Physico-chemical and nutritional characterization of dried mangoes consumed in Chad for better post-harvest valorization

Abstract

Dried mangoes collected from five localities (Doba, Bebedjia, Koumra, Moundou, and Bongor) were labeled DbaA, Bja, Mdou, Kmr, and Bgr, respectively, and then transported to the laboratory in a refrigerated cooler for physico-chemical analyses using standard methods.

These analyses showed that water content was not significantly influenced ($p = 0.0014$) by the locality of dried mango production. Protein, carbohydrate, lipid, and energy contents per 100 g ranged from 3.89 to 3.93 g, 94.91 to 104.72 g, 1.35 to 2.07 g, and 360.48 to 381.36 kcal/100 g, respectively. Dried mangoes from Doba were higher in reducing sugars (77.73 g/100g), while those from Moundou were lower (76.51 g/100g). Starch and amylopectin contents were not significantly affected by production locality, with values ranging from 110.32 to 112.07 g/100g and 94.28 to 97.20 g/100 g, respectively. Calcium (Ca), sodium (Na), potassium (K), magnesium (Mg), and iron (Fe) were represented in all samples with respective contents of 72.66 and 73.49 mg/100 g, 11.41 and 12.58 mg/100 g, 79.15 and 85.97, 68.78 and 70.59 mg/100 g, and 1.05 and 1.79 mg/100 g. Vitamin C and carotenoid contents varied, respectively, from 69.37 to 70.15 µg/100 g and from 249.25 to 274.15 µg/100 g. Principal Component Analysis revealed that samples E1DOBA and E2BGA and E3Kmr and E4Mdr have the same physico-chemical characteristics. Thus, these results demonstrate that respecting the drying and storage conditions for dried mango fruits, regardless of the zone, would enable the best possible preservation of nutritional properties while ensuring year-round availability.

Keywords: dried mangoes, physico-chemical properties, vitamins, collection area, Chad

1. Introduction

Chad is a country located in Central Africa with a suitable climate for the cultivation and development of fruits, vegetables, and citrus fruits. Among them, mango occupies an important place in production, marketing, and export (SNV, 2014), hence its appellation of "King of Fruits." More than 50 million metric tons are produced per year, and less than 4% of this production is exported (Vannière*et al*., 2004; Siddiq *et al*., 2017). In Chad, it represents the most important national fruit production and is therefore considered a jewel for the country's economic growth (Kanté-Traore*et al*., 2020). Average annual national mango production stands at 13,000 metric tons and is expected to double by 2020 (Aboubakar *et al*., 2009). Mangoes are produced, processed, and consumed in almost all parts of the country, including Bongor, Moundou, Doba, Bebedjia, and Koumra. Several dozen varieties from orchards in different localities have been recorded on the markets, with a preponderance of Amélie, Brooks, Kent, Keitt, Lippens, and Springfield varieties (Guira and Zongo, 2006). These are mainly sought after for their sweet flavors, soft textures, and rich nutrients (Kanté-Traore et al., 2020).

Mangoes sold on market stalls in Chad are usually fresh, which poses storage problems, as they are no longer viable after 3 to 4 days, resulting in post-harvest losses that can amount to over 40% of production (ITC, 2011). This is all the more pronounced in Chad, where the average temperature is between 25 and 40°C, making it ideal for the growth of mesophilic pathogens (Sawadogo-Lingani, 1993).

To compensate for this and limit this loss, arboriculturists and merchants often opt for preservation methods using chemical agents such as formalin, citric acid, benzaldehyde, ash, etc., most of which are not without consequences for the product's physico-chemical and hygienic qualities (Kanté-Traore et al., 2020). What's more, adding value to this fruit by transforming it into a wide range of by-products such as juices, nectars, jams and syrups poses the problem of the availability of financial resources for the acquisition of equipment and the lack of knowledge about the processes involved (Djioua, 2010; ITC, 2011; Kouassi, 2012).

Thus, drying as a means of preservation appears to be an ideal solution, as it is inexpensive and easy to master (Bélem et al., 2017). It is also favored by the right climatic conditions (year-round sunshine and low humidity) and accounts for 80% of artisanal mango processing via solar drying and drying in airtight ovens. Although this solution may seem like a panacea, it is still in its infancy due to the low capacity of artisanal units, the lack of conservation/processing infrastructures and an unskilled workforce (Kouassi, 2012). Failure to master these processing methods (drying) also affects several other parameters, such as organoleptic properties like color, which is the main element influencing marketability (Djioua, 2010). It also affects physico-chemical properties, notably nutrient content, which can be lost with drying. These observations demonstrate the importance of controlling drying conditions (Djantou et al., 2004).

Mango plays a very important nutritional role, providing micronutrients required for the proper functioning of the human body and protecting against major chronic diseases such as cardiovascular, neurodegenerative and metabolic diseases, as well as cancers (Kim et al., 2003; Chiou et al., 2007). It's an excellent source of carbohydrates, β-carotene (provitamin A), vitamin C, polyphenols and fibre (Lee and Kader, 2000; Sawadogo-Lingani et al., 2002; Vazquez-Caicedo et al, 2004, 2005; Veda et al., 2007; Manthey and Perkins-Veazie, 2009; Robles-Sanchez et al., 2009; Ma et al., 2011; Liu et al., 2013; Ara et al., 2014; Kothalawala and Jayasinghe, 2017).

Consumption of half a portion of fruit contributes 100% of the recommended daily intake of vitamin A and up to 70% of that of vitamin C (Bélem et al., 2017). Mango pulp, made up of around 80% water and 20% dry matter, is recognized for its high nutritional value and medium energy intake (60 kcal per 100 g of pulp). Its composition depends on several intrinsic and extrinsic factors, such as variety, geographical area, climate, ripening stage, storage conditions, etc. (Martin and He, 2009; Tharanathan et al., 2006). This supply of provitamin A makes this fruit an important element in the fight against vitamin A deficiency and its corollaries, affecting more than 250 million children under 5 worldwide, with a high prevalence in Africa (WHO, 1995; Sibetcheu et al., 1999). Alongside these vitamins and minerals, it also provides fiber and antioxidant compounds with numerous biological properties (notably anti-diabetic) (Lauricella et al., 2017; Micha et al., 2017).

In addition to the influence of drying on the physico-chemical properties of mangoes, there is also an influence of agro-ecological zone and variety. Thus, in order to assess the impact of drying and drying methods on mango properties, the aim of the present study was to evaluate the physico-chemical properties of dried mangoes from five (5) localities in Chad.

