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Polyphenols, Carotenoids, Vitamin C Content in Tropical Fruits and Vegetables and Impact of Processing Methods

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Abstract

Thirty-five fruits and seventeen vegetables from Martinique were evaluated for total phenol content (TPC), Vitamin C and carotenoid content. TPC, Vitamin C and carotenoid contents ranged from 11.7 to 978.6 mg/100g, 0.1 to 2853.8 mg/100g and 9.7 to 9269.7 µg/100g respectively. Fruits and vegetables from Martinique have equivalent or higher TPC, Vitamin C and carotenoid contents than fruits and vegetables from temperate climates. Cashew apple had high values for all three parameters (55.8 mg/100g of Vitamin C, 603 mg/100g of TPC and 924 µg/100g of carotenoids). Bassignac mango and mamey apple had the highest carotenoid contents, with 3800.3 and 3199.7 µg/100g respectively. Acerola had the highest Vitamin C and polyphenol contents with 2853.8 µg/100g and 727.4 mg/100g respectively. Pigeon peas had high values for all three parameters (569.2 mg/100g of Vitamin C, 978.6 mg/100g of TPC and 364.3 µg/100g of carotenoids). Pumpkin and watercress had the highest carotenoid content, with 9269.7 and 4339 µg/100g respectively. TPC, Vitamin C and carotenoid content were significantly impacted by processing techniques. TPC, Vitamin C and carotenoid contents decreased by up to 75.78%, 100% and 70.18% respectively, depending on the processing technique used.

Keywords

Martinique Fruits and Vegetables, Total Polyphenols, Vitamin C, Carotenoids, Technology Process, Food Composition, Food Analysis, Nutritional Quality

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1. Introduction

Limited information on the nutritional profile of tropical fruits is available but several examples cited below suggest the high nutritional potential of tropical fruits and vegetables. Studies in Africa have shown that high levels of β-carotene in sweet potato (*Ipomoea batatas*) could allow diets low in Vitamin A to be rebalanced and thus decrease deficiencies [1]. Similarly, acerola (*Malpighia punicifolia*) is known to be one of the richest fruits in terms of Vitamin C content (Souci, 2008), whilst 100 g of fresh guava (*Psidium guajava*) provides more than 400% of the recommended daily intake [2]. Many reports are on Asian [3] and African [4] varieties, which are different from those grown in Martinique (F.W.I.). Analytical methods are different and fruits are cultivated under different conditions.

Fruits and vegetables provide an optimum mix of antioxidants, such as Vitamin C, polyphenols and carotenoids [5]-[7]. Fruits are rich in antioxidants that help in lowering incidences of degenerative diseases such as cancer, arthritis, arteriosclerosis, heart disease, inflammation, brain dysfunction and acceleration of the ageing process [8]-[10]. Phenolic compounds represent a major portion of the antioxidants found in many plants [11]. Vitamin C is also abundant in many fruits and its role in disease prevention may be due to its ability to scavenge free radicals in biological systems [12]. It has been reported that the contribution of phenolic compounds to antioxidant activities is much greater than that of Vitamin C [13].

The impact of processing methods on tropical fruits and vegetables has been little studied. This impact on nutrients from temperate fruits and vegetables is a little known. For broccoli, there was an influence of cooking mode, with a loss of 97% of flavonoids for microwave-cooked florets, whereas steaming had less significant effects [14]. Blanching broccoli in water led to a 37% loss of total polyphenols [15]. Similarly, Akissoe *et al*. [16] reported a 40% drop in polyphenol content in yams during blanching, regardless of temperature. However, Malkeet [17] did not observe significant loss of polyphenols in boiled, baked or microwaved sweet potato flesh, although for polyphenols in the skin, losses of 42%, 55% and 37% were noted for cooking in the microwave, oven and water respectively. An increase of 40% in anthocyanins after 30 minutes of steaming was reported by Yang and Gadi [18], but this increase is not significant (5%) for longer times.

In this study, selected tropical fruits and vegetables from Martinique were analyzed in order to highlight their nutritional qualities and health benefits and assess the impact of processing, with the ultimate aim being to promote local plant biodiversity. To carry out the study it was necessary to obtain nutritional information for Martinique-grown tropical plants in terms of total polyphenol, Vitamin C and carotenoid contents. In addition, the impact of transformation processes on the nutritional quality of six fruits and vegetables (mamey apple, pumpkin, mandarin, okra, sweet potato and christophine) had to be established.

2. Materials and Methods

2.1. Sampling Procedure

The varieties selected are representative of varieties cultivated in Martinique. A representative sample was obtained from local markets. Samples were collected from a selection of thirty-five fruits and seventeen vegetables, taking into account geographical and varietal diversity, ratio of production and seasonality. A minimum of 30 pieces for each fruit and vegetable were collected for analysis.

The protocol was applied to the physicochemical characterization of each variety. Preparations were made using pilot equipment. Raw material was treated as it is consumed in Martinique. Fruits were peeled and seeded if necessary, the pulp collected and crushed or pressed and then filtered according to the fruit in question. Vegetables were peeled if necessary and steamed, depending on vegetable type. The samples obtained were frozen and stored at −18˚C in sealed plastic bags pending analysis.

2.2. Physicochemical and Nutritional Characterization of Fruits and Vegetables

2.2.1. Total Polyphenols

Total polyphenols were determined using Folin and Ciocalteu's method described in Georgé *et al*. [19]. Only the measure of raw extracts was considered. 300 mg to 1 g of sample was homogenized with 10 mL of extraction solution (acetone/water, 7/3 vol/vol) for 10 min. The raw extract was obtained after filtration (Whatman). Polyphenols are commonly determined using Folin-Ciocalteu reagent. Absorbance at 760 nm was determined using a spectrophotometer (JENWAY 7305). Results are expressed in mg of gallic acid equivalent/100g.

2.2.2. Total Carotenoids

Total carotenoids were determined using a colorimetric method. 2 g of samples were extracted for 30 minutes with 50 mL of a ternary solvent (hexane/ethanol/acetone 50/25/25). After filtration (Whatman), solvent was washed three times with 25 mL distilled water. Absorbance at 450 nm was determined using a spectrophotometer (JENWAY 7305). Results were obtained using the Beer-Lambert law and expressed in µg/100g.

