Carbohydrate and bioactive compounds composition of starchy tropical fruits and tubers, in relation to pre and postharvest conditions: A review

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Abstract: In some tropical countries, people are suffering from both undernourishment and noncommunicable disorders, such as overweight/obesity. Starchy tropical fruits and tubers are of particular interest for their carbohydrate content and for the micronutrients they provide. The present study summarizes the content in carbohydrate, phenolics, carotenoids, and vitamin C, as well as the antioxidant activity of a wide range of tropical fruits and tubers. The energy content of fruits and tubers studied is in the range of 1,200 to 1,800 kJ/100 g of dry weight. They are thus important staple foods and, due to their diversity and seasonality, they can provide energy all year long by alternating the resources in the human diet. Starchy fruit and tuber crops have antiobesity properties as they are bulky, rich in moisture, and contain less than 2% of fat. Noncolored fruit and tubers provide total phenolics at about 20 to 140 mEq/100 g fresh weight. They thus have a high antioxidant capacity, as related to their total phenolic content but also to the presence of carotenoids, such as lutein, mostly in *Dioscorea bulbifera* and cocoyam. Yellow and orange-fleshed varieties contain more total phenolics and also more provitamin A carotenoids than noncolored fleshed ones. The contents in total phenolic and carotenoid greatly vary with the species and variety. The influence of pre and postharvest conditions on micronutrient content is discussed. Further studies on new processing methods are needed to maximize polyphenols and carotenoids retention in the foods and increase the bioaccessibility of these compounds.

Keywords: antioxidant activity, carbohydrates, carotenoids, phenolics, tropical resources

Practical Application: This paper provides information on the nutritional quality of starchy tropical fruits and tubers. Nutritional quality is studied from the point of view of providing energy and bioactive compounds. The paper aims to promote the use of local resources in tropical areas, which could ultimately limit the adverse effects of food globalization on noncommunicable disorders. It could also lead to tropical countries being less dependent on food imports.

1. INTRODUCTION

Between 2005 and 2015, there was a 18% decrease in the number of undernourished people in the world. However, 11% of the world's population is still suffering from hunger. Of these, more than 95% are living in developing countries (FAO, IFAD, & WFP, 2017). Numerous changes in human diets have simultaneously occurred due to globalization of food and lifestyle (Martins, Barros, & Ferreira, 2016). These changes heavily affect tropical countries and have resulted in a higher consumption of high energy density and low-nutrients foods (Faller & Fialho, 2009a). Such unbalanced diets are a triggering factor for an increase in metabolic and degenerative disorders in humans (Clerici & Carvalho-Silva, 2011; Martins et al., 2016). Therefore, undernourishment and noncommunicable disorders, such as overweight/obesity, now coexist in some developing countries. As an example, the prevalence of overweight is higher than 40% in South America, North Africa, and the Middle East (WHO, 2019). Moreover, two billion people suffer from micronutrient deficiency (Sanginga & Mbabu, 2015). In particular, vitamin A deficiency leads to acquired blindness in 140 million young children. Thus, it is still an important public health problem in some countries of the sub-Saharan and South-East Asian regions (Davey, Van den Bergh, Markham, Swennen, & Keulemans, 2009; Ekesa, Nabuuma, Blomme, & Van den Bergh, 2015). Plant-derived foods have a high antioxidant activity, which might be related to health benefits, especially where noncommunicable diseases are concerned (Chandrasekara & Kumar, 2016; Isabelle et al., 2010). This antioxidant activity might be mainly due to their phenolic content (Alothman, Bhat, & Karim, 2009; Haminiuk, Maciel, Plata-Oviedo, & Peralta, 2012), but also to their vitamin C and carotenoid contents (Carocho & Ferreira, 2013).

Starchy fruits and tubers, such as banana, cassava, yam, and sweet potato, are described as staple foods in many tropical countries (Lassois, Busogoro, & Jijakli, 2009; Mejia-Agüero, Galeno, Hernandez-Hernandez, Matehus, & Tovar, 2012; Satheesh & Solomon, 2019; Wani et al., 2017). There has been less focus on their use as sources of bioactive compounds. Having a better knowledge of those starchy staples as sources of natural antioxidants (Rumbaoa, Cornago, & Geronimo, 2009), taking into account their biodiversity, could contribute both to providing energy in the human diets and to health benefits (Wani et al.,

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doi: 10.1111/1750-3841.15002
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Journal of Food Science A Publication of the Institute of Food Technologists

Table 1–World production and supply of starchy fruits and tubers as compared to cereals (FAOSTAT, 2017).