2. Materials and methods

2.1. Study framework and period

The study was experimental and prospective. It took place in four Provinces of the Meridionale zone, namely the Province of *Logone Occidentale*, more precisely in Moundou, the Province of *Logone Orientale* in the localities of Doba and Bebedjia, the Province of

*Mandoul*in the locality of Koumra and finally the Province of *Mayo Kebi Est* in the area of Bongor. These different provinces and localities were chosen for their high production, consumption and marketing of dried mangoes. The experimental study took place at the Laboratoire de Recherche en Sciences des Aliments et Nutrition (LARSAN) of the Faculté des Sciences de la SantéHumaine (FSSH) of the Université de N'Djamena from March to July 2023.

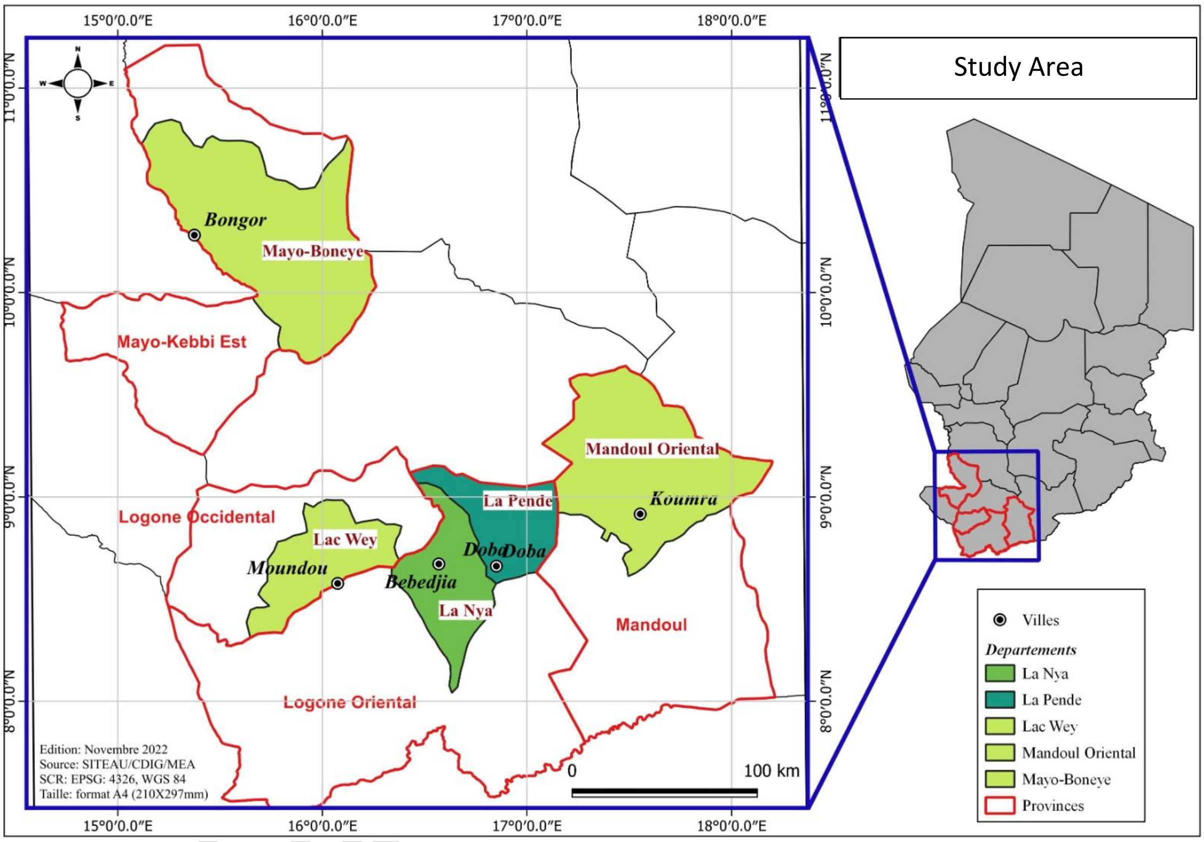

Figure 1: Study and sample collection area

2.2 Sampling

Once the various study areas had been identified, 100 samples of dried mangoes were collected from the various vendors in order to obtain an overall representation of the locality (20 samples per locality). After that, the samples were driven in a refrigerated cooler to the lab. After arriving at the laboratory, the dried mangoes were crushed, packaged in polystyrene plastic, and kept in a desiccator so they could be used in the various assays later on.

2.3. Determination of the chemical composition of 100 dried mango samples

Moisture content is determined using the AACC (1990) method. After 3 hoursdrying time, the cup was removed from the oven, cooled in a desiccator (P_2O_5) and weighed again (M2).

WC = (M1-M2)/(M1-M0)(1)

Protein content was determined using the Kjedahl method, which consists in converting organic nitrogen into ammoniacal nitrogen by mineralization with concentrated sulphuric acid, thus quantifying protein (AOAC, 1990). Formula 1 below was used to convert the rate of nitrogen release into protein:

Protein content (%)=N (rate of nitrogen release)*6.25 (conversion factor)(2)

Lipids were extracted with Soxhlet for 7 h using hexane as solvent. They were expressed as a percentage of dry matter (AOAC, 1990). The standard method described by AOAC (1990) was used to determine fiber content after digestion with 1.25% sulfuric acid for 30 min, followed by vacuum extraction and oven drying before weighing. The AOAC (1990) standard method was used to quantify total ash.

The AOAC (1990) standard method enabled us to quantify digestible carbohydrates in all samples by difference according to formula 3:

Protein content (%)=100-(%water+%proteins+ %lipids+ %ash+ %total fiber)(3)

The energy values of the diets were obtained from the sum of the products of each major nutrient (carbohydrates, proteins, lipids) and its corresponding Atwater heat coefficient.

The Fisher and Stein (1961) 3,5-Dinitrosalycilic acid (DNS) method was used to quantify reducing sugars. The lugol (iodine-iodide solution) method by Jarvis and Walker (1993) was used to determine starch content. The colorimetric method of Chrastyl (1987) was used to quantify amylose. The amylopectin content was obtained by deduction between starch and amylose according to the formula below:

Amylopectin (%)=100-% amylose (4)

Minerals such as calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), zinc (Zn), (Fe) and copper (Cu) were determined on the ashes after prior digestion with HNO_3/HCl according to the standard protocol of AOAC (1990). Some were complexed before reading on a Perkin-Elmer Analyst 700 Atomic Absorption Spectrophotometer (AAS) in Norwalk, CT, USA, while others were read directly after digestion. Ca/Mg and Na/K mass ratios were also assessed.