2.2.3. Vitamin C

Vitamin C was measured using the K-ASCO 11/05 Megazyme kit. 100 µL of samples were incubated for 3 min at 37˚C with phosphate/citrate buffer and ascorbic acid oxidase. 200 µL of tetrazolium salt were added and incubated for 3 min at 37˚C. 200 µL of reactive agent were added and absorbance at 578 nm was immediately read using a spectrophotometer (JENWAY 7305). Results were obtained using the Beer-Lambert law and expressed in µg/100g. The recommended daily intake determined by the World Health Organization is about 60 mg.

For temperate fruits and vegetables, data was based on the worldwide food composition tables.

2.3. Processing of Fruits and Vegetables

Raw material processing was performed according to the suitability of the plant (crisps, canned in syrup, fresh-cut packaged, filtered pasteurized pure juice, flour, frozen or steamed). Treatment of plants was carried out with pilot equipment from the institute's technological hall. All fruits and vegetables were washed, sanitized and peeled before processing.

2.3.1. Steaming

Vegetables were cut into pieces of 2 - 4 mm thickness in a BIRO cubing machine and cooked at 110˚C/100% relative humidity in a FRIMA steam oven until a core temperature of 90˚C was reached. Pieces were then ground for 3 min at 1500 rpm with a STEPHAN UM44. Samples were frozen in an ACFRI freezing cell and stored at −18˚C before analysis.

2.3.2. Crisps

Vegetables were cut into pieces of 2 mm thickness using a slicing machine. Slices were then immersed in sunflower oil at 120˚C and −0.85 bar for 400 seconds in a FEMAG vacuum fryer. After frying, the product was drained on paper and centrifuged for 30 seconds to dry and remove excess oils. Samples were ground for 3 min with a STEPHAN UM44 and stored at ambient temperature before analysis.

2.3.3. Fresh-Cut Packaged

Vegetables were grated into 2 mm thick pieces with a ROBOT-COUPE slicing machine. Samples were ground for 3 min with a STEPHAN UM44 and frozen at −18˚C before analysis.

2.3.4. Canning

400 g of fruits were added to 300 mL of syrup (20˚ Brix, pH 4.5, 75˚C) in 4/4 cans. Cans were sealed with a BERTUZZI sealer and sterilized in a BARRIQUAND autoclave for 20 - 30 min at 100˚C - 115˚C. Vegetables were blanched for 2 min at 100˚C in an AURIOL cooking pot. They were then placed in 4/4 cans with blanching water at 70˚C added with 10 mg/g salt and 2 mg/g citric acid. Cans were sealed with a BERTUZZI sealer and sterilized in a BARRIQUAND autoclave for 20 - 30 min at 100˚C - 115˚C. All cans were then opened and products were ground for 3 min at 1500 rpm in a STEPHAN UM44. Samples were frozen in an ACFRI freezing cell and stored at −18˚C before analysis.

2.3.5. Filtered (Pasteurized) Pure Juice

Mandarins were peeled and sliced prior to pressing with a BERTUZZI hydraulic press. Juice was filtered and then stored at −18˚C before analysis. For pasteurized juice, juice was pasteurized in a BERTUZZI pasteurizer (heat treatment 90˚C for 4 min) and then stored at −18˚C pending analysis.

2.3.6. Flour

Sweet potatoes were cut into thin 2 mm thick slices in a slicing machine and dried for 24 hr at 50˚C, 40% relative humidity and 70% ventilation in a FEMAG drier. Dried slices were ground for 3 minutes at 1500 rpm in a STEPHAN UM 44 and then passed through a 300 µm sieve with a SAMAP mill. Flour was stored at ambient temperature before analysis.

2.3.7. Frozen

Vegetables were cut into 2 - 4 mm thick slices in a slicing machine, blanched for 2 minutes in a FRIMA steam oven at 90˚C 100% relative humidity, ground for 3 min at 1500 rpm in a STEPHAN UM 44 and frozen at −18˚C in an ACFRI freezing cell and stored at −18˚C before analysis.

2.4. Data Statistical Analysis

The physical and chemical mean values of triplicate measurements or analysis were statistically analysed. *Analysis of Variance* (*ANOVA*) based on *Student Test*, *Principal Component Analysis* (*PCA*) and *Duncan's Multiple Range Test* (DMRT) were performed using the StatGraphics CENTURION® XV 2005 software and Uniwin PLUS® 2005 v6.1.

3. Results

3.1. Food Compositions of Different Fruits and Vegetables

We wanted to highlight the nutritional profile and potential uses of fruits and vegetables from Martinique. We compared them with commonly consumed temperate plants known for their nutritional potential. Analysis of the results is summarized in **Table 1** and **Table 2**. The TPC ranged from 11.7 to 978.6 mg, gallic acid equiv/100g. Vitamin C and carotenoid content ranged from 0.1 to 2853.8 mg/100g and 9.7 to 9269.7 µg/100g respectively. **Table 3** represents TPC, Vitamin C and carotenoid content for temperate fruits and vegetables.

3.1.1. Food Compositions of Fruits and Vegetables from Martinique

Figure 1(a) represents vegetables' polyphenol content (mg/100g). The pigeonpea was the richest vegetable studied in terms of total polyphenol content. With 978.6 mg/100g, their TPC was almost four times higher than for artichokes and Brussels sprouts. Okra, yams, malanga, and sweet potatoes were richer in polyphenols than shallots and broccoli. **Figure 1(b)** shows fruits' polyphenol content in mg/100g. Eight fruits from Martinique were richer than strawberries in terms of polyphenol content. Acerola was richer in polyphenols than acai, with a value of 727 mg/100g and was the richest fruit from Martinique in terms of polyphenols. Cashew apple and star apple had high values, with 603.0 and 515.0 mg/100g respectively.

