

Pulp and Peel Colours of a Local Plantain Variety (Batard) and a Plantain-Like Hybrid (Carbap K74) are Influenced by Ripening and Boiling Method

Gérard NGOH NEWILAH^{1,2*}, Dallonnes FANGUENG KAMGO³, Cédric KENDINE VEPOWO^{2,4}, Annie TAKAM NGOUNO¹, Marlyne-Joséphine MANANGA³ and Dominique DUFOUR^{5,6}

¹University of Dschang, PO Box 96, Dschang, Cameroon.

²Centre Africain de Recherches sur Bananiers et Plantains, PO Box 832, Douala, Cameroon.

³University of Yaoundé I, PO Box 812, Yaoundé, Cameroon.

⁴University of Douala, PO Box 24157, Douala, Cameroon.

⁵CIRAD, UMR Qualisud, F-34398 Montpellier, France.

⁶Qualisud, Avignon Université, CIRAD, Institut Agro, IRD, Université de Montpellier, Université La Réunion, Montpellier, France.

*Correspondence:

Gérard NGOH NEWILAH, University of Dschang, PO Box 96, Dschang, Cameroon.

Received: 10 Mar 2026; Accepted: 11 Apr 2026; Published: 22 Apr 2026

Citation: Gérard NGOH NEWILAH, Dallonnes FANGUENG KAMGO, Cédric KENDINE VEPOWO, et al. Pulp and Peel Colours of a Local Plantain Variety (Batard) and a Plantain-Like Hybrid (Carbap K74) are Influenced by Ripening and Boiling Method. Food Sci Nutr Res. 2026; 9(2): 1-10.

ABSTRACT

This study explores the influence of ripening and cooking on colour parameters of plantain pulp and peel. It is a preliminary study for the establishment of a correlation between colour parameters, ripening and cooking time. Bunches of a plantain landrace (BATARD) and a plantain-like hybrid (CARBAP K74) were harvested in an experimental plot in Njombé-Cameroon. Fruits at three postharvest maturity stages: unripe, starting ripe and ripe were boiled according to two cooking methods: boiling with peel and boiling without peel at different cooking times: 0, 10, 20, 30, 40, 50 and 60 minutes. Colour values L^ (lightness), a^* (redness) and b^* (yellowness) were determined using a chromameter; while ΔE (colour intensity) was computed. During ripening, pulp and peel colour parameters changed significantly depending on Musa clone. Irrespective of boiling method and maturity stage, pulp ΔE values were significantly different and higher for BATARD compared to CARBAP K74. Maximum ΔE values were observed when boiled with peel for each genotype, with BATARD presenting the greatest ΔE (40.68) at T30 while CARBAP K74 had 28.91 at T60. Moreover, when boiled without peel, maximum ΔE values were obtained at T60 for BATARD (34.56) and CARBAP K74 (27.57). R^2 values for the relationship between L^* , a^* and b^* values versus cooking time were in the range of 0.01 and 0.76. This study highlights the importance of colour in foods and their changes during ripening and processing. The b^* parameter is crucial for evaluating the acceptability of a high-quality boiled plantain pulp. Investigations, including a large number of plantain clones may enable food scientists to define references that could help breeders to rapidly screen and select new clones that meet users' and consumers' requirements regarding boiled plantains.*

Keywords

Boiling, Colour parameters, Cooking time, Plantain, Ripening.

Introduction

The production of banana fruits (*Musa* sp) including plantains, cooking bananas and dessert bananas was estimated in 2018 at about 139,470,376 metric tons (MT), with 15% representing that

of plantains [1]. Banana production in Cameroon was estimated in 2024 at 805,352 MT, while plantain production reached 4,663,349 MT [2]. Bananas represent an essential source of income for value chain actors as they constitute the third most important commodity after rice and cassava [3]. Plantains constitute a staple food crop for about 70 million people and serve as an important source of carbohydrates for the populations of West and Central

Africa [4]. Cultivated in about 120 countries mainly in tropical and subtropical regions, plantains are classified into 4 main types: French, French horn, False horn and True horn [5]. In addition, plantains contribute significantly to the diversification of the diet, to the energy intake complemented by minerals and vitamins important for health [6]. In Cameroon, the consumption of its fruits varies according to the production areas and it is estimated at 109 - 128 kg/year/inhabitant [3]. They are consumed mainly as fresh fruit or as a cooked or fried vegetable, but are also subject to many processing techniques (boiling, frying, boiling and pounding, boiling and mashing, roasting, etc.) for the production of fried, roasted, mashed, boiled, kneaded foodstuffs such as chips, fries, fritters, puree, jam, ketchup, alcohol, wine, beer, flours consumed worldwide in general, and in Cameroon in particular [7,8].

Boiling is the most used cooking method by the majority of African households [9,10]. Despite improving some sensory qualities of foods, boiling seems to have a negative influence on the nutritional profile of foods. Plantains and cooking bananas can be mainly cooked and consumed at different stages of maturity with or without peel [11-13]. As a climacteric fruit, plantain undergoes ripening by the release of ethylene characterized by changes in peel colour, softening of the fruit, loss of astringency and development of a characteristic flavour [14]. It is also characterised by significant changes in physicochemical properties of the fruit such as pulp to peel ratio, pulp and peel pH, pulp and peel dry matter content, pulp total soluble solids, pulp total titratable acidity [13]. The green to golden yellow colour change in plantains during ripening is due to the unmasking of carotenoid pigments in the plastids by the degradation of chlorophyll [15]. Heat treatments are widely applied in food processing. Chlorophyll is sensitive to heat treatments, which cause some structural changes [16].

Agronomic yield and technological performance are considered important criteria by plantain producers and processors, but the main criterion for consumers is the sensory quality including colour, taste, and texture [13]. Consumers rely primarily on pulp colour to judge the quality of boiled plantain. The colours of both peel and pulp are therefore important selection criteria since consumers make specific correlations between the colour and the overall quality of boiled plantain products. Thus, colour is a key visual criterion for assessing the quality of raw and boiled plantain. Consumers associate peel colour with a specific flavour or use [17]. Although the current demand for plantains and their products is high, consumer needs and tastes are changing over time [18]. According to studies conducted by [13] on consumer-oriented analyses, good quality raw plantains should have a green peel colour and yellow or orange pulp colour. When cooked they should be presentable with an attractive colour. However, in-depth knowledge of the traits that consumers prefer will enable researchers to select new plantain clones with acceptable attributes. The use of a colour chart to determine the colour of plantain, is subjective and subject to several errors. Several objective and reliable instrumental methods have been established to determine the colour of plantains using a chromameter.

