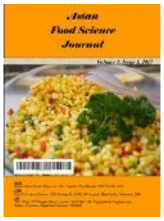

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Biochemical Characteristics of Mangoes Cultivated in Chad: Characterisation of the Functional Diversity

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Authors' contributions

This work was carried out in collaboration between all authors. Author ASP performed labor experiment and the statistical analysis, managed the literature searches and wrote the first draft of the manuscript. Author JAN designed the study and wrote the protocol. Authors JAN and DG managed the analyses of the study and the final manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Mango is one of the most consumed fruits in Chad and several varieties are cultivated there. However, their biochemical characteristics are still unknown. The objective of this study was to determine the biochemical characteristics of mango varieties cultivated in Chad. Moisture, dry matter, chlorophyll *a*, chlorophyll *b*, lycopene β-carotene contents, pH and total soluble solids were determined in ripened mango fruits with firmness between 2 and 3 kgf. The results showed that Mangotine, José Tchad and Bangui mango varieties had a significantly higher total soluble solids (19.37 to 20.86°Brix) and dry matter content (24.57 to 25.48%), while Maïduguri, Kent and Smith varieties were richer in water (80.20 to 80.75%). The José Tchad variety also had the highest pH

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(4.74) and the highest β-carotene content (0.11 mg/10 g). The peels of all varieties of mangoes were richer in β-carotene than their pulp. Lycopene was found in the peel and pulp of some mango varieties, and the peel of Mangotine contain more lycopene than the pulp. The results indicated a functional diversity of Chad mango varieties as related to some biochemical features. Furthermore, besides the pulp, the peel of these fruits could be considered as an important alternative source of β-carotene, a precursor of vitamin A.

Keywords: Mango varieties; biochemical characteristics; functional diversity; growth regions; Chad.

1. INTRODUCTION

Mango is one of the major fruits in the tropical and subtropical zones, where it occupies a very important place, hence, it is considered as the “King of fruits” [1]. The mango tree, *Mangifera indica* L., belongs to the family Anacardiaceae and is native to eastern part of the Indo-Burma region at the foot of the Himalayas [2]. Mango is a drupe cultivated in Chad since the colonial period, with regard to the local varieties. On the other hand, the improved varieties commonly known as "grafted mangoes" were recently introduced by the Chadian Institute of Agronomic Research for Development which provides its extension. More than 14 varieties of mangoes are cultivated in Chad and their harvest usually starts in February and culminates in March, April and May [3]. In Chad, they are produced mainly for local consumption in fresh and secondarily in dried or processed form. They are very nutritious, rich in water, mineral salts, vitamins and carbohydrates, and also contain proteins, lipids, carotenoids, polyphenols, omega-3 and omega-6 fatty acids [4]. However, no study exists specifically to the best our knowledge, on the biochemical features of mango fruits produced in Chad.

The objective of this work was to determine the biochemical characteristics of mango varieties cultivated in Chad.

2. MATERIALS AND METHODS

2.1 Characteristics of Study Areas

This study was carried out during April, May and July 2017 at the Research Unit of Applied Botany of the Faculty of Sciences of the University of Dschang with the mangoes harvested in the regions of Logone Occidental, Logone Oriental, Mandoul and Mayo Kebbi Ouest in the south of Chad. The climate of this region is of the dry tropical type with two seasons, e dry (October-April) and rainy (May-September). Those regions are covered with open forests and shrub savannas and record rainfall up to 1,200 to 1,300 mm per year in the south [5]. Soil analysis in different regions has shown that they are favourable for the cultivation of mango trees (Table 1). Mean daily temperature and relative humidity during the mango harvest months in the different regions are presented in Table 2.