The total carotenoid content of fruits and vegetables was also analyzed. The comparison of tropical (colored) and temperate (black) vegetables' total carotenoid content (µg/100g) is represented in **Figure 2(a)**. Both pumpkin varieties, cress and sweet potatoes were rich in total carotenoids. Pumpkin was richer than carrot and spinach. Sweet potato and cress had higher contents than broccoli. Sweet potato was even 300 times richer than potato, each vegetable registering 2443.3 µg/100g and 6.46 µg/100g respectively. Less colourful vegetables such as cucumber, dasheen, bur cucumber or cassava are poorest in total carotenoids. **Figure 2(b)** shows the total carotenoid content of fruits from Martinique. Mamey apple and macaque mandarin had total carotenoid contents higher than 2000 µg/100g and were the richest fruits studied. However, mamey apple had a content almost twice that of apricots from temperate regions (*Prunus armeniaca*). Christophine's total carotenoid content was 28 times higher than globally studied christophine. Tomatoes from Martinique had a carotenoid content equivalent to tomatoes from temperate regions. Finally, malay apple, custard apple and soursop did not contain carotenoids.

Figure 3(a) represents Vitamin C contents (mg/100g) of vegetables from Martinique. Pigeonpea was the richest vegetable for Vitamin C with 569 mg/100g. Its content was three times higher than for peppers and could cover more than 949% of the recommended daily intake (RDI) of Vitamin C. Massisi ranked fifth with 73 mg/100 which nevertheless covers 122% of the RDI. A comparison of Vitamin C content (in mg/100g) of tropical (colored) and temperate (black) fruits, is presented in **Figure 3(b)**. Acerola was the richest for Vitamin C with 2853.8 mg/100g. 100 g provided more than 4700% of the RDI. 2 g of acerola was sufficient to cover 100% of the RDI of Vitamin C. Its Vitamin C content was more than 1.5 times higher than acerola studied around the world (1700 mg/100g), almost 18 times higher than blackcurrant (179 mg/100g) and 47 times higher than kiwi (60 mg/100g). Cashew apple and guava were in second and third position with 555.8 and 491.6 mg/100g respec-

Table 1. Food composition table for fruits cultivated in Martinique.

Scientific Names	Fruits	Total Polyphenols (mg/100g)	Total Carotenoids (µg/100g)	Vitamin C (mg/100g)
Anacardium occidentale	Cashew apple	603 ± 14	924 ± 31	555.8 ± 22.3
Ananas comosus	Pineapple	73.3 ± 5.3	497 ± 17	38.3 ± 1.0
Annona muricata	Soursop	183.4 ± 56.7	0	16.3 ± 0.3
Annona squamosa	Custard apple	388.3 ± 7.7	0	11.5 ± 0.1
Artocarpus heterophyllus	Jackfruit	101.7 ± 2.1	131.7 ± 12.3	13.6 ± 1.3
Averrhoa carambola	Star fruit	366.3 ± 7.3	112 ± 19	14.2 ± 0.3
Carica papaya	Raw papaya	43.5 ± 2.4	113 ± 11	39.3 ± 0.3
Carica papaya	Cooked papaya	38.6 ± 4.8	83.3 ± 3.1	25.7 ± 0.3
Chrysophyllum cainito	Star apple	515 ± 21	26.3 ± 1.5	5.6 ± 1.8
Citrullus lanatus	Watermelon	22.8 ± 4.2	541.7 ± 39.1	7.9 ± 0.2
Citrus aurantifolia	Giant key lime	213.2 ± 20.7	63.8 ± 76.3	23.7 ± 0.3
Citrus aurantifolia	Lemon	111.7 ± 9.7	446.8 ± 247.4	23.2 ± 0.9
Citrus aurentium	Bitter orange	350 ± 74	575.2 ± 141.7	44.5 ± 0.8
Citrus latifolia	Lima citrus	31.7 ± 2.7	310.3 ± 24.6	18.5 ± 0.3
Citrus maxima	Shaddock	112.7 ± 9.7	909.8 ± 381.9	44.2 ± 2.5
Citrus maxima	Grapefruit	59.2 ± 2.3	448.4 ± 248.1	35.6 ± 1.2
Citrus reticulata	Common mandarin	102.2 ± 1.4	714.7 ± 4.1	26.7 ± 0.6
Citrus reticulata	Macaque mandarin	76.2 ± 0.3	2136.7 ± 16.2	6.1 ± 0.0
Citrus sinensis	Orange	131.8 ± 11.9	331.6 ± 195.8	41.2 ± 0.7
Citrus spp,	Sour orange	83.5 ± 4.3	525.3 ± 59.6	29.9 ± 0.9
Cucumis melo	Melon	42.4 ± 2.4	535.7 ± 46.1	27.2 ± 0.3
Lycopersicum esculentum	Tomato	42 ± 1.3	660 ± 29	15.2 ± 0.2
Malpighia punicifolia	Acerola	727.4 ± 200.4	422.3 ± 10.3	2853.8 ± 10.6
Mammea americana	Mamey apple	117.1 ± 0.3	3199.7 ± 12.4	2.7 ± 0.0
Mangifera indica	Bassignac mango	95.58 ± 6.11	2183.00 ± 642.05	16.0 ± 11.3
Mangifera indica	Moussache mango	57.0 ± 20.0	449.33 ± 633.11	30.85 ± 1.06
Mangifera indica	Green mango	86.40 ± 14.91	276.17 ± 388.67	28.20 ± 0.85
Mangifera indica	Julie mango	117.50 ± 7.37	954.00 ± 52.33	34.50 ± 13.44
Passiflora edulis	Passion fruit	50.4 ± 1.4	339 ± 46	54.3 ± 2.3
Passiflora laurifolia	Water melon	44 ± 9	11 ± 2	41.4 ± 0.3
Psidium guajava	Guava	422.7 ± 25.6	604.3 ± 12.1	491.6 ± 1.7
Punica granatum	Pomegranate	189.6 ± 35.9	9.7 ± 1.1	19.8 ± 1.0
Spondias cythera Sonnerat	Ripe golden apple	157 ± 13	752.7 ± 14.3	20.1 ± 0.2
Spondias cythera Sonnerat	Green golden apple	158 ± 5	836.3 ± 9.3	23.9 ± 0.4
Spondias mombin	Hog plum	250.9 ± 8.3	821 ± 22	10.1 ± 0.1
Syzygium malaccense	Malay apple	301 ± 23	0	0.3 ± 0.1

Data are expressed per 100 g of fresh edible material. An asterix indicates fruits treated in juice for analyses.

Table 2. Food composition table for vegetables cultivated in Martinique.