	World production (x 10^6 T)	Main area of production	Food supply (g/capita/day)	Energy supply (kJ/capita/day)	Energy supply (% energy needed)
Total cereals	2,759	Asia: 49%	403	6,470	53.7
Roots, tubers, and banana crops	1,028	Asia: 48%	207	1,010	8.6
Potatoes	388	Asia: 50%	95[a]	470	3.9
Cassava	292	Africa: 61%	40[b]	200	1.7
Sweet potato	112	Asia: 71%	22	130	1.1
Yam	73	Africa: 97%	12	50	0.4
Taro	10	Africa: 73%	Not available	Not available	Not available
Banana	114	Asia: 54%	33	120	1.0
Plantain	39	Africa: 60%	10	40	0.3

[a]Food supply for potatoes and products.
[b]Food supply for cassava and products.

2017). This paper aims to study potato, cassava, yam, sweet potato, taro, cocoyam, dessert and cooking bananas, breadfruit, and jackfruit for their carbohydrate composition. It also examines their phenolic, carotenoid, and vitamin C content in relation to their genetic variability and pre and postharvest conditions. Processing is also taken into account as in starchy foods cooking modifies the content in total phenolics and antioxidant activity. Such changes are in relation to modifications in the physical state of starch, as reported in cassava (Silva de Lima et al., 2017).

2. WORLD PRODUCTION OF STARCHY TROPICAL FRUITS AND TUBERS AND THEIR CARBOHYDRATE AND MICRONUTRIENT COMPOSITION

2.1 World production

According to data from the Food and Agriculture Organization (FAO), world production of starchy fruits and tubers is 2.7 times lower than cereal production (Table 1) (FAOSTAT, 2017). Therefore, cereals provide up to 6,470 kJ/capita/day in the human diet, that is, an average of 53.7% of the total energy consumed daily. Worldwide, starchy fruits and tubers provide on average 8.6% of the dietary energy, corresponding to an intake of 1,010 kJ/capita/day. However, there is a wide variation from one region to another. In Africa, they supply 26% of the energy consumed each day. The corresponding figure is only 13% in the Caribbean and no more than 2% in Oceania (FAOSTAT, 2017). In Africa, people globally consume 540 g of fresh tubers per capita, mainly cassava and yam, and 75 g of banana and plantain every day. Africa is, therefore, the main area of production of cassava, yam, taro, and plantain (Table 1). In this area, cassava and yam provide energy to 500 and 60 million people, respectively (Sanginga & Mbabu, 2015). These data clearly show that starchy fruits and tubers are major staple foods in some tropical regions, such as Africa, the Caribbean, and to a lesser extent South Asia. The low quantity of starchy local foods eaten in Oceania, nowadays, is quite startling. It may be due to the very quick replacement of local foods by rice and other imported foods in the Pacific Islands.

2.2 Carbohydrate composition

Starchy fruits and tubers have been used as important sources of energy over the years due to the carbohydrates (that is, starch, soluble sugars, and dietary fiber) they provide. Starch is the major component of the dry weight (DW) of the edible part of these plant foods (Table 2). In tuber crops, the starch content of the pulp is in the range of 65% to 87% of DW. The lowest starch content was recorded in sweet potato and *Dioscorea (D.) trifida* and the highest in cassava and cocoyam. As compared to other components, starch content shows a weak variability with the species or the variety, as previously reported by Champagne, Legendre, and Lebot (2009). Among tubers, sweet potato and *Dioscorea esculenta* are the richest in total sugars, providing about 10 to 11 g of total sugars/100 g DW (Champagne et al., 2009). The content in total sugars of other tubers is generally low, at about 1.2% to 5.7% of DW (Lebot, Malapa, & Molisale, 2018a). However, it greatly depends on the genotype (Champagne et al., 2009; Otegbayo, Asiedu, & Bokanga, 2011).