2.2 Plant Material

Thirteen varieties of mango (*Mangifera indica* L.) cultivated in Chad were studied (4 local varieties and 9 improved varieties). Local mango varieties viz., Bangui, Kassai, Maiduguri and Mangotine were included. Improved mango varieties were consisted of Davis haden, Eldon, José Tchad, Julie Kassawa, Keitt, Kent, Palmer, Smith and Valencia. The varieties of local mangos are propagated by seedling while the improved varieties are propagated mainly by grafting. Fruits were collected from 7 to 10 years old mango trees in 2017. It should be noted that among the 14 varieties cultivated in Chad [3], the Cœur de Boeuf improved variety did not produce in 2017 in all regions. This is why 13 varieties were studied. Five ripe mangoes of each variety and region were analysed, for a total of 20 fruits per variety. Most biochemical parameters were determined using ripe mangoes with a firmness of 2.5 kgf. However, mature green mangoes with firmness greater than 3.5 kgf were used to perform qualitative thin layer chromatographic analysis of pigments in the peel, in order to get insight into the pigment composition of these fruits. The firmness of the mangoes was measured using a GY-2 SAUTER GmbH penetrometer. The work was carried out progressively according to the availability of the different varieties during the months of April, May and July 2017 at the Applied Botany Research Unit of the Faculty of Science of Dschang University.

Table 1. Main characteristics of the soil of study regions

Regions	Characteristics of the soil										
	Ca*	Mg*	pH H_2O	pH KCL	CO (%)	MO (%)	CEC*	P Ass$^{\beta}$	K*	Na*	N$^{\beta}$
R1	0.87	0.30	6.16	4.9	3	6	9.18	20.40	0.18	0.04	203.33
R2	4.26	0.25	6.83	5.73	2	3	9.32	29.27	0.18	0.026	200
R3	0.76	0.44	6.46	5.1	2.6	5	9.33	23.68	0.11	0.013	183.33
R4	1.26	0.76	7	5.66	2.66	5	9.32	23.85	0.11	0.04	196.66

*R1: Logone Occidental; R2: Logone Orientale; R3: Mandoul; R4: Mayo Kebbi Ouest; CEC: Cation exchange capacity; OM: Organic matter; Ass P: assimilable phosphorus; pH H_2O: pH which corresponds to the actual acidity of the soil; pH: theoretical pH of soil; *: centimol of positive charges/Kg; $^{\beta}$: mg/kg sol*

Table 2. Mean daily temperature and relative humidity during the harvest months of mangoes (April, May and July) study regions

Regions	Temperature (°C)	Humidity (%)
Logone Occidentale	31,71	66,83
Logone Orientale	35,66	42,86
Mandoul	35,27	43,41
Mayo Kebbi Ouest	36,6	41,5

2.3 Methods

2.3.1 Measurement of moisture, dry matter content, pH and total soluble solids in mango pulp extract

The determination of the moisture content (MC) and the dry matter content (DMC) was made according to the AOAC method [6] by placing 2 fresh fruits without their endocarp after weighing in a New Brunswick Scientific GMBH oven at 80°C for 96 hours. MC and DMC were respectively calculated using the following formulae:

MC = (MI-M2) / MI x 100 and DMC (%) = 100 – MC

Where, MI: fresh matter weight, M2: weight of dry matter.

The mango juice was obtained after grinding the mango pulp and filtration using a polyester cloth. This juice was used for determination of the pH and total soluble solids. The total soluble solids (TSS) of mango pulp in degree Brix was determined using a 0-32% ATC Refractometer according to the method of Navarre and Navarre [7]. One or two drops of mango juice free of bubbles and particles were deposited on the prism of the refractometer.

2.3.2 Thin layer chromatography

The qualitative analysis by thin layer chromatography of the pigments (chlorophylls and carotenoids) of mature-green mango was performed in two stages:

1) Extraction of pigments

It consisted of crushing 15 g of mango peel with a little sand manually in a laboratory mortar and pestle. Then 5 ml of chloroform-acetone (2/3, v/v) solvents mixture was added to the sample to extract the pigments