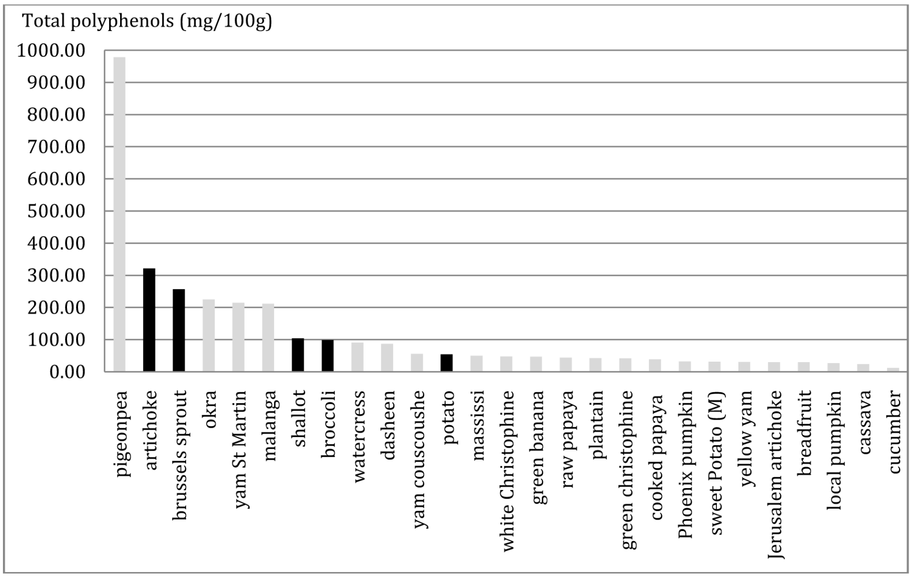
Scientific Names	Vegetables	Total Polyphenols (mg/100g)	Total Carotenoids (µg/100g)	Vitamin C (mg/100g)
Abelmoschus esculentus	Okra	224.9 ± 25.3	552.3 ± 35.2	2.9 ± 0.0
Artocarpus altilis	Breadfruit	29.4 ± 0.2	245.0 ± 20.6	8.2 ± 0.1
Cajanus cajan	Pigeonpea	978.6 ± 34.8	364.3 ± 9.3	569.2 ± 41.1
Calathea allouia	Jerusalem artichoke	29.8 ± 4.4	136.3 ± 7.6	9.7 ± 0.4
Colocasia esculenta	Dasheen	87.0 ± 8.5	51.3 ± 1.5	4.1 ± 0.1
Cucumis anguria	Bur cucumber	49.4 ± 7.7	16.7 ± 3.2	73.2 ± 1.2
*Cucumis sativus**	Cucumber	11.7 ± 4.5	52.0 ± 1.9	0.3 ± 0.0
Cucurbita moschata	Local pumpkin	27.03 ± 1.86	9269.7 ± 25.6	0.1 ± 0.0
Cucurbita moschata	Phoenix pumpkin	31.5 ± 0.1	7714.7 ± 20.7	0.1 ± 0.0
Dioscorea alata	St. Marteen yam	214.1 ± 5.1	86.3 ± 1.5	22.0 ± 0.6
Dioscorea cayenensis-rotunda	Yellow yam	30.5 ± 1.4	444.1 ± 0.1	8.5 ± 0.1
Dioscorea trifida	Couscoushe yam	55.9 ± 2.4	73.3 ± 4.2	0.87 ± 0.05
Ipomoea batatas	Sweet potato	30.8 ± 2.2	2443.3 ± 25.2	12.5 ± 0.5
Manihot esculenta	Sweet cassava	23.9 ± 1.4	0	21.3 ± 0.7
Musa spp.	Plantain	42.1 ± 0.1	862.0 ± 11.8	6.1 ± 0.1
Musa spp.	Green banana	46.6 ± 1.4	247.7 ± 2.3	9.2 ± 0.1
Nasturtium officinale	Watercress	90.6 ± 8.6	4339.0 ± 15.9	2.7 ± 0.5
Sechium edule	White Christophine	47.2 ± 8.8	291.0 ± 7.5	7.4 ± 0.2
Sechium edule	Green Christophine	41.2 ± 9.4	414.3 ± 23.4	12.5 ± 0.3
Xanthosoma sagittifolium	Malanga	211.4 ± 29.0	355.7 ± 9.6	19.3 ± 1.2

Data are expressed per 100 g of fresh edible material. An asterix indicates raw vegetables for analyses.

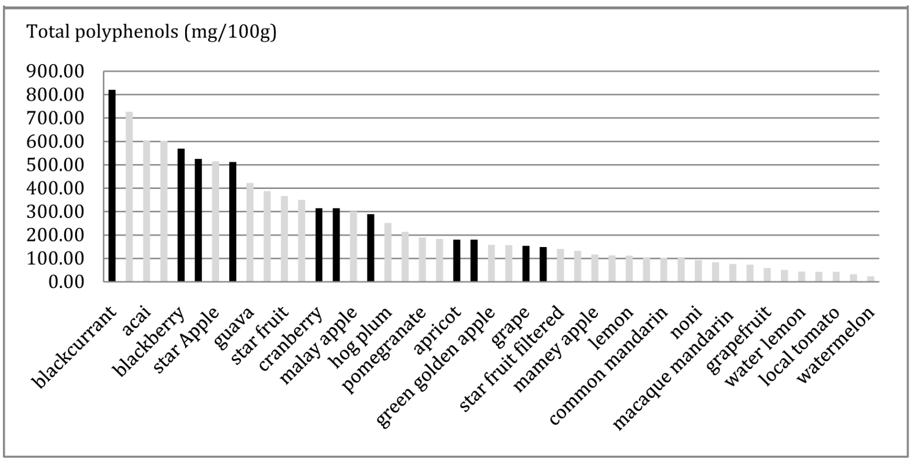
Table 3. Food composition table for temperate fruits and vegetables.