This study therefore aims at contributing to the knowledge related to colour changes during plantain ripening and processing, with the main objective of determining the effect of boiling on plantain pulps and peel colour kinetics at three postharvest maturity stages.

Materials and Methods

Sampling

A local plantain variety (*BATARD*) and a plantain-like hybrid (*CARBAP K74*), a free BSV plantain clone selected within the CARBAP/CIRAD breeding partnership were considered in this study. Bunches were harvested at optimum physiological maturity (i.e presence of a ripe fruit on the 1st or 2nd hand). They were collected from a CARBAP's experimental plot located in Njombe – Penja Subdivision, Mounjo Division, Littoral Region of Cameroon (latitude 4°35' N, longitude 9°39' E and 80m altitude above sea level). This plot was put into use in September 2019 within the framework of the RTBfoods Project. After bunch harvest early in the morning, fruits from the 2nd and 3rd hands were selected, randomized and allowed to ripen at room temperature (23-25°C) in rectangular opened cartons. Maturity stages were defined based on peel colour change described by [17]. Thus, fruits at stage 1 (unripe), stage 3 (start ripe) and stage 5 (ripe) presented green peel colour, mixed green and yellow peel colour and yellow peel colour with green ends respectively as shown in Figure 1. At each ripening stage, plantain fruits were separated into three batches: the first batch (raw) served as a control, the second batch was used for boiling without peel, and the third batch was boiled with peel. In this study, boiling refers to cooking by immersion of pulps or entire fruits in boiling water. The cooking processes were carried out in triplicate for each batch that subsequently undergoes colour measurements on the raw fruit, the cooked pulp and the cooked peel using a Chromameter.

Boiling treatments

Boiling was carried out under similar household conditions using aluminium pots (30 cm wide, 16.5 cm high and 4 cm thick), gas stoves, cooking knives, strainers, trays, plastic basins and running tap water. For each clone, depending on the cooking methods (with peel or without peel) whole fruits or pulps, weighing approximately 150-300 g were introduced into 3 L of boiling water (at 100°C) to keep the fruits or pulps completely immersed in water. For each cooking time, three fruits or pulps of the same genotype at the same ripening stage were boiled, removed and placed in a tray for cooling (5 minutes) at room temperature (23-25°C). Colour measurements were then carried out on the cooled boiled products.

Colour measurement

The chromameter was standardized and the samples were placed in the sample holder. The CIE L*, a* and b* tristimulus parameters of the pulps and peels before and after cooking were determined in triplicate using a chromameter (CR-410, Konica Minolta Sensing Inc. Osaka, Japan). The chromameter operates according to the CIE L*, a* and b* colour schemes with:

L* representing brightness (ranging from 0 = black and 100 = white);

a* representing red-green (positive values are red, negative values

are green and 0 is neutral);
 b* representing yellow-blue (positive values are yellow, negative values are blue and 0 is neutral).

Colour was assessed by using the protocol described by [17]. Peel colour was measured by placing the measuring head on the fruit surface (peel surface) and taking approximately 2-3 readings (at the middle, at the apex and the peduncle of each fruit). The mean value was considered as the peel colour of the fruit. Pulp colour on the other hand was measured by cutting the fruit or pulp transversely at the midpoint and placing the measuring head at the centre of each half. After obtaining each parameter, the colour intensity (ΔE) was calculated using the following equations [19].

Where ΔL , Δa , Δb represent the derivation of the individual values from their respective sample.

$$\Delta E = \sqrt{((\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2)}$$

Where subscript "0" is the initial values of L^* , a^* and b^* at time T0 for each maturity stage.

$$\Delta E = ((L^*_{0} - L^*)^2 + (a^*_{0} - a^*)^2 + (b^*_{0} - b^*)^2)^{1/2}$$

Statistical analysis of data

Analyses were performed in triplicate. Data obtained were expressed as mean \pm standard deviation and were analysed using XLSTAT 2014. Pearson correlation coefficients and regression equations were obtained between colour parameters and cooking time of boiled plantain at three postharvest maturity stages.

Results and Discussion

i) Effect of ripening on peel and pulp colours

Colour appreciation is a very subjective issue which depends on various factors that might make consumers like or dislike a food product. Hence, depending on the cooking time, the maturity stage and the genotype itself, the colour of plantain pulps could vary significantly (Figure 1).

Table 1 shows that for *CARBAP K74* raw pulps, brightness (L) decreases significantly ($p < 0.05$) during postharvest ripening, while yellowness (b^*) increases, reflecting the progressive degradation of chlorophyll and the exposure of carotenoids. For *BATARD* raw pulps, L^* values vary between unripe and ripe stages, with a maximum at the start-ripe stage. Meanwhile, b^*

values also increase during ripening, although the differences are not statistically significant. Regarding raw peel colour, it appears that the parameters L^* , a^* and b^* of *BATARD* cultivar increase significantly ($p < 0.05$) with ripening. For *CARBAP K74*, only the redness index (a^*) increases significantly ($p < 0.05$) with ripening. The colour variation observed between *BATARD* and *CARBAP K74* may be explained by their genotypic differences, pigment composition, and browning potential. *BATARD* is a triploid *AAB* cultivar, while *CARBAP K74* is an improved hybrid with *AAAB* genomic constitution. Pigment analyses indicate that *BATARD* pulps generally contain higher carotenoid levels, which contribute to stronger yellowness (b), whereas *CARBAP K74* maintains higher brightness (L^*) at the unripe stage. Differences in browning potential also play a role: *BATARD* shows higher susceptibility to enzymatic browning due to polyphenol oxidase activity, while *CARBAP K74* exhibits greater postharvest stability [20].

ii) Effect of boiling on plantain pulp colour

Plantain pulp derived from boiling with or without its peel is the final product consumed. Photos of pulp slices from *BATARD* fruits boiled without peel at three cooking times and three maturity stages are displayed in Figure 2. These cooking times were chosen because of their significant change in pulp colour.