2.4. Calorific value, recommended daily allowance (RDA)

The contribution of calorific value, protein and lipid content to the Recommended Daily Allowance (RDA), expressed as a percentage (%), was obtained from the following formula 5:

$$\mathbf{RDA\ (\%)=X/Y*100\ (5)}$$

Where X represents the content or energy value per 100 g of this food and Y the recommended intake.

2.5. Determination of carotenoid and vitamin C content

Using High Performance Liquid Chromatography (HPLC, AGILENT 1100), the β-carotene content of the lyophilisates of dried mango slices was ascertained. An Eppendorf tube containing a suspension in 10 ml of tetrahydrofuran (THF) solution was thoroughly shaken.

2.5. Statistical analysis

Results were expressed as mean ± standard deviation. Analysis of variance (ANOVA) was used to compare means, and a Fisher post hoc test was used to classify them using Minitab 18.0 software. The accepted probability threshold was 5%. A Principal Component Analysis was performed using XLSTAT version 2014 software to group the different sources of dried eats according to composition.

3. Results

3.1 Approximate chemical composition of dried mangoes

Table 1. Approximate chemical composition of dried mangoes.

Sites	Dba	Bbja	Mdou	Kmr	Bgr	p value
Water content g/100g	15.14±0.46[b]	13.90±0.06[a]	15.31±0.88[b]	15.13±0.44[b]	14.96±0.11[b]	0.0014 **
starch g/100g	111.67±1.85[b]	110.32±1.33[ab]	110.86±0.47[b]	108.24±1.49[a]	112.07±0.54[b]	0.000994 ***
Reducingsugars g/100g	77.73±0.44[a]	77.49±0.86[a]	76.51±0.75[a]	77.08±0.47[a]	77.72±1.01[a]	0.0785
Total carbohydrates g/100g	104.33±0.89[c]	97.20±1.61[b]	94.91±0.52[a]	104.28±0.67[c]	104.72±0.64[c]	1.06e-13 ***

Sites	Dba	Bbja	Mdou	Kmr	Bgr	p value
Ash (g/ 100g)	2.63±0.07^{b}	2.87±0.02^{c}	2.41±0.04^{ab}	2.35±0.05^{a}	2.59±0.25^{b}	1.19e-05***
Proteinsg/100g	3.90±0.10^{a}	3.90±0.06^{a}	3.91±0.02^{a}	3.93±0.05^{a}	3.89±0.09^{a}	0.958
Lipids g/100g	2.07±0.02^{c}	1.87±0.02^{bc}	1.41±0.04^{a}	1.35±0.05^{a}	1.71±0.31^{b}	3.77e-07 ***
Pectin g/100g	94.33±0.89^{a}	97.20±1.61^{b}	94.91±0.52^{a}	94.28±0.67^{a}	94.72±0.64^{a}	0.000484 ***
Total Fiber g/100g	3.130±0.048^{b}	3.732±0.052^{c}	2.910±0.020^{a}	3.846±0.132^{cd}	3.934±0.122^{d}	2.63e-14 ***
Energy kcal/100g	451.572±3.956^{c}	421.364±6.499^{b}	407.972±2.357^{a}	449.010±4.980^{c}	449.426±4.797^{c}	5.98e-13 ***

Means ± standard deviations followed by the same letter in the same row indicate that differences are not significant (P>0.05). Dba: Doba ;Bbja: Bebedjia ;Kmr: Koumra ; Mdou: Moundou ;Bgr: Bongor.

3.2 Composition of reducing sugars and starch in dried mangoes.

Table 2. Composition of reducing sugars and starch in dried mango powders.

Sites	Dba	Bbja	Mdou	Kmr	Bgr	p value
Starch g/100g	111.67±1.85^{b}	110.32±1.33^{ab}	110.86±0.47^{b}	108.24±1.49^{a}	112.07±0.54^{b}	0.000994 ***
Reducingsugars g/100g	77.73±0.44^{a}	77.49±0.86^{a}	76.51±0.75^{a}	77.08±0.47^{a}	77.72±1.01^{a}	0.0785
Total sugars g/100g	104.33±0.89^{c}	97.20±1.61^{b}	94.91±0.52^{a}	104.28±0.67^{c}	104.72±0.64^{c}	1.06e-13 ***
Amylopectin g/100	94.334±0.892^{a}	97.198±1.613^{b}	94.906±0.524^{a}	94.282±0.672^{a}	94.722±0.635^{a}	0.000484 ***
Amylose g/100g	19.512±0.308^{c}	17.420±0.674^{b}	15.112±0.414^{a}	20.910±0.412^{d}	15.052±0.360^{a}	4.49e-15 ***
Amylose/ Amylopectin	4.830±0.112^{b}	5.580±0.160^{c}	6.278±0.142^{d}	4.506±0.091^{a}	6.292±0.107^{d}	3.98e-16 ***

Means ± standard deviations followed by the same letter in the same row indicate that differences are not significant (P>0.05). Dba :Doba ; Bbj :Bebedjia ; Kmr: Koumra ; Mdou: Moundou ; Bgr : Bongor.

3.3 Mineral composition of dried mango fruits from five locations in Chad.

Table 3. Composition and mineral ratios of dried mangoes.

Sites	K (ug/ 100g)	Mg (ug/ 100 g)	Fe (mg/ 100 g)	Ca (mg/ 100 g)	Na (mg/ 100 g)
Dba	85.97±4.93^{a}	70.24±0.46^{c}	1.05±0.11^{a}	73.25±0.52^{ab}	11.41±0.29^{a}
Bbja	80.92±6.94^{a}	70.59±0.38^{c}	1.50±0.45^{ab}	73.35±0.46^{ab}	11.50±0.45^{a}
Mdou	83.21±1.81^{a}	70.06±0.37^{bc}	1.18±0.27^{a}	72.66±0.47^{a}	11.50±0.19^{a}
Kmr	79.15±0.46^{a}	69.53±0.20^{b}	1.26±0.14^{a}	73.49±0.17^{a}	11.55±0.45^{a}
Bgr	82.59±0.25^{a}	68.78±0.30^{a}	1.79±0.20^{b}	72.89±0.07^{ab}	12.58±0.39^{b}
p value	0.112	8.97e-07 ***	0.00213 **	0.0163	0.00028 ***

Means ± standard deviations followed by the same letter in the same row indicate that differences are not significant (P>0.05). Dba :Doba ; Bbj :Bebedjia ; Kmr: Koumra ; Mdou: Moundou ; Bgr : Bongor.