Scientific Names	Fruits and Vegetables	Total Polyphenols (mg/100g)	Vitamin C (mg/100g)	Total Carotenoids (µg/100g)
Euterpe oleracea	Acai	604.69 ± 0.00	58.72 ± 0.00	5.07 ± 0.00
Malus domestica	Apple	179.1 ± 148.3	-	-
Prunus armeniaca	Apricot	133.00 ± 0.00	-	-
Cynara scolymus	Artichoke	321.3 ± 166.7	-	-
Rubus fruticosus	Blackberry	569.43 ± 226.05	24.57 ± 9.15	0.27 ± 0.00
Ribes nigrum	Blackcurrant	820.64 ± 230.06	179.50 ± 16.46	8 ± 0
Vaccinium corymbosum	Blueberries	525 ± 0	16.97 ± 10.09	30 ± 0
Brassica oleracea	Broccoli	98.9 ± 13.5	-	-
Brassica oleracea	Brussels Sprout	220.75 ± 183.49	-	-
Vaccinium macrocarpon	Cranberry	198 ± 101	11.60 ± 1.42	200 ± 0
Vitis vinifera	Grapes	153.39 ± 49.86	6.24 ± 3.34	30 ± 0
Actinidia deliciosa	Kiwi	315 ± 0	78.33 ± 17.15	50 ± 0
Morinda citrifolia	Noni	91.9 ± 0.0	53.2 ± 0.0	3.5 ± 0.0
Hylocereus undatus	Pitahaya	-	29 ± 0	-
Solanum tuberosum	Potato	53.86 ± 34.87	13.50 ± 4.95	5.2 ± 0.0
Rubus idaeus	Raspberry	148.10 ± 93.55	26.20 ± 2.67	30 ± 0
Allium cepa	Shallot	-	-	-
Fragaria virginiana	Strawberry	289.20 ± 95.22	64.81 ± 13.20	20 ± 0

Data presented here represent averages from worldwide food composition tables or values found in literature [20]-[35].



(a)



(b)

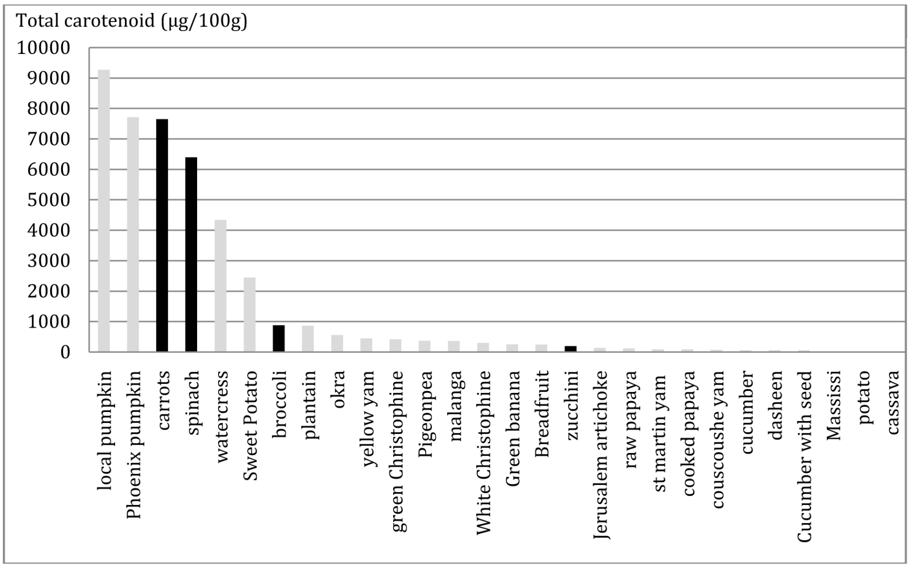
Figure 1. Comparison of total polyphenol content (mg/100g) of tropical (grey) and temperate (black) vegetables (a) and fruit (b).

tively. Their Vitamin C content was also higher than blackcurrant (more than 3 times higher) and kiwi (more than 9 times higher). Lower down on the scale, pineapple, papaya, passion fruit, and guava covered more than 70% of RDI, with levels of between 54.3 and 38.3 mg/100g.

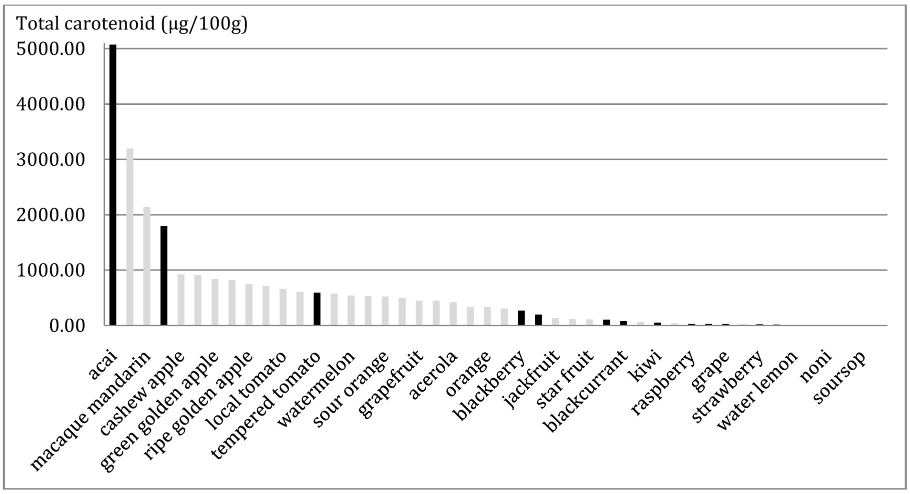
3.1.2. Food Compositions of Temperate Fruits and Vegetables

Figure 1(a) represents vegetables' polyphenol content (mg/100g). Temperate vegetables have been added for comparison (artichoke, brussels sprout, shallot and broccoli, shown in black in the figures). Pigeon peas were nine times richer in polyphenols than shallots, with 104 mg/100g. **Figure 1(b)** shows fruits' polyphenol content in mg/100g. Temperate fruits with a high nutritional profile have been added for comparison (black bars in the charts). Apples, grapes and raspberries, commonly found and widely consumed in temperate climates, have lower polyphenol values—less than 180 mg/100g.

Total carotenoid content (µg/100g) is represented in **Figure 2(a)**. Temperate fruits and vegetables were less rich in total carotenoids than fruits and vegetables from Martinique. **Figure 2(b)** shows the total carotenoid content of commonly consumed temperate fruits, and "super fruits" known for their high levels of carotenoids. Acai had a content 1.6 times higher than mamey apple.