Whether processed with or without peel, the change in colour of the cooked pulp after 10 min is visible to the naked eye. The colouration observed intensifies as cooking time increases (Figure 1). Instrumental data presented in Table 2 confirm this trend: while brightness values (L) decrease progressively with longer cooking times, the redness (a^*), yellowness (b^*), and overall colour intensity (ΔE) increase. Boiling with peel better preserves pulp brightness, but irrespective of cultivars and ripening stages, the same pattern of decreasing L^* and increasing a^* , b^* , and ΔE is consistently observed. At harvest, *CARBAP K74* pulps generally presented higher brightness (L) values compared to *BATARD*, particularly at the unripe stage, which corresponds to the cream or ivory colour reported in preliminary studies. However, during cooking the differences in brightness between the two clones were not always statistically significant, especially at the start-ripe stage. At stage 5 (ripe), *BATARD* pulps tended to exhibit higher L values compared to *CARBAP K74*, although the differences were not consistently statistically significant according to the data presented in Table 2.

Table 1: Colour parameters of analysed fruits during ripening.

Genotype	Maturity stage	Pulp colour			Peel colour		
		L^*	a^*	b^*	L^*	a^*	b^*
CARBAP K74	Unripe (ST1)	77.51 ^a	1.38 ^a	27.55 ^b	55.21 ^a	-15.10 ^b	36.97 ^a
	Start ripe (ST3)	77.50 ^a	-0.23 ^a	31.97 ^{ab}	63.06 ^a	-8.84 ^{ab}	41.58 ^a
	Ripe (ST5)	67.45 ^b	2.11 ^a	36.54 ^a	58.45 ^a	-1.75 ^a	37.98 ^a
BATARD	Unripe (ST1)	74.48 ^a	5.25 ^a	36.12 ^a	58.17 ^b	-16.23 ^c	37.24 ^b
	Start ripe (ST3)	78.72 ^a	2.94 ^b	36.35 ^a	66.27 ^a	-8.44 ^b	43.51 ^a
	Ripe (ST5)	74.09 ^a	4.23 ^{ab}	42.45 ^a	71.28 ^a	-1.49 ^a	45.62 ^a

Colour values are described by L^* =lightness, a^* =redness, b^* =yellowness on the CIE LAB Colour Chart (CIE=International Commission on Illumination), ΔE =Colour intensity. ST=stage.

The averages of the three trials in the same column, with the same superscripts, for each genotype are not significantly different at $p \leq 0.05$ (Tukey's test).

Table 2: Colour parameters of *Musa* pulps boiled without and with peels.