3.4. Vitamin composition of dried mangoes.

Table 4. Vitamin composition of dried mangoes.

Sites	Vitamine C (mg/100 g)	Total Carotenoids (ug/100 g)
Dba	69.37 ± 0.58[a]	265.97 ± 343.34[a]
Bbja	70.05 ± 0.45[a]	249.25 ± 412.35[a]
Mdou	70.04 ± 0.36[a]	255.44 ± 422.12[a]
Kmr	70.15 ± 0.79[a]	274.15 ± 466.70[a]
Bgr	69.68 ± 0.37[a]	258.48 ± 432.98[a]
p value	0.161	0.906

Means ± standard deviations followed by the same letter in the same row indicate that differences are not significant (P>0.05).

3.5. Physico-chemical profile of dried mangoes sold in Chad: Principal Component Analysis (PCA) and Hierarchical Ascending Classification (HAC).

Table 5. Contribution of observations to the formation of the different axes

	Contributions of observations (%)			**Square cosines of observations**			
Samples	F1	F2	F3	F1	F2	F3	Class
Dba	23.3482	13.8300	2.1580	**0.5272**	0.2435	0.0215	1
Bbja	6.2927	6.9211	12.3208	**0.2136**	0.1832	0.1848	1
Kmr	7.8684	15.3444	55.1842	0.1765	0.2684	**0.5469**	2
Mdou	7.4257	45.3802	24.2244	0.1371	**0.6531**	0.1975	2
Bgr	55.0650	18.5243	6.1125	**0.7619**	0.1998	0.0374	3

Table 6. Contribution of variables to the formation of the different axes

	Contributions of variables (%)			Square cosines of variables			
	F1	F2	F3	F1	F2	F3	Class
Vitamine C	5.7826	2.2975	2.7268	**0.5434**	0.1683	0.1132	1
Carotenoids	0.1722	11.6803	0.0601	0.0162	**0.8558**	0.0025	2
Reducingsugars	7.4852	3.8362	0.2027	**0.7034**	0.2811	0.0084	3
Water content	2.3600	4.8182	0.3313	0.2218	**0.3530**	0.0138	3
Lipids	1.9031	10.4314	1.3693	0.1788	**0.7643**	0.0568	3
Starch	6.0477	2.7401	3.4436	**0.5683**	0.2008	0.1429	3
Amylose	4.6870	2.5487	6.1320	**0.4404**	0.1867	0.2545	3
Amylopectin	4.6870	2.5487	6.1320	**0.4404**	0.1867	0.2545	4
Amylose/amylopectin	4.1108	3.4623	6.3003	**0.3863**	0.2537	0.2615	3
Mg	10.3671	0.1794	0.2091	**0.9742**	0.0131	0.0087	4
Ca	5.7984	0.2838	10.3986	**0.5449**	0.0208	0.4316	5
Proteins	4.0991	3.6508	7.6507	**0.3852**	0.2675	0.3175	3
Ash	0.7467	0.0696	16.9053	0.0702	0.0051	**0.7016**	3
Na	9.4570	1.1011	0.4067	**0.8886**	0.0807	0.0169	4
K	5.3357	6.3428	0.7932	**0.5014**	0.4647	0.0329	6
Fibers	2.5936	8.7608	2.7409	0.2437	**0.6419**	0.1138	3
carbohydrates	3.3814	8.6470	1.1311	0.3177	**0.6336**	0.0469	4
Energy	1.3864	7.7840	6.6989	0.1303	**0.5703**	0.2780	7
Fe	0.2719	10.3553	3.8054	0.0255	**0.7587**	0.1579	3

