Original Research Article

Preliminary evaluation of the flours produced from the fruits of Borassus *aethiopum* Mart acclimated in Côte d'Ivoire for food products development

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ABSTRACT

Aims: This study was intended to examine the nutritional and functional attributes of the flours of Palmyra palm (*Borassus aethiopum*) fruits (PF) in view of exploring their full potential as a functional ingredient in food products and food product development.
Methodology: Mature and ripe PF collected from the center region (PFCR) and the east region (PFER) were first analyzed for their morphological characteristics and then peeled, sliced, dried, and milled. Flours were evaluated for their physicochemical attributes and functional properties using standard methods.
Results: PFER were observed to be smaller and contained mostly 3 kernels while PFCR were bigger and contained generally 2 kernels. However, the amount of pulp collected from PFCR (37.78%±5.28) did not statistically differ (*P=0.08*)) from that of PFER (42.01%±3.38). The flour produced from PFER had a darker orange-yellow color and was richer in proteins (4.20±0.62%), fat (2.15±0.07%) crude fiber (22.50±0.71%), carotenoids (12.20±0.35%), and minerals while flour produced from PFCR had a higher pH (4.77±0.0) and contained more ash (4.10±0.14%), carbohydrates (69.85±0.040%), total sugars (17.28±0.18%) and reducing sugars (2.69±1.93%). No significant difference ($p>0.05$) was shown in foaming capacity, loose and packed densities, Hausner ratio, and Carr Index. However, foam stability, water absorption capacity (2.09±0.54 g/g), oil absorption capacity (0.88±1.79 g/g), swelling capacity (4.21±2.53 g/g), and solubility index (46.15±0.92%) were found to be statistically higher ($p<0.05$) for PFCR flour. Variabilities in the results could be ascribed to both the degree of ripeness of the fruits and the geographical locations. The low pH, as well as moisture and fat content of the flours, may denote a good preservation quality and therefore long shelf life. Results showed that the low density of PF flours may promote well digestibility and that flours might be suitable for soup and gravy preparation as well as for biscuits, crackers, and cookie formulations.

***Keywords:** Palmyra palm fruit pulp, flour, Center region, East region, functional properties, antinutritional factors, Borassus aethiopum Mart*

1. INTRODUCTION

A report by WFP [1], pointed out an ongoing rise (3 years in a row) of hunger in the world, and the greatest prevalence of this hunger is mostly seen in Africa where a combination of conflicts and climate change are the leading causes. This awareness about food insecurity in the world and mostly in Africa should command the need to preserve and valorize existing natural resources and mostly those providing food and income to the rural population [2].

Palmyra palm (*Borassus aethiopum* Mart) is a dioecious tree that can live 100 years and possesses more than 800 uses [3]. In Asia, the palm has been domesticated and is greatly exploited at both the traditional and industrial levels. Domestication was possible due to the little exigence for water and space [4]. In Africa, this kind of management is quite inexistent; and regrettably, the abusive use of this wild resource is threatening its sustainability. Currently, several studies aiming at increasing knowledge and management of this wild palm have been undertaken across West Africa. A study on sustainable exploitation of *Borassus aethiopum, Elaeis guineensis,* and *Raphia hookeri* for the extraction of palm wine in Côte d'Ivoire was conducted by Mollet et al. [5] to establish a suitability index for each palm species in each village of Côte d'Ivoire. Gbesso et al. [6,7] highlighted the techno-economic aspect of the palm in the center of Benin as well as its geographic distribution in the soudano-guinéenne zone. A survey on views on preventing *Borassus aethiopum* from extinction among four communities in Ghana was reported by Agyarko et al. [8]. Results of the study on the latitudinal distribution, co-occurring tree species, and structural diversity of the threatened palm *Borassus aethiopum* (Arecaceae) in Benin were reported by Salako et al. [9]. Kouakou [10] revealed an approach to the spatial structure of *Borassus aethiopum* Mart found in lamto reserve (Côte d'Ivoire). Traditional knowledge and cultural importance of *Borassus aethiopum* Mart as well as predictions about the potential impact of climate change on the declining agroforestry species of *Borassus aethiopum* Mart in Benin were described by Salako et al. [11,12].

Palmyra fruits remain so underutilized by the local population that about 60% of the fruits are lost [13]. Therefore, to reduce the post-harvest losses of the fruits of *B. aethiopum*, studies aiming at revealing their nutritional quality and transformation abilities have also been checked by researchers. Ali et al. [13], Oryema & Oryem-Origa [14], and Lamayi et al. [15] reported that the fruits contained vitamins and minerals needed for the proper functioning of the body, thus showing their usefulness as food supplements. The anti-diabetic effect of the aqueous extract revealed by Issaka et al. [16] highlighted their possible utilization by the pharmaceutical industries. Nectar [17] and Juice [18,19] made with the fresh pulp were reported to have acceptable characteristics. For PF juice making, Koffi et al. [20] emphasized using sensory analysis as a decision-making tool. Adzinyo et al. [21] underlined the possibility of using the fruit sap to produce high sensory attributes of fruit-flavored syrup. The potential use of PF by the pectin industry has been indicated by Assoi et al. [22,23].