In fruits, the starch content of the pulp highly varies with the maturation stage. The pulp of mature breadfruit and mature plantain supplies about 78 g of starch/100 g of DW, which is richer than that of dessert banana (Table 2) (Gibert et al., 2009; Soares et al., 2011). A difference of up to 15 g of starch per 100 g of DW, between plantain and dessert banana, has been reported, even when they both have the same genotype (*Acuminata Acuminata Balbisiana* [AAB]) (Soares et al., 2011). Ripening induces starch degradation and accumulation of soluble sugars, mainly sucrose, glucose, and fructose. When they are ripe, the pulp of plantain still provides a starch content of 28 to 41 g/100 g of DW, which is higher than that of dessert bananas (Soares et al., 2011). However, due to the almost complete degradation of starch, over-ripe plantain exhibits a content in soluble sugars similar to that of dessert bananas, including Cavendish variety (Fils-Lycaon et al., 2011). The starch content of the pulp of breadfruit and the seeds of jackfruit is about 78 g/100 g of DW, which is close to the starch content of cooking banana (Table 2). Starch resistant to *in vitro* enzymatic hydrolysis is in the range of 5.0 to 19.6 g/100 g DW in cassava grown in Venezuela, varying with the variety (Mejia-Agüero et al., 2012). Chinese yam (*Dioscorea opposita*) and breadfruit have been reported to contain 55 to 62 and 8.4 g of resistant starch/100 g DW, respectively (Chen et al., 2017; Tan et al., 2017). The presence of resistant starch induces a slow degradation of starch. Resistant starch is a favorable factor to limit noncommunicable disorders, mainly obesity and diabetes. It should be taken into account when rating starchy fruit, root, and tuber crops for their nutritional benefits.

According to Champagne et al. (2009), the cellulose content of tubers varies from 2.1 g/100 g of DW in some *Dioscoreaceae* to 4.2 g in sweet potato. Globally, root and tuber crops have a rather good nutritional profile with high contents in fibers and a low lipid content, under 1 g/100 g DW in yam and sweet potato (Adepoju, Boyejo, & Adeniji, 2018; De Oliveira et al., 2019; Perez et al., 2011). However, they are deficient in vitamins, with the exception of vitamin C in cassava and *Dioscorea cayenensis* and vitamin

Table 2–Carbohydrate composition and energy content of the edible part of tropical starchy fruits and tubers.

		Area of origin[a,b]	Dry weight (DW) (%)	Starch (g/100 g of DW)	Total sugars (g/100 g of DW)	Fibers (g/100 g of DW)	Energy (kJ/100 g of DW)	Authors
Tubers pulp	Potato *Solanum tuberosum*	Highlands of South America	25	61 to 80	4.8	9.6 (TDF)	1,150	(a)
	Cassava *Manihot esculenta*	South America	34 to 38	74 to 87	4.4 to 5.0	3.4 (C)	1,580[c]	(d)
	Sweet potato *Ipomea batatas*	Central America	23 to 44	65 to 70	10.2	2.6 to 4.2 (C) 0.5 to 4.5 (CF)	1,370[c] to 1,560	(e)
	Yam *Dioscorea cayenensis-rotundata*	Western Africa	31 to 43	70 to 86	1.9 to 4.6	0.51 (CF) to 2.1 (C)	1,230 to 1,360	(f)
	Dioscorea dumetorum	Western Africa	30	68	1.2 to 3.8	2.9 to 3.7 (C)	1,600	(g)
	Dioscorea alata	South Asia	24 to 43	65 to 76	2.1 to 5.7	2.3 (CF) 14 (TDF)	1,500 to 1,630	(h)
	Dioscorea esculenta	South Asia	19 to 33	78	5.0 to 11.3	2.1 (C)	1,570 to 1,790	(i)
	Dioscorea bulbifera			73	7.4	2.9 (C)	1,530	(j)
	Dioscorea trifida	Tropical part of America	25 to 31	63	2.3	4.3 to 12.7 (TDF)	1,630[c]	(k)
	Taro *Colocasia esculenta*	South-East Asia	14 to 30	78	5.1	3.4 (C)	1,220 to 1,480[c]	(l)
	Cocoyam *Xanthosoma sagitifolium*	South America	28 to 40	86	2.2	3.3 (C)	1,240 to 1,560[c]	(l)
Fruits	Dessert banana pulp *Musa* sp.	South-East Asia	22 to 31	44 to 61 (MG) 2 to 6 (FR)	0.5 (MG) 12 to 16 (FR)	2.1 to 4.4. (TDF)	1,200[c]	(m)
	Cooking banana pulp Plantain (*Musa paradisiaca*)	South-East Asia	32 to 44	74 to 80 (MG)	0.7 to 1.6 (MG)	2.8 (TDF)	1,100 to 1,300[c]	(n)
				28 to 41 (FR)	9.0 (FR)	1.4 to 1.8 (CF)		
			43 (MG)		1.4 to 3.1 (MG)	3.3 (TDF, MG)		
	Nonplantain		33 (R)	52 to 85 (MG) 17 (R)	14 (R)	1.6 (CF, R)	1,500 (MG)	
	Breadfruit pulp *Artocarpus altilis*	Oceania	27.5 (MG) to 21.5 (R)	77 (MG)			1,140 to 1,640	(o)
	Jackfruit seeds *Artocarpus heterophyllus*	India	37 to 53 (MG) 46 (R)	79 (MG)		8.9 (CF, MG) 7.3 (CF, R)	1,650	(p)