2) Separation of pigments by thin layer chromatography

Five millilitres of the mobile phase constituted by a mixture of benzene-chloroform-acetone (6/3/2, v/v) solvents were introduced into a Pierron cylindrical chromatography tank (10 cm height and 6 cm in diameter). The stationary phase was a thin layer of silica which covered an aluminium plate (silica gel 60 F254, Merck, Darmstadt, Germany). The crude extract was spotted 5 times with a capillary pipette at the lower end of the aluminium plate (7 cm x 4 cm). This plate was then deposited in a chromatography tank containing the benzene-chloroform-acetone mixture 6/3/2, v/v) and the tank was then covered with an aluminium foil. After 3 to 4 minutes, the chromatogram was taken out of the chromatography tank when the solvent front was at minus 0.5 cm from the top end of the plate. Finally, the plate was visualised and photographed. An orange spot corresponded to carotenes, green-blue to chlorophyll *a*, yellow-green to chlorophyll *b*, and yellow to xanthophylls.

2.3.3 Determination of chlorophyll, lycopene, and β-carotene contents in the peel and mango pulp

The quantitative analysis of chlorophyll, lycopene and β-carotene in the peel and the pulp of ripe mangoes was made using a Biochrom Libra S22 spectrophotometer. Ten grams of small pieces (about 1cm in diameter) of mango peel and 10 g of mango pulp were introduced separately into test tubes, and then 10 ml of acetone-hexane (4:6) were added to each test tube. The mixtures were stored in a refrigerator at 4°C for 48 hours. The optical densities of the extracts were spectrometrically determined at 663, 645, 505 and 453 nm and the chlorophyll *a*, chlorophyll *b*, lycopene and β-carotene contents were calculated using the formulae of Nagata, et al. [8].

2.3.4 Experimental design

The design used in this experiment was a Complete Randomised Design (CRD) with 13 treatments (varieties) and 20 replications.

2.3.5 Statistical analysis

The data obtained were subjected to analysis of variance (ANOVA) using the XLSTAT 2014.5.03 (Kovach Computing Services, United Kingdom) software. The Student-Newman-Keuls test was used to analyse the significance of the results at a probability threshold set at < 5%.

3. RESULTS AND DISCUSSION

3.1 Fresh Peel Biochemical Characteristics of Mango Varieties

Thin layer chromatographic analysis of extracts from peels of different varieties of mature green mangoes (firmness >3.5 kgf) cultivated in Chad revealed the presence of several pigments (Fig. 1). There were different pigments in the peel of mature mangoes, such as chlorophyll a (blue-green), chlorophyll b (yellow-green), β-carotene (orange), lycopene (red) and xanthophylls (yellow) as shown in the thin layer chromatographic profile of the Bangui variety.

Ripe mango varieties cultivated in Chad had a β-Carotene content in the peel varying between of 0.03 mg/10 g and 0.11 mg/10 g. The mango peel had a higher β-carotene content than its pulp as clear from the β-carotene peel/β-carotene pulp ratio. This ratio varied from 0.93 to 5.40 mg/10 g (Table 3). These results corroborate the study of Moura, et al. [9] on Cassava, maize and sweet potato and those of Chen, et al. [10] on apple. Moura, et al. [9] reported that content and types of carotenoids in plants depend on the pre and