Furthermore, to reduce losses and increase consumption and availability during off-seasons, drying of PF fruits has been reported. Effects of drying temperature on the quality attributes of the flour were reported by Tiho et al. [24] while Abe-Inge et al. [25,26] focused on the impacts of the application of various drying techniques. Few research studies conducted in Ghana reported the use of this flour in food product development. Peprah et al. [27] highlighted the effect of the incorporation of PF flour on the phytochemical constituents of the composite flour as well as on the quality of the resulting bread. The composite bread obtained was enriched in phytochemicals. Abe-Inge et al. [28] indicated that noodles with enhanced nutritional quality and highly appreciated were obtained by incorporation of 5% PF flour in the formulation.

Because data cannot be borrowed across countries due to environmental variabilities and, also because proper mixing, processing, baking, and storage of a particular flour relies mostly on knowledge of its functional properties [29], this ongoing study aims at investigating the nutritional and functional properties of the flours produced from Palmyra fruits acclimated in Côte d'Ivoire. In addition, impacts of the geographical location of the palm (center and east regions) were also assessed to underline not only their effects on the functional properties but also on the physicochemical, and nutritional attributes of the flours.

2. MATERIAL AND METHODS

2.1. Fruits collection and Palmyra palm fruits (PF) flours preparation

Mature and ripe fruits of *Borassus aethiopum* Mart were purchased during the peak season at the main market of Didievi (Center Region) and Koun-Fao (East Region). After washing and peeling, the pulp was removed using a stainless-steel knife. A hundred fruits were randomly selected from each lot and the average weight of the whole fruits, pulp, peelings, and sepals were recorded. Each collected pulp was chopped, and oven dried at 60°C for 48h in an oven (Neo-Tech SA, Belgique) [22], packed in polyethylene bags, and then stored at room temperature. The dried pulp was ground into a fine powder, packed in zip-lock bags, and kept at 4°C until analysis was performed.

2.2. Proximate Analysis and Energy calculation

Proximate compositions; namely ash, moisture, proteins, and fat; were assessed from PF flours by AOAC method [30]. The crude fiber was obtained after acid hydrolysis, drying, and incineration at 550˚C for 3h. Carbohydrate content was calculated by difference based on analytical values involving moisture, proteins, and fat contents. The available energy was calculated according to the method of Atwater using the caloric value by compounds [31].

2.3. Mineral Analysis

The mineral was determined using the protocol described by Niamke et al. [32]. After incineration at 550˚C for 3h and 2 mL of half-diluted hydrochloric acid (HCL) was added to the gray-white ash and then evaporated at 120˚C on a sand bath followed by drying at 105˚C for 1h. To the filtrate of the dry extract recovered with 2 mL of half-diluted HCL, distilled water and lanthanum chloride was added. Mineral contents were measured using an Atomic Absorption Spectrometer, AAS 20 of varian type.

2.4. Carotenoids content

Carotenoid was analyzed following the method described by Soro et al. [33]. Five (5) mL of hexane were added to the mixture of 1 g of flour, 2.5 mL of 96GL alcohol, and 0.1 mL of alcoholic hydroquinone. After mixing, samples were centrifuged at 3000 rpm at 4˚C for 20 min. Then, a 4 mL aliquot of the supernatant was used for the spectrophotometric reading at 450 nm (Spectrophotometric Colorimeter 20 D+) and determination was done using β-carotene as standard.

2.5. Color Analysis

The color values of the flour were measured with a handheld color meter (color reader CR-10 Plus, Konica Minolta INC, Japan) set with a standard illuminant D65 and 10° observer. The measurements were performed using a measuring aperture of 8 mm diameter directly placed on the surface of the flour. The color of the pulp was analyzed using CIE L*a*b*c*h* color space.

2.6. Determination of acidity, total, and reducing sugars

The pH and titratable acidity were measured using a 10% w/v flour suspension [34]. After 1h of standing at room temperature, the suspension was filtrated, and pH was measured using a handheld pH meter (HI 8010, HANNA instruments). The total titratable acidity of the filtrate was determined by potentiometric titration (pH 8.2) with 0.1 M sodium hydroxide and the result was expressed as % citric [35]. Total soluble solids (TSS) content was analyzed with the same filtrate using ATAGO pocket Brix-Acidity refractometer (Hybrid pal-bx/acid15, Atago CO., LTD). Total sugars [36] and reducing sugars [37] were determined using the ethanolic extract of the fruit flour according to Agbo et al. [38] method.

2.3. Total polyphenolics and antinutrients content and Minerals bioavailability

Total polyphenols, oxalate, and phytic acid were determined as described by Niamke et al. [32] while alkaloid was determined according to Day & Underwood [39]. To evaluate the bioavailability of minerals, the molar ratios of the antinutrient and the mineral content were calculated as reported by Combo et al. [40].

2.4. Functional properties of flours produced from PFCR and PFER

2.4.1 Water absorption

Water or oil absorption Capacity was determined by mixing 1g of flour with 10 ml distilled water or oil (density of 0.893 g/ml) in a weighted centrifuge tube. The slurry was agitated and allowed to stand for 1h at room temperature and centrifuged at 5000 g for 20 min [41]. The supernatant was discarded, and the tubes were drained for 10 min in a position of 45° angle. Adhering drops were removed using absorption paper and the weight of each tube was taken. Water or oil absorption capacity was calculated as gram of water or oil absorbed per gram of flour.