Plantain clone	Ripening stage	Cooking time (min)	Pulp colour parameters							
			Pulp boiled without peel				Pulp boiled with peel			
			L*	a*	b*	ΔE	L*	a*	b*	ΔE
CARBAP K74	Unripe (ST 1)	T0	77.51 ^a	1.38 ^{abcd}	27.55 ^{bedef}	0.00 ^d	77.51 ^a	1.38 ^{abcd}	27.55 ^{ab}	0.00 ^f
		T10	68.07 ^{ab}	-2.82 ^{ef}	30.22 ^{abcde}	11.34 ^{bcd}	77.09 ^a	-2.89 ^{cd}	29.39 ^{ab}	5.10 ^{ef}
		T20	62.63 ^{bc}	-2.57 ^{ef}	29.43 ^{abcdef}	16.03 ^{abc}	65.17 ^{bcd}	-2.26 ^{bcd}	28.61 ^{ab}	13.21 ^{cde}
		T30	56.46 ^{bcd}	-2.11 ^{def}	26.25 ^{bcdef}	21.53 ^{ab}	59.07 ^{cdef}	-3.17 ^d	31.03 ^{ab}	19.30 ^{abcd}
		T40	51.64 ^{cd}	-0.89 ^{abcdef}	29.18 ^{bcdef}	26.48 ^a	56.64 ^{defg}	-1.85 ^{abcd}	28.47 ^{ab}	21.22 ^{abc}
		T50	53.97 ^{cd}	0.44 ^{abcdef}	26.29 ^{bcdef}	23.78 ^{ab}	54.16 ^{efg}	-0.26 ^{abcd}	27.82 ^{ab}	23.49 ^{abc}
	T60	51.90 ^{cd}	-1.13 ^{bcdef}	30.34 ^{abcd}	25.91 ^a	54.61 ^{efg}	1.56 ^{abc}	27.13 ^{ab}	23.21 ^{abc}	
	Start ripe (ST 3)	T0	77.50 ^a	-0.23 ^{abcdef}	31.97 ^{ab}	0.00 ^d	77.50 ^a	-0.23 ^{abcd}	31.97 ^{ab}	0.00 ^f
		T10	61.24 ^{bcd}	-3.02 ^{ef}	31.17 ^{abc}	16.58 ^{abc}	63.57 ^{bcd}	-2.44 ^{bcd}	30.11 ^{ab}	14.32 ^{bcd}
		T20	53.92 ^{cd}	-2.93 ^{ef}	27.57 ^{bcdef}	24.42 ^a	53.78 ^{fg}	-2.81 ^{cd}	27.94 ^{ab}	24.21 ^{abc}
		T30	52.97 ^{cd}	-1.57 ^{cdef}	25.18 ^{bcdef}	25.51 ^a	51.87 ^{fg}	-2.26 ^{bcd}	28.41 ^{ab}	26.09 ^{ab}
		T40	56.00 ^{bcd}	-0.93 ^{abcdef}	27.39 ^{bcdef}	22.03 ^{ab}	52.14 ^{fg}	-1.15 ^{abcd}	25.73 ^b	26.37 ^a
		T50	52.00 ^{cd}	-0.44 ^{abcdef}	27.76 ^{bcdef}	26.09 ^a	52.35 ^{fg}	-1.24 ^{abcd}	28.31 ^{ab}	26.20 ^{ab}
	T60	51.28 ^{cd}	2.58 ^{ab}	24.15 ^{cdef}	27.58 ^a	51.80 ^{fg}	-0.03 ^{abcd}	28.05 ^{ab}	27.40 ^a	
	Ripe (ST 5)	T0	67.45 ^{ab}	2.11 ^{abc}	36.54 ^a	0.00 ^d	67.45 ^{bc}	2.11 ^{ab}	36.54 ^a	0.00 ^f
		T10	63.10 ^{bc}	-3.14 ^f	31.41 ^{ab}	8.78 ^{cd}	70.67 ^{ab}	-2.62 ^{cd}	30.72 ^{ab}	8.63 ^{def}
		T20	58.52 ^{bcd}	-2.08 ^{def}	25.58 ^{bcdef}	15.28 ^{abc}	51.59 ^{fg}	-2.57 ^{bcd}	24.80 ^b	20.92 ^{abc}
		T30	51.82 ^{cd}	-1.30 ^{cdef}	23.90 ^{def}	20.53 ^{abc}	55.13 ^{efg}	-1.52 ^{abcd}	25.64 ^b	17.99 ^{abcd}
T40		53.69 ^{cd}	0.60 ^{abcde}	23.08 ^{ef}	19.79 ^{abc}	55.29 ^{efg}	-1.46 ^{abcd}	25.66 ^b	17.36 ^{abcd}	
T50		52.13 ^{cd}	1.66 ^{abc}	22.60 ^f	20.83 ^{abc}	48.79 ^g	0.95 ^{abcd}	21.50 ^b	24.68 ^{abc}	
T60	49.51 ^d	2.66 ^a	22.26 ^f	23.06 ^{ab}	52.23 ^{fg}	2.47 ^a	22.41 ^b	21.06 ^{abc}		
BATARD	Unripe (ST 1)	T0	74.48 ^{ab}	5.25 ^a	36.12 ^{cd}	0.00 ^d	74.48 ^{abc}	5.25 ^a	36.12 ^{cd}	0.00 ^g
		T10	71.58 ^{abc}	1.33 ^{cde}	34.90 ^d	6.41 ^{cd}	72.97 ^{abcd}	1.55 ^{bcd}	33.71 ^d	7.34 ^{fg}
		T20	66.75 ^{abcde}	-0.95 ^e	41.47 ^{abcd}	9.26 ^{bcd}	69.21 ^{abcde}	-0.59 ^{de}	39.78 ^{abcd}	10.75 ^{def}
		T30	58.98 ^{bcdefgh}	0.16 ^{cde}	41.12 ^{abcd}	18.45 ^{abcd}	63.18 ^{bcd}	-0.80 ^{de}	40.07 ^{abcd}	14.00 ^{cdef}
		T40	50.90 ^{efgh}	0.49 ^{cde}	36.92 ^{cd}	18.63 ^{abcd}	60.40 ^{efgh}	-0.55 ^{de}	40.31 ^{abcd}	16.16 ^{bcdef}
		T50	55.22 ^{defgh}	1.07 ^{cde}	36.80 ^{cd}	13.87 ^{abcd}	58.05 ^{efgh}	-0.27 ^{cde}	38.72 ^{abcd}	17.83 ^{bcde}
	T60	50.94 ^{efgh}	0.95 ^{cde}	34.73 ^d	17.95 ^{abcd}	53.65 ^{fgh}	1.33 ^{bcd}	40.78 ^{abcd}	22.12 ^{abc}	
	Start ripe (ST 3)	T0	78.72 ^a	2.94 ^{abc}	36.35 ^{cd}	0.00 ^d	78.72 ^a	2.94 ^{abc}	36.35 ^{cd}	0.00 ^g
		T10	71.88 ^{abc}	-1.18 ^e	44.81 ^{abcd}	11.68 ^{abcd}	75.27 ^{ab}	0.84 ^{cde}	43.30 ^{abcd}	8.35 ^{efg}
		T20	65.20 ^{abcdefg}	-1.22 ^e	46.35 ^{abc}	19.01 ^{abcd}	68.87 ^{abcde}	-0.96 ^{de}	49.54 ^{ab}	17.05 ^{bcdef}
		T30	66.17 ^{abcdef}	-1.03 ^e	48.57 ^{ab}	17.92 ^{abcd}	62.61 ^{cdefg}	-1.67 ^e	46.60 ^{abc}	20.05 ^{abcd}
		T40	58.38 ^{cdefgh}	-0.74 ^e	42.44 ^{abcd}	22.16 ^{abc}	61.24 ^{defgh}	-1.18 ^{de}	44.36 ^{abcd}	20.25 ^{abcd}
		T50	51.21 ^{defgh}	-0.08 ^{de}	38.10 ^{bcd}	27.73 ^{ab}	60.68 ^{defgh}	-0.68 ^{de}	42.36 ^{abcd}	19.63 ^{abcd}
	T60	48.77 ^h	0.99 ^{cde}	37.61 ^{bcd}	30.12 ^a	49.90 ^h	0.60 ^{cde}	37.25 ^{bcd}	28.96 ^a	
	Ripe (ST 5)	T0	74.09 ^{abc}	4.23 ^{ab}	42.45 ^{abcd}	0.00 ^d	74.09 ^{abc}	4.23 ^{ab}	42.45 ^{abcd}	0.00 ^g
		T10	67.16 ^{abcd}	-0.06 ^{de}	49.61 ^a	10.94 ^{abcd}	67.83 ^{abcde}	1.42 ^{bcd}	45.64 ^{abcd}	10.24 ^{defg}
		T20	58.33 ^{cdefgh}	-0.73 ^e	46.07 ^{abcd}	17.50 ^{abcd}	62.60 ^{cdefg}	-1.05 ^{de}	49.99 ^a	16.74 ^{bcdef}
		T30	53.23 ^{defgh}	-0.65 ^e	40.12 ^{abcd}	21.58 ^{abc}	53.25 ^{fgh}	-1.01 ^{de}	42.61 ^{abcd}	21.77 ^{abc}
T40		51.38 ^{defgh}	0.30 ^{cde}	40.71 ^{abcd}	23.09 ^{abc}	50.78 ^{gh}	-0.36 ^{de}	41.48 ^{abcd}	24.04 ^{abc}	
T50		50.26 ^{fgh}	0.71 ^{cde}	38.51 ^{abcd}	24.47 ^{abc}	51.75 ^{fgh}	-0.38 ^{de}	38.17 ^{abcd}	23.39 ^{abc}	
T60	49.76 ^{gh}	2.25 ^{bcd}	36.80 ^{cd}	25.05 ^{abc}	50.17 ^h	0.00 ^{cde}	37.57 ^{bcd}	24.88 ^{ab}		

Colour values are described by L*=lightness, a*=redness, b*=yellowness on the CIE LAB Colour Chart (CIE=International Commission on Illumination), ΔE=Colour intensity. ST: Stage

The averages of the three trials in the same column, with the same superscripts, for each variety are not significantly different at $p \leq 0.05$ (Tukey's test)