(a) Chandrasekara & Kumar, 2016
(b) Lassois et al., 2009
(c) Estimated energy content calculated from carbohydrates, protein, and fat using 16.74, 16.74, and 37.67 kJ/g, respectively.
C, cellulose; CF, crude fiber; TDF, total dietary fiber; MG, mature green; R, ripe.
(d) Champagne et al., 2009; Mejia-Agüero et al., 2012; Lebot et al., 2018a
(e) Champagne et al., 2009; De Oliveira et al., 2019; Sateesh & Solomon, 2019
(f) Adepoju et al., 2018; Baah, Maziya-Dixon, Asiedu, Oduro, & Ellis, 2009; Champagne et al., 2009; Otegbayo et al., 2011; Wireko-Manu, Ellis, Oduro, Asiedu, & Maziya-Dixon, 2011
(g) Lebot et al., 2018a; Otegbayo et al., 2011
(h) Baah et al., 2009; Ezeocha & Ojimelukwe, 2012; Lebot et al., 2018a; Njoh Ellong et al., 2015; Otegbayo et al., 2011; Wireko-Manu et al., 2011
(i) Champagne et al., 2009; Lebot et al., 2018a
(j) Champagne et al., 2009
(k) Lebot et al., 2018a; Perez et al., 2011
(l) Champagne et al., 2009
(m) Gibert et al., 2009; Soares et al., 2011
(n) Fils-Lycaon et al., 2011; Gibert et al., 2009; Khawas et al., 2014; Soares et al., 2011
(o) Bramont et al., 2018; Clerici & Carvalho-Silva, 2011; Englberger et al., 2014
(p) Bramont et al., 2018; Juárez-Barrientos et al., 2017; Madrigal-Aldana et al., 2011

A in yellow-orange fleshed roots (Chandrasekara & Kumar, 2016).

It is noteworthy that the energy contents of the plant foods cited in the present study are all in the range of 1,100 to 1,800 kJ.100 g^{-1} of DW. This is related to the carbohydrate contents of these crops, which were alike and amounted 73% to 96% of dry matter, as reported in yam, sweet potato, and jackfruit seeds (De Oliveira et al., 2019; Juárez-Barrientos et al., 2017; Perez et al., 2011). These starchy fruits and tubers are major staple foods that can be used all year long or if there is a grains shortage. Moreover, the plant foods studied here are bulky, and generally contain low levels of lipids and sugars. So, tubers and mature green plantain and banana should be recommended for their antiobesity activity.