2.4.2 Swelling Capacity and Solubility index

Swelling capacity (SC) and solubility index (SI) were determined using a modified method by Abe-Inge et al. [28]. In pre-weighed centrifuge tubes containing 10 ml of distilled water 1 g of flour was added and the suspension was vortexed and heated at 85°C for 30 min. After cooling, the tubes were centrifuged at 3,000 rpm for 15 min and the supernatants were decanted in different pre-weighted petri dishes and evaporated at 105°C to dryness in a Neo-Tech air oven (Neo-Tech SA, Belgium). The tubes containing the sediment were then weighted.

$$\text{Solubility Index (\%)} = \text{W1 x 100/[Ws x (1} - \text{MC)]}$$

$$\text{Swelling Capacity} = \text{W2 x 100/[Wdm x (100} - \text{Solubility)]}$$

W1 = weight of the dried supernatant; W2 = weight of the swollen granules; Ws = weight of the sample; MC = Moisture content of the sample, dry basis (decimal); Wds = weigh of dry mater [Ws x (1-MC)]

2.4.3. Foaming capacity and Foam stability

Foaming capacity and stability were determined as described by Dossou [42] with some modifications. To 100 ml of distilled water, 2 g of dried fruit pulp were added. The suspension was mixed, and the volume (V1) was recorded using a 250 ml graduated cylinder. The suspension was poured into a kitchen blender (500W Moulinex faciclic glass, LM310E10, China) at intermediate speed for 2 min. The whipped suspension was poured into a 250 ml graduated cylinder and the volume of the whole mixture (V2) was recorded. Foaming capacity (FC) and Foam stability (FS) were calculated using the following equations:

$$Foaming\ Capacity (\%) = ((\mathrm{V1} - \mathrm{V2})\ \ \mathrm{x}\ 100)/\mathrm{V1}$$

$$Foam\ Stability\ (\%) = (\mathrm{V3}\ \mathrm{x}\ 100)/\mathrm{V2}$$

V1 = volume of the initial suspension; V2 = volume of the whole mixture after whipping; V3 = volume of the remaining foam

2.4.4. Bulk density

The loose bulk density (g/ml) of the flour was determined by transferring 100 g of flour into a 250 ml graduated glass cylinder. The surface of the powder was level off and the volume of the flour was recorded. The packed bulk density of the flour was determined as previously described, but the volume was measured after tapping the cylinder on the bench top several times until the powder stopped settling (about 2 min) [43]. The Carr Index (CI) and the Hausner ratio (HR) were determined to respectively evaluate the flowability and the cohesiveness of the pulp flour. Both CI and HR were calculated based on the values of the loose and packed density according to the following equations:

$$\text{Carr Index (\%)} = (\text{Packed density} - \text{Loose density})\ \ \text{x}\ 100)/\text{Packed density}$$

$$\text{Hausner ratio} = (\text{Packed density})/(\text{Loose density})$$

2.5. Statistical Analysis

All experiments were conducted in triplicate. Means were expressed with their standard deviation and the paired student's *t-test* of the Statistical Program for Social Science Software (SPSS 22.0, USA) was used to compare the means.

3. RESULTS AND DISCUSSION

3.1. Morphological characteristics of the fresh fruits

In general, the weight of Palmyra fruits from the East Region (PFER) varied from 741.02 g to 1371.16 g and around 90% of them contained 3 kernels. On the contrary, Palmyra fruits from the Center Region (PFCR) weighed between 1075.30 g and 2298.47 g and around 50% of them carried only 2 kernels. This low kernel number for PFCR could be linked to the occurrence of higher ovary abortion during the development of the fruits [24]. Compared to previous studies of fruits from CR, PFCR was smaller than fruits from Yamoussoukro (1591.35 ± 458.92 g) [24] but much bigger than those from Dimbokro (1303.89 g) [22]. These variations could be ascribed to agricultural practices that might have affected the environmental condition of the palm [24].

Table 1: Morphological characteristics of PF collected from the ER and CR

Parameters	PFER (Koun-Fao)	PFCR (Didevi)	*P*-value
Average weight	1075.28^{b}±201.95	1445.35^{a}±346.96	0.018
Water content (g/100g)	74.97^{b}±0.01	75.92^{a}±0.5	0.040
Peelings			
Average weight (g)	43.8^{b}±23.02	144.51^{a}±30.99	0.000
Percentage (%)	3.62^{b}±2.13	10.10^{a}±1.14	0.014
Mesocarp (Pulp)			
Average weight (g)	452.67^{a}±93.22	555.85^{a}±189.63	0.188
Percentage (%)	42.01^{a}±3.38	37.78^{a}±5.28	0.08
Kernel			
Average weight (g)	513.12^{b}±77.67	591.15^{a}±149.65	0.001
Percentage (%)	48.93±4.99	40.91±5.36	
Sepals			
Average weight (g)	62.14^{b}±13.81	89.91^{a}±38.31	0.000
Percentage (%)	5.97^{b}±1.31	9.28^{a}±2.77	0.004

Per line, means±sd bearing different alphabets are significantly different at 5% significance; PFER: Palmyra fruits collected from the east region of Côte d'Ivoire; PFCR: Palmyra fruits collected from the center region of Côte d'Ivoire

Fresh pulp of PF contained a high amount of water (74.97-75.92 g/100 g) (Table 1) and PFCR contained more (*P*= *.04*) water than PFER. These results showed that PF from Côte d'Ivoire (PFCI) had a higher water content than fruits from Ghana (69. 00 g/100 g) [25] but less than those from Uganda (80.30 g/100 g) [14] and Cameroon (79.13-81.36 g/100 g) [13].

