC}	4.99 (0.02)^{aB}	0.79 (0.00)^{aA}	11.68 (1.14)^{aA}	35.46 (1.12)^{aB}	39.48 (1.01)^{aC}	16.48 (0.42)^{aA}
	Ebang			1	0.27 (0.02)^{bE}	0.71 (0.06)^{bE}	0.44 (0.01)^{bD}	0.08 (0.04)^{bC}	0.30 (0.02)^{bC}	1.52 (0.14)^{bD}	1.78 (0.12)^{bD}	0.75 (0.07)^{bC}
		Bafia	Cameroon	5	2.97 (0.03)^{aD}	14.88 (0.08)^{aC}	3.10 (0.46)^{aBC}	0.69 (0.03)^{aB}	11.22 (0.52)^{aB}	29.89 (1.03)^{aC}	32.86 (1.07)^{aC}	14.13 (0.49)^{aB}
				7	2.62 (0.37)^{aD}	13.79 (0.34)^{aC}	2.47 (0.17)^{aC}	0.66 (0.19)^{aB}	8.01 (1.58)^{aB}	24.93 (1.60)^{aC}	27.55 (1.22)^{aC}	11.89 (0.68)^{aB}
				1	0.54 (0.04)^{bE}	0.12 (0.06)^{bE}	0.15 (0.04)^{cD}	0.03 (0.01)^{bC}	0.04 (0.02)^{bC}	0.34 (0.07)^{bD}	0.89 (0.03)^{bD}	0.17 (0.04)^{bC}
		Ntui	Cameroon	5	5.44 (0.00)^{aBC}	19.56 (0.04)^{aBC}	5.41 (0.08)^{aB}	0.75 (0.04)^{aB}	13.21 (0.13)^{aB}	38.94 (0.13)^{aC}	44.38 (0.13)^{aC}	17.95 (0.05)^{aB}
				7	4.57 (0.27)^{aC}	16.12 (0.23)^{aC}	3.83 (0.43)^{bBC}	0.77 (0.12)^{aB}	11.09 (0.21)^{aB}	31.80 (0.76)^{aC}	36.38 (1.03)^{aC}	14.52 (0.36)^{aB}
				1	0.98 (0.12)^{cE}	2.63 (0.03)^{cD}	0.35 (0.07)^{cD}	0.05 (0.01)^{bC}	0.08 (0.02)^{bC}	3.12 (0.08)^{bD}	4.10 (0.19)^{bD}	1.57 (0.04)^{cC}
		Mitzic	Gabon	5	8.23 (0.27)^{aA}	21.69 (1.82)^{aB}	7.11 (0.12)^{aA}	2.04 (0.02)^{aA}	18.68 (0.04)^{aB}	49.52 (1.93)^{aB}	57.74 (2.19)^{aB}	23.17 (0.97)^{aA}
				7	4.83 (0.20)^{bC}	16.63 (0.75)^{bBC}	5.52 (0.00)^{bB}	1.80 (0.02)^{aA}	12.69 (0.20)^{aB}	36.64 (0.97)^{aC}	41.47 (0.77)^{aC}	17.09 (0.46)^{bB}
				1	0.60 (0.02)^{cE}	2.79 (0.04)^{cD}	1.69 (0.18)^{bD}	0.35 (0.01)^{bC}	1.03 (0.11)^{cC}	5.86 (0.05)^{cD}	6.46 (0.07)^{cD}	2.90 (0.04)^{cC}
		Ntoum	Gabon	5	6.04 (0.39)^{aB}	32.27 (2.01)^{aA}	4.81 (0.09)^{aB}	1.46 (0.02)^{aA}	31.94 (0.07)^{aA}	70.48 (2.01)^{aA}	76.53 (1.62)^{aA}	32.04 (1.00)^{aA}
				7	4.88 (0.21)^{bC}	14.84 90.38)^{bC}	5.03 (0.04)^{aB}	1.42 (0.17)^{aA}	12.71 (1.28)^{bB}	34.00 (0.69)^{bC}	38.87 (0.90)^{bC}	15.54 (0.17)^{bB}
	Big Ebanga			1	0.44 (0.02)^{bE}	0.32 (0.05)^{cF}	0.32 (0.04)^{bD}	0.05 (0.00)^{bC}	0.07 (0.03)^{cE}	0.75 (0.07)^{cD}	1.19 (0.09)^{cD}	0.38 (0.04)^{cC}
		Bandounga	Cameroon	5	3.65 (0.60)^{aCD}	25.64 (0.32)^{aB}	5.27 (0.61)^{aAB}	0.83 (0.02)^{aB}	19.82 (0.20)^{aB}	51.56 (1.12)^{aB}	55.21 (1.72)^{aB}	24.28 (0.56)^{aA}
				7	2.60 (0.02)^{aD}	13.28 (0.85)^{bD}	4.63 (0.07)^{aB}	0.73 (0.02)^{aB}	6.08 (0.16)^{bD}	24.72 (0.78)^{bC}	27.32 (0.77)^{bC}	11.95 (0.41)^{bB}
				1	0.65 (0.10)^{bE}	0.93 (0.04)^{cF}	0.44 (0.07)^{cD}	0.09 (0.02)^{bC}	0.20 (0.11)^{cE}	1.67 (0.25)^{bD}	2.32 (0.35)^{bD}	0.83 (0.11)^{bC}
		Njombe	Cameroon	5	3.07 (0.11)^{aD}	16.20 (2.06)^{aC}	4.80 (0.28)^{aB}	0.61 (0.00)^{aB}	13.36 (0.02)^{aC}	34.97 (2.32)^{aC}	38.03 (2.21)^{aC}	16.02 (1.17)^{aB}
				7	2.82 (0.17)^{aD}	10.84 (0.76)^{bD}	3.24 (0.42)^{bBC}	0.78 (0.08)^{aB}	7.12 (0.36)^{bD}	21.99 (1.47)^{aC}	24.82 (1.64)^{aC}	10.19 (0.70)^{aB}
				1	0.69 (0.22)^{b}	3.90 (0.12)^{cE}	1.85 (0.08)^{bC}	0.41 (0.08)^{cC}	1.61 (0.25)^{bE}	7.76 (0.54)^{cD}	8.46 (0.32)^{cD}	3.83 (0.26)^{cC}
		Komi	Gabon	5	4.39 (0.16)^{aC}	26.39 (0.05)^{aB}	5.46 (0.25)^{aA}	1.96 (0.00)^{aA}	21.83 (0.04)^{aB}	55.64 (0.34)^{aB}	60.03 (0.18)^{aB}	25.81 (0.17)^{aA}
				7	4.09 (0.06)^{aC}	11.18 (0.25)^{bD}	5.00 (0.09)^{aAB}	0.96 (0.00)^{bB}	4.35 (0.04)^{bD}	21.49 (0.38)^{bC}	25.58 (0.43)^{bC}	10.38 (0.19)^{bB}
				1	1.13 (0.11)^{cE}	2.35 (0.64)^{cE}	0.74 (0.06)^{bD}	0.16 (0.01)^{cC}	2.01 (0.07)^{bDE}	5.26 (0.64)^{cD}	6.39 (0.75)^{cD}	2.43 (0.33)^{cC}
		Remboue	Gabon	5	8.52 (0.07)^{aA}	39.04 (0.51)^{aA}	6.92 (0.32)^{aA}	1.94 (0.32)^{aA}	32.45 (0.32)^{aA}	80.36 (0.19)^{aA}	88.88 (0.26)^{aA}	36.48 (0.13)^{aA}
				7	5.74 (0.14)^{bB}	10.24 (0.02)^{bD}	5.84 (0.28)^{aA}	0.71 (0.08)^{bB}	5.78 (0.85)^{bD}	22.58 (1.23)^{bC}	28.32 (1.37)^{bC}	10.62 (0.50)^{bB}
	Red Ebang			1	0.60 (0.16)^{bD}	1.10 (0.09)^{cE}	0.42 (0.13)^{cE}	0.08 (0.05)^{bD}	0.51 (0.03)^{bC}	2.11 (0.06)^{bE}	2.71 (0.22)^{bE}	1.03 (0.04)^{bC}
		Oyem	Gabon	5	4.56 (0.02)^{aB}	32.73 (1.69)^{aB}	5.00 (0.07)^{aC}	0.93 (0.00)^{aC}	18.38 (0.02)^{aB}	43.72 (0.78)^{aC}	48.28 (0.76)^{aC}	20.56 (0.39)^{aB}
				7	3.93 (0.21)^{aBC}	19.41 (0.86)^{bC}	3.66 (0.00)^{bD}	0.69 (0.17)^{aC}	13.29 (1.05)^{aB}	50.37 (2.57)^{aC}	54.30 (2.36)^{aC}	24.05 (1.18)^{aB}
				1	3.69 (0.06)^{bC}	8.20 (0.50)^{cD}	3.59 (0.03)^{cD}	0.71 (0.02)^{bC}	2.20 (0.04)^{cC}	14.70 (0.52)^{cD}	18.39 (0.57)^{cD}	7.29 (0.26)^{cC}
		Bitam	Gabon	5	11.54 (0.07)^{aA}	59.05 (1.76)^{aA}	10.16 (0.04)^{aA}	1.73 (0.04)^{aAB}	35.05 (0.31)^{aA}	106.0 (1.46)^{aA}	117.54 (1.38)^{aA}	49.63 (0.76)^{aA}
				7	4.86 (0.04)^{bB}	25.33 (2.37)^{bC}	7.34 (0.61)^{bB}	1.32 (0.20)^{aB}	12.81 (1.27)^{bB}	46.80 (1.92)^{bC}	51.66 (1.88)^{bC}	22.26 (1.12)^{bB}
	Egnongui			1	0.54 (0.07)^{b}	0.18 (0.08)^{cE}	0.61 (0.03)^{cE}	0.08 (0.03)^{cD}	0.52 (0.05)^{bC}	1.39 (0.03)^{cE}	1.92 (0.09)^{cE}	0.67 (0.02)^{bC}
		Bitam	Gabon	5	4.66 (0.24)^{a}	36.21 (2.31)^{aB}	7.02 (0.62)^{aB}	2.36 (0.28)^{aA}	35.13 (1.23)^{aA}	80.71 (0.17)^{aB}	85.37 (0.42)^{aB}	37.39 (0.17)^{aAB}
				7	4.08 (0.16)^{a}	26.95 (0.18)^{bC}	5.28 (0.27)^{bC}	1.53 (0.11)^{bB}	23.85 (0.20)^{aA}	57.60 (0.00)^{bC}	61.68 (0.16)^{bC}	26.59 (0.03)^{aB}
True Horn	Assugmbele			1	0.63 (0.10)^{bD}	1.78 (0.12)^{cE}	0.84 (0.12)^{cD}	0.15 (0.03)^{bD}	0.79 (0.10)^{bB}	3.56 (0.37)^{bC}	4.18 (0.47)^{bD}	1.77 (0.19)^{bC}
		Bafia	Cameroon	5	4.34 (0.00)^{aB}	22.73 (0.00)^{aBC}	5.31 (0.00)^{aB}	0.74 (0.00)^{aC}	12.00 (0.00)^{aA}	40.77 (0.00)^{aAB}	45.11 (0.00)^{aBC}	19.77 (0.00)^{aB}
				7	3.06 (0.17)^{aC}	18.37 (0.15)^{bC}	3.65 (0.22)^{bC}	0.81 (0.00)^{aC}	10.75 (0.08)^{aA}	33.58 (0.29)^{aB}	36.64 (0.45)^{aC}	16.07 (0.16)^{aB}
				1	0.68 (0.10)^{bD}	0.69 (0.21)^{cE}	0.49 (0.06)^{bD}	0.07 (0.02)^{bCD}	0.16 (0.09)^{cB}	1.40 (0.39)^{bC}	2.09 (0.49)^{cD}	0.70 (0.19)^{cC}
		Ntui	Cameroon	5	5.31 (0.02)^{aAB}	26.68 (0.32)^{aB}	5.33 (0.14)^{aB}	0.75 (0.02)^{aC}	13.77 (0.11)^{aA}	46.52 (0.30)^{aAB}	51.84 (0.32)^{aB}	21.99 (0.14)^{aB}
				7	4.67 (0.50)^{aB}	20.34 (1.38)^{bC}	4.49 (0.17)^{aBC}	0.66 (0.02)^{aC}	9.36 (0.50)^{bB}	34.85 (1.73)^{aB}	39.52 (2.23)^{bC}	16.50 (0.80)^{bB}
				1	0.51 (0.01)^{cD}	3.92 (0.31)^{cD}	1.73 (0.14)^{bD}	0.42 (0.04)^{bCD}	1.85 (0.18)^{cB}	7.92 (0.03)^{cC}	8.43 (0.03)^{cD}	3.88 (0.02)^{cC}
		Komi	Gabon	5	6.21 (0.40)^{aA}	27.72 (0.00)^{aB}	6.42 (0.07)^{aB}	1.23 (0.04)^{aB}	19.87 (0.04)^{aA}	55.23 (0.07)^{aA}	61.44 (0.47)^{aAB}	25.68 (0.03)^{aB}
				7	4.72 (0.09)^{bB}	20.73 (0.88)^{bC}	5.31 (0.20)^{aB}	1.60 (0.04)^{aAB}	10.20 (1.08)^{bA}	37.42 (1.57)^{bB}	42.14 (1.48)^{bBC}	17.97 (0.73)^{bB}
				1	0.70 (0.00)^{bD}	2.19 (0.34)^{cD}	1.61 (0.03)^{cD}	0.34 (0.06)^{cCD}	0.52 (0.12)^{bB}	4.66 (0.42)^{cC}	5.36 (0.42)^{cD}	2.35 (0.20)^{cC}
		Mitzic	Gabon	5	4.49 (0.04)^{aB}	38.07 (1.22)^{aA}	8.24 (0.07)^{aA}	2.13 (0.02)^{aA}	15.39 (0.13)^{aA}	69.78 (0.78)^{aA}	74.27 (0.74)^{aA}	33.08 (0.20)^{aA}
				7	3.76 (0.18)^{aBC}	25.66 (0.52)^{bB}	6.64 (0.05)^{bB}	1.02 (0.00)^{bB}	17.85 (0.14)^{aA}	51.17 (0.43)^{bA}	54.93 (0.25)^{bB}	23.87 (0.23)^{bB}
	Assangda	Bafia	Cameroon	1	0.63 (0.06)^{bC}	1.37 (0.07)^{cD}	1.47 (0.17)^{cC}	0.28 (0.10)^{bC}	0.38 (0.05)^{cB}	3.50 (0.05)^{cC}	4.13 (0.11)^{cC}	1.78 (0.02)^{cB}