(a)



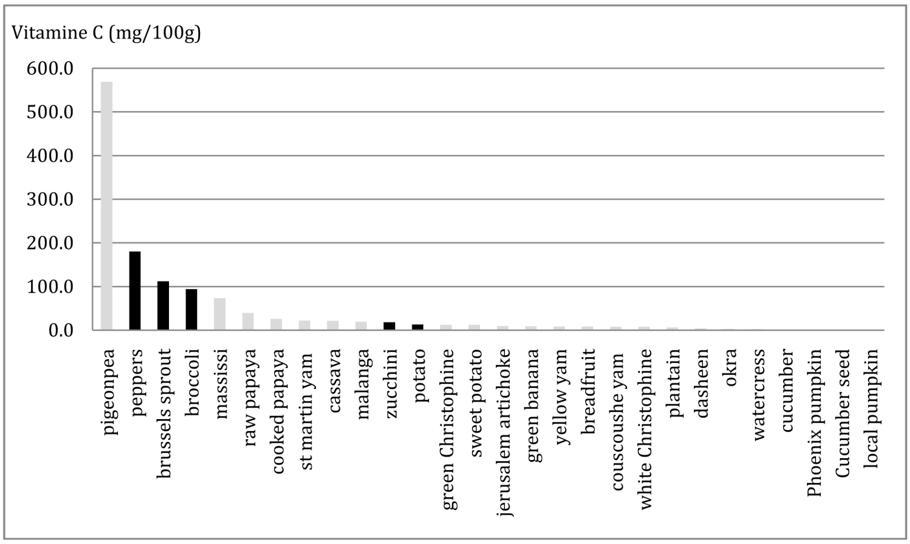
(b)

Figure 2. Comparison of total carotenoid content (µg/100g) in tropical (colored) and temperate (black) vegetables (a) and fruit (b).

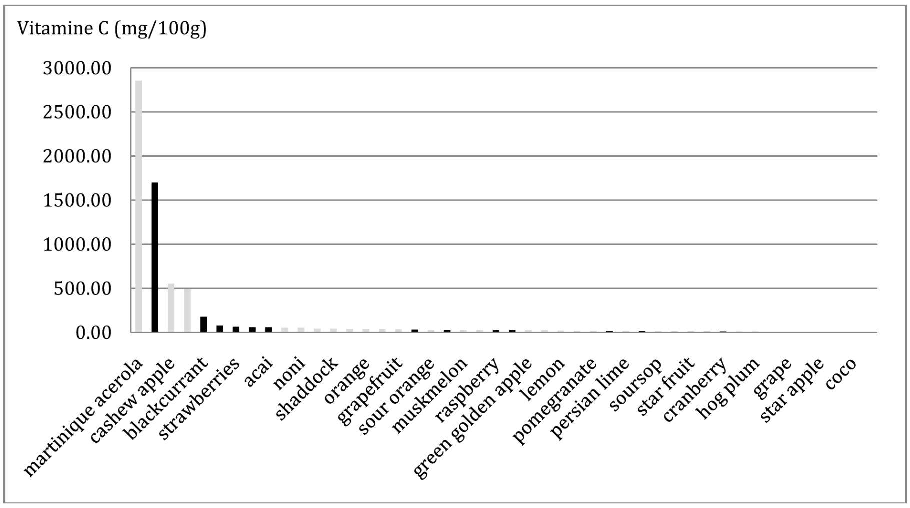
Figure 3(a) represents Vitamin C contents (mg/100g) of some vegetables known for their high Vitamin C contents, and other commonly consumed vegetables (peppers, Brussels sprouts, broccoli, zucchini). Martinique fruits and vegetables are richer in Vitamin C than temperate fruits and vegetables.

3.2. Impact of Processing on Micronutrients

Data from the processing of some of the fruits and vegetables from Martinique was established. Two fruits and four vegetables were specifically studied here: mamey, mandarin, pumpkin, okra, sweet potato and christophine. Results are summarized in **Table 4**. This allowed a comparison of the nutritional composition of the raw material and the processed material, to highlight the impact of processesing on micronutrients. Data is for 100 g of dry matter. For almost all fruits and vegetables studied, raw materials had the highest total polyphenols, carotenoids and Vitamin C content. Mamey apple was rich in polyphenols and total carotenoids. Raw materials had 804.17 mg of polyphenols and 21.97 mg of total carotenoids. Mandarin was also rich in polyphenols, total carotenoid and Vitamin C, with 1022.11 mg, 7.15 mg and 266.79 mg respectively. Pumpkin was rich in total carotenoids, with 97.79 mg. Christophine was rich in polyphenols and a good source of Vitamin C, with 278.23 mg and 77.43



(a)



(b)

Figure 3. Comparison of Vitamin C content (mg/100g) in tropical (colored) and temperate (black) vegetables (a) and fruit (b).

mg respectively. Sweet potatoes were rich in total polyphenols (373.84 mg) and carotenoids (3.84 mg), and were a source of Vitamin C (16.00 mg). Sweet potato flour was very rich in carotenoids (3.43 mg) and total polyphenols (587.77 mg). Okra was rich in total polyphenols, with 1800.90 mg. Its total polyphenol content was 19 times richer than broccoli.

3.2.1. Impact on Total Polyphenols

The total polyphenol content was statistically the highest (5%) in the raw material for all fruits and vegetables, except for pumpkin, where it was higher in the fresh-cut packaged product. Heat treatments had a statistically significant effect (5%) on total polyphenol content. The processes of pasteurization, sterilization (canning) and vacuum frying (chips) were in the lowest statistical groups. Steaming had the least impact on total polyphenols. Cooking methods had a statistically significant effect (5%) on total polyphenol content. The more fruits and vegetables were heated, the more their polyphenol content decreased.

For products made from mamey apples, a significant loss of total polyphenols between the raw material and processed products was observed. The loss was statistically higher in chips. There was a 42% loss of total polyphenols in canned products and 76% in chips compared to the raw material. During the preparation of peach sy-

Table 4. Impact of processing on micronutrients for fruits and vegetables from Martinique. Letters (a, b, c) indicate a significant difference at 5% (Fischer test). All results are expressed per 100 g of dry matter.