Even though PFER were smaller they provided an amount of fresh pulp (42.01 g/100 g) (*P*= *.08*) similar to PFCR (37.78 g/100 g). Regarding previous studies of fruits from CR, the amount of pulp of PFCR (37.78 g/100 g) was higher than that of Yamoussoukro (32.26 g/100 g) [24] but comparable to that of Dimbokro (38.94 g/100 g) [22]. Compared to the Asian variety (*B. Flabellifer*) (53.44 g/100 g) [44], a lower amount of pulp was obtained from *B. aethiopum*.

3.2. Nutritional parameters, Carotenoid content, and Color values of flours produced from PFCR and PFER

As shown in Table 2, the moisture content of PFER (2.65 g/100 g) and PFCR (2.36 g/100 g) flours was low and comparable to that of defatted avocado pear seeds [31]. Low moisture is preferable as it increases stability during storage due to the inhibition of the growth of microorganisms. PFCR flour exhibited a higher content of ash (*P*= *.00*), carbohydrates (*P*= *.01*), total sugars (*P*= *.03*), and reducing sugars (*P*= *.00*) while PFER flour was richer in protein (*P*= *.00*), fat (*P*= *.03*), and crude fiber (*P=0.00*). These differences could be accountable to environmental factors such as soil composition, degree of sunshine, rainfalls, etc. [43].

PF from Ghana [28] and Uganda [14] had higher ash content (about 3.3 g/100 g) than PFER (2.35 g/100 g) but lower ash content than PFCR (4.1 g/100 g). Moreover, PF flour had a higher ash content than commercial wheat flour (Soft flour, 0.34 g/100 g) and whole wheat flour (1.6 g/100 g) [45]; but lower ash content than pumpkin pulp (9.29 g/100 g) and peels (9.57 g/ 100g) flours [46].

Table 2: Nutritional parameters, carotenoid contents, and color values of flours produced from PFER and PFCR

Parameters	PFER flour (Koun-Fao)	PFCR flour (Didevi)	*P*-value
Proximate (g/100 g)			
Moisture	2.65^{a} ±0.08	2.36^{a} ±0.29	0.06
Ash	2.35^{b} ±0.07	4.10^{a} ±0.14	0.00
Proteins	4.20^{a} ±0.62	2.84^{b} ±0.62	0.00
Fat	2.15^{a} ±0.07	1.85^{b} ±0.21	0.03
Crude Fiber	22.50^{a} ±0.71	19.00^{b} ±0.70	0.00
Carbohydrates	66.15^{b} ±0.30	69.85^{a} ±0.40	0.01
Total Sugars (g/100 g)	16.00^{b} ±0.04	17.28^{a} ±0.18	0.03
Reducing Sugars (mg/100 g)	198.17^{b} ±0.52	268.67^{a} ±1.93	0.00
Total soluble solids (°Brix)	6.20^{a} ±0.46	5.71^{a} ±0.37	0.22
Energy value (Kcal/100 g)	366.11^{a} ±0.58	361.65^{a} ±1.57	0.06
pH	4.12^{b} ±0.00	4.77^{a} ±0.00	0.00
Titratable acidity (citric acid, g/100 ml)	0.14^{a} ±0.003	0.07^{b} ±0.01	0.00

Per line, means±sd bearing different alphabets are significantly different at 5% significance; PFER: Palmyra fruits collected from the east region of Côte d'Ivoire; PFCR: Palmyra fruits collected from the center region of Côte d'Ivoire

Protein and fat levels were low and were in the range reported for *Borassus aethiopum* fruits [22,14,28]. Fat level (1.85-2.15 g/100 g) in PF flours was within the range reported as being sufficient for the human being [31]. The low-fat content of PF flours may indicate greater stability against rancidity during storage [25]. The protein content of PF flours (2.84-4.20 g/ 00 g) was lower than that of whole wheat flour (8.9 g/100 g) [45]. The amount of protein in PFER flour was close to that of banana flour (4.40 g/100 g) [47] but greater than that of PF flour from Ghana (3.66 g/100 g) [28].

PF flour could be considered a good source of fiber (19.0-22.50 g/100 g) since values fall within the daily recommended amount for an average man (18-32 g) [48]. Higher fiber content was found in PF flours than in whole wheat (1.44 g/100 g) and commercial soft wheat (0.32 g/100 g) flours [45], as well as in PF flour from Ghana (14.45 g/100 g) [28] and Uganda (Gulu region, 4.5 g/100 g) [14].

PF flour could also be considered a good energy-giving food due to its high total carbohydrate (66.15-69.85 g/ 100g) content. Also, in addition to its fiber contents, PF flour could be used as a flour substitute in food product development. The higher amount of carbohydrates, total sugars (17.28 g/100 g), and reducing sugars (268.67 mg/100 g) of PFCR flour could be due to variability in environmental and storage conditions as well as possible differences in stage of maturity and ripeness of the fruits [49,50]. Since high levels of total sugars and reducing sugars may favor fermentation and browning reactions, content less than 2 g/100 g of reducing sugars was recommended to prevent any discoloration during processing [51].