(*continued on next page*)

Table 3 (*continued*)

Bunch type	Cultivar	Location	Country	Maturity stage	Lutein (μg g^{-1} FW)	α-carotene (μg g^{-1} FW)	13-*cis*-BC (μg g^{-1} FW)	9-*cis*-BC (μg g^{-1} FW)	*trans*-BC (μg g^{-1} FW)	pVACs (μg g^{-1} FW)	TC (μg g^{-1} FW)	BCE (μg g^{-1} FW)
				5	3.12 (0.02)^{aB}	17.96 (1.67)^{aA}	5.13 (0.40)^{aA}	0.90 (0.28)^{aA}	13.90 (0.58)^{aA}	37.89 (2.13)^{aA}	41.00 (2.15)^{aA}	18.13 (1.02)^{aA}
				7	2.97 (0.12)^{aB}	11.61 (0.62)^{bC}	3.25 (0.13)^{bB}	0.74 (0.03)^{aAB}	8.72 (0.32)^{bA}	24.31 (0.78)^{bB}	27.28 (0.66)^{bB}	11.57 (0.36)^{bA}
				1	0.46 (0.01)^{bC}	0.38 (0.08)^{cD}	0.50 (0.06)^{bC}	0.11 (0.08)^{bC}	0.22 (0.02)^{cB}	1.21 (0.04)^{cC}	1.67 (0.03)^{cC}	0.61 (0.02)^{bB}
		Ntui	Cameroon	5	3.98 (0.27)^{aA}	14.18 (2.13)^{aB}	4.62 (0.10)^{aAB}	0.85 (0.20)^{aA}	10.69 (0.03)^{aA}	30.34 (2.46)^{aA}	34.32 (2.73)^{aB}	14.50 (1.24)^{aA}
				7	3.14 (0.22)^{aB}	10.64 (0.20)^{bC}	3.48 (0.13)^{aB}	0.52 (0.13)^{aB}	6.45 (0.15)^{bA}	21.10 (0.22)^{bB}	24.23 (0.00)^{bB}	10.15 (0.11)^{aA}
				1	0.64 (0.18)^{bC}	1.97 (0.06)^{cD}	1.32 (0.09)^{cC}	0.27 (0.04)^{cC}	0.42 (0.06)^{cB}	3.98 (0.06)^{cC}	4.61 (0.24)^{cC}	2.01 (0.03)^{cB}
		Oyem	Gabon	5	4.49 (0.20)^{aA}	20.39 (1.41)^{aA}	6.06 (0.07)^{aA}	1.25 (0.10)^{aA}	11.47 (0.20)^{aA}	39.16 (1.78)^{aA}	43.65 (1.98)^{aA}	18.95 (0.88)^{aA}
				7	3.61 (0.09)^{aAB}	10.21 (0.41)^{bC}	3.92 (0.09)^{bB}	0.71 (0.05)^{bAB}	7.76 (0.12)^{bA}	22.60 (0.15)^{bB}	26.21 (0.24)^{bB}	10.77 (0.08)^{bA}
				1	0.67 (0.02)^{bC}	0.84 (0.01)^{cD}	0.80 (0.06)^{bC}	0.09 (0.07)^{bC}	0.14 (0.04)^{bB}	1.87 (0.03)^{cC}	2.54 (0.02)^{cC}	0.95 (0.01)^{bB}
		Mitzic	Gabon	5	4.51 (0.05)^{aA}	18.05 (0.14)^{aA}	4.90 (0.05)^{aAB}	1.15 (0.00)^{aA}	13.74 (0.99)^{aA}	37.84 (0.80)^{aA}	42.35 (0.75)^{aA}	17.83 (0.31)^{aA}
				7	3.21 (0.04)^{aB}	12.82 (1.25)^{bBC}	4.09 (0.16)^{aB}	0.93 (0.09)^{aA}	11.13 (0.26)^{aA}	28.97 (1.05)^{bAB}	32.17 (1.09)^{bB}	13.55 (0.56)^{aA}

Maturity stage: 1=mature green; 5=all yellow with only tips remaining green (ripe); and 7=yellow and lightly flecked with brown (fully ripe).
13-*cis*-BC = 13-*cis*-β-carotene; 9-*cis*-BC = 9-*cis*-β-carotene; *trans*-BC = *trans*-β-carotene; pVACs = provitamin A carotenoids; TC = total carotenoids; BCE = β-carotene equivalents.
Means (± standard deviation) within a column followed by different lower-case letters (ripening stages) and different upper-case letters (cultivars), differ by LSD test ($p < 0.05$).

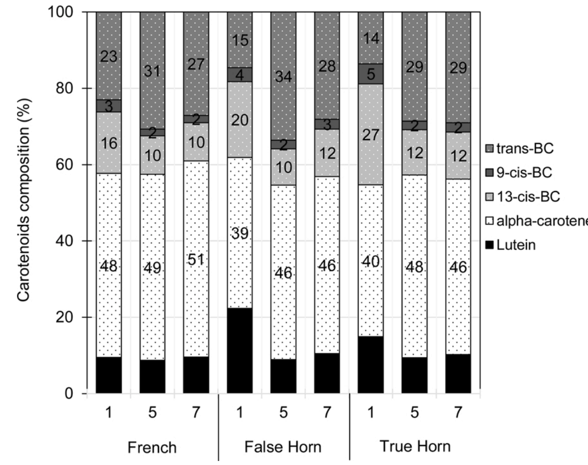


Fig. 3. Proportion of the relative carotenoid composition across the different bunch types of plantain (French, False Horn, and True Horn) when unripe (stage 1), ripe (stage 5), and overripe (stage 7).