Plant	Product/Process	Total Polyphenols (mg)	Total Carotenoids (mg)	Vitamin C (mg)
Mamey	crushed raw (raw material)	804.17 ± 7.27 a	21.97 ± 0.31 a	18.60 ± 0.21 a
	canned	463.88 ± 2.60 b	9.95 ± 0.14 b	0.00 ± 0.00 b
	crisps	194.77 ± 2.15 c	6.55 ± 0.16 c	0.20 ± 0.00 b
p		0.0000	0.0000	0.0000
Pumpkin	steamed crushed (raw material)	333.23 ± 14.26 c	97.79 ± 17.23 a	-
	fresh-cut packaged	467.89 ± 45.95 a	79.44 ± 12.24 b	
	frozen	406.25 ± 18.17 b	64.29 ± 3.93 c	
	crisps	380.71 ± 72.49 bc	29.61 ± 1.06 d	
p		0.0004	0.0000	
Mandarin	pure filtered juice (raw material)	1022.11 ± 15.20 a	7.15 ± 0.16 a	266.79 ± 10.29 a
	pure filtered pasteurized juice	851.33 ± 57.24 b	7.55 ± 0.46 a	248.17 ± 19.47 a
	canned	469.88 ± 76.13 c	5.48 ± 0.82 b	1.25 ± 0.17 b
p		0.0001	0.0081	0.0000
Okra	steamed crushed (raw material)	1800.90 ± 209.16 a	4.43 ± 0.33 b	-
	frozen	1341.23 ± 18.74 b	10.36 ± 0.96 a	
	canned	1049.45 ± 63.60 c	1.55 ± 0.13 c	
p		0.0010	0.0000	
Sweet potato	steamed crushed (raw material)	373.84 ± 7.36 b	3.84 ± 0.14 b	16.00 ± 0.07 a
	frozen	340.27 ± 8.10 b	6.22 ± 0.08 a	10.83 ± 0.12 b
	flour	587.77 ± 29.25 a	3.43 ± 0.06 c	0.00 ± 0.00 c
p		0.0000	0.0000	0.0000
Christophine (white)	steamed crushed (raw material)	278.23 ± 28.52 a	-	77.43 ± 3.86 a
	frozen	285.11 ± 55.61 a		72.81 ± 5.66 a
	canned	249.73 ± 17.71 a		3.42 ± 0.85 b
p		0.5565		0.0000

rup, Asami *et al*. [36] reported losses of 21% of total polyphenols. Fresh-cut packaged pumpkin had a significantly higher polyphenol content. Statistically, pumpkin chips contained the fewest polyphenols compared to other products made from the vegetable. Price *et al*. [37] showed that cooking onions by boiling or frying caused a loss of 25% of flavonol glycosides.

For mandarins, there was a difference of 53% between the polyphenol content of the pure fresh juice and pure pasteurized juice. For canned fruit, the gap between fresh and processed widens to 86%. Jiratanan and Liu [38] showed that after treatment at 121˚C, beetroot polyphenol content changed only slightly while French beans had a marked loss (−30%).

In the case of christophine and okra, the total polyphenol content was significantly (5%) the highest in raw and frozen material, whilst canned products were in the lowest statistical group.

Statistically, sweet potato flour had the lowest polyphenol content. It was almost 3.5 times lower than for steamed sweet potatoes. After drying for 24 hours at 60˚C, Yang and Gadi [18] found an increase of 50% in phenolic anthocyanins but not for total anthocyanins. Conversely, Asami *et al*. [39] showed significantly decreased polyphenol content (−1/3) in dried strawberries.

3.2.2. Impact on Total Carotenoids

There was a significant loss of carotenoids following food processing of mamey apples. The highest loss was for chips. Nevertheless, chips still had a carotenoid content 100 times greater than that of potato chips [2]. For dry matter, there was a loss of 55% of total carotenoids in canned products and 70% in chips compared to raw material. Cano and de Ancos [40] reported a degradation of total carotenoids in canned mangoes. Only β-carotene was maintained at 90%. Heat treatment of canned papaya slices caused a loss of 39% of carotenoids [41].

For pumpkin, primary raw material (cooked/crushed) had the statistically higher carotenoid content (compared with dry matter). Chips had a significantly lower carotenoid content. Frozen pumpkin cubes were in third position behind fresh-cut packaged.

Total carotenoid content of mandarin products was significantly higher in pure juice. Canned mandarin had the lowest content. In a study on total carotenoid composition of cashew apple juice, both fresh and pasteurized, Cecchi and Rodriguez-Amaya [42] reported a loss of carotenoids during the manufacturing process, which including sieving and heating, while carotenoid degradation increased with higher temperatures.

Carotenoid content was statistically higher in frozen okra and in raw material (cooked and crushed). Canned okra was in the lowest statistical group. There was a difference of +57% in frozen compared to raw material and a difference of +85% between frozen and canned.

Total carotenoid content of frozen sweet potatoes was statistically the highest. It was more than 1.5 times higher than the crushed cooked sweet potato (raw material). Carotenoid content measured by Reddy and Sistrunk [43] in oven-cooked, steamed and canned sweet potatoes showed no significant difference. Water and microwave cooking nevertheless resulted in the lowest contents. Statistically, sweet potato flour had the least total carotenoids. This low content is due to oxidation of these compounds during the manufacturing process. Bechoff *et al*. [44] evaluated the loss of carotenoids at between 13% and 33% for different drying methods.

3.2.3. Impact on Vitamin C

A significant loss (5%) of the total Vitamin C between raw material and processed products in mamey apples was observed. There was no significant difference between canned and chips.

There was no significant difference between pure filtered mandarin juice and the pasteurized juice. There was lower loss of Vitamin C in orange juices following conventional treatment (9%), but much less when lower temperatures were applied [45]. Vitamin C content was significantly lower in canned mandarin. The loss of Vitamin C during sterilization is very significant. Vitamin C content of canned mandarin slices was the lowest and the difference compared to filtered fresh juice was more than 99%.

Vitamin C content of steamed sweet potatoes (raw material) was statistically the highest, followed by blanched frozen sweet potatoes. Amiot-Carlin *et al*. [45] reported that Vitamin C content generally decreased significantly following technological operations such as blanching. For peppers, a 12% loss of Vitamin C was observed after blanching [46].