PFCR had a higher level of total sugars but exhibited a similar level of total soluble solids (TSS) (P= *.22*) as PFER. Since TSS is affected to a greater instance by the total sugar content as well as by a small portion of soluble protein, amino acid, and other organic substances of the fruit [52]; and also because TSS value provides information on both maturity and ripeness of the fruits while total sugar content highlights the degree of ripeness [50], it could thus be inferred that the collected fruits were all mature and ripe but PFCR had a higher degree of ripeness as compared to PFER.

Fruit acidity is usually evaluated through its pH and titratable acidity. PF flours titratable acidity and pH values ranged from 0.07 to 0.14 g/100 ml and 4.12 to 4.77 respectively. This low pH could be advantageous for shelf-life extension of PF flours due to the inhibition of spoilage and pathogenic microorganisms [44]. PFCR flour was less acidic than that of PFER probably because of oxidation of fruit acid during ripening [50] or departure of the volatile acidity and organic compounds during drying [53]. Results of the TA and pH agreed with comments made on the degree of ripeness of the fruits collected from ER and CR.

3.3. Carotenoid contents and Color values of flours produced from PFCR and PFER

The PFCR flour (9.53 mg/100 g) and PFER (12.0 mg/100 g) (Table 3) could be classified as good sources of carotenoids since their contents fall within the Recommended Daily Allowance (RDA) [54]. PF carotenoids are reported as a mixture, in a varying composition, of α-carotene and β-zeacarotene (pro-vitamin A) and lycopene, and zeta-carotene (non-pro-vitamin A) [55] and a reduction of about 39-42% of its level was reported during drying of PF pulp [13]. The PF flours carotenoid content was higher than that of dehydrated sweet potatoes (*Ipomea batatas*) (7.6-9.8 mg/100 g) but close to that of dehydrated carrots (*Daucus carota*) (10.9-17.4 mg/100 g) [56].

Table 3: Carotenoid contents and color values of PFER and PFCR flours

Parameters	PFER flour (Koun-Fao)	PFCR flour (Didevi)	*P-value*
Carotenoids (mg/100 g)	$12.20^{a}\pm0.35$	$9.53^{b}\pm0.35$	<0.001
Color values			
L*	$63.25^{b}\pm0.21$	$71.15^{a}\pm0.20$	0.00
a*	$14.85^{a}\pm0.21$	$13.60^{b}\pm0.28$	0.00
b*	$30.65^{b}\pm0.35$	$31.80^{a}\pm0.57$	0.02
c*	$34.05^{a}\pm0.35$	$34.60^{a}\pm0.57$	0.26
h*	$64.10^{b}\pm0.14$	$66.85^{a}\pm0.07$	0.00

Per line, means±sd bearing different alphabets are significantly different at 5% significance; PFER: Palmyra fruits collected from the east region of Côte d'Ivoire; PFCR: Palmyra fruits collected from the center region of Côte d'Ivoire

The PF flour displayed a yellow-orange coloration probably due to the presence of naturally occurring carotenoid pigments [57]. Results showed that PFCR and PFER flours color profiles were different. As indicated by the lower degree of lightness (L*), PFER flour (63.25) was darker in color than PFCR flour (71.15). Indeed, when seen through naked eyes, PFCR flour appeared whiter than PFER. Moreover, the higher value of (a*, reddish color) and lower value of (b*, yellow color) revealed a more intense yellow-orange color for PFER flour, probably because of its higher content of carotenoids [58] which are generally held responsible for the yellow and red color of fruits. Since the color of a product reflects the sensory attractiveness and quality, PF flours could be used as healthy organic and natural coloring ingredients in food products.

3.4. Mineral contents of flours produced from PFCR and PFER

Values reported in Table 4 for essential minerals such as Mg, Ca, Zn, K, and P were within the Recommended Daily Allowance (RDA) for adults [15,59]. These data support the use of PF flours as healthy ingredients due to their richness in relevant minerals. Moreover, Table 4 shows that minerals occurred in various proportions in PFCR and PFER flours and K was the highest among all the minerals investigated. Similar observations were reported about potassium content of defatted and undefatted avocado pear (*Persia americana*) seed flours [31]. The richness of PFER flour in minerals might be due to the impact of geographical location since plant's hydro-mineral absorption depends on the soil nutrient status. It should be remarked that variability in minerals could also be caused by the methods used during drying [26]. PF from Côte d'Ivoire was richer in Mg, Ca, Zn, and K than PF from Nigeria [15].

Table 4: Mineral contents (mg/100 g) of PFER and PFCR flours

Parameters	PFER flour (Koun-Fao)	PFCR flour (Didevi)	*P*-value
Magnesium (Mg)	506^{a}±2.65	460.67^{b}±4.04	<0.001
Calcium (Ca)	135.67^{a}±3.21	121.33^{b}±5.13	0.015
Sodium (Na)	53.67^{a}±3.06	44.67^{b}±3.51	0.030
Iron (Fe)	0.33^{a}±0.03	0.19^{b}±0.02	0.002
Zinc (Zn)	5.14^{a}±0.02	4.16^{b}±0.05	<0.001
Potassium (K)	2276.67^{a}±6.11	1250^{b}±4.00	<0.001
Phosphorus (P)	603^{a}±3.61	504.33^{b}±4.16	<0.001