Figure 2. Observations and variables Biplot

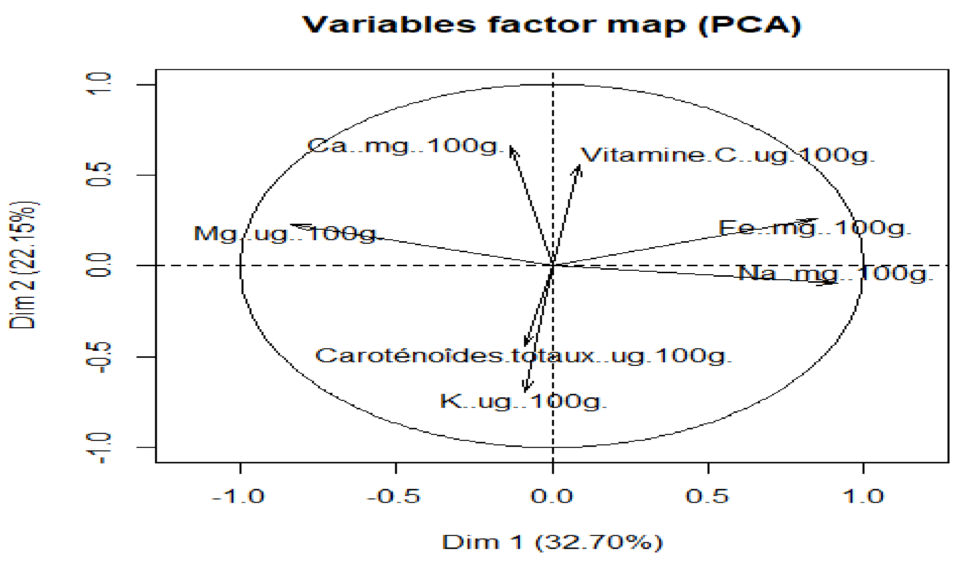

Table7. Pearson correlation matrix (r) of the different variables

Variables	VITC	Carotenoids	Reducingsugars	TE	Lipides	Amidon	Amylose	Amylopectine	Amy/amyp	Mg	Zn	Ca	Protéines	Cendres	Na	K	Fibres	Glucides	Energie	Fe
VITC	**1**																			
Caroténoïdes	-0,3418	**1**																		
Sucres réducteurs	**-0,8403**	**0,5626**	**1**																	
TE	**0,8988**	-0,3881	**-0,7534**	**1**																
Lipides	0,0362	**0,7456**	0,1301	-0,2877	**1**															
Amidon	**0,7365**	-0,3864	**-0,9295**	**0,7672**	-0,1609	**1**														
Amylose	-0,3528	**0,5809**	**0,8029**	-0,2895	0,2199	**-0,7826**	**1**													
Amylopectine	0,3528	**-0,5809**	**-0,8029**	0,2895	-0,2199	**0,7826**	**-1,0000**	**1**												
Amylose/amylopectine	-0,3614	**0,6307**	**0,8086**	-0,3306	0,3017	**-0,7944**	**0,9961**	**-0,9961**	**1**											
Mg	**-0,7168**	0,2494	**0,8917**	-0,4814	-0,2945	**-0,8118**	**0,7733**	**-0,7733**	**0,7387**	**1**										
Ca	**-0,8023**	0,2787	**0,6308**	-0,4767	-0,3423	-0,3571	0,2388	-0,2388	0,2119	**0,6872**	**0,7725**	**1**								
Protéines	-0,3626	-0,3102	0,1800	0,0597	**-0,8477**	0,0281	-0,0365	0,0365	-0,1087	**0,5117**	**0,8551**	**0,7628**	**1**							
Cendres	0,2501	-0,1768	-0,0675	-0,1224	0,3707	-0,2891	0,1152	-0,1152	0,1514	-0,2051	-0,4748	**-0,7603**	**-0,7549**	**1**						
Na	**-0,5729**	-0,0948	**0,6182**	-0,2150	**-0,6771**	-0,4994	0,4777	-0,4777	0,4133	**0,8932**	**0,9981**	**0,7464**	**0,8254**	-0,4343	**1**					
K	**-0,7275**	**0,7227**	**0,9693**	**-0,6972**	0,3400	**-0,8986**	**0,8668**	**-0,8668**	**0,8860**	**0,7959**	0,4250	0,5034	-0,0100	-0,0017	0,4540	**1**				
Fibres	0,0677	**-0,7042**	0,0223	0,2669	**-0,8290**	-0,1482	0,1429	-0,1429	0,0679	0,4252	**0,6315**	0,0260	**0,5263**	0,1065	**0,6462**	-0,1362	**1**			
Glucides	0,0336	**0,6903**	-0,0742	-0,2060	**0,8829**	0,1626	-0,1250	0,1250	-0,0471	-0,4826	**-0,7160**	-0,1568	**-0,6322**	0,0048	**-0,7244**	0,1055	**-0,9901**	**1**		
Energie	-0,1600	**0,7308**	0,0369	-0,2468	**0,6882**	0,1764	-0,1289	0,1289	-0,0677	-0,3095	-0,4460	0,1966	-0,2922	-0,3612	-0,4691	0,1681	**-0,9648**	**0,9249**	**1**	
Fe	-0,4739	**0,7201**	0,3116	**-0,6431**	**0,7326**	-0,1909	-0,0129	0,0129	0,0607	-0,1101	-0,3586	0,2561	-0,3672	-0,1148	-0,3747	0,4010	**-0,9047**	**0,8594**	**0,8899**	**1**

Les valeurs en gras sont différentes de 0 à un niveau de signification alpha=0.05

VITC: Vitamine C; TE: Teneur en eau; Amy/amyp: Rapport Amylose/Amylopectine.

4- Discussion

The water content is shown in Table 1. According to Sawadogo-Lingani (1993), it influences the preservation and perishability of foodstuffs, and, especially in mango. A water content higher than 14% favors microbial, enzymatic, and chemical activity, thus reducing the shelf life of organics. In fact, according to Ndangui (2015) and Tambo et al. (2019), this parameter is influenced by variety, climatic conditions, (rainfall), and drying conditions (drying time and type). Our analyses show that this parameter was not significantly affected ($p = 0.0014$ 0.05) by the fruit source. This content varied between 13.90 ± 0.46 (Bebedja) and 15.31 ± 0.88 (Moundou). The contents obtained were all lower than the 14% reported by Ndangui (2015) as the limit for good preservation, especially in tropical zones where humidity generally reaches 50%. The contents obtained were lower than those obtained by Kameni et al. (2003), which ranged from 16.8% to 22.6% for the Amelie, Zill, Irwin and Locale varieties. This can be dueto more advanced fruit ripening and use of a slow-flow solar dryer, the reduced drying time, cultivation in an area (Cameroon) with higher rainfall and humidity, and the variety of mangoes used, which are richer in water as explained by Ndangui (2015) and Tambo et al. (2019. Indeed. Kameni et al. (2002) reported in their work that the use of more mature fruits resulted in dried products with a higher water content. The results obtained by Bélem et al. (2017) are in the same range (4.14 to 4.19%) as those of this study. Thus, these results demonstrate that dried fruit, regardless of locality, can be preserved over a very long period of time (more than 6 months).

Ash represents the inorganic part of the material and thus provides information on its mineral content. A content less than 5% is recommended for supplementary feeds (FAO/WHO, 2006). Table 6 shows that the samples obtained significantly (p 0.05) influenced this parameter. Overall, variation was significant ($p = 1.06$ 0.05) between localities. The content varied between 2.35 and 2.87 g/100g. The high content observed in the Bebedja sample is thought to be linked to the variety used in this locality, climatic conditions, particularly rainfall, which is lower and therefore favors the absorption of minerals present in the soil, the nature of the soil and its composition, and the type of drying applied. Mwamba et al. (2018) also reported the influence of drying type on ash content, demonstrating the positive impact of oven drying. In fact, solar drying leads to prolonged exposure of the food matrix, resulting in a possible loss of minerals by diffusion with the eliminated water.

The contents obtained are in the same range as those of previous studies (Mwamba et al., 2018) and Djantou (2010), which ranged from 1.59 to 2.60% and 1.98 to 2.57%, respectively. However, they were lower than those of Rakotonantoandro (2010), which ranged from 4.27 to 7.46%. These results show that these dried fruits could be used in the formulation of food supplements.Proteins play many physiological and structural roles in the body. Their proportions in dried fruits depend on drying conditions (drying time and temperature), variety, climatic conditions, the nature of the soil, and the state of maturity of the plant (Bélem et al., 2017). Protein content ranged from 3.89 to 3.93 g/100 g. It was not significantly ($p = 0.906$ 0.05) affected by area of origin. The high protein content in samples collected at Koumra could be explained by the overexpression of protein synthesis genes to the detriment of lipids and carbohydrates in this variety. The negative correlation observed between this parameter and carbohydrates ($r = -0.6322$) and lipids ($r = -0.8477$) confirms this assertion. In addition, drying at temperatures above 60°C by arboriculturists in the four other localities would have resulted in a loss of protein due to the formation of melanoids during the Maillard reaction. The values obtained are five times higher than those of Traoreen (2013) and Mwamba et al. (2018). These results show that dried mangoes from different localities could easily be used to supplement porridges and thus combat protein-energy malnutrition.