Sweet potato flour was in the lowest statistical group with a total loss of Vitamin C. Vitamin C was sensitive to air drying. For peppers, the result of drying was an 88% loss of Vitamin C [46].

There was no significant difference (5%) in the Vitamin C content of steamed and blanched frozen christophine (raw material). Vitamin C content was significantly lowest in canned. Blanched frozen christophines were 1.5 times richer in Vitamin C than global values for zucchini and frozen green beans.

4. Discussion

This study highlights the nutritional profile and potential uses of fruits and vegetables from Martinique. Overall, fruit and vegetable from Martinique were richer than temperate fruits and vegetables in polyphenols, Vitamin C and total carotenoids. The antioxidant potential of tropical fruits and vegetables is little studied to date, and this first study demonstrates the richness of these plants, often not consumed. Lim *et al*. [47] found that guava, papaya and star fruit have higher primary antioxidant potential than orange (as measured by scavenging DPPH and iron (III) reducing assays). Luximon-Ramma *et al*. [4] demonstrated in common Mauritian exotic fruits, that there were strong correlations between antioxidant activity and total polyphenols, while very poor correlations were observed between Vitamin C content and antioxidant activity. The highest antioxidant capacities were observed in starfruit and guava. These Mauritian fruits were also characterized by high levels of total polyphenols. Mauritian exotic fruits are thus a significant source of phenolic antioxidants, which may have potential beneficial effects on health, such as fruits from Martinique. Finally, Ruffino *et al*. [48] showed promising perspectives for the exploitation of tropical fruit species with considerable levels of nutrients and antioxidant capacity, such as the considerable antioxidant capacity found for acerola, comparable to the fruit of Martinique.

In general, processing treatments had an effect on various nutrient contents in plants from Martinique. Heat treatment and cooking had a statistically significant effect. Boiling caused the diffusion of total polyphenols, while steaming had less impact. There was a statistically significant effect of vacuum frying on total carotenoid content. This loss was due to the distribution of carotenoids, which are soluble compounds, in the cooking oil. Total carotenoids were sensitive to oxidation and, to a lesser extent, sterilization. There was a statistically significant effect (5%) on Vitamin C content from sterilization, vacuum frying, drying and steaming. This effect was even more pronounced the higher the temperature and the longer the processing time. There is higher nutritional value in consuming a portion of fresh mamey because of its Vitamin C and antioxidant content. Although chips concentrated nutrients (carotenoids and total polyphenols) compared to raw material, their consumption provided fat and carbohydrates. A portion of mamey chips provides twice the level of carotenoids, 1.5 times the total polyphenols and twice as much fibre compared to the fresh fruit, but five times the carbohydrates and more than 100 times the fat. Pumpkin is of high nutritional value with a high carotenoid content. It is better to consume a steamed pumpkin portion for its carotenoid content whilst fresh-cut packaged is of value for the total polyphenol content. As for fresh mamey, we found that processing into chips concentrated nutrients (total polyphenols and carotenoids) but added fat. Pasteurization had little impact on nutritional and functional quality of mandarins. However, filtration of juice leads to the retention of several nutrients. Finally, sterilization resulted in a significant loss of vitamins. From a nutritional standpoint, it is better to consume pure mandarin juice for its Vitamin C and polyphenol contents. Steamed or frozen Okra (subsequently steamed) were very rich in total carotenoids and total polyphenols. Consumption in these forms offers a higher nutritional profile than consumption of the canned vegetable. Steamed sweet potato from Martinique was rich in carotenoids and polyphenols and a source of Vitamin C. Consumption of steamed or frozen (subsequently blanched) offers a higher nutritional profile than its consumption as sweet potato flour. Similarly, consumption of christophine after steaming offers more nutrients than its frozen or canned form. It was rich in antioxidants and a source of Vitamin C.

Cooking methods statistically decreased total polyphenol contents. Polyphenols are hydrosoluble and losses observed during blanching/freezing and sterilization processes are due to diffusion of these nutrients in blanching water and in cooking juices. Anthocyanin content decreased as blanching time increased [49]. Boiling in water caused flavonol losses of 20% and 40% respectively for onions and asparagus [50]. Price *et al*. [37] showed that canning did not cause chemical degradation of glycosides and flavonol, but losses occured through diffusion into cooking solutions, which varied depending on the compound. Vacuum frying had a statistically significant effect on carotenoid content. This loss was due to the diffusion of carotenoids, which are soluble compounds, in the frying oil. Total carotenoids might be susceptible to oxidation and sterilization, but to a lesser extent. Sahlin *et al*. [51] reported that frying tomato slices led to a higher loss of lycopene than boiling or steaming (decrease of 50% compared to fresh slices). Similarly, frying carrots showed a higher decrease in total carotenoid content than boiling or steaming [52]. The loss of carotenoids in the fresh-cut packaged products may be due to their oxidation during the manufacturing process. Degradation of carotenoids was due to light (photo-oxidation) or heat [53]. We observed a decrease in Vitamin C content during processing. In a study on the effects of different cooking methods on vegetables, Miglio *et al*. [52] showed a total loss of ascorbic acid when carrots were fried. Rickman *et al*. [54] reported systematic losses of ascorbic acid during heat treatment—up to 90% for canned carrots.

5. Conclusions

Tropical plants studied here had high nutritional and functional potential, especially in terms of antioxidant (polyphenols, carotenoids) and vitamin (nutrition) levels. The results showed that these values are equivalent to or even much higher than the levels found in commonly-consumed temperate plants known for their nutritional qualities. Fruits and vegetables from Martinique had a significant advantage in terms of their antioxidant capacity.

In conclusion, in order to get the most nutritional and functional value from tropical fruits and vegetables, it is recommended to consume them in fresh form for fruits, whilst vegetables should be eaten raw or cooked lightly using a method such as steaming. Boiling causes the diffusion of minerals and total polyphenols. Vacuum frying promotes a loss of total carotenoids and adds much more fat to the end product. Finally, cooking for longer times and at high temperatures, which is the case for sterilization (canning), causes a sharp decrease in vitamin content. Overall, this study shows that fruits and vegetables grown in Martinique provide numerous health benefits for humans.

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