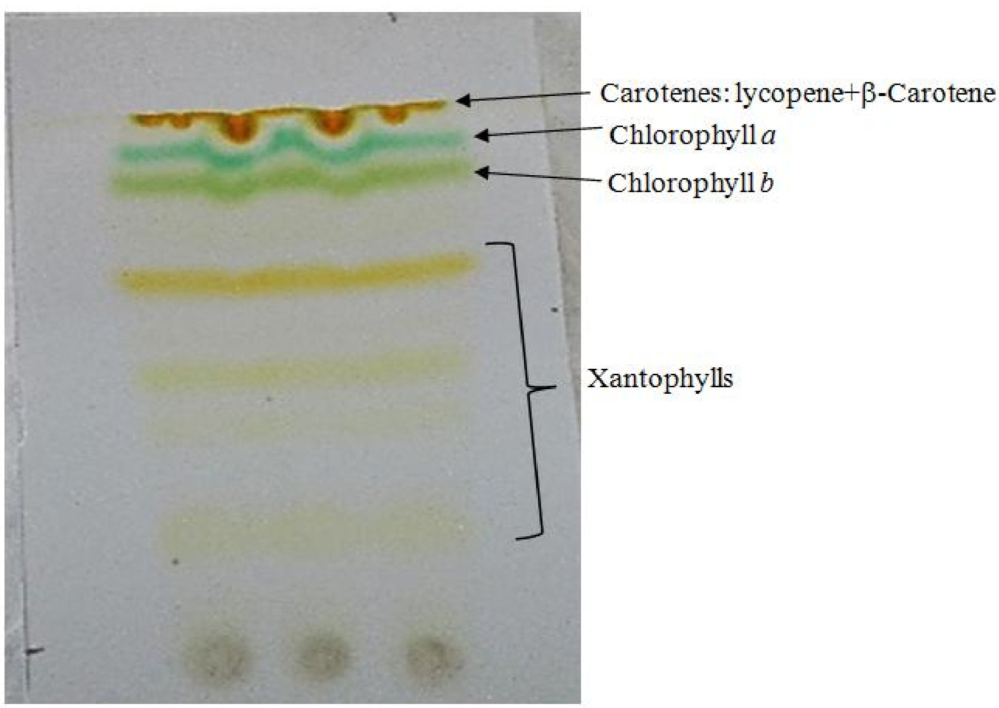

Fig. 1. Thin layer chromatographic profile pigments from the peel mature green Bangui mango variety

post-harvesting factors, genotype, cultivation methods, climatic conditions, ripening stage and processing methods. Different parts of the same plant may also contain different types and amounts of carotenoids. For example, the peel of the fruits is generally richer in carotenoids compared to the pulp. β-carotene is a natural pigment responsible for the orange colour in various fruits [11]. At the current stage of this work, no scientific literature has evoked and explained this important β-carotene content in the peel of mangoes. Nevertheless, the β-carotene content in the peel of mangoes would be related to its role as the protective envelope of the pulp and the endosperm. Carotenoid contents are often correlated with protection mechanisms against high sunlight [12]. In the plant, carotenoids contribute to several major physiological functions and contribute to the adaptation of the plant to microclimatic variations [13]. Thus, plant performance in physiological and evolutionary terms is partly based on their ability to adjust their carotenoid content at the right time and in the right tissue [14]. It would prevent degradation of the peel and pulp and especially the modification of the genetic material, contained in the nucleus and thus ensure the maintenance of hereditary traits. Mango varieties with a high β-Carotene content in the peel were Eldon, Davis haden, José Chad, Julie Kassawa, Keitt, Kent, Palmer, Smith and Valencia. These β-Carotene contents found in the peel of mango fruits could be a result of functional diversity. Since the peel of mango has a high level of β-carotene, the consumption of mango without its peel does not allow to fully enjoy the virtues of this fruit. Thus, it would be better to consume the mango with all its peel to benefit from all its nutritional virtues.

The chlorophyll *a* and chlorophyll *b* contents determined in the peel of ripe mango fruits varied respectively from 0.01 mg/10 g to 0.05 mg/10 g and from 0 to 0.02 mg/10 g (Table 3). The chlorophyll pigments are an indicator of oxygen production and carbon sequestration [15]. These contents were lower than those found by Youmbi, et al. [16] in the peels of *Spondias cytherea*. These authors obtained a content of 9.3 mg/10 g for chlorophyll *a* and 2.3 mg/10 g for chlorophyll *b*. These differences could be explained by the specific diversity and mostly by the degradation of chlorophylls during ripening of mangoes. Kader [17] mentioned that during ripening, the degradation of chlorophylls was induced by changes in pH, oxidative conditions and the action of chlorophyllase enzyme. Besides, chlorophyll *a* content was higher than that of chlorophyll *b* as Srichaikul, et al. [18] showed in their work. Chlorophyll a and chlorophyll *b* were practically absent from the pulp of ripe mangoes grown in Chad.