French Sombre from Tsouka (22.1 μg g^{-1} FW), Red Essong from Ntui (21.7 μg g^{-1} FW), and Batard from Njombe (20.8 μg g^{-1} FW) exhibited the highest value of pVACs among the cultivars. At stage 5, the maximum value of pVACs was found in Red Ebang from Bitam (106.0 μg g^{-1} FW), French Sombre from Tsouka (104.5 μg g^{-1} FW), and Essong from Mitzic (101.2 μg g^{-1} FW). At stage 7, the richest in pVACs were Essong from Mitzic (93.6 μg g^{-1} FW), Essong from Bitam (68.4 μg g^{-1} FW), and French Sombre from Tsouka (66.5 μg g^{-1} FW).

Higher levels of pVACs were more likely to be observed in growing areas with a hotter and more humid environment like Njombe and Bandounga than in Ntui, Bafia, and Batchenga (Tables 2, 3, and 5) . However, this might not be the case in Gabon as higher levels of pVACs were observed in locations where average temperature and rainfall are lower, like in Bitam and Mitzic. This indicates that environmental factors affect pVAC content, but we cannot yet attribute this to one or more specific factors. A study by Passo Tsamo et al. (2015) reported that soil fertility, temperature, and annual rainfall at Njombe, Cameroon, were more suitable for growing plantain with more diverse bioactive compound profiles than in the Bansoa area, Cameroon. Besides, Borges et al. (2014) determined the profile of carotenoids in different cultivars of banana and plantain aiming to select superior cultivars for the development of biofortified crops. They concluded that the level of provitamin A carotenoids and other carotenoids varied depending upon the environmental conditions of the growing regions. This result might be explained by the fact that other related factors such as soil fertility, agronomic practices, developmental stage, abiotic and biotic stresses, and storage conditions could also affect the variation of bioactive compounds in fruits (Coyago-Cruz et al., 2018; Kumar et al., 2019). For instance, a study by Coyago-Cruz et al. (2018) showed that the levels of carotenoids changed more frequently as a function of the fruit developmental stage, cultivar, and season, although irrigation treatment had no effect.

3.4. *Interaction across factors on the variability of provitamin A carotenoids*

The interaction effects of the four factors are presented in Table 6. The two-way interaction effects between R × C, R × T, and R × L were statistically significant ($p < 0.05$) in both countries. In addition, the three-way interaction effects between R × C × L as well as that of R × T × L were significant ($p < 0.001$). However, insignificant effects for the following interactions: C × T, C × L, and T × L were observed. The results reported in Table 6 are mostly consistent with the descriptive evidence presented in the previous sections and so offer useful insights to

Table 4
Carotenoids in plantain cultivars at ripening stages 1, 5, and 7 without location effect.

Bunch type	Cultivar	Maturity stage	Lutein (μg g^{-1} FW)	α-carotene (μg g^{-1} FW)	13-*cis*-BC (μg g^{-1} FW)	9-*cis*-BC (μg g^{-1} FW)	*trans*-BC (μg g^{-1} FW)	pVACs (μg g^{-1} FW)	TC (μg g^{-1} FW)	BCE (μg g^{-1} FW)
French	Essong	1	0.64 (0.23)^{bD}	1.29 (1.03)^{cC}	0.86 (0.57)^{bC}	0.23 (0.28)^{bC}	0.41 (0.21)^{bC}	2.78 (1.83)^{bD}	3.43 (1.95)^{bE}	1.39 (0.92)^{bC}
		5	4.48 (0.33)^{aC}	42.52 (12.25)^{aA}	6.42 (1.59)^{aB}	1.39 (0.49)^{aA}	27.01 (10.15)^{aAB}	77.34 (23.33)^{aB}	81.82 (23.25)^{aAB}	36.16 (11.04)^{aA}
		7	5.12 (0.77)^{aBC}	29.74 (17.42)^{bB}	5.50 (2.15)^{aB}	1.54 (1.45)^{aA}	16.72 (10.73)^{aB}	53.49 (31.21)^{aBC}	58.61 (31.27)^{aC}	25.24 (14.81)^{aAB}
	Red Essong	1	1.73 (1.28)^{bD}	8.56 (4.95)^{bC}	2.26 (0.50)^{bC}	0.55 (0.11)^{aB}	3.61 (2.26)^{bC}	14.99 (7.78)^{bCD}	16.72 (9.04)^{bD}	7.23 (3.68)^{bB}
		5	7.69 (0.85)^{aB}	28.12 (13.65)^{aB}	6.06 (1.27)^{aB}	0.74 (0.14)^{aB}	13.81 (0.78)^{aB}	48.72 (11.74)^{aBC}	56.42 (12.36)^{aC}	23.13 (5.84)^{aAB}
		7	6.21 (0.32)^{aB}	22.74 (10.54)^{aBC}	5.02 (1.68)^{aB}	0.73 (0.23)^{aB}	10.84 (0.72)^{aB}	39.33 (9.00)^{aC}	45.54 (8.69)^{aCD}	18.64 (4.40)^{aB}
	Batard	1	0.83 (0.20)^{cD}	4.87 (4.00)^{cC}	1.78 (0.83)^{bC}	0.36 (0.16)^{bC}	2.54 (3.08)^{bC}	9.55 (7.66)^{bCD}	10.38 (7.83)^{cE}	4.62 (3.59)^{bBC}
		5	6.37 (0.46)^{aB}	27.85 (7.76)^{aB}	7.42 (1.98)^{aAB}	1.46 (0.40)^{aA}	20.03 (4.49)^{aB}	56.76 (7.34)^{aB}	63.13 (7.57)^{aC}	26.80 (3.73)^{aAB}
		7	4.26 (1.32)^{bC}	18.49 (12.18)^{bC}	4.23 (1.98)^{abB}	0.90 (0.31)^{abAB}	11.44 (5.11)^{abB}	35.06 (19.22)^{aC}	39.32 (19.71)^{bD}	16.50 (9.20)^{aB}
	Njock Kon	1	0.70 (0.25)^{bD}	0.68 (0.15)^{bC}	0.31 (0.01)^{bC}	0.09 (0.03)^{bC}	0.29 (0.10)^{bC}	1.36 (0.29)^{bD}	2.06 (0.53)^{bE}	0.68 (0.14)^{bC}
		5	4.22 (0.07)^{aC}	33.48 (3.76)^{aB}	5.91 (0.47)^{aB}	0.85 (0.00)^{aAB}	17.78 (0.05)^{aB}	58.02 (4.27)^{aB}	62.24 (4.20)^{aC}	27.62 (2.15)^{aAB}
		7	3.98 (0.93)^{aC}	27.95 (0.05)^{aB}	5.43 (0.03)^{aB}	0.76 (0.03)^{aB}	16.71 (1.64)^{aB}	50.84 (1.69)^{aB}	54.83 (2.63)^{aC}	24.09 (0.70)^{aAB}
	Elat	1	0.59 (0.08)^{bD}	3.24 (2.71)^{bC}	1.00 (0.45)^{cC}	0.09 (0.02)^{bC}	1.53 (1.59)^{bC}	5.85 (4.70)^{bD}	6.44 (4.78)^{bE}	2.83 (2.23)^{bC}
		5	5.21 (1.30)^{aBC}	37.19 (7.89)^{aAB}	8.53 (1.18)^{aAB}	1.08 (0.25)^{aAB}	16.99 (5.61)^{aB}	63.79 (14.57)^{aB}	69.00 (15.80)^{aC}	30.56 (6.87)^{aAB}
		7	4.57 (1.57)^{aC}	30.86 (4.26)^{aB}	6.21 (0.83)^{bB}	0.95 (0.19)^{aAB}	16.57 (4.03)^{aB}	54.59 (8.57)^{aB}	59.16 (10.12)^{aC}	25.70 (4.15)^{aAB}
	French Sombre	1	1.09 (0.02)^{cD}	10.57 (1.33)^{cC}	3.23 (1.05)^{cC}	0.55 (0.11)^{bB}	7.73 (0.28)^{cBC}	22.09 (0.10)^{cC}	23.18 (0.08)^{cD}	10.52 (0.05)^{cB}
		5	14.70 (0.32)^{aA}	51.88 (5.76)^{aA}	11.39 (0.84)^{aA}	1.45 (0.02)^{aA}	39.83 (3.00)^{aA}	104.56 (7.90)^{aA}	119.26 (7.58)^{aA}	48.80 (3.63)^{aA}
		7	6.56 (0.20)^{bB}	38.10 (1.10)^{bAB}	5.50 (0.47)^{bB}	0.83 (0.05)^{abAB}	22.01 (1.74)^{bB}	66.47 (1.16)^{bB}	73.03 (1.36)^{bB}	31.00 (0.40)^{bAB}
		1	0.53 (0.04)^{bD}	5.87 (0.30)^{cC}	1.21 (0.11)^{bC}	0.04 (0.02)^{cC}	1.11 (0.14)^{cC}	8.23 (0.53)^{cCD}	8.75 (0.57)^{cE}	4.04 (0.25)^{cBC}
	French Clair	5	6.80 (0.93)^{aB}	47.06 (0.67)^{aA}	7.86 (0.13)^{aAB}	1.52 (0.22)^{aA}	27.18 (1.80)^{aAB}	83.62 (0.78)^{aB}	90.42 (1.70)^{aAB}	38.89 (0.17)^{aA}
		7	6.49 (0.06)^{aB}	28.57 (0.61)^{bB}	7.31 (1.53)^{aAB}	0.61 (0.06)^{bB}	9.23 (0.15)^{bBC}	45.72 (2.24)^{bBC}	52.21 (2.18)^{bC}	21.89 (1.14)^{bAB}
False Horn	Mbouroukou 1	1	0.40 (0.02)^{bB}	0.61 (0.15)^{cC}	0.55 (0.07)^{bB}	0.05 (0.03)^{bC}	0.43 (0.11)^{cC}	1.63 (0.13)^{cE}	2.03 (0.15)^{cC}	0.81 (0.07)^{cC}
		5	4.38 (0.10)^{aA}	40.15 (1.63)^{aA}	7.43 (0.24)^{aA}	1.51 (0.02)^{aB}	17.51 (0.21)^{aAB}	66.60 (1.62)^{aAB}	70.98 (1.72)^{aA}	31.93 (0.78)^{aA}
		7	4.46 (0.25)^{aA}	21.09 (0.21)^{bAB}	6.58 (0.27)^{aA}	1.10 (0.00)^{aB}	5.28 (0.09)^{bBC}	34.06 (0.57)^{bC}	38.52 (0.32)^{bAB}	16.72 (0.28)^{bAB}
	Mbouroukou 2	1	0.68 (0.14)^{bB}	0.88 (0.14)^{cC}	0.74 (0.01)^{bB}	0.12 (0.00)^{bC}	0.20 (0.04)^{bC}	1.95 (0.20)^{cE}	2.63 (0.06)^{bC}	0.98 (0.10)^{cC}
		5	4.62 (0.04)^{aA}	35.29 (2.06)^{aA}	6.95 (0.34)^{aA}	2.00 (0.04)^{aA}	29.08 (0.19)^{aA}	73.32 (1.57)^{aA}	77.93 (1.61)^{aA}	34.04 (0.80)^{aA}
		7	4.27 (0.25)^{aA}	26.44 (0.22)^{bAB}	6.51 (0.00)^{aA}	1.79 (0.04)^{aB}	24.24 (0.54)^{aA}	58.98 (0.36)^{bB}	63.24 (0.61)^{aA}	27.11 (0.12)^{bA}
	Mbouroukou 3	1	1.27 (1.30)^{bB}	0.60 (0.58)^{bC}	0.48 (0.40)^{bB}	0.07 (0.03)^{bC}	0.19 (0.15)^{bC}	1.35 (1.14)^{cE}	2.62 (2.41)^{bC}	0.67 (0.57)^{bC}
		5	5.77 (0.68)^{aA}	24.84 (4.65)^{aAB}	5.44 (0.65)^{aA}	1.08 (0.13)^{aB}	13.54 (0.71)^{aB}	46.18 (6.97)^{aB}	51.94 (7.55)^{aA}	21.50 (3.34)^{aA}
		7	4.68 (0.55)^{aA}	19.73 (3.32)^{aAB}	5.08 (0.69)^{aA}	0.72 (0.06)^{aBC}	11.32 (3.01)^{aB}	36.86 (6.72)^{bC}	41.53 (6.93)^{aA}	17.09 (3.08)^{aAB}
	Ebang	1	0.60 (0.27)^{bB}	1.56 (1.25)^{bC}	0.66 (0.65)^{bB}	0.13 (0.14)^{bC}	0.36 (0.42)^{bC}	2.71 (2.21)^{bE}	3.31 (2.31)^{bC}	1.35 (1.09)^{bC}
		5	5.67 (2.01)^{aA}	22.10 (6.89)^{aAB}	5.11 (1.54)^{aA}	1.24 (0.59)^{aB}	18.76 (8.65)^{aAB}	47.21 (16.21)^{aB}	52.88 (17.41)^{aA}	21.82 (7.20)^{aA}
		7	4.23 (1.02)^{aA}	15.34 (1.24)^{aB}	4.21 (1.27)^{aA}	1.16 (0.51)^{aB}	11.13 (2.19)^{aB}	31.84 (4.71)^{aC}	36.07 (5.65)^{aAB}	14.76 (2.05)^{aAB}
	Big Ebanga	1	0.73 (0.29)^{bB}	1.87 (1.50)^{cC}	0.84 (0.64)^{bB}	0.18 (0.15)^{bC}	0.97 (0.92)^{cC}	3.86 (3.03)^{cE}	4.59 (3.18)^{cC}	1.87 (1.47)^{bC}
		5	4.91 (2.30)^{aA}	26.82 (8.72)^{aAB}	5.61 (0.90)^{aA}	1.34 (0.68)^{aB}	21.87 (7.34)^{aA}	55.63 (17.39)^{aB}	60.54 (19.59)^{aA}	25.65 (7.80)^{aA}
		7	3.81 (1.34)^{aA}	11.39 (1.30)^{bB}	4.68 (1.02)^{aA}	0.80 (0.11)^{aBC}	5.83 (1.12)^{bBC}	22.69 (1.54)^{bD}	26.51 (1.72)^{bB}	10.78 (0.82)^{aB}
	Red Ebang	1	2.15 (1.79)^{bAB}	4.65 (4.11)^{bC}	2.01 (1.83)^{bB}	0.40 (0.36)^{bC}	1.35 (0.97)^{cC}	8.40 (7.27)^{bE}	10.55 (9.06)^{bB}	4.16 (3.62)^{bC}
		5	8.05 (4.03)^{aA}	39.23 (22.92)^{aA}	7.58 (2.98)^{aA}	1.33 (0.46)^{aB}	26.72 (9.63)^{aA}	74.86 (35.97)^{aA}	82.91 (39.99)^{aA}	35.09 (16.79)^{aA}
		7	4.39 (0.55)^{aA}	29.03 (4.59)^{aA}	5.50 (2.16)^{aA}	1.00 (0.39)^{aB}	13.05 (0.99)^{bB}	48.59 (2.77)^{aB}	52.98 (2.32)^{aA}	23.16 (1.40)^{aA}