Per line, means±sd bearing different alphabets are significantly different at 5% significance; PFCR: Palmyra fruits collected from the center region of Côte d'Ivoire; PFER: Palmyra fruits collected from the east region of Côte d'Ivoire

3.5. Polyphenol contents, antinutrients, and minerals bioavailability of PF flours

Polyphenolic compounds are known to have antibacterial, antiviral, antimutagenic, and anticarcinogenic effects and their presence in food has been suggested to prevent the occurrence of chronic diseases [60]. Figure 1 revealed that PFER flour (402 mg GAE/100 g) was richer in polyphenolic compounds (*P= .00*) compared to PFCR flour (270 mgGAE/100 g). Since polyphenols and carotenoids are antioxidant phytochemicals, it could thus be inferred that PFER flour would exhibit higher antioxidant properties [61] than PFCR flour.

knowledge of the nature and levels of antinutritional factors in a particular food is important as it helps design various processing methods to reduce them to safe levels [62]. The PFER flour had a higher content of antinutrients than PFCR flour. All antinutritional factors evaluated in this study were present in various amounts, and higher levels were observed for tannins (258-338 mg/100 g). High tannins (12.56 mg/ g) were also reported for the mesocarp of the Asian Palmyra palm variety [63]. PFCI flour contained more tannins (23.78-25.28 mg/100 g) but less oxalate and alkaloids than PF flour from Ghana [26].

Adverse effects due to hydrolysable tannins (tannic acid) found in fruits may occur when their levels are higher than 1.5 mg/100 g [64]. The high level of tannins in PFCR flour (258 mg/100 g) and PFER flour (338 mg/100 g) must therefore be reduced to safe levels during processing.

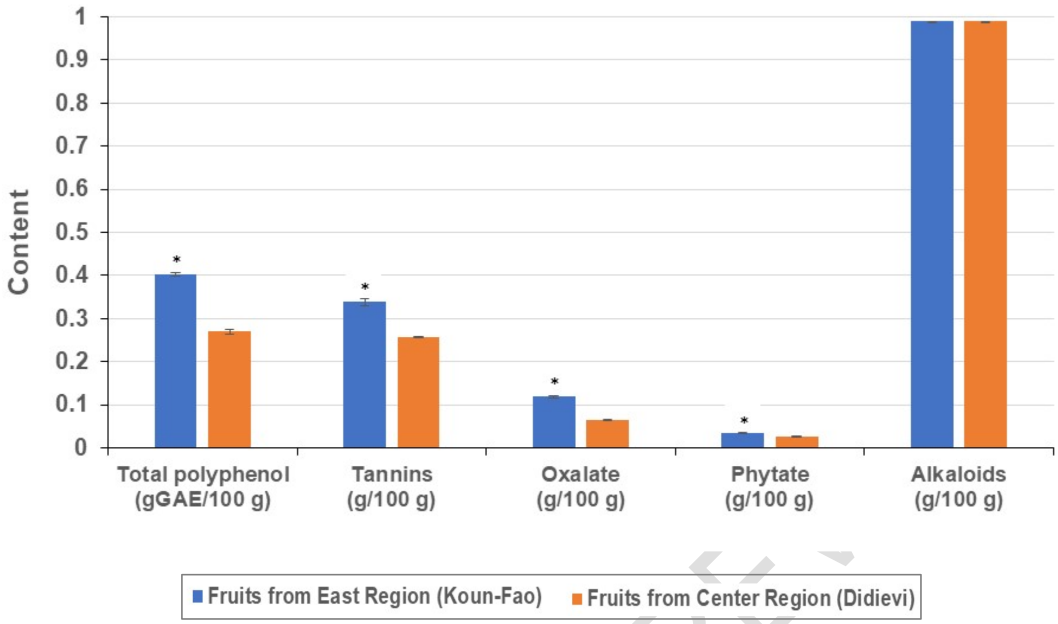

Fig. 1. **Polyphenol and antinutrient contents of flours produced from PFER and PFCR.**
*PFER: Palmyra fruits collected from the east region of Côte d'Ivoire; PFCR: Palmyra fruits collected from the center region of Côte d'Ivoire. *Significant at P < 0.05. Means values ± standard error of means of 3 experiments*

For oxalate, Savage [65] suggested evaluating its adverse effects based on the oxalate/Ca ratio. The oxalate content of PFCR flour (64.63 mg/100 g) and PFER flour (118.25 mg/100 g) may not pose any calcium bioavailability problems since the oxalate/Ca ratios (0.243-0.396) were low. Oxalate/Ca ratio lower than 1 was also reported for the wild fruits of *Leea guineesis* G. Don (0.7978) [66].

Phytate levels (Figure 1) found in PFCR flour (26.0 mg/100 g) and PFER flour (35.39 mg/100 g) were higher than the recommended level (25 mg/100 g) mentioned by Nisar et al. [67]. Nevertheless, the molar ratios of phytate/Ca and phytate/Zn were below their respective critical value of 0.5 and 10 while the phytate/Fe ratio was above its critical value (0.4) as shown in Table 5 [68]. Hence, PFCR and PFER flours might impair the bioavailability of iron but not that of calcium and zinc.

Alkaloid levels in PFER and PFCR flours were similar (0.99 mg/100 g); in addition, they were lower than the critical level (20 g/100 g) reported causing neurological disorders and gastrointestinal problems [69].