The lycopene content of the peel and pulp of ripe mangoes cultivated in Chad ranged from 0 to 5.00 μg/10 g and from 0 to 6.00 μg/10 g, respectively (Tables 3 and 4). These values are inferior to those obtained (35 μg/10 g) by Shi, et al. [19] on mangoes in Malaysia and those of Maiani, et al. [20], which ranged from 1 to 72.4 μg/10 g. These differences could be due to the varietal diversity and degree of ripening. According to Shi, et al. [19], lycopene content in fresh fruit is influenced by the cultivars, agricultural practices, maturity stage and environmental factors. Lycopene plays the role of antioxidant by limiting the action of reactive oxygen species and is also involved in the determinism of fruit colouring. Its presence in some ripe fruits confers to tissues a yellow to red colour and makes them attractive to pollinating insects in flowers, or to predators for fruits to allow seed dispersal [21]. Its degradation leads to the formation of volatile aromatic compounds. Thus, lycopene, a major red pigment found in tomato and watermelon, is responsible for many aromas such as geranial [22]. Lycopene peel /lycopene pulp ratio varied from 0 to 8.73 (Table 3). Only the Mangotine variety showed a high content of lycopene in the peel. Lycopene and β-carotene had a functional implication. According to Saini, et al. [23], the biosynthesis of carotenoids in plants has been extensively studied; however their importance for plants and animals is still not well established.

3.2 Fresh Pulp Biochemical Parameters of Ripe Mango Varieties

The results in Table 4 shows that the total soluble solids of local mango varied from 16.29 to 20.86°Brix, while that of improved mango varieties ranged from 16.82 to 20.06°Brix. These results are comparable to those of Kameni et al. [24] obtained with mangoes from North Cameroon and those of Dick et al. [25] obtained with mangoes from North of Ivory Coast. Kameni et al. [24] showed that total soluble solids ranged from 15.83 to 17.17°Brix for improved mango varieties while it was 21.67°Brix for local mango varieties cultivated in northern Cameroon. Furthermore, Dick et al. [25] determined total

Table 3. Biochemical characteristics of the fresh peel of ripe mango varieties

Varieties	Fresh peel biochemical characteristics					
	β-carotène (mg/10 g)	lycopène (µg/10 g)	chl *a* (mg/10 g)	chl *b* (mg/10 g)	Peel β-carotène/pulp β-carotène	Peel lycopène /pulp lycopène
Bangui	0.03[c]	3.00[a]	0.01[ab]	0.01[a]	3.11[a]	0.23[b]
Davis haden	0.08[ab]	0.00[a]	0.01[ab]	0.01[a]	1.31[a]	0.00[b]
Eldon	0.11[a]	0.00[a]	0.05[a]	0.00[a]	1.62[a]	0.00[b]
José Tchad	0.10[ab]	0.00[a]	0.01[ab]	0.00[a]	0.99[a]	0.00[b]
Julie	0.08[ab]	0.00[a]	0.03[ab]	0.00[a]	2.38[a]	0.00[b]
Kassawa						
Kassaï	0.03[c]	2.00[a]	0.01[ab]	0.01[a]	2.24[a]	0.01[b]
Keitt	0.08[ab]	0.00[a]	0.01[ab]	0.00[a]	1.08[a]	0.00[b]
Kent	0.07[ab]	2.00[a]	0.02[ab]	0.01[a]	5.40[a]	0.00[b]
Maïduguri	0.03[c]	1.00[a]	0.02[ab]	0.02[a]	2.00[a]	0.00[b]
Mangotine	0.03[c]	5.00[a]	0.02[ab]	0.02[a]	1.26[a]	8.73[a]
Palmer	0.07[b]	0.00[a]	0.02[ab]	0.00[a]	0.93[a]	0.00[b]
Smith	0.08[ab]	0.00[a]	0.01[ab]	0.00[a]	1.62[a]	0.00[b]
Valencia	0.09[ab]	0.00[a]	0.02[ab]	0.00[a]	1.12[a]	0.00[b]