(*continued on next page*)

Table 4 (*continued*)

Bunch type	Cultivar	Maturity stage	Lutein (µg g^{-1} FW)	α-carotene (µg g^{-1} FW)	13-*cis*-BC (µg g^{-1} FW)	9-*cis*-BC (µg g^{-1} FW)	*trans*-BC (µg g^{-1} FW)	pVACs (µg g^{-1} FW)	TC (µg g^{-1} FW)	BCE (µg g^{-1} FW)
	Egnongui	1	0.54 (0.07)^{bB}	0.18 (0.08)^{cC}	0.61 (0.03)^{bB}	0.08 (0.03)^{cC}	0.52 (0.05)^{cC}	1.39 (0.03)^{cE}	1.92 (0.09)^{cC}	0.67 (0.02)^{cC}
		5	4.66 (0.24)^{aA}	36.21 (2.31)^{aA}	7.02 (0.62)^{aA}	2.36 (0.28)^{aA}	35.13 (1.23)^{aA}	80.71 (0.17)^{aA}	85.37 (0.42)^{aA}	37.39 (0.17)^{aA}
		7	4.08 (0.16)^{aA}	26.95 (0.18)^{bAB}	5.28 (0.27)^{aA}	1.53 (0.11)^{bB}	23.85 (0.20)^{bA}	57.60 (0.00)^{bB}	61.68 (0.16)^{bA}	26.59 (0.03)^{bA}
True Horn	Assugmbele	1	0.63 (0.09)^{bB}	2.14 (1.26)^{bC}	1.17 (0.56)^{bC}	0.25 (0.15)^{bB}	0.83 (0.68)^{bC}	4.38 (2.53)^{bC}	5.01 (2.47)^{bC}	2.18 (1.23)^{bC}
		5	5.09 (0.81)^{aA}	28.80 (6.08)^{aA}	6.32 (1.28)^{aA}	1.21 (0.61)^{aA}	15.26 (3.12)^{aA}	53.08 (11.69)^{aA}	58.16 (11.72)^{aA}	25.13 (5.40)^{aA}
		7	4.05 (0.76)^{aA}	21.28 (2.94)^{aA}	5.02 (1.19)^{aA}	1.02 (0.38)^{aA}	12.04 (3.65)^{aA}	39.26 (7.56)^{aAB}	43.31 (7.54)^{aA}	18.60 (3.36)^{aA}
	Assangda	1	0.60 (0.12)^{bB}	1.14 (0.64)^{bC}	1.02 (0.42)^{cC}	0.19 (0.11)^{bB}	0.29 (0.13)^{bC}	2.64 (1.21)^{bC}	3.24 (1.27)^{cC}	1.34 (0.61)^{bC}
		5	4.02 (0.62)^{aA}	17.64 (2.64)^{aAB}	5.18 (0.60)^{aA}	1.04 (0.22)^{aA}	12.45 (1.56)^{aA}	36.31 (3.99)^{aAB}	40.33 (4.14)^{aA}	17.35 (1.94)^{aA}
		7	3.23 (0.27)^{aA}	11.32 (1.21)^{aB}	3.68 (0.37)^{bB}	0.73 (0.17)^{aA}	8.51 (1.84)^{aB}	24.24 (3.20)^{aB}	27.48 (3.17)^{bB}	11.51 (1.39)^{aB}
French		1	0.86 (0.58)^{bB}	4.36 (4.06)^{bB}	1.45 (0.94)^{bB}	0.29 (0.24)^{bB}	2.08 (2.60)^{bB}	8.18 (7.47)^{bB}	9.04 (7.87)^{bB}	3.96 (3.54)^{bB}
		5	6.33 (2.62)^{aA}	35.42 (11.23)^{aA}	7.31 (1.96)^{aA}	1.26 (0.43)^{aA}	22.30 (8.90)^{aA}	66.29 (19.39)^{aA}	72.62 (20.53)^{aA}	31.19 (9.00)^{aA}
		7	5.08 (1.28)^{aA}	27.22 (13.94)^{aA}	5.31 (1.80)^{aA}	1.02 (0.81)^{aA}	14.36 (6.97)^{aA}	47.91 (22.08)^{aA}	52.99 (22.39)^{aA}	22.63 (10.51)^{aA}
False Horn		1	0.94 (0.95)^{bB}	1.66 (2.05)^{bB}	0.83 (0.87)^{bB}	0.15 (0.18)^{bB}	0.61 (0.70)^{bB}	3.26 (3.65)^{bB}	4.20 (4.37)^{bB}	1.60 (1.80)^{bB}
		5	5.59 (2.21)^{aA}	28.77 (11.26)^{aA}	5.98 (1.60)^{aA}	1.38 (0.56)^{aA}	21.14 (8.51)^{aA}	57.51 (20.23)^{aA}	63.10 (21.74)^{aA}	26.75 (9.38)^{aA}
		7	4.24 (0.90)^{aA}	18.66 (6.62)^{aA}	5.01 (1.29)^{aA}	1.03 (0.41)^{aA}	11.33 (5.86)^{aA}	36.03 (12.20)^{aA}	40.27 (12.43)^{aA}	16.89 (5.61)^{aA}
True Horn		1	0.61 (0.10)^{bB}	1.64 (1.09)^{bB}	1.09 (0.49)^{bB}	0.22 (0.13)^{bB}	0.56 (0.55)^{bB}	3.51 (2.12)^{bB}	4.13 (2.11)^{bB}	1.76 (1.04)^{bB}
		5	4.56 (0.89)^{aA}	23.22 (7.33)^{aA}	5.75 (1.13)^{aA}	1.12 (0.45)^{aA}	13.85 (2.79)^{aA}	44.69 (12.09)^{aA}	49.25 (12.53)^{aA}	21.24 (5.61)^{aA}
		7	3.64 (0.70)^{aA}	16.30 (5.58)^{aA}	4.35 (1.09)^{aA}	0.87 (0.32)^{aA}	10.28 (3.33)^{aA}	31.75 (9.57)^{aA}	35.39 (9.90)^{aA}	15.06 (4.43)^{aA}

Maturity stage: 1=mature green; 5=all yellow with only tips remaining green (ripe); and 7=yellow and lightly flecked with brown (fully ripe).
13-*cis*-BC = 13-*cis*-β-carotene; 9-*cis*-BC = 9-*cis*-β-carotene; *trans*-BC = *trans*-β-carotene; pVACs = provitamin A carotenoids; TC = total carotenoids; BCE = β-carotene equivalents; TP = total phenolic.
Means (± standard deviation) within a column followed by different lower-case letters (ripening stages) and different upper-case letters (cultivars within the same bunch type/between bunch types), differ by LSD test ($p < 0.05$).