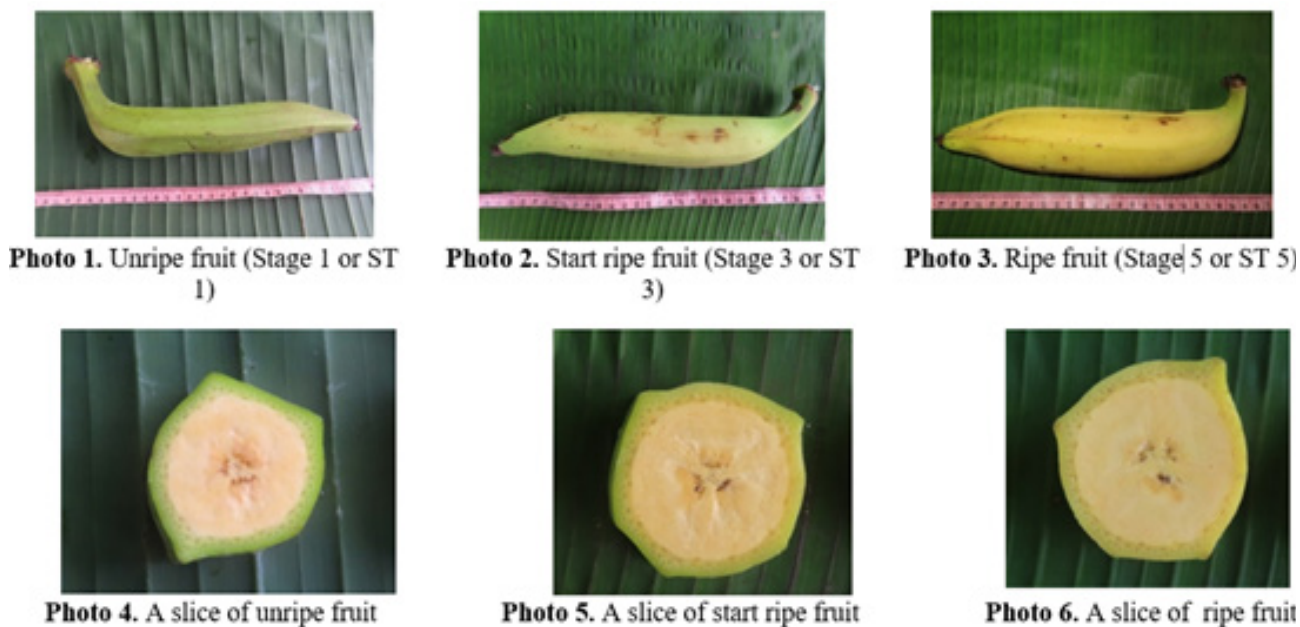


Figure 1: Images of fruits at different ripening stages and their respective cross sections.

The colour parameter a^* represents red-green with positive values for red, negative values for green, and 0 for neutral. At harvest, the pulp of *CARBAP K74* exhibited the lowest positive value of a^* index compared to that of *BATARD*. Whether treated with or without peel, the redness values of the pulps decreased significantly for the two genotypes at stages 1 and 3. For stage 3 and stage 5, a spectacular increase of a^* parameter is observed at the end of the cooking process (between the 50th and the 60th minutes of boiling). *BATARD* pulps present the highest values compared to the *CARBAP K74* irrespective of the ripening stages.

The colour parameter b^* , also called the yellowing index, represents the yellow-blue axis, with positive values for yellow and negative values for blue. It is characteristic of the pulp colour sought by consumers. Irrespective of the genotypes, b^* increases significantly during ripening because chlorophyll pigments are degraded, thereby unmasking carotenoids such as β -carotene and lutein. These pigments accumulate and become more visible as the fruit matures, explaining the rise in b^* values. Whether treated with or without peel, *BATARD* pulps presented a higher yellowing index compared to *CARBAP K74*, consistent with their greater carotenoid content (Table 2). During boiling, b^* values also increase progressively with cooking time, particularly in *BATARD* pulps, as heat promotes the release and visibility of carotenoids. This explains why there is the more intense yellow colour observed in ripe and long-boiled samples. In fact, [21] suggest that during ripening there is the degradation of chlorophyll pigments revealing the carotenoids that are already at their peak in the fruit at maturity. In general, b^* values were higher in *BATARD* than in *CARBAP K74* irrespective of the boiling methods.

Considering both boiling methods, the colour intensity (ΔE) increased significantly with cooking times for all three ripening

stages; but it was less intense with unripe pulps boiled without peel for both varieties. This could be explained by the degradation of chlorophyll pigments which is not seen in pulps cooked with peel as the latter plays a role of a barrier for the degradation of flavanols. The increase in colour intensity (ΔE) in the pulps of *BATARD* and *CARBAP K74* after more than 40 minutes of boiling is mainly due to the release and enhanced visibility of carotenoids, rather than a true increase in their content. Heat treatment disrupts cell structures, allowing carotenoids to be more exposed, which intensifies the yellow-orange colour observed [22]. Hence, this confirms that to obtain the attractive colour always mentioned by consumers, plantain should be boiled between 40 and 60 minutes either without peel or with peel.

iii) Effect of boiling on the colour of plantain peels

Boiling plantains with peel induces colour changes similar to those observed in boiled green vegetables. These changes are characterized by the degradation of pigments and the loss of the initial vivid colour, leading to faded and indistinct hues depending on the maturity stage (Figure 2). The colour parameters of boiled plantain peels are presented in Table 3. Significant differences are observed mostly for a^* and b^* parameters than for L^* . Indeed, plantain peels are generally green in colour when unripe, turning yellow when start ripe or yellow when ripe. Therefore, depending on the stage of maturity, a^* or b^* values will show more significant differences than the L^* values. The variation from green to red is given by the monochromatic variable “a”. The a^* values of the peels of the two genotypes analysed increase significantly during ripening and boiling with changes from negative to positive values at the end of the cooking process of start ripe and ripe fruits of *CARBAP K74* meanwhile no negative values were exhibited at the same ripening stages with *BATARD*.



Figure 2: Cross sections of BATARD pulps boiled without peel at three ripening stages and boiling times.