chl a: chlorophyll a; chl b: chlorophyll b.Values bearing different letters within the same column are statistically different at 5% level according to SNK test

soluble solids values ranging from 14.2 to 20°Brix for mangoes cultivated in the north of Ivory Coast. The similarity of results obtained in this study with those from other authors could be explained by the proximity of the growth regions, the similarity of growth conditions and the degree of ripening of mangoes used. The amount of carbohydrate varies with cultivar and according to leaf area and photosynthetic capacity and is also favoured by high intensity of light [26]. It can also be influenced by climatic conditions [27]. According to Delroise [28], the quality of a fruit depends on the genetic factors and also on its history, that is to say, the climatic conditions, the characteristics of the ground and the cultural practices involved in the methods of harvesting and in the conditions of conservation after harvest. The sugar content varies greatly depending on the species and within them depending on the variety. Local mango varieties have usually higher carbohydrate contents than mangoes of improved varieties. This is the case of the variety Mangotine (the smallest caliber) which had the highest total soluble solids (20.86 °Brix) in the present study. These results confirm those of Kumar [29] which indicated that the small variety "Neeludin" (93.03 cm^3) accumulated more reducing sugars (22.22°Brix) than non-reducing sugars. In general, mango varieties cultivated in Chad are rich in sugars. According to Fréhaut [30], carbohydrate accumulated in mangoes in mainly the form of starch. During ripening, this starch is degraded into soluble sugars (glucose, fructose and sucrose). Mango is, therefore, an important source of energy for human [31]. The work of Bello-Perez, et al. [32] showed that Mango is a climacteric fruit composed mainly of water and carbohydrates. Fructose and sucrose are the main sugars of mango. They are two to ten times more present quantitatively than glucose according to the stage of ripening. They are the substrates that allow by the catabolic pathways to provide the necessary energy and materials to the cells [30]. All varieties of mangoes cultivated in Chad have this important trait of quality. The plant uses soluble sugars to integrate the internal and external elements and to maintain a constant level of certain nutritional characteristics, to manage the hormonal processes of growth and development and to articulate the responses to biotic and abiotic stresses [33]. The variation of total soluble solids between local and improved varieties observed in the present study was an indication of a functional diversity. Besides, these sugars in mango (sucrose and fructose) are absorbed quickly by the organism and are much less hyperglycemic than most starchy foods [34].

Globally, all varieties of mangoes cultivated in Chad had a pH between 4.46 and 4.74 (Table 4). These values are superior to those obtained by Kasse [35] on Senegal mangoes (3.91) and close to those obtained by Kameni et al. [24] on North Cameroon mangoes (3.7 and 4.2). These differences could be explained by the stage of ripening of the analysed fruits, because according to Kameni et al. [24], the pH increases with the degree of ripening. These differences could be also due to the endogenous properties of the variety because the pH of mangoes with high carbon inputs is always higher than that of low carbon inputs [28]. This parameter would, therefore, result from the functional diversity. Moreover, a pH of about 3 to 8 is very favourable to the development of yeasts and moulds [36]. Mangoes are susceptible to the development of yeasts and moulds. Therefore, to harvest and handle these fruits, phytosanitary and hygienic precautions are essential to better preserve them and minimize post-harvest losses.

The moisture content of mango varieties cultivated in Chad ranged from 74.52 to 80.75% (Table 4). These results are comparable to those of Djantou [37] and Mamiro, et al. [38] who reported the range of moisture from 77.5 to 80.1%. But, they are different from those obtained by Othman and Mbogo [39], who recorded moisture from 56.3 to 86.1%. This difference could be explained by the varietal diversity and agroclimatic conditions. On the one hand, water is physiologically essential to the development of the fruit; it participates in the maintenance of structures, cellular enlargement and allows cell movements and metabolism [28], and on the other hand, it is at the origin of tissue turgescence, an essential factor of quality [40]. However, the high water content of mangoes determines the perishability of these fruits [31]. This shows that naturally, mangoes cannot be stored for a long time under ambient temperature conditions. Besides, the greater the amount of water, the more the compounds such as vitamin C, carotenoids and phenolic compounds are diluted and are found in low concentration in the fruit [41]. These data showed that water and sugars had the highest contents among all the biochemical constituents of the pulp of mango varieties. These results are similar to those of several authors such as Bello-Pérez, et al. [32] on mango, and Youmbi, et al. [16] on *Spondias cytherea*.