Table 5
Retinol activity equivalent (RAE) and dietary reference intake (DRI) of plantain cultivars grown in Cameroon and Gabon at ripening stage 1, 5, and 7.

Bunch type	Cultivar	Location	Country	Maturity stage	RAE (ug g^{-1} FW)	DRI (%) for children 1−5 years old at 100 g day^{-1}	DRI (%) for adult and pregnant women at 100 g day^{-1}	DRI (%) for adult men at 100 g day^{-1}
French	Essong			1	0.08 (0.01)^{bC}	2.03 (0.22)^{cE}	1.16 (0.13)^{cE}	0.90 (0.10)^{bD}
		Bafia	Cameroon	5	1.77 (0.01)^{aB}	44.33 (0.21)^{aC}	25.33 (0.12)^{aC}	19.70 (0.09)^{aC}
				7	1.23 (0.09)^{aB}	30.74 (2.24)^{bC}	17.56 (1.28)^{bD}	13.66 (1.00)^{aC}
				1	0.02 (0.00)^{cC}	0.52 (0.10)^{cE}	0.30 (0.06)^{cE}	0.23 (0.04)^{cD}
		Ntui	Cameroon	5	2.69 (0.11)^{aA}	67.15 (2.75)^{aB}	38.37 (1.57)^{aB}	29.85 (1.22)^{aB}
				7	0.80 (0.05)^{bC}	19.99 (1.20)^{bD}	11.42 (0.69)^{bD}	8.88 (0.54)^{bCD}
				1	0.15 (0.02)^{cC}	3.79 (0.43)^{cE}	2.17 (0.24)^{cE}	1.68 (0.19)^{cD}
		Bitam	Gabon	5	3.62 (0.20)^{aA}	90.49 (5.00)^{aA}	51.71 (2.85)^{aA}	40.22 (2.22)^{aA}
				7	2.70 (0.01)^{bA}	67.38 (0.15)^{bB}	38.50 (0.08)^{bB}	29.95 (0.07)^{bB}
				1	0.21 (0.02)^{bC}	5.23 (0.49)^{bE}	2.99 (0.28)^{bE}	2.32 (0.22)^{cD}
		Mitzic	Gabon	5	3.97 (0.01)^{aA}	99.36 (0.33)^{aA}	56.78 (0.19)^{aA}	44.16 (0.15)^{aA}
				7	3.69 (0.08)^{aA}	88.05 (0.04)^{aA}	50.31 (0.02)^{aA}	39.13 (0.02)^{bA}
	Red Essong			1	0.34 (0.06)^{bB}	8.49 (1.53)^{bC}	4.85 (0.87)^{cC}	3.77 (0.68)^{bC}
		Batchenga	Cameroon	5	1.51 (0.05)^{aA}	37.70 (1.17)^{aB}	21.54 (0.67)^{aAB}	16.75 (0.52)^{aAB}
				7	1.24 (0.04)^{aA}	30.93 (1.12)^{aB}	17.68 (0.64)^{bB}	13.75 (0.50)^{aB}
				1	0.87 (0.03)^{cB}	21.64 (0.81)^{cB}	12.37 (0.46)^{cB}	9.62 (0.36)^{bB}
		Ntui	Cameroon	5	2.35 (0.06)^{aA}	58.68 (1.61)^{aA}	33.53 (0.92)^{aA}	26.08 (0.72)^{aA}
				7	1.87 (0.03)^{bA}	46.75 (0.68)^{bA}	26.72 (0.39)^{bA}	20.78 (0.30)^{aA}
	Batard			1	0.82 (0.00)^{cB}	20.47 (0.03)^{bC}	11.70 (0.01)^{bC}	9.10 (0.01)^{cC}
		Njombe	Cameroon	5	2.56 (0.10)^{aA}	64.01 (2.57)^{aA}	36.58 (1.47)^{aA}	28.45 (1.14)^{aA}
				7	1.18 (0.00)^{bB}	29.52 (0.03)^{bC}	16.87 (0.02)^{bC}	13.12 (0.01)^{bC}
				1	0.44 (0.03)^{cBC}	10.89 (0.85)^{cD}	6.22 (0.49)^{cCD}	4.84 (0.38)^{cCD}
		Medakoe	Gabon	5	1.83 (0.00)^{aA}	45.72 (0.05)^{aB}	26.12 (0.03)^{aB}	20.32 (0.02)^{aB}
				7	0.98 (0.05)^{bB}	24.60 (1.27)^{bC}	14.06 (0.72)^{bC}	10.93 (0.56)^{bC}
				1	0.09 (0.01)^{cC}	2.34 (0.16)^{cE}	1.34 (0.09)^{cD}	1.04 (0.07)^{cD}
		Oyem	Gabon	5	2.44 (0.10)^{aA}	60.91 (2.41)^{aA}	34.81 (1.37)^{aA}	27.07 (1.07)^{aA}
				7	0.75 (0.00)^{bB}	18.69 (0.05)^{bCD}	10.68 (0.03)^{bC}	8.31 (0.02)^{bC}
		Komi	Gabon	1	0.19 (0.02)^{bC}	4.83 (0.53)^{cE}	2.76 (0.30)^{cD}	2.15 (0.24)^{cD}
				5	2.88 (0.05)^{aA}	72.06 (1.33)^{aA}	41.18 (0.76)^{aA}	32.03 (0.59)^{aA}

(*continued on next page*)

Table 5 (*continued*)