During ripening, b^* values of CARBAP K74 peels show a U trend meanwhile BATARD peels presented a continuous significant increasing values. Boiling enables b^* values decrease with lowest values at the end of the cooking process independently to genotypes. The loss of green and yellow colour in plantain peels during cooking may be due to the activation of the chlorophyll degradation pathway. It has been shown that chlorophylls and their degradation products are present in plantains during ripening [21,23]. However, the degradation of chlorophyll in bananas and plantains follows the same path as the senescence of the leaves [23]. Besides, temperature plays an important role in the degradation of chlorophyll, hence the decrease of the a^* (green - red) value during boiling. It has been proven that high temperatures, over a short period (blanching), could be a beneficial approach to preserve chlorophyll [16]. Considering both varieties of plantains, the colour intensity (ΔE) of the peels increased significantly with cooking time for all three stages of ripeness; but it was intense in the peels of the landrace at all stages compared to the plantain-like hybrid. The more pronounced colour of BATARD peels can be attributed to a higher concentration of carotenoids, resulting from genetic and enzymatic differences in pigment biosynthesis, as well as an increased extraction of these pigments during boiling, which enhances their release and intensity [24].

iv) Analysis of correlations between colour parameters of plantain pulps and peels, and cooking time

Table 4 shows Pearson correlation coefficients between colour parameters of pulp and peel as well as cooking time at three postharvest maturity stages. A significant strong negative correlation exists between L^* values of boiled pulp and cooking time at all postharvest maturity stages, while b^* values exhibited a significant medium negative correlation with cooking time only at

stage 5. With respect to peel colour, a significant ($p < 0.01$) positive correlation was observed between a^* values and cooking time at all ripening stages while a significant negative correlation was observed between b^* values and cooking time at stages 3 and 5. Also, cooking time influence negatively L^* values. In terms of colour parameters, a significant positive correlation was observed between L^* and b^* values. This correlation was medium for the pulp colour and strong for the peel colour. These parameters (L^* and b^*) were on the other hand significantly strongly negatively correlated with a^* values for the peel colour.

v) Regression analysis between colour parameters of plantain pulp, peel and cooking time

A regression analysis was performed between L^* , a^* and b^* values of pulp and peel against cooking time at three postharvest maturity stages. Table 5 highlights regression equations and coefficients of determination. The R^2 values for the various models illustrate the proportion of variability in the data accounted by the model. L^* value of unripe pulp has the highest R^2 with cooking time. Similar trends are observed at stages 3 and 5 of ripening. Peels exhibited high R^2 values with the cooking time for the a^* value especially at stage 1. Overall, for plantain pulp and peel, the R^2 values for the relationship between L^* , a^* and b^* values versus cooking time range between 0.01 and 0.76. These R^2 values showed that most of the variability in cooking time was accounted for by L^* and a^* values respectively for the plantain pulp and the plantain peel at all postharvest maturity stages. The analysis of the equations for the b^* parameter of plantain pulps shows that it has a significant influence on the perceived quality of boiled plantain pulps, with a stronger relationship at stages 1 and 3. Colour variations strongly impact the product's acceptability. At stage 1, its impact is reduced, suggesting that other factors may become more important at this

Table 3: Colour parameters of plantain peel after boiling.

Plantain clone	Ripening stage	Cooking time (min)	Peel colour parameters			
			L*	a*	b*	ΔE
CARBAP K74	Unripe (ST 1)	T0	55.21 ^a	-15.10 ^f	36.97 ^{abc}	0.00 ^b
		T10	50.27 ^a	-5.44 ^{de}	31.98 ^{abcd}	12.30 ^{ab}
		T20	54.24 ^a	-3.18 ^{cde}	31.32 ^{abcd}	13.38 ^{ab}
		T30	53.29 ^a	-2.02 ^{bcd}	29.86 ^{bcd}	15.04 ^{ab}
		T40	50.71 ^a	-1.26 ^{abcd}	28.14 ^{bcd}	17.12 ^{ab}
		T50	53.49 ^a	-0.93 ^{abcd}	28.95 ^{bcd}	16.45 ^{ab}
	T60	49.73 ^a	-0.24 ^{abcd}	23.82 ^d	21.35 ^a	
	Start ripe (ST 3)	T0	63.06 ^a	-8.84 ^{ef}	41.58 ^a	0.00 ^b
		T10	54.43 ^a	-5.78 ^{de}	36.85 ^{abc}	11.07 ^{ab}
		T20	57.47 ^a	-2.81 ^{cde}	34.52 ^{abcd}	11.07 ^{ab}
		T30	57.23 ^a	-1.82 ^{bcd}	32.60 ^{abcd}	13.00 ^{ab}
		T40	54.63 ^a	-0.17 ^{abcd}	30.05 ^{bcd}	16.81 ^{ab}
		T50	54.61 ^a	1.11 ^{abc}	30.11 ^{bcd}	17.47 ^{ab}
	T60	55.12 ^a	1.36 ^{abc}	29.48 ^{bcd}	17.88 ^{ab}	
	Ripe (ST 5)	T0	58.45 ^a	-1.75 ^{bcd}	37.98 ^{abc}	0.00 ^b
		T10	60.79 ^a	-2.95 ^{cde}	39.47 ^{ab}	11.23 ^{ab}
		T20	56.56 ^a	0.24 ^{abcd}	33.07 ^{abcd}	12.97 ^{ab}
		T30	59.26 ^a	-0.03 ^{abcd}	34.56 ^{abcd}	17.08 ^{ab}
T40		55.81 ^a	1.30 ^{abc}	33.88 ^{abcd}	14.16 ^{ab}	
T50		55.76 ^a	3.95 ^{ab}	27.59 ^{cd}	16.76 ^{ab}	
T60	51.57 ^a	4.62 ^a	26.93 ^{cd}	16.33 ^{ab}		
BATARD	Unripe (ST 1)	T0	58.17 ^{ab}	-16.23 ⁱ	37.24 ^{ab}	0.00 ^b
		T10	41.49 ^c	-2.72 ^g	14.38 ^c	31.48 ^a
		T20	47.07 ^{bc}	-2.26 ^g	20.43 ^{bc}	24.78 ^a
		T30	46.09 ^{bc}	-1.37 ^{efg}	19.62 ^c	26.30 ^a
		T40	46.99 ^{bc}	-1.83 ^{fg}	19.73 ^c	25.47 ^a
		T50	44.29 ^{bc}	-0.65 ^{defg}	17.25 ^c	29.04 ^a
	T60	44.57 ^{bc}	-0.42 ^{cdefg}	17.07 ^c	29.14 ^a	
	Start ripe (ST 3)	T0	66.27 ^a	-8.44 ^h	43.51 ^a	0.00 ^b
		T10	47.70 ^{bc}	0.80 ^{bcddefg}	22.14 ^{bc}	30.32 ^a
		T20	48.30 ^{bc}	1.70 ^{abcddef}	22.02 ^{bc}	30.23 ^a
		T30	46.59 ^{bc}	2.78 ^{abcd}	21.56 ^{bc}	32.11 ^a
		T40	50.24 ^{bc}	1.68 ^{abcddef}	21.70 ^{bc}	29.37 ^a
		T50	46.08 ^{bc}	2.20 ^{abcde}	19.26 ^c	33.72 ^a
	T60	45.85 ^{bc}	4.24 ^{ab}	20.12 ^{bc}	33.79 ^a	
	Ripe (ST 5)	T0	71.28 ^a	-1.49 ^{fg}	45.62 ^a	0.00 ^b
		T10	50.07 ^{bc}	1.84 ^{abcddef}	22.30 ^{bc}	31.73 ^a
		T20	46.62 ^{bc}	3.24 ^{abc}	19.33 ^c	36.41 ^a
		T30	46.03 ^{bc}	3.68 ^{ab}	18.37 ^c	37.56 ^a
		T40	45.11 ^{bc}	4.50 ^a	18.32 ^c	38.38 ^a
		T50	42.76 ^c	4.79 ^a	18.25 ^c	40.13 ^a
	T60	48.12 ^{bc}	4.95 ^a	20.70 ^{bc}	34.74 ^a	