The dry matter content (DMC) of mangoes cultivated in Chad recorded from 19.25 to 25.48% (Table 4), whereas Djantou [37] found a DMC of 21.15% in Cameroon mangoes. These differences could mainly be due to the varietal diversity and pedoclimatic conditions. DMC is one of the determinants of the quality of a fruit. This is because several studies made it possible to establish a correlation between the quality of a fruit and the DMC. Indeed, Dorais [42] has shown that a low DMC leads to a less firmness of the fruit, a less tasty fruit, a bad post-harvest performance and a shorter conservation. The composition of a ripe fruit results mainly from the amount of assimilating matter (dry matter) that has been received and stored during the development period [30,42]. Consequently, fruits with low dry matter content soften faster after harvest and their visual appearance also deteriorates more rapidly. The increase in dry matter content could be due to a greater loss of water from the fruits as related to greater transpiration but also to a higher accumulation of solutes from photosynthesis [43]. The variability of this quality parameter within mango varieties cultivated in Chad would be correlated with functional diversity.

The β-carotene content of the pulp of mango varieties cultivated in Chad varied from 0.02 mg/10 g to 0.11 mg/10 g (Table 4). Maini, et al. [20] showed that the carotene content of mango pulp ranged from 0.01 and 0.03 mg/10 g. Penicaud, et al. [44] reported the composition of some fruits and vegetables rich in β-carotene including orange (0.001-0.014 mg/10 g), spinach (0.09-0.19 mg/10 g), carrot (0.65-0.83 mg/10 g), and sweet potato (0.85-0.93 mg/10 g). The β-carotene content of the pulp of mango varieties cultivated in Chad were found to be superior to those of Maini, et al. [20] and to those obtained by Penicaud, et al. [44] on orange. In contrast, the carotene content of Chad mangoes is lower than that of carrot, spinach and potato. In general, vegetables are a comparatively richer source of carotenoids than fruits; however, carotenoids from fruits are more bioavailable than those from vegetables [23]. Climatic conditions and growing locations also significantly influence the content of carotenoids in plants. High temperatures induced the production of more carotenoids in tomatoes and this enhancement depended on the fruit developmental stage [45]. According to Gautier, et al. [46], as for primary metabolites, the composition of the fruit in secondary metabolites such as β-carotene changes with its degree of ripening and depends on the type cultivars. Carotenoids are essential structural components of the photosynthetic apparatus which protect cells against photo-oxidative damage and also play an ecological role of attracting pollinators and seed dispersers due to distinct colours in leaves, flowers and fruits [23]. They also play a role in photoprotection and stabilisation by dissipating excess light energy in the form of heat, thus limiting the production of free radicals and also serving as precursors for the