Bunch type	Cultivar	Location	Country	Maturity stage	RAE (ug g^{-1} FW)	DRI (%) for children 1−5 years old at 100 g day^{-1}	DRI (%) for adult and pregnant women at 100 g day^{-1}	DRI (%) for adult men at 100 g day^{-1}
				7	2.01 (0.09)^{aA}	50.19 (2.32)^{bB}	28.68 (1.33)^{bB}	22.30 (1.03)^{bB}
	Njock Kon			1	0.06 (0.01)^{b}	1.41 (0.29)^{b}	0.81 (0.17)^{b}	0.63 (0.13)^{b}
		Bandounga	Cameroon	5	2.30 (0.18)^{a}	57.54 (4.47)^{a}	32.88 (2.55)^{a}	25.57 (1.99)^{a}
				7	2.01 (0.06)^{a}	50.18 (1.45)^{a}	28.68 (0.83)^{a}	22.30 (0.65)^{a}
	Elat			1	0.08 (0.01)^{bC}	1.88 (0.29)^{cC}	1.08 (0.16)^{bC}	0.84 (0.13)^{bC}
		Batchenga	Cameroon	5	2.05 (0.07)^{aB}	51.30 (1.70)^{aB}	29.32 (0.97)^{aB}	22.80 (0.76)^{aB}
				7	1.85 (0.09)^{aB}	46.17 (2.24)^{bB}	26.38 (1.28)^{aB}	20.52 (1.00)^{aB}
				1	0.40 (0.01)^{cC}	9.91 (0.13)^{cC}	5.66 (0.08)^{cC}	4.40 (0.06)^{cC}
		Ntui	Cameroon	5	3.04 (0.05)^{aA}	76.02 (1.24)^{aA}	43.44 (0.71)^{aA}	33.79 (0.55)^{aA}
				7	2.44 (0.06)^{bAB}	60.91 (1.59)^{bA}	34.81 (0.91)^{bA}	27.07 (0.71)^{bB}
	French Sombre			1	0.88 (0.00)^{c}	21.92 (0.10)^{c}	12.52 (0.05)^{c}	9.74 (0.04)^{c}
		Tsouka	Gabon	5	4.07 (0.30)^{a}	101.66 (7.57)^{a}	58.09 (4.32)^{a}	45.18 (3.36)^{a}
				7	2.58 (0.03)^{b}	64.59 (0.84)^{b}	36.91 (0.48)^{b}	28.71 (0.37)^{b}
			Gabon	1	0.34 (0.02)^{c}	8.41 (0.53)^{c}	4.81 (0.30)^{c}	3.74 (0.24)^{c}
	French Clair	Mitzic		5	3.24 (0.01)^{a}	81.01 (0.35)^{a}	46.29 (0.20)^{a}	36.01 (0.15)^{a}
				7	1.82 (0.10)^{b}	45.61 (2.38)^{b}	26.06 (1.36)^{b}	20.27 (1.06)^{b}
False Horn	Mbouroukou 1			1	0.07 (0.01)^{c}	1.68 (0.15)^{c}	0.96 (0.09)^{c}	0.75 (0.07)^{c}
		Oyem	Gabon	5	2.66 (0.07)^{a}	66.53 (1.63)^{a}	38.02 (0.93)^{a}	29.57 (0.72)^{a}
				7	1.39 (0.02)^{b}	34.84 (0.59)^{b}	19.91 (0.34)^{b}	15.48 (0.26)^{b}
	Mbouroukou 2			1	0.08 (0.01)^{b}	2.04 (0.20)^{c}	1.17 (0.11)^{c}	0.91 (0.09)^{c}
		Ntoum	Gabon	5	2.84 (0.07)^{a}	70.92 (1.66)^{a}	40.53 (0.95)^{a}	31.52 (0.74)^{a}
				7	2.26 (0.01)^{a}	56.47 (0.26)^{b}	32.27 (0.15)^{b}	25.10 (0.11)^{b}
	Mbouroukou 3			1	0.11 (0.02)^{cC}	2.86 (0.46)^{cD}	1.63 (0.26)^{cC}	1.27 (0.21)^{bB}
		Bandounga	Cameroon	5	2.14 (0.00)^{aA}	53.38 (0.04)^{aA}	30.50 (0.02)^{aA}	23.72 (0.02)^{aA}
				7	1.73 (0.03)^{bA}	43.20 (0.64)^{bB}	24.69 (0.37)^{bA}	19.20 (0.28)^{aA}
				1	0.04 (0.00)^{bC}	0.98 (0.05)^{cD}	0.56 (0.03)^{cC}	0.44 (0.02)^{bB}
		Njombe	Cameroon	5	1.69 (0.09)^{aA}	42.30 (2.19)^{aB}	24.17 (1.25)^{aA}	18.80 (0.97)^{aA}
				7	1.17 (0.10)^{aB}	29.26 (2.43)^{bC}	16.72 (1.39)^{bB}	13.01 (1.08)^{aA}
				1	0.02 (0.01)^{bC}	0.38 (0.14)^{bD}	0.22 (0.08)^{bC}	0.17 (0.06)^{bB}
		Ntui	Cameroon	5	1.55 (0.07)^{aAB}	38.71 (1.70)^{aB}	22.12 (0.97)^{aAB}	17.20 (0.75)^{aA}
				7	1.37 (0.04)^{aB}	34.33 (0.88)^{aBC}	19.62 (0.50)^{aB}	15.26 (0.39)^{aA}
	Ebang			1	0.06 (0.01)^{bC}	1.56 (0.15)^{bE}	0.89 (0.08)^{bD}	0.70 (0.07)^{bC}
		Bafia	Cameroon	5	1.18 (0.04)^{aBC}	29.45 (1.01)^{aD}	16.83 (0.58)^{aC}	13.09 (0.45)^{aB}
				7	0.99 (0.06)^{aC}	24.77 (1.41)^{aD}	14.15 (0.81)^{aC}	11.01 (0.63)^{aB}
				1	0.01 (0.00)^{bC}	0.36 (0.08)^{bE}	0.20 (0.04)^{bD}	0.16 (0.03)^{bC}
		Ntui	Cameroon	5	1.50 (0.00)^{aB}	37.40 (0.11)^{aC}	21.37 (0.06)^{aBC}	16.62 (0.05)^{aB}
				7	1.21 (0.03)^{aBC}	30.25 (0.75)^{aC}	17.29 (0.43)^{aC}	13.45 (0.33)^{aB}
				1	0.13 (0.00)^{bC}	3.26 (0.08)^{cE}	1.87 (0.05)^{bD}	1.45 (0.04)^{bC}
		Mitzic	Gabon	5	1.93 (0.08)^{aA}	48.27 (2.02)^{aB}	27.59 (1.16)^{aB}	21.46 (0.90)^{aA}
				7	1.42 (0.04)^{aB}	35.60 (0.97)^{bC}	20.35 (0.55)^{aBC}	15.82 (0.43)^{aB}
				1	0.24 (0.00)^{cC}	6.03 (0.08)^{cE}	3.45 (0.05)^{cD}	2.68 (0.04)^{cC}
		Ntoum	Gabon	5	2.67 (0.08)^{aA}	66.75 (2.07)^{aA}	38.14 (1.19)^{aA}	29.67 (0.92)^{aA}
				7	1.29 (0.01)^{bBC}	32.37 (0.36)^{bC}	18.50 (0.20)^{bC}	14.39 (0.16)^{bB}
	Big Ebanga			1	0.03 (0.00)^{cD}	0.80 (0.08)^{cD}	0.46 (0.05)^{cD}	0.35 (0.04)^{cD}
		Bandounga	Cameroon	5	2.02 (0.05)^{aB}	50.59 (1.17)^{aB}	28.91 (0.67)^{aB}	22.48 (0.52)^{aB}
				7	1.00 (0.03)^{bC}	24.89 (0.85)^{bC}	14.22 (0.49)^{bC}	11.06 (0.38)^{bC}
				1	0.07 (0.01)^{cD}	1.72 (0.23)^{cD}	0.98 (0.13)^{cD}	0.77 (0.10)^{cD}
		Njombe	Cameroon	5	1.34 (0.10)^{aC}	33.38 (2.44)^{aC}	19.07 (1.39)^{aC}	14.83 (1.08)^{aC}
				7	0.85 (0.06)^{bC}	21.23 (1.46)^{bC}	12.13 (0.83)^{bC}	9.44 (0.65)^{bC}
				1	0.32 (0.02)^{cD}	7.98 (0.53)^{cD}	4.56 (0.31)^{cD}	3.55 (0.24)^{cD}
		Komi	Gabon	5	2.15 (0.01)^{aB}	53.77 (0.36)^{aB}	30.72 (0.21)^{aAB}	23.90 (0.16)^{aB}
				7	0.87 (0.02)^{bC}	21.63 (0.39)^{bC}	12.36 (0.22)^{bC}	9.61 (0.17)^{bC}
				1	0.20 (0.03)^{cD}	5.07 (0.69)^{cD}	2.90 (0.39)^{cD}	2.25 (0.31)^{cD}
		Remboue	Gabon	5	3.04 (0.01)^{aA}	76.01 (0.28)^{aA}	43.43 (0.16)^{aA}	33.78 (0.12)^{aA}
				7	0.89 (0.04)^{bC}	22.13 (1.04)^{bC}	12.65 (0.59)^{bC}	9.84 (0.46)^{bC}
	Red Ebang			1	0.09 (0.00)^{bC}	2.16 (0.08)^{cD}	1.23 (0.04)^{bC}	0.96 (0.03)^{bC}
		Oyem	Gabon	5	2.00 (0.10)^{aB}	50.10 (2.46)^{aB}	28.63 (1.40)^{aB}	22.27 (1.09)^{aB}
				7	1.71 (0.03)^{aB}	42.84 (0.81)^{bB}	24.48 (0.46)^{aB}	19.04 (0.36)^{aB}
				1	0.61 (0.02)^{cC}	15.19 (0.55)^{cC}	8.68 (0.31)^{cC}	6.75 (0.24)^{cC}
		Bitam	Gabon	5	4.14 (0.06)^{aA}	103.39 (1.58)^{aA}	59.08 (0.91)^{aA}	45.95 (0.70)^{aA}
				7	1.86 (0.09)^{bB}	46.38 (2.33)^{bB}	26.50 (1.33)^{bB}	20.61 (1.04)^{bB}
	Egnongui			1	0.06 (0.00)^{c}	1.39 (0.04)^{c}	0.80 (0.02)^{c}	0.62 (0.02)^{c}
		Bitam	Gabon	5	3.12 (0.01)^{a}	77.89 (0.36)^{a}	44.51 (0.21)^{a}	34.62 (0.16)^{a}
				7	2.22 (0.00)^{b}	55.39 (0.06)^{b}	31.65 (0.04)^{b}	24.62 (0.03)^{b}
True Horn	Assugmbele	Bafia	Cameroon	1	0.15 (0.02)^{bE}	3.68 (0.39)^{cD}	2.11 (0.22)^{cC}	1.64 (0.17)^{bD}
				5	1.65 (0.00)^{aC}	41.19 (0.00)^{aBC}	23.53 (0.00)^{aAB}	18.30 (0.00)^{aBC}

(*continued on next page*)

Table 5 (*continued*)

Bunch type	Cultivar	Location	Country	Maturity stage	RAE (ug g^{-1} FW)	DRI (%) for children 1−5 years old at 100 g day^{-1}	DRI (%) for adult and pregnant women at 100 g day^{-1}	DRI (%) for adult men at 100 g day^{-1}
				7	1.34 (0.01)^{aD}	33.48 (0.32)^{bC}	19.13 (0.19)^{bB}	14.88 (0.14)^{aC}
				1	0.06 (0.02)^{bE}	1.46 (0.39)^{cD}	0.84 (0.22)^{cC}	0.65 (0.17)^{cD}
		Ntui	Cameroon	5	1.83 (0.01)^{aB}	45.81 (0.29)^{aBC}	26.18 (0.16)^{aAB}	20.36 (0.13)^{aB}
				7	1.37 (0.07)^{aD}	34.37 (1.67)^{bC}	19.64 (0.96)^{bB}	15.28 (0.74)^{bC}
				1	0.32 (0.00)^{cE}	8.09 (0.05)^{cD}	4.62 (0.03)^{cC}	3.60 (0.02)^{cD}
		Komi	Gabon	5	2.14 (0.00)^{aB}	53.50 (0.07)^{aAB}	30.57 (0.04)^{aAB}	23.78 (0.03)^{aB}
				7	1.50 (0.06)^{bC}	37.44 (1.52)^{bBC}	21.39 (0.87)^{bB}	16.64 (0.68)^{bC}
				1	0.20 (0.02)^{cE}	4.89 (0.42)^{cD}	2.79 (0.24)^{cC}	2.17 (0.19)^{cD}
		Mitzic	Gabon	5	2.76 (0.02)^{aA}	68.92 (0.41)^{aA}	39.38 (0.23)^{aA}	30.63 (0.18)^{aA}
				7	1.99 (0.02)^{bB}	49.73 (0.49)^{bB}	28.42 (0.28)^{bAB}	22.10 (0.22)^{bB}
	Assangda			1	0.15 (0.00)^{cC}	3.70 (0.04)^{cC}	2.11 (0.02)^{cC}	1.64 (0.02)^{cC}
		Bafia	Cameroon	5	1.51 (0.08)^{aA}	37.77 (2.12)^{aA}	21.58 (1.21)^{aA}	16.79 (0.94)^{aA}
				7	0.96 (0.03)^{bB}	24.11 (0.74)^{bB}	13.77 (0.43)^{bB}	10.71 (0.33)^{bB}
				1	0.05 (0.00)^{cC}	1.27 (0.04)^{cC}	0.73 (0.03)^{cC}	0.56 (0.02)^{cC}
		Ntui	Cameroon	5	1.21 (0.10)^{aAB}	30.21 (2.58)^{aAB}	17.26 (1.47)^{aAB}	13.43 (1.15)^{aAB}
				7	0.85 (0.01)^{bB}	21.14 (0.22)^{bB}	12.08 (0.13)^{bB}	9.40 (0.10)^{bB}
				1	0.17 (0.00)^{cC}	4.18 (0.06)^{cC}	2.39 (0.03)^{cC}	1.86 (0.02)^{cC}
		Oyem	Gabon	5	1.58 (0.07)^{aA}	39.47 (1.83)^{aA}	22.55 (1.05)^{aA}	17.54 (0.81)^{aA}
				7	0.90 (0.01)^{bB}	22.45 (0.17)^{bB}	12.83 (0.10)^{bB}	9.98 (0.08)^{bB}
				1	0.08 (0.00)^{bC}	1.99 (0.03)^{cC}	1.14 (0.02)^{cC}	0.88 (0.01)^{cC}
		Mitzic	Gabon	5	1.49 (0.03)^{aA}	37.14 (0.64)^{aA}	21.22 (0.36)^{aA}	16.51 (0.28)^{aA}
				7	1.13 (0.05)^{aAB}	28.22 (1.16)^{bAB}	16.13 (0.66)^{bAB}	12.54 (0.51)^{bB}