Colour values are described by L*=lightness, a*=redness, b*=yellowness on the CIE LAB Colour Chart (CIE=International Commission on Illumination), ΔE=Colour intensity. ST=stage.

The averages of the three trials in the same column, with the same superscripts, for each variety are not significantly different at $p \leq 0.05$ (Tukey's test)

Table 4: Pearson correlation coefficient between colour parameters of pulp and peel as well as cooking time of boiled plantain at three postharvest maturity stages.

Ripening stage	Parameter	Pulp				Peel			
		Cooking time	L* value	a* value	b* value	Cooking time	L* value	a* value	b* value
Unripe (ST 1)	Cooking time	1				1			
	L* value	-0.872**	1			-0.307*	1		
	a* value	-0.161	0.212	1		0.739**	-0.589**	1	
	b* value	0.048	0.034	0.151	1	-0.457**	0.928**	-0.686**	1
Start ripe (ST 3)	Cooking time	1				1			
	L* value	-0.791**	1			-0.461**	1		
	a* value	0.064	0.148	1		0.747**	-0.784**	1	
	b* value	-0.138	0.468**	-0.072	1	-0.529**	0.930**	-0.799**	1
Ripe (ST 5)	Cooking time	1				1			
	L* value	-0.807**	1			-0.473**	1		
	a* value	0.036	0.156	1		0.730**	-0.740**	1	
	b* value	-0.390**	0.453**	0.072	1	-0.522**	0.936**	-0.796**	1

* Significant at $p < 0.05$ for correlative relationships

** Significant at $p < 0.01$ for correlative relationships

Colour values are described by L*=lightness, a*=redness, b*=yellowness on the CIE LAB Colour Chart (CIE=International Commission on Illumination), ΔE =Colour intensity. ST: Stage.

Table 5: Regression analysis between L*, a* and b* values of pulp and peel versus cooking time at three postharvest maturity stages.

Ripening stage	Colour Parameter	pulp		peel	
		Regression equation	R ²	Regression equation	R ²
Unripe (ST 1)	L*	$y = 0.01L^2 - 2.73L + 173.17$	0.76	$y = -0.17L^2 + 15.37L - 306.29$	0.19
	a*	$y = -1.11a^2 - 0.13a + 35.70$	0.18	$y = 0.33a^2 + 8.40a + 48.65$	0.68
	b*	$y = 0.05b^2 - 3.44b + 83.78$	0.01	$y = -0.15b^2 + 6.05b - 19.85$	0.42
Start ripe (ST 3)	L*	$y = -0.002L^2 - 1.34L + 117.42$	0.63	$y = -0.12L^2 + 11.09L - 228.85$	0.32
	a*	$y = -0.63a^2 + 0.28a + 32.68$	0.03	$y = 0.12a^2 + 4.35a + 31.47$	0.57
	b*	$y = 0.05b^2 - 4.03b + 105.93$	0.05	$y = -0.12b^2 + 5.62b - 23.94$	0.51
Ripe (ST 5)	L*	$y = 0.02L^2 - 4.14L + 204.13$	0.65	$y = -0.09L^2 + 8.64L - 173.51$	0.35
	a*	$y = -1.53a^2 + 2.23a + 36.54$	0.15	$y = 0.35a^2 + 4.18a + 17.57$	0.56
	b*	$y = 0.01b^2 - 1.75b + 73.50$	0.16	$y = -0.09b^2 + 4.31b - 10.20$	0.44

L = L* value; a = a* value; b = b* value; y = cooking time (minutes)

Colour values are described by L*=lightness, a*=redness, b*=yellowness on the CIE LAB Colour Chart (CIE=International Commission on Illumination), ΔE = Colour intensity. ST: Stage.

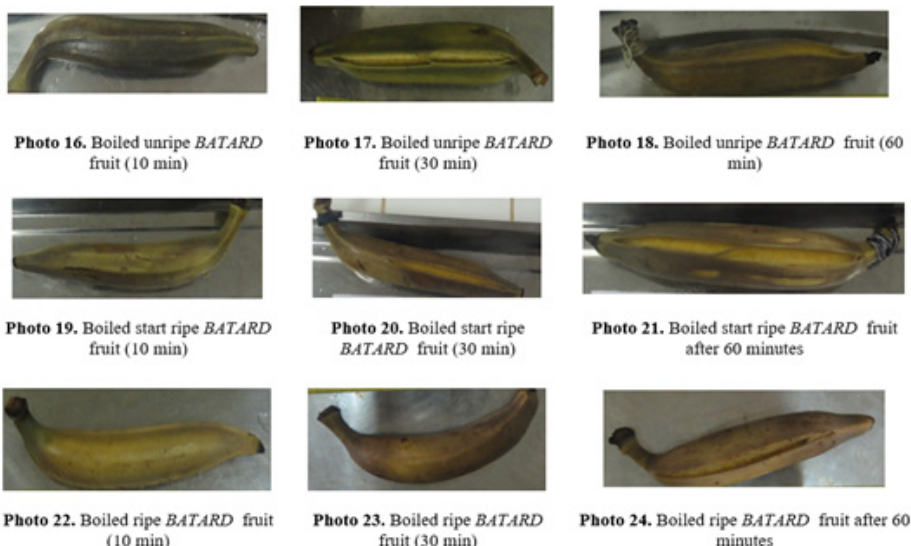


Figure 3: Photos of BATARD fruits at various ripening stages and boiling times.

stage. It is crucial to control the b^* parameter during the cooking of boiled pulps, particularly at stages 1 and 3, to optimize the visual quality and acceptability of the final product. The same observations are made with a^* in plantain peels.