Lipid content was not significantly different ($p < 0.05$). It ranged from 1.35 to 2.07 g/100 g. Overall, contents were below the 5-8% recommended by the Codex Stan (2013) standard for the formulation of supplementary feeds. Indeed, many authors (Djantou, 2006; Traore, 2013; Mwamba et al., 2018) have reported the non-lipidic food character of fruits. The drop in this parameter in samples from Koumra and Bongor is linked to varietal differences, with advanced ripening in fruit from these localities resulting in a loss of this compound, as well as the type of drying used. Mwamba et al. (2018) reported a low lipid content in solar-dried fruit, probably due to oxidation. The values obtained are higher than those of Nabalma (1995), Sawadogo-Lingani et al. (2002), and Traore (2013), which ranged from 0.6% to 1.85%. The use of this fruit therefore requires supplementation with lipid sources.

Digestible carbohydrates represent the main form of metabolites that can be metabolized by the body for energy production. Its content ranges from 76.51 to 77.73 g/100 g with nonsignificant variation (p=>0.05) between different samples. Carbohydrates depend on the proportion of lipids and proteins in the plant (Tambo et al., 2019a.b). The values obtained are higher than those of Nabalma (1995); Traore (2013); Mwamba et al. (2018), which were 61.81%. 58.82-63.11% and 68.52% respectively. A varietal difference associated with inadequate drying conditions would explain these differences (Kameni et al., 2003). Indeed, Mwamba et al. (2018) reported an improvement in total carbohydrate content with oven drying compared to solar drying. The contents obtained by Kameni et al. (2003) and Belem et al. (2017) are in the same range as those of this study. The values obtained are broadly in line with the Codex Stan (2013) standard, which recommends a carbohydrate content of between 65 and 85%.

Fiber represents carbohydrate fraction not digestible by enzymes of the human gastrointestinal tract, and is responsible for intestinal transit speed. Fiber is inversely related to digestible carbohydrates (r= 2.63-14***). Levels were significantly (p=2.63-14 <0.05) affected by production locality, and consequently ranged from 2.910 (Moundou) to 3.94 g /100g (Bongor). The lower content observed in Koumra samples can be explained by the advanced state of maturity due to the degradation of fibers by microorganisms, producing sugars of lower molecular weight. In addition, oxidation of these fibers into organic compounds by intrinsic enzymes as well as by microorganisms would also reflect this lowering (Kameni et al., 2003). Kameni et al. (2003) obtained fiber contents between 0.7 and 1.80% in four varieties of dried mango, which is far lower than what we obtained in this work. Overall, the values obtained are in line with the Codex Stan (2013) standard, which recommends less than 5.60% fiber in supplementary foods.

Energy density was also assessed, showing that dried mangoes from Bebedja and Moundou had the lowest and highest energy densities, respectively. This parameter ranged from 407.972 ± 2.357 to 451.572 ± 3.956 kcal/100 g of DM. The high energy density observed with the Doba and Moundou samples is mainly linked to their high lipid content, as confirmed by the positive correlation (r = 0.6882) between these two parameters. There was also a significant influence (p = 5.98e-13 *** <0.05) of production area on energy density. The values obtained are on the whole lower than those recommended (720 kcal) by FAO/WHO (2006) to cover the energy needs of weaning-age children and thus effectively combat protein-energy malnutrition. These results suggest supplementation with lipid sources such as soy (Klang et al., 2019a). The values obtained are similar to those of Eucharia et al. (2020), which ranged from 359 to 361.44 kcal.

Reducing sugars are responsible for fruit sweetness and consumer acceptability. The content of this parameter evolves positively with ripening, unlike starch content, as shown by the negative correlation coefficient (r= -0.9295) between the two parameters. Indeed, during ripening. amylases naturally present in fruit degrade starch at its amylose residues, releasing low-molecular-weight carbohydrates such as dextrins, fructose, glucose and maltose (Kameni et al.. 2003; Bélem et al.. 2017). The evolution of reducing sugar content is associated with those of carotenoids (r= 0.5626) but contrary to those of vitamin C (r= -0.8403) and amylopectin (r= -0.8029). Reducing sugar content was significantly ($p=0.001<0.05$) affected by powder origin. Samples from Doba had the highest content (77.73±0.44b), while those from Moundou had the lowest (76.51±0.75a). Samples from Dba and Bongor were statistically similar, which could be explained by the use of similar varieties in both localities, as well as drying at almost similar stages of ripeness (Belem et al., 2017). The values obtained are lower than the 39.30% and 48.95% reported by Belem et al. (2017) on the Amelie and Brooks varieties from Burkina Faso respectively. Similarly, 75.06% obtained by Djantou (2006) on Kent was higher. These differences are linked to the drying conditions, the varieties studied and the climatic conditions in the growing areas. Indeed, drying at high temperatures would lead to complexation of simple sugars at their aldehydic or ketonic functions with amine groups, thus reducing their content (Bélem et al., 2017). On the other hand, these results are similar to those obtained by Kameni et al. (2003)which ranged from 10.80 to 24.70%. The results obtained show that the various dried mangoes could be used as a natural sweetening agent in supplemental foods and thus limit the dangers associated with refined sugars.

Starch, amylose and amylopectin contents were significantly ($p=<0.05$) affected by dried mango sources. They ranged respectively from 108.2 to 112.07 g/100 g starch. The difference in varieties with other localities, the less advanced state of ripening, the storage in a dry environment with no activity, the high starch content of Bongor powders can be explained by the consequent microbial presence, the absence of microorganisms with amylase activity and the drying conditions. Kameni et al (2003) also reported a positive relationship between low ripening and starch content in mangoes. The starch contents obtained are higher than those reported by Djantou (2006) in his study, which ranged from 1.60 to 1.69%. This can be explained by the higher water content in this author's matriceswhich has a diluting effect on nutrients. Indeed, many studies have reported an increase in nutrient concentration in dried mangoes with decreasing water activity(Jiokap et al., 2001 and Saliha et al., 2005). The opposite trend was observed between amylose and amylopectin in all samplesas demonstrated by the negative correlation coefficient (r= -1.000) between the two parameters. Indeed, Tambo *et al*., 2019a.b and Dongmo *et al*., 2020have also reported such observations in their work. The disparity observed in the composition of these two macronutrients is thought to be directly related to the nature of starch (degree of branching), the mango variety, storage conditions and the pretreatments applied. The amylose/amylopectin ratio is an indicator of the rheological properties of a flour or powder and its ability to be used in formulations (Klang et al., 2019b). It is highly dependent on amylose composition (a positive correlation of 0.9961 between the two parameters). It follows from Table 2 that this parameter was significantly (p=<0.05) affected by the source of dried mangoes. The Amylose/Amylopectin ratio ranged from 4.506 (Koumra) to 6.278 (Moundou). These results demonstrate the high heat-treatment instability of dried mangoes from Moundou. The higher the value, the greater the tendency of the matrix to retrograde following heat treatment, making the formulations unstable. The use of dried mangoes from Moundou in the formulation of supplementary feeds should therefore be carried out at the end of cooking, to avoid thickindigestible porridges (Dongmo et al., 2020).