It should be remarked that nutrient deficiency related to consumption of PF flours cannot be properly assessed based only on these 4 antinutrient factors analyzed herein. Therefore, further studies must be undertaken to highlight the levels and potential effects of any other antinutritional factors that might be present.

Table 5: Values of Molar Ratio between Antinutrient and Mineral of flours produced from PFER and PFCR

Molar ratio	PFER flour (Koun-Fao)	PFCR flour (Didevi)	Critical level
Phytate/Ca	0.016±0.00	0.013±0.00	0.24
Phytate/Fe	9.175±0.98	11.741±1.51	0.4
Phytate/Zn	0.678±0.01	0.616±0.03	10
Oxalate/Ca	0.396±0.02	0.243±0.01	1

PFER: Palmyra fruits collected from the east region of Côte d'Ivoire; PFCR: Palmyra fruits collected from the center region of Côte d'Ivoire

3.6. Functional properties of flours produced from PFER and PFCR

Water absorption capacity (WAC), oil absorption capacity (OAC), swelling capacity (SC), solubility index (SI), and Foam stability (FS) varied significantly ($p < .05$) in the two flours (Table 6).

WAC is generally enhanced by proteins and carbohydrates [29] and it helps retain a softer texture in bakery products. PFCR flour (2.02 g/g) exhibited higher WAC than PFER flour (1.83 g/g) probably due to its higher amount of carbohydrates and type of fibers present [29]. WAC of PF flours was equivalent to that of pumpkin flours (1.52-2.56 g/g) [57], higher than that of wheat flour (1.68 g/g) [70]; but lower than that of PF flours from Ghana (3.07-5.17 g/g) [26]. WAC highlighted the use of PF flours in soup and gravies preparation [71] as well as in food processing where hydration, to improve handling characteristics, is required [31].

Table 6: Functional properties of flours produced from PFER and PFCR

Parameters	PFER flour (Koun-Fao)	PFCR flour (Didevi)	*P*-value
Water Absorption Capacity (g/g)	1.83^{b}±1.17	2.09^{a}±0.54	0.00
Oil Absorption Capacity (g/g)	0.82^{b}±0.25	0.88^{a}±1.79	0.01
Swelling Capacity (g/g)	3.81^{b}±3.39	4.21^{a}±2.53	0.00
Solubility index (SI) (g/100 g)	42.38^{b}±0.08	46.15^{a}±0.92	0.03
Foaming Capacity (%)	22.50^{a}±0.71	25.00^{a}±1.41	0.15
Loose bulk density (g/mL)	0.61^{a}±0.01	0.59^{a}±0.02	0.33
Packed bulk density (g/mL)	0.79^{a}±0.03	0.77^{a}±0.06	0.70
Hausner ratio	1.31^{a}±0.06	1.33^{a}±0.05	0.76
Carr Index (%)	22.78^{a}±2.31	21.53^{a}±0.16	0.28

Per line, means±sd bearing different alphabets are significantly different at 5% significance; PFER: Palmyra fruits collected from the east region of Côte d'Ivoire; PFCR: Palmyra fruits collected from the center region of Côte d'Ivoire

OAC is affected both by proteins and insoluble dietary fiber fractions [29], and it increases the soft texture to the mouthfeel and flavor retention. OAC of PFCR flour (0.88 g/g) was higher than that of PFER flour (0.82 g/g) and this might indicate more hydrophobic interaction sites [72] in this flour. OAC of PF collected from ER and CR were similar to that of the oven-dried (0.83 g/g) PF from Ghana [25] but lower than that of wheat flour (1.06 g/g) [70] and plantain flours (2.13-2.30 g/g) [73].

The SC expresses the volume occupied by the fruit fibers in presence of excess water [29]. PFCR flour (4.21 g/g) exhibited a higher SC than PFER flour (3.81 g/g) despite its lower fiber content, and this could be linked to the fiber compositions. SC of the studied PF flour was lower than that of cassava flour (8.75-12.43 g/g), wheat flour (13.45 g/g) [70], and PF flour from Ghana (4.33-5.6 g/g) [25].

The SI of PFCR flour (46.15 g/100 g) was higher than that of PFER flour (42.38 g/100 g) which might be indicating the occurrence of a greater amount of soluble substances. SI of PF flour was higher than that of ripe plantain flours (8.59-29.67 g/100 g) [73] and PF flour from Ghana (14.0-33.41 g/100 g) [25]. According to Awuchi et al. [74], this high SI found could be highlighting a high digestibility of these PF flours.

Both PFER and PFCR flours exhibited similar foaming ability (about 25%) and this could be revealing a likeness in their concentration of soluble proteins in the aqueous phase. FC of PFCI flours was higher than that of PF flour from Ghana (2.0-23%) [25] but lower than that of macadamia flours (31-126%) [75]. The foam of PFCR flour was more stable compared to that of PFER flour. For both flours a steady decrease of FS was remarked with time and no more foam was noticeable for PFER flour after only 5 min of standing (Figure 2). This might be indicating that larger amounts of big air bubbles surrounded by thinner and less flexible protein films were formed during the whipping of PFER flour suspension [75]. The FC and FS results revealed that PF flours studied herein might be suitable for biscuits, cookies, and crackers formulations [76].