2.3 Micronutrient composition

Many authors have dealt with the macronutriment composition of these plant foods. However, less is known about the micronutriments they contain and the related health benefits. *D. opposita* in China (Chen et al., 2017), *Dioscorea bulbifera* in Africa and India (Ikiriza et al., 2019) are considered as medicinal plants due to the phytochemicals they provide. Moreover, people pay attention to orange-fleshed sweet potato (OFSP), banana, and plantain, and to yellow varieties of yam and cassava in relation to the β-carotene and provitamin A they supply (Chandrasekara & Kumar, 2016; Satheesh & Solomon, 2019). Tuber and root crops contain bioactive compounds, that is, secondary metabolites exhibiting pharmacological and toxicological effects in humans (Chandrasekara & Kumar, 2016). The bioactive compounds

Table 3–Contents in total phenolics, vitamin C, carotenoids, and the presence of other bioactive compounds in the edible part of tropical starchy fruits and tubers.

		Total phenolics (mEq/100 g FW)	Flavonoids (mg CE/100 g FW)	Vitamin C (mg/100 g FW)	Total carotenoids (µg/100 g FW)	Provitamin A carotenoids (µg/100 g FW)	9-*cis*-β-carotene (µg/100 g FW)	Lutein (µg/100 g FW)	Other bioactive compounds	Authors
Tubers pulp	Potato *Solanum tuberosum*	8 to 18	8.5	8.6 to 19.7	66; 98; 307			2.9; 42.1; 69.2; 116.5	Glycoalkaloids (α-chaconine, α-solanine)	(a)
	Cassava *Manihot esculenta*	8	2.2	20.6		14 to 679	tr. - 189.1	n.d. – 4.9	Cyanogenic acid glycosides	(b)
	Sweet potato *Ipomea batatas*	44 – 50; 105; 261; 365 (OF)	16.5	0.3 to 3.2	34 - 112 72; 191 (OF)	n.d - 145.4; 21.9 (OF)	n.d.; 282; 980 (OF)	n.d. – 134 (OF)	Bioactive protein (sporamin), phytates, oxalates	(c)
	Yam									
	D. cayenensis rotundata	34	15.1	14.4		tr. - 7.7 – 10; 34.2 - 52.9	n.d.	n.d. - tr.	Saponins (dioscin, gracilllin)	(d)
	D. dumetorum				1,873	40.5 - 297.9; 890	30		Alkaloids (dioscorine), phytates, oxalates	(e)
	D. alata	26 – 140; 478	1.4 to 4.1	3.1 to 3.9		tr. - 16; 56.3 - 87.1	n.d.	n.d .- tr.	Bioactive protein (saponins), alkaloids (dioscorine)	(f)
	D. esculenta	20 to 51				tr. - 7	n.d.	tr.	Saponins (dioscin, gracillin)	(g)
	D. bulbifera					n.d .- 11	n.d.	12.4 to 67.9		(h)
	Taro *Colocasia esculenta*	139	71			tr. - 146	tr. - 18.0	tr. - 11.4	Oxalates, phytates	(i)
	Cocoyam *X. sagitifolium*	94	14.5			n.d.	n.d.	11.4 to 19.1		(j)
Fruit pulp	Dessert banana *Musa* sp.	1.1 -70; 161 (MG)	0.011 to 5.6	4.5 to 12.7	54; 197	58; 170 (MG)	0 to 43 (MG)	6 to 90 (MG)		(k)
	Cooking banana									
	Plantain *Musa paradisiaca*	38-60 -198 (MG)	40.2 to 95.0 (MG)	0.2 - 6.1 - 9.3	62 (MG) -124 (R)	27 to 84		7 to 40	Oxalates, phytates	(l)
	Nonplantain	40-77 -168 (MG) 31 (R)			0.15 (MG)- 0.16 (R)				Oxalates, phytates	
	Bread fruit *Artocarpus altilis*	34 to 137	1.1 to 1.6	9.9	19 (MG) - 45 (R)	<5 (MG) - 15 (R)				(m)
	Jackfruit pulp *Artocarpus heterophyllus*	47 to 70	1.4	2.0 to 14.8	34 – 140 - 396	10 – 53 - 315	0.36 to 0.99	15 to 55		(n)