Conclusion

Colour is among the important criteria that guide boiled plantain choice. The boiling methods, the boiling time and the ripening stages influenced the colour of the pulps and the colour of the peels of analysed genotypes. The colour parameters (L^* , a^* , b^* and ΔE) varied significantly during ripening, between raw and boiled pulps, and also between raw and boiled peels. The degradation of starch and chlorophyll pigments during ripening, as well as the water absorption capacity and the degradation of chlorophyll during boiling, are precursors of colour changes in plantains fruits. The values of ΔE , a^* and b^* were the best predictors of colour for both genotypes. It was found that regardless of boiling and ripening stage, the pulp colour of the local variety (*BATARD*) is more intense and attractive than that of the plantain-like hybrid (*CARBAP K74*); which is a key quality trait for boiled plantain preferences. The b^* parameter is crucial for evaluating the acceptability of a high-quality cooked plantain pulp. It appears that the pulps are perceived as more attractive when cooked with the peel. This phenomenon can be explained by better preservation of colour characteristics related to the b^* parameter during cooking with the peel, which positively influences the visual acceptability of the final product. In addition, the setting up of the relationship between colour parameters of plantain pulps and peels as well as cooking time could improve varietal selection.

Acknowledgements

This research was carried out at the Post-Harvest Technology Laboratory of *Centre Africain de Recherches sur Bananiers et Plantains* (CARBAP) within a collaborative framework, including the University of Dschang, the University of Yaounde I, and the University of Douala in Cameroon, as well as *Centre de Coopération Internationale en Recherche Agronomique pour le Développement* (CIRAD) in France. It was supported by the RTBfoods Project <https://rtbfoods.cirad.fr> through a grant “OPP1178942: Breeding RTB products for end user preferences”, to CIRAD - Montpellier, France, by the Bill & Melinda Gates Foundation.

References

1. Lescot T. Banana genetic diversity. *Close-Up*. 2020; 269: 98-102.
2. <https://www.fao.org/faostat/en/#data/QCL>
3. Dury S, Bricas N, Tchango-Tchango J, et al. The determinants of urban plantain consumption in Cameroon. *Food Quality and Preference*. 2002; 13: 81-88.
4. Pick C, Foure E, Frison EA. Bananas and Food Security: les productions bananières, un enjeu économique majeur pour la sécurité alimentaire. *International symposium Douala Cameroun*. 1998; 10-14.
5. Ibobondji L, Ngoh G, Kodjo T, et al. Musalogue: Catalogue de germoplasme de Musa. *Plantains d'Afrique occidentale et*

- centrale Collection CARBAP. Bioversity International. 2018.
6. Amah D, Alamu E, Adesokan M, et al. Variability of carotenoids in a Musa germplasm collection and implications for provitamin: A biofortification. *Food Chemistry*. 2019; 2: 1-8.
 7. Robert A, Elsie AWS, Hayford D. Effect of cooking methods and ripening stages on the nutritional compositions of plantain (*Musa paradisiaca*). *International Journal of Food Science and Biotechnology*. 2017; 2: 134-140.
 8. Ngoh Newilah G, Tchango JT, Fokou É, et al. Processing and food uses of bananas and plantains in Cameroon. *Fruits*. 2005; 60: 245-253.
 9. Ekesa B, Kimiywe J, Davey M, et al. Banana and plantain (*Musa spp*) cultivar preference, local processing techniques and consumption patterns in Eastern Democratic Republic of Congo. *Int J Agric Sci*. 2012; 4: 312-319.
 10. Odenigbo M, Asumugha V, Ubbor S, et al. Proximate composition and consumption pattern of plantain and cooking banana. *Br J Appl Sci Technol*. 2013; 3: 1035-1043.
 11. Dufour D, Gibert O, Giraldo A, et al. Differentiation between Cooking Bananas and Dessert Bananas. 2. Thermal and Functional Characterization of Cultivated Colombian Musaceae (*Musa sp.*). *J Agric Food Chem*. 2009; 57: 7870-7876.
 12. Yussif E. *The Facet of Black Culture*. Amazon USA. 2013.
 13. Ngoh Newilah G, Kendine Vepowo C, Takam Ngouno A, et al. Analysis of consumer-oriented quality characteristics of raw and boiled plantains in Cameroon : Implication for breeding. *Int J Food Sci Technol*. 2021; 56: 1135-1147.
 14. Thompson AK, Burden OJ. *Harvesting and Fruit Care. Bananas and Plantains*. 1995; 403-433.
 15. Seymour GB, Thompson AK, John P. Inhibition of degreening in the peel of bananas ripened at tropical temperatures. *Annals of Applied Biology*. 1987; 110: 145-151.
 16. Caballero B, Finglas PM, Toldrá F. *Encyclopedia of food and health*. Academic Press is an imprint of Elsevier. 2016.
 17. http://www.bioversityinternational.org/fileadmin/_migrated/uploads/tx_news/Routine_postharvest_screening_of_banana_plantain_hybrids_Criteria_and_methods_235_FR.pdf
 18. Horvat A, Granato G, Fogliano V, et al. Understanding consumer data use in new product development and the product life cycle in European food firms—An empirical study. *Food Quality and Preference*. 2019; 76: 20-32.
 19. Hunt R. *Measuring Colour*. Ellis Horwood New York. 1991; 75-76.
 20. Tourjee KR, Barrett DM, Romero MV, et al. Measuring flesh colour variability among processing clingstone peach genotypes differing in carotenoid composition. *J Am Soc Hort Sci*. 1998; 123: 433-437.
 21. Adi DD, Oduro I, Tortoe C. Physicochemical changes in plantain during normal storage ripening. *Scientific African*. 2019; e00164.

-
22. Ngoh G, Tembe Tembe J, Nkouandou M, et al. Effects of drying and boiling on some specific dietary carotenoids profiles and levels of plantain pulp (BATARD cv.) Produced in Cameroon. *International Journal of Agriculture Environment and Bioresearch*. 2018; 3: 06-20.
 23. Yang X, Zhang Z, Joyce D, et al. Characterization of chlorophyll degradation in banana and plantain during ripening at high temperature. *Food Chemistry*. 2009; 11: 383-390.
 24. Jiang Y, Ye J, Hu Y, et al. Extraction and Synthesis of Typical Carotenoids: Lycopene, β -Carotene, and Astaxanthin. *Molecules*. 2024; 29: 45-49.