Maturity stage: 1=mature green; 5=all yellow with only green tips remaining (ripe); and 7=yellow and lightly flecked with brown (fully ripe).
RAE = retinol activity equivalent; DRI = dietary reference intake.
Means (± standard deviation) within a column followed by different lower-case letters (ripening stages) and different upper-case letters (cultivars), differ by LSD test ($p < 0.05$).

explain variations in pVACs content in the study areas.

3.5. Contribution to vitamin A requirements

Depending on consumers' preference and eating habits, plantain can be consumed at different ripening stages. For example, unripe plantain is mostly consumed in cooked form or processed to other products such as chips and flour, while plantain can also be consumed fresh as an energy-giving food at the ripened stage. It can also be transformed into different local dishes, depending on sociocultural contexts and norms (Honfo et al., 2011). In this study, the average RAE values for all plantain cultivars varied widely from 0.02 to 0.88 μg g^{-1} FW at maturity stage 1, from 1.2–4.1 μg g^{-1} FW at stage 5, and from 0.8 to 3.7 μg g^{-1} FW at stage 7, depending on cultivar, location, and ripening stage (Table 5). At stage 1, the highest value of RAE was identified in French Sombre from Tsouka (0.9 μg g^{-1} FW), followed by Red Essong from Ntui (0.9 μg g^{-1} FW) and Batard from Njombe (0.8 μg g^{-1} FW). Red Ebang from Bitam (4.1 μg g^{-1} FW), French Sombre from Tsouka (4.1 μg g^{-1} FW), and Essong from Mitzic (4.0 μg g^{-1} FW) had the highest RAE value at stage 5. The higher level of RAE was obtained in the overripe stage of Essong from Mitzic (3.7 μg g^{-1} FW) and Bitam (2.7 μg g^{-1} FW), and in French Sombre from Tsouka. Varying by cultivars, the RAE value significantly increased ($p < 0.05$) by between 3.2 and 55.9 times during the ripening process, although a reduction in RAE value by about 1.5 times was observed in overripe pulp when compared with ripe pulp. Without the location effect, the most substantial loss of RAE value during ripening was found in Egnongui (55.9 times), Njock Kon (40.8 times), and Mbouroukou 1 (39.6 times). The least loss of RAE value was found in Red Essong (3.2 times), French Sombre (4.6 times), and Batard (6.3 times) (Table 7).

With regard to the DRIs of vitamin A for children 1–5 years old (400 μg RAE), women of productive age (700 μg RAE), and men (900 μg RAE) (FAO/WHO, 2002), the results showed that 100 g of plantain, both unripe and overripe, was not sufficient to provide the DRIs for all types (Table 5). Although 100 g of ripe fruit (which is less than one fruit) from Red Ebang from Bitam and French Sombre from Tsouka could provide enough vitamin A to meet more than 100 % of the DRIs of the children aged 1–5 years old, neither would provide the DRIs of vitamin A for both adult women and men. Daily consumption by women and men of 100 g of ripe plantain (taking an average weight per finger into account) would be able to meet 20.7–58.1 % of the 700 μg RAE DRI for women

Table 6
Mean squares of combined ANOVA for provitamin A carotenoids (pVACs) in plantain as affected by cultivar, bunch type, location, and ripening stage interactions.

Factor Interactions	Cameroon (N = 114)			Gabon (N = 120)		
	MS	F-statistics	p-value	MS	F-statistics	p-value
R × C	1606.8**	37.1	0.0	2730.3**	24.2	0.0
R × T	5237.6***	65.9	0.0	10662.0***	42.9	0.0
R × L	2858.0**	27.7	0.0	4137.0**	22.4	0.0
C × T	602.3	1.4	0.2	1347.8	1.5	0.1
C × L	423.4	0.9	0.5	1041.6	1.1	0.3
T × L	572.4	1.3	0.2	1176.0	1.3	0.2
R × C × T	–	–	–	–	–	–
R × C × L	895.2***	477.8	0.0	1818.5***	729.0	0.0
R × T × L	1438.0***	27.6	0.0	2414.7***	27.3	0.0
T × C × L	–	–	–	–	–	–
R × C × T × L	–	–	–	–	–	–

L = Location; T = Bunch type; C = Cultivar; R = Ripening stage; MS = Mean squares.
***, **, and * refer to significance at 1%, 5%, and 10 % respectively.

Table 7
Retinol activity equivalent (RAE) and dietary reference intake (DRI) of plantain cultivars at ripening stage 1, 5, and 7 without location effect.