Mineral malnutrition or hidden hunger is the most widespread form of malnutrition today. It affects more than one child in three and is therefore a major health problem for which solutions are constantly being sought (FAO/WHO. 2006). Minerals play many physiological roles in the body, including cofactor of metabolic reactions (Ca. Fe. K. Na. Mg), transmission of nerve impulses, bone solidification, second messenger (calcium), maintenance of osmotic pressure (sodium and potassium), muscle contraction (calcium), bone rigidity and bone formation (phosphorus. calcium and magnesium), energy production, heart function, formation and function of many proteins such as hemoglobin involved in oxygen transport (FAO. 2001; Badham et al., 2007; Ogbonnaya et al., 2010).Results from Table 4 showed that all minerals were significantly affected by locality of origin with (p=<0.05) respectively for calcium,iron, magnesium, sodium, potassium and copper. Levels varied from 79.15±0.46 (Koumra) to 85.97±4.93 ug/100 g (Doba), from 68.78±0.30 (Bongor) to 70.59±0.38 ug/100 g

(Bebedja), from 1.05±0.11 (Doba) to 1.79±0.20b mg/100 g (Bongor), from 72.66±0.47 (Moundou) to 73.49±0.17 mg/100 g (Koumra), from 11.41±0.29 (Doba) to 11.55±0.45 mg/100 g (Koumra) for potassium, magnesium, iron, calcium and sodium respectively. Overall, dried mangoes from Doba,Moundou and Bebedja had the highest mineral content, unlike those from Koumra and Bongor. The differences noted between the different fruits are thought to be the result of variations in the varieties used. The drying method used (particularly solar drying)which leads to greater mineral loss ; the high drying temperature, which could facilitate increased diffusion of ions, Climatic conditions, storage conditions and fruit maturity (Sawadogo and Traore, 2001; Kameni et al., 2002; Perez et al., 2005; Djantou, 2006; Mwamba et al., 2018). Calcium levels were 20 times higher than those of Djantou (2006), similar for potassium but lower for sodium and magnesium. Iron content was lower than Sawadogo et al. (2002) and Mwamba et al. (2018). at 6 and 7 mg/100 g respectively. Comparison with recommended daily values shows that all samples (E1DOBA and E2BGA) are within the recommended range for calcium (1000 mg). These results suggest a high consumption of dried mangoes. For iron, magnesium and sodium they were all below the recommended daily requirements of 8-18 mg/100g, 127-1500 mg/100g and 8-12 mg respectively. This suggests a need for supplementation with other sources of these minerals in all samples (Klang et al., 2019a.b).

Vitamins A and C play numerous physiological roles in the body. They prevent the onset of diseases such as cancer through their antioxidant potential, protect against night blindnessand strengthen the immune system and intellect (Siebetcheu et al., 1999). Carotenoid content was significantly (p=>0.05) unaffected by collection area. Amounts varied from 249.25±412.35 µg/100 g DM for Bebedja to 274.15±466.70 µg/100 g DM for Koumra. The difference observed can be explained by the drying conditions (time-temperature pair), the degree of sunshine in the locality, the ripeness of the mango, the type of dryer used (solar or electric) and the variety of mango (Sawadogo and Traore, 2001; Mwamba et al., 2018). Indeed, the low values obtained with certain samples can be explained by the use of solar dryingwhich would lengthen exposureresulting in oxidation of carotenoids and loss through evaporation (Mwamba et al., 2018). Similarly, mangoes from this locality would be at a less advanced stage of ripening, thus reducing carotenoid content (Tamini et al., 2007). Indeed, Some et al. (2014) reported an improvement in carotenoid content as the ripening stage advanced (39 to 80%). The values obtained would enable daily vitamin A requirements to be covered by more than 80%. This suggests the use of dried mangoes in the formulation of substitute foods for children and the elderly. The values obtained are higher than those of Savadogo et al. (2023) who worked on Kent, Keitt and Springfield varieties from three towns in Burkina Faso (Orodara, Banfora and Bobo-Dioulasso).

As far as vitamin C is concerned, an increase is observed with the reduction of carotenoids in the various samples, as demonstrated by the negative correlation (r= -0.3418) obtained between the two parameters. Indeed, Some et al (2014) and Sawadogo-Lingani and Traoré (2001) reported that younger mango fruits had higher vitamin C contents, as these degrade into other compounds such as furfural as maturity advances. He also found that there was no significant difference ($p=0.161>0.05$) between all the other samples. Results ranged from 69.37±0.58 mg/100 g of dried mangoes for Doba to 70.15±0.79 mg/100 g of dried mangoes for Koumra. These results suggest that traders in Doba use less mature fruit, unlike those in other localities. Similarly, the varieties used in this locality are genetically more inclined to synthesize vitamin C. In addition, the richness in reducing sugars in samples from localities such as Koumra and Moundou could induce Maillard reactions during drying at high temperatures, leading to vitamin C degradation (Mwamba et al., 2018). The results obtained are in the same range as those of Belem et al. (2017), which ranged from 116.20 mg/100 g DM for the commercially mature Amelie variety to 205.77 mg/100 g DM for the immature Amelie variety. Adeyemi et al (2017) obtained lower results than this work (between 77.57 and 53.24 mg/100 g DM in melon-based fruit juice). These results demonstrate the benefits of using melon powders in high-fat dishes that are susceptible to oxidation, as well as recommending them to people suffering from obesity and cardiovascular disease.