Table 4. Biochemical characteristics of the fresh pulp of ripe mango varieties

Varieties	Fresh pulp biochemical charactéristics					
	TSS (Brix°)	pH	MC (%)	DMC (%)	β-carotène (mg/10 g)	lycopène (μg/10 g)
Bangui	19.37^{bc}	4.62^{ab}	75.43^{f}	24.57^{ab}	0.03^{cd}	2.00^{a}
Davis haden	18.33^{cd}	4.46^{b}	78.54^{abc}	21.46^{def}	0.07^{b}	3.00^{a}
Eldon	18.28^{cd}	4.58^{b}	76.53^{cd}	23.47^{abcd}	0.08^{b}	0.00^{a}
José Tchad	20.06^{ab}	4.74^{a}	74.70^{f}	25.30^{a}	0.11^{a}	1.00^{a}
Julie	17.13^{ef}	4.60^{ab}	79.71^{ab}	20.29^{efg}	0.05^{b}	3.00^{a}
Kassawa						
Kassaï	16.29^{f}	4.64^{ab}	75.88^{ef}	24.12^{abc}	0.02^{cd}	1.00^{a}
Keitt	17.75^{de}	4.61^{ab}	79.15^{ab}	20.85^{efg}	0.08^{b}	1.00^{a}
Kent	19.61^{b}	4.56^{b}	80.20^{ab}	19.80^{gf}	0.06^{b}	2.00^{a}
Maïduguri	16.47^{ef}	4.58^{b}	80.75^{a}	19.25^{g}	0.02^{cd}	0.00^{a}
Mangotine	20.86^{a}	4.70^{ab}	74.52^{f}	25.48^{a}	0.04^{bc}	0.00^{a}
Palmer	18.48^{cd}	4.64^{ab}	77.73^{bc}	22.27^{cde}	0.07^{b}	4.00^{a}
Smith	17.09^{def}	4.61^{ab}	80.49^{ab}	19.51^{fg}	0.06^{b}	6.00^{a}
Valencia	16.82^{def}	4.58^{b}	77.32^{bc}	22.68^{bcde}	0.08^{b}	0.00^{a}

TSS: total soluble solids; MC: moisture content; DMC: dry matter content; chl a: chlorophyll a; chl b: chlorophyll b. Values bearing different letters within the same column are statistically different at 5% level according to SNK test

biosynthesis of the phytohormone abscisic acid (ABA) [47]. The enzymatic and non-enzymatic products of carotenoid degradation are also perfume and aroma, as well as the attraction or repulsion of insects [48]. Silva and Agostini-Costa [49] comparatively studied the content of carotenoids in buriti fruits (*Mauritia flexuosa*) grown in Cerrado and Amazon biomes. Amazon region is characterised by higher temperatures and humidity and dense forest vegetation, compared to Cerrado. The result showed significantly high total carotenoids content (52.86 mg/100 g) in fruits grown in Amazon region, compared to the fruits grown in Cerrado (31.13 mg/100 g). These studies suggested that exposure to high temperatures and higher sunlight incidence may have enhanced the carotenoids biosynthesis, to protect the fruits from photooxidation. In human and animal nutrition, carotenoids lead functional ingredients [50]. In terms of food, β-carotene is the essential precursor of vitamin A, whose beneficial effects seem to have been recognised for a very long time. They can act as an antioxidant against free radicals and also intervene in the regulation of the organism's natural defences [51]. The β-carotene content is, therefore, one of the major determinants of the organoleptic and nutritional quality of mango. Regular consumption of mangoes could improve the health of populations in developing countries in general and especially palliate vitamin A deficiency in particular. Kelly and Alan de Brauw [52] reported that this fruitcorrected vitamin A deficiency and reduced diarrhoea incidence by 15% and measles incidence by 50% in children aged six months to five years. Further, they found that vitamin A supplementation reduced all-cause mortality for these children by 24%. The elimination of vitamin A deficiency, which is a public health priority in sub-Saharan Africa, would be effective with a diet rich in fruits, particularly mangoes.

4. CONCLUSION

This study revealed a functional diversity of the mango varieties cultivated in Chad, as the biochemical characteristics of the mangoes studied vary according to the varieties and growing regions. The differences observed according to the regions could be explained by the climate and the nature of the soil. Mangotine and José Tchad varieties cultivated in the Mayo Kebbi Ouest region have the highest total soluble solids. On the whole, all varieties of mangos cultivated in Chad are rich in water and sugar. Furthermore, it has been found that the mango peel has a β-carotene (provitamin A) content significantly higher than its pulp. The use of mango peel as an alternative source of provitamin A would overcome vitamin A deficiency, the primary cause of blindness in developing countries. The regular consumption of this fruit can improve the diet and therefore the health of urban and especially rural populations. This study constitutes a baseline database for the biochemical characteristics of mangoes cultivated in Chad.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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