Bunch type	Cultivar	Maturity stage	RAE (ug g^{-1} FW)	DRI (%) for children 1−5 years old at 100 g day^{-1}	DRI (%) for adult and pregnant women at 100 g day^{-1}	DRI (%) for adult men at 100 g day^{-1}
French	Essong	1	0.12 (0.08)^{bC}	2.89 (1.92)^{bE}	1.65 (1.10)^{bE}	1.29 (0.85)^{bC}
		5	3.01 (0.92)^{aAB}	75.34 (23.00)^{aB}	43.05 (13.14)^{aB}	33.48 (10.22)^{aB}
		7	2.10 (1.23)^{aB}	52.58 (30.86)^{aB}	30.04 (17.64)^{aB}	22.91 (13.05)^{aB}
	Red Essong	1	0.60 (0.31)^{bC}	15.07 (7.66)^{bD}	8.61 (4.38)^{bD}	6.70 (3.40)^{bC}
		5	1.93 (0.49)^{aB}	48.19 (12.17)^{aBC}	27.54 (6.95)^{aBC}	21.42 (5.41)^{aB}
		7	1.55 (0.37)^{aBC}	38.84 (9.16)^{aC}	22.20 (5.24)^{aC}	17.26 (4.07)^{aB}
	Batard	1	0.39 (0.30)^{cC}	9.63 (7.48)^{cE}	5.51 (4.27)^{cE}	4.28 (3.32)^{cC}
		5	2.23 (0.31)^{aB}	60.67 (10.30)^{aB}	34.67 (5.89)^{aB}	26.97 (4.58)^{aB}
		7	1.37 (0.77)^{bBC}	30.75 (12.72)^{bC}	17.57 (7.27)^{bC}	13.67 (5.65)^{bBC}
	Njock Kon	1	0.06 (0.01)^{bC}	1.41 (0.29)$_{bE}$	0.81 (0.17)^{bE}	0.63 (0.13)^{bC}
		5	2.30 (0.18)^{aB}	57.54 (4.47)^{aB}	32.88 (2.55)^{aB}	25.57 (1.99)^{aB}
		7	2.01 (0.06)^{aB}	50.18 (1.45)^{aB}	28.68 (0.83)^{aB}	22.30 (0.65)^{aB}
	Elat	1	0.24 (0.19)^{bC}	5.90 (4.64)^{bE}	3.37 (2.65)^{bE}	2.62 (2.06)^{bC}
		5	2.55 (0.57)^{aB}	63.66 (14.32)^{aB}	36.38 (8.18)^{aB}	28.29 (6.36)^{aB}
		7	2.14 (0.35)^{aB}	53.54 (8.66)^{aB}	30.59 (4.95)^{aB}	23.80 (3.85)^{aB}
	French Sombre	1	0.88 (0.00)^{cC}	21.92 (0.10)^{cD}	12.52 (0.05)^{cD}	9.74 (0.04)^{cC}
		5	4.07 (0.30)^{aA}	101.66 (7.57)^{aA}	58.09 (4.32)^{aA}	45.18 (3.36)^{aA}
		7	2.58 (0.03)^{bB}	64.59 (0.84)^{bB}	36.91 (0.48)^{bB}	28.71 (0.37)^{bB}
		1	0.34 (0.02)^{cC}	8.41 (0.53)^{cE}	4.81 (0.30)^{cE}	3.74 (0.24)^{cC}
	French clair	5	3.24 (0.01)^{aA}	81.01 (0.35)^{aB}	46.29 (0.20)^{aB}	36.01 (0.15)^{aB}
		7	1.82 (0.10)^{bB}	45.61 (2.38)^{bC}	26.06 (1.36)^{bC}	20.27 (1.06)^{bB}
False Horn	Mbouroukou 1	1	0.07 (0.01)^{cC}	1.68 (0.15)^{cD}	0.96 (0.09)^{cD}	0.75 (0.07)^{cD}
		5	2.66 (0.07)^{aA}	66.53 (1.63)^{aA}	38.02 (0.93)^{aA}	29.57 (0.72)^{aA}
		7	1.39 (0.02)^{bB}	34.84 (0.59)^{bC}	19.91 (0.34)^{bC}	15.48 (0.26)^{bC}
	Mbouroukou 2	1	0.08 (0.01)^{bC}	2.04 (0.20)^{cD}	1.17 (0.11)^{cD}	0.91 (0.09)^{cC}
		5	2.84 (0.07)^{aA}	70.92 (1.66)^{aA}	40.53 (0.95)^{aA}	31.52 (0.74)^{aA}
		7	2.26 (0.01)^{aAB}	56.47 (0.26)^{bB}	32.27 (0.15)^{bB}	25.10 (0.11)^{bB}
	Mbouroukou 3	1	0.06 (0.05)^{bC}	1.41 (1.18)^{bD}	0.80 (0.67)^{bD}	0.62 (0.52)^{bD}
		5	1.79 (0.28)^{aAB}	44.79 (6.95)^{aB}	25.60 (3.97)^{aB}	19.91 (3.09)^{aB}
		7	1.42 (0.26)^{aB}	35.60 (6.42)^{aC}	20.34 (3.67)^{aC}	15.82 (2.85)^{aC}
	Ebang	1	0.11 (0.09)^{bC}	2.81 (2.28)^{bD}	1.60 (1.30)^{bD}	1.25 (1.01)^{bD}
		5	1.82 (0.60)^{aAB}	45.47 (15.00)^{aB}	25.98 (8.57)^{aB}	20.21 (6.67)^{aB}
		7	1.23 (0.17)^{aB}	30.75 (4.28)^{aC}	17.57 (2.44)^{aC}	13.67 (1.90)^{aC}
	Big Ebanga	1	0.16 (0.12)^{cC}	3.89 (3.06)^{cD}	2.22 (1.75)^{cD}	1.73 (1.36)^{cD}
		5	2.14 (0.65)^{aAB}	53.44 (16.25)^{aB}	30.54 (9.28)^{aB}	23.75 (7.22)^{aB}
		7	0.90 (0.07)^{bBC}	22.47 (1.71)^{bC}	12.84 (0.98)^{bC}	9.99 (0.76)^{bC}
	Red Ebang	1	0.35 (0.30)^{bC}	8.67 (7.53)^{bD}	4.96 (4.30)^{bD}	3.85 (3.35)^{bD}
		5	2.92 (1.40)^{aA}	73.11 (34.97)^{aA}	41.78 (19.98)^{aA}	32.49 (15.54)^{aA}
		7	1.93 (0.12)^{aAB}	48.24 (2.91)^{aB}	27.57 (1.66)^{aB}	21.44 (1.29)^{aB}
	Egnongui	1	0.06 (0.00)^{cC}	1.39 (0.04)^{cD}	0.80 (0.02)^{cD}	0.62 (0.02)^{cD}
		5	3.12 (0.01)^{aA}	77.89 (0.36)^{aA}	44.51 (0.21)^{aA}	34.62 (0.16)^{aA}
		7	2.22 (0.00)^{bAB}	55.39 (0.06)^{bB}	31.65 (0.04)^{bB}	24.62 (0.03)^{bB}
True Horn	Assugmbele	1	0.18 (0.10)^{bB}	4.53 (2.57)^{bB}	2.59 (1.47)^{bC}	2.01 (1.14)^{bC}
		5	2.09 (0.45)^{aA}	52.35 (11.26)^{aA}	29.92 (6.43)^{aA}	23.27 (5.00)^{aA}
		7	1.55 (0.28)^{aA}	38.75 (7.01)^{aA}	22.15 (4.01)^{aA}	17.22 (3.12)^{aA}
	Assangda	1	0.11 (0.05)^{bB}	2.79 (1.28)^{bB}	1.59 (0.73)^{bC}	1.24 (0.57)^{bC}
		5	1.45 (0.16)^{aA}	36.15 (4.05)^{aA}	20.66 (2.31)^{aA}	16.07 (1.80)^{aA}
		7	0.96 (0.12)^{aA}	23.98 (2.90)^{aA}	13.70 (1.66)^{aB}	10.66 (1.29)^{aB}
French		1	0.33 (0.30)^{cB}	8.25 (7.38)^{bB}	4.71 (4.22)^{bB}	3.67 (3.28)^{bB}
		5	2.60 (0.75)^{aA}	67.20 (19.38)^{aA}	38.40 (11.07)^{aA}	29.87 (8.61)^{aA}
		7	1.89 (0.88)^{bA}	45.23 (20.03)^{aA}	25.85 (11.44)^{aA}	19.98 (8.61)^{aA}
False Horn		1	0.13 (0.15)^{bB}	3.34 (3.75)^{bB}	1.91 (1.14)^{bB}	1.49 (1.67)^{bB}
		5	2.23 (0.78)^{aA}	55.72 (19.53)^{aA}	31.84 (11.16)^{aA}	24.77 (8.68)^{aA}
		7	1.41 (0.47)^{aA}	35.18 (11.69)^{aA}	20.10 (6.68)^{aA}	15.63 (5.20)^{aA}
True Horn		1	0.15 (0.09)^{bB}	3.66 (2.16)^{bB}	2.09 (1.23)^{bB}	1.63 (0.96)^{bB}
		5	1.77 (0.47)^{aA}	44.25 (11.70)^{aA}	25.29 (6.68)^{aA}	19.67 (5.20)^{aA}
		7	1.25 (0.37)^{aA}	31.37 (9.22)^{aA}	17.92 (5.27)^{aA}	13.94 (4.10)^{aA}

Maturity stage: 1=mature green; 5=all yellow with only green tips remaining (ripe); and 7=yellow and lightly flecked with brown (fully ripe).
RAE = retinol activity equivalent; DRI = dietary reference intake.
Means (± standard deviation) within a column followed by different lower-case letters (ripening stages) and different upper-case letters (cultivars within the same type/between types), differ by LSD test ($p < 0.05$).

and 16.1–45.2 % of the 900 μg RAE DRI for men. This result indicated that more than 100 % of the DRIs for children could be met from consuming one finger of the average weight of ripe Essong, Batard, Njock Kon, French Sombre, French Clair, Mbouroukou 1, Mbouroukou 3, Big Ebanga, Red Ebang, Egnongui, Assugmbele, or Assangda. In addition, it could be observed that more than 100 % of the DRIs of vitamin A for adult women and men could be provided when approximately 1.4 and 1.8 fingers of ripe plantain were consumed. In comparison, 1.2 fingers per day of overripe plantain are required to meet more than 100 % of DRIs of vitamin A for children 1–5 years old, 2.2 fingers for adult women, and 2.8 fingers for adult men. Ngoh Newilah et al. (2009), Fungo and Pillay (2011), and Ekesa et al. (2015) also reported a high potential of different banana and plantain cultivars to meet from one-half to total vitamin A requirements of children 1–5 years old and adult women.

Each cultivar could potentially be used for different cooking purposes, depending on traditional eating patterns and consumer preferences to enhance the nutritional status of the population through promotion or incorporation in agricultural systems. For example, the unripe pulp of French Sombre, Red Essong, and Batard was more suitable for making plantain chips, flour, and porridge as it exhibited the highest level of pVACs; ripe pulp of French Sombre, French Clair, and Egnongui was found to be the most suitable for frying as *dodo* or roasting. For some who prefer to use overripe plantain pulp as an ingredient in producing bakery products, such as muffins and cakes, French Sombre, Mbourokou 2, and Elat would be suggested. However, thermal processing could contribute to both beneficial and adverse modifications of the respective RAE and DRI values (Ekesa et al., 2012). For instance, Borges et al. (2019c) suggested that thermal processing, mainly by boiling, can increase the functional and nutritional value of plantain. This could be delineated by the fact that most phytochemical compounds are bound to other molecules or cell structures. Heat treatment has demonstrated its potential to damage the cell membrane, thus generating an opportunity for the bound phytochemical compounds to be released from chromoplasts into the cytoplasmic medium. Therefore, the released bioactive constituents become more amenable for extraction. In addition, a two-fold increase in total pVACs in boiled plantain was described by Ekesa et al. (2012). They also mentioned that the bioaccessibility of all-*trans* β-carotene depends on the food recipes, and it could be positively modified when pVACs-rich ingredients like palm oil or amaranth were added. On the other hand, a higher loss of carotenoids and other bioactive compounds was also reported in some processing methods such as hot air drying (Udomkun et al., 2015) and frying (Ekesa et al., 2013; Barakat and Rohn, 2014).

4. Conclusions

This study provides data on the pVAC content of plantain by collecting fruits at different ripening stages in 16 different cultivars with three different bunch types across 13 locations in Cameroon and Gabon. The concentration of pVACs varied depending on cultivar, bunch type, ripening stage, location, and interaction effects. Although fresh and ripe plantain contained high levels of pVACs that could meet the daily estimated vitamin A requirements for pre-school children, adult and pregnant women, as well as adult men, the consumption quantity still depends on cultivar and cooking method. To conserve the nutritional value of plantain, therefore, optimization of each cooking process, especially with respect to temperature and time, must be considered. In addition, the effect of storage conditions and packaging materials on the pVACs and other bioactive compounds should also be incorporated into future studies.

Ethical statement

This study does not involve any human or animal testing.

CRediT authorship contribution statement

Patchimaporn Udomkun: Conceptualization, Methodology, Formal analysis, Writing - original draft. **Cargele Masso:** Conceptualization, Investigation, Visualization, Writing - review & editing. **Rony Swennen:** Investigation, Writing - review & editing. **Tesfamicheal Wossen:** Software, Formal analysis, Writing - review & editing. **Delphine Amah:** Conceptualization, Writing - review & editing. **Apollin Fotso:** Conceptualization, Writing - review & editing. **Jules Lienou:** Data curation, Writing - review & editing. **Michael Adesokan:** Methodology, Formal analysis. **Emmanuel Njukwe:** Conceptualization, Writing - review & editing. **Bernard Vanlauwe:** Investigation, Supervision, Writing - review & editing.

Declaration of Competing Interest

The authors have no conflict of interest.

Acknowledgments

This work was carried out through financial support from the African Union Research Grants, Reference: HRST/ST/AURG-II/CALL2/2018 via a project titled “Enhancing nutritional quality of plantain food products through improved access to endophyte primed and high provitamin A plantain cultivars under integrated soil fertility management practices in Nigeria, Cameroon, and Gabon” to the International Institute of Tropical Agriculture. The authors thank the donor who supported this work through their contributions to the CGIAR Fund (http://www.cgiar.org/who-we-are/cgiar-fund/fund-donors-2/), and in particular to the CGIAR Research Program Roots, Tubers, and Bananas (RTB-CRP). The authors are also grateful to Mrs Rose Ndango (IITA, Cameroon) and Dr Meklit Chernet (IITA, Kenya).

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.jfca.2020.103636.

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