Principal Component Analysis (PCA) was applied to investigate the association between the physico-chemical properties that are the variables and the different samples representing the observations. Hierarchical Ascending Classification (HAC), which groups observations according to their physico-chemical affinities, gave us 3 classes (Table 5). Small group correlations show that the Dba samples Bbja, Kmr, Mdou and E5Bgr form classes 1, 1, 2, 2 and 3 respectively. Kameni et al (2002; 2003) also reported a certain similarity in the physicochemical composition of dried mango fruits from different varieties at different commercial maturity. Table 5 also shows that observations Dba, Bbj and Bgr form the F1 axis, Mdou the F2 axis and Kmr the F3 axis. These results suggest that the variables or physico-chemical properties responsible for the formation of these axes are not significantly different.

The contribution of the variables to the formation of the different axes is presented in Table 6, and shows that vitamin C, reducing sugars, starch, amylose, amylopectin, amylose/amylopectin ratio, ions such as Mg, Ca, Na, K and proteins are correlated with the Dba, Bbj and Bgr samples and contribute to the formation of the F1 axis. In fact, samples from Bongor showed the best nutrient contents, surely linked to the best production and storage conditions. Carotenoid, water, lipid, fiber, carbohydrate and iron contents, as well as energy density, are responsible for the formation of the F2 axis. Indeed, observation E4Mdou is rich in carotenoids and water due to its advanced maturity. Ash and the Ca/Mg ratio are responsible for the formation of the F3 axis. Hierarchical Ascending Classification (HAC) of physico-chemical parameters revealed the existence of 7 classes, enabling variables to be correlated with each other.

Figure 2 shows the Biplot correlation between observations and variables. It can be seen from these figures that observations E1Dba and E2Bbj are very rich in starch, amylopectin, vitamin C and water content. Indeed, many authors (Adeyemi et al., 2017; Mwamba et al., 2018) have reported high water content in low-maturity samples. In addition, starch, vitamin C and amylopectin content decrease with increasing maturity. These observations suggest that arboriculturists in Doba and Bebedjia harvest and process fruit at an early stage of ripening. Samples from Koumra and Moundou are essentially rich in carotenoids, iron, lipids, carbohydrates and energy. The high lipid and carbohydrate content of these samples is responsible for their high energy density. The advanced maturity of these samples before processing is responsible for their high carotenoid contents, as demonstrated by Bélem et al. (2017). Iron richness is linked to transport by the abundant carotenoids in these matrices. A positive correlation (r= 0.7201) between these two parameters confirms these observations. The third group consists of the Bongor sample, which is associated with proteins, fibers and ions such as Ca and Na. The overexpression of genes responsible for the synthesis of proteins and other ions in the variety used in the Bongor locality are at the origin of these results.

Vitamin C and carotenoids form classes 1 and 2 respectively. Plants have the capacity to synthesize these powerful antioxidants and plant colorants in their free state within the plant.

The second class is made up of reducing sugars, water content, lipids, starch, amylose, amylose/amylopectin ratio, iron, proteins, ash and fiber. In this class, we note a negative correlation between water content and the elements amylose (r= -0.2895), reducing sugars (r= -0.7534; $p<0.05$), iron (r= -0.6431; $p<0.05$). Indeed, Bélem et al. (2017) reported that a decrease in water content increased the concentration of the various nutrients in the matrix and thus their contents. The negative correlation (r= -0.9295; $p<0.05$) observed between reducing sugar and starch content is linked to starch hydrolysis with the formation of simple sugars by the plant's intrinsic enzymes (amylases) during the ripening process. An improvement in the quantity of reducing sugars with amylose content (r= 0.8029; $p<0.05$) would be linked to the low crystallinity of this molecule, unlike amylopectin, which makes it very easily digestible by enzymes (Kenfack et al., 2021). A positive correlation was also observed between amylose and lipids, which is contrary to the work of many authors (Klang et al., 2019a, b; Tambo et al., 2019a,b; Kenfack et al., 2021). The positive association (r= 0.5263; $p<0.05$) between proteins and fibers is linked to the existence of proteins in the form of glycoproteins on the surface of certain membranes (Dongmo et al., 2020). Proteins were also positively associated with Iron (r= -0.3672). Protein synthesis requires the action of numerous enzymes that use metal ions such as Calcium and Magnesium as cofactors for their activities. The involvement of ions in enzyme activity is also concentration-dependent (Tambo et al., 2023).

The low iron content in the various samples would thus explain the negative correlation with protein content. Moreover, enzymes being proteins require the presence of ions for their enzymatic activities; they are thus called metalloenzymes (Tambo et al., 2018). The amylose/amylopectin ratio is positively related to amylose content ($p<0.05$). Dongmo et al (2020) also reported the same observations.

The fourth class is formed by carbohydrates, amylopectin, Magnesium, net Sodium. In fact, the positive improvement in amylopectin content with carbohydrates can be explained by the fact that amylopectin is one of the digestible carbohydrates whose synthesis is generally greater in cereals, fruit and vegetables than in amylose. Due to their high electroneutrality, carbohydrates are incapable of forming electrostatic interactions, hence their negative association with Sodium and Magnesium ($p<0.05$).

Classes 5, 6 and 7 are respectively formed by Calcium, Potassium and energy value. Ions can exist in the plant either in a complexed state with other elements (phytates, oxalates...), or in a free state. In the free state, they are more available and therefore easily assimilated. The formation of classes 5 and 6 thus demonstrates good availability of these two ions in dried mango fruit from the five localities.

Conclusion

The aim of this study was to assess the influence of collection areas on the physico-chemical properties of dried mango fruit, it was found that dried fruit from all localities kept well, as their water content was within the norm. Dried fruits from Bongor had the highest protein and fiber content, while those from Koumra were richer in lipids and carbohydrates, and had a high energy density. The sample from Doba was the least rich in nutrients. Contents of reducing sugars, starch, amylose and amylopectin were influenced by production localities, with a negative trend between starch and reducing sugar contents. Dried fruit from Moundou had the highest reducing sugar content, in contrast to starch content. Calcium was highest in all samples, while copper was lowest. Dried mango fruit from Doba was generally less rich in minerals, while the opposite was true of dried fruit from Bongor. Vitamin C and carotenoid levels were inversely proportional in all matrices. They were respectively higher in dried mango fruit from Doba and Moundou. Principal Component Analysis revealed a similarity in composition between dried fruits from Doba and Bebedjia, Koumra and Moundou, and Bongor alone. The results obtained show that dried fruits have a good nutritional value and could therefore be used in food supplements.

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