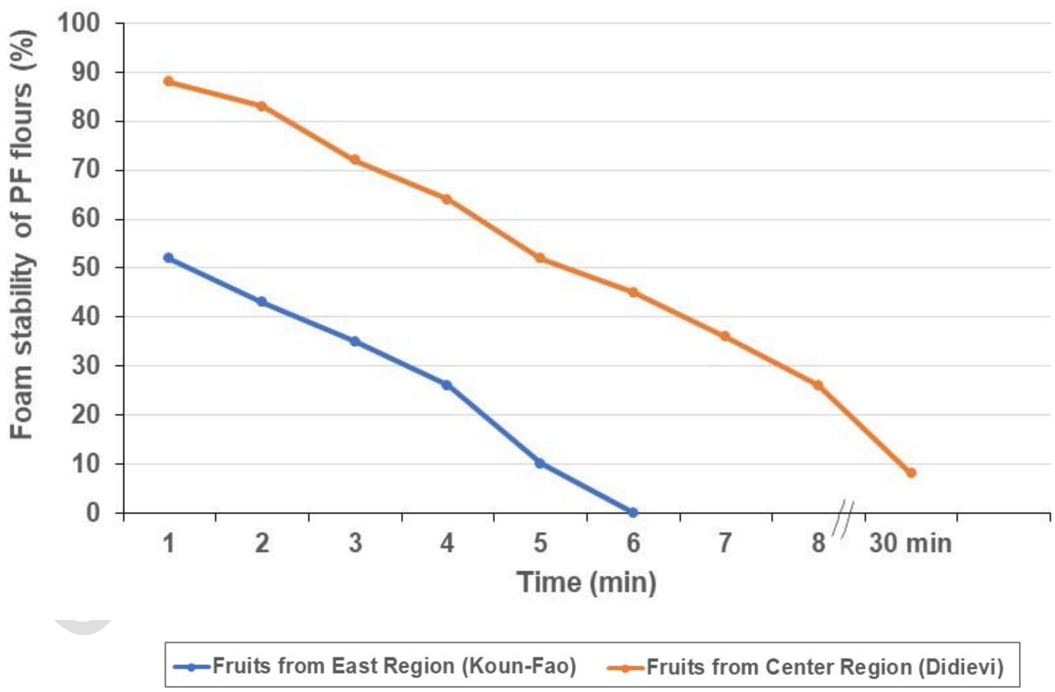

Fig. 2. Foam stability of PF flours over 30 min of standing after whipping

PF: Palmyra fruits collected from the east region and the center region of Côte d'Ivoire

As depicted in Table 5, similarities in functional properties such as loose bulk density (0.59 and 0.61 g/mL) (*P=0.33*), packed bulk density (0.77 to 0.79 g/mL) (*P=0.70*), Hausner ratio

(1.31-1.33) (*P=0.76*), and Carr Index (21.53-22.78%) (*P=0.28*) were observed for PFER and PFCR flours.

The low bulk density of PFRC and PFCR flours might imply that these flours would promote well digestibility due to reduced dietary bulkiness and would be an advantage in complementary food formulation. This may also imply that a similar quantity of the flours would be packaged in a constant volume [77]. The bulk density of PFCI flours was similar to that of oven-dried PF from Ghana (LBD: 0.63 g/mL and PBD: 0.77 g/mL) [25] but higher than that of wheat flour (LBD: 0.48 g/mL and PBD: 0.71 g/mL) [70].

Flowability properties of PFCR and PFER flours could be evaluated in terms of Carr Index as fair (20-35%) [78] or passable (21-25%) [79] and in terms of Hausner ratio (cohesiveness) as intermediate (1.2-1.4) [78]. Flour produced from oven-dried PF from Ghana exhibited better flowability characteristics (Car Index: 18.75% and Hausner ratio:1.3) than that of the oven-dried pulp of PFCI. Since flowability properties are reported to be influenced by moisture content and the hygroscopic and electrostatic nature of the flour as well as by the particle size, shape, and particle size distribution [78] this difference could be attributed to variability in these parameters. The values of Hausner ratio below 1.4 may be revealing the probable easiness of conveying, blending, and packaging PFCR and PFER flours, which might therefore imply their suitability for industrial uses (Ajayi et al. [80].

4. CONCLUSION

The morphological characterization revealed that PFER was smaller than the PFCR but both provided a similar amount of fresh pulp. The significant differences ($p<0.05$) observed in terms of color, nutritional quality, antinutritional factors, WAC, OAC, SC, SI, and FS revealed that PF flour characteristics might be influenced not only by the geographical location but also by the degree of ripeness of the fruits. The PFER flour was found richer in protein, fat, crude fibers, polyphenols, carotenoids, and minerals than PFCR flour which in turn exhibited higher WAC, OAC SC, and SI. In general, PFCR and PFER flours are good sources of fiber, carbohydrates, minerals, carotenoids, and polyphenols and could thus be suggested as food supplements. Moreover, their low bulk density may be beneficial as it might promote well digestibility. The PFCR and PFER flours hydration and foaming properties suggested their incorporation in soup and gravy preparation as well in biscuits, crackers, and cookie formulations; their orange-yellow color could be used as an organic natural colorant to improve food coloration. Moisture and fat contents as well as the pH may favor a better keeping quality and therefore increased shelf life. So, PFCR and PFER flours exhibited high potential as functional ingredients for the food industry but due to their high contents of phytate and tannins, strategies aiming at reducing these antinutrients to safe levels should be considered during processing.

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