mEq/100 g FW : mg G.A.E.100 g^{-1} FW: mg gallic acid (or chlorogenic acid) equivalent. 100 g^{-1} of fresh weight; Provitamin A carotenoids = α-carotene + β-carotene + β-cryptoxanthin.
FW, fresh weight; CE, catechin equivalent; *D., Dioscorea; OF, Orange-fleshed.*
tr., traces; n.d., not detected.
MG, mature-green; R, ripe.
(a) Chandrasekara & Kumar, 2016; Dilworth et al., 2012; Hamouz et al., 2016; Lachman et al., 2013
(b) Champagne et al., 2010; Chandrasekara & Kumar, 2016; Omar et al., 2012
(c) Champagne et al., 2010; Dako et al., 2016; De Oliveira et al., 2019; Dilworth et al., 2012; Rumbaoa et al., 2009; Sateesh & Solomon, 2019
(d) Adepoju et al., 2018; Champagne et al., 2010; Dilworth et al., 2012; Price et al., 2018
(e) Abiodun & Akinoso, 2014; Ferede et al., 2010; Price et al., 2018
(f) Champagne et al., 2010; Cornago et al., 2011; Dilworth et al., 2012; Ezeocha & Ojimelukwe, 2012; Fang et al., 2011; Njoh Ellong et al., 2015; Price et al., 2018
(g) Champagne et al., 2010; Cornago et al., 2011
(h) Champagne et al., 2010; Lebot et al., 2018a
(i) Champagne et al., 2010; Dilworth et al., 2012; Kaushal et al., 2012
(j) Champagne et al., 2010; Dilworth et al., 2012
(k) Alothman et al., 2009; Ekesa et al., 2015; Lokesh et al., 2014; Passo Tsamo et al., 2014; Singh et al., 2016
(l) Ekesa et al., 2015; Isabelle et al., 2010; Khawas et al., 2014; Lokesh et al., 2014; Passo Tsamo et al., 2014; Singh et al., 2016; Sulaiman et al., 2011
(m) Bramont et al., 2018; Dilworth et al., 2012; Englberger et al., 2014
(n) Bramont et al., 2018; Clerici & Carvalho-Silva, 2011; De Faria et al., 2009; Isabelle et al., 2010

in tuber and roots are phenolics, including flavonoids and anthocyanins, carotenoids and vitamin C (Adepoju et al., 2018; Ikiriza et al., 2019; Satheesh & Solomon, 2019). Starchy tropical fruits and tubers also contain antinutrient compounds, such as tannins, oxalate, phytate, and saponins as recorded in unpeeled sweet potato in Ethiopia, taro in India, and in *D. cayenensis* and *Dioscorea alata* in Nigeria (Table 3) (Adepoju et al., 2018; Dako, Retta, & Desse, 2016; Ezeocha & Ojimelukwe, 2012; Kaushal, Kumar, & Sharma, 2012). Tannins and phytates were also found in cooking nonplantain banana (ABB) in India (Khawas, Das, Sit, Badwaik, & Deka, 2014). In the present study, we are dealing mostly with secondary metabolites with health benefits, which are involved in antioxidant activity and vitamin A metabolism.

Table 3 shows the total phenolic, total flavonoid, vitamin C, total carotenoid, provitamin A carotenoid, and lutein contents of the edible parts of the crops in which we are interested. Phenolics are compounds with an aromatic ring plus at least one hydroxyl group and they have an antioxidant activity (Chandrasekara & Kumar, 2016). Vitamin C, also called ascorbic acid, is not an antioxidant compound *per se*, but it can reduce oxidized phenolics and thus renew the original pool of phenolics. Carotenoids are pigments linked to the yellow-orange color of many fruits and vegetables. Some of them, mainly α- and β- carotene and β-cryptoxanthin, have a provitamin A activity (De Faria, de Rosso, & Mercadante, 2009). Others, such as lutein, which is a xanthophyll, have no provitamin A activity, but have an antioxidant potential (Price, Bhattacharjee, Lopez-Montes, & Fraser, 2018; Satheesh & Solomon, 2019). In Table 3, the figures highlighted in orange, red, or purple correspond, respectively, to varieties with orange, red, or purple flesh. It has previously been pointed out that potatoes should be considered as considerably richer source of micronutrients than of energy, as they contain several vitamins, especially vitamin C, and phenolics (Lachman et al., 2013). Table 3 indicates that tropical tubers, especially sweet potato, taro, cocoyam, and some species of yam (*D. alata*), have a much higher total phenolic content than potato, with the exception of cassava which is the poorest. Noncolored tropical tubers provide 20 mEq to 140 mEq total phenolics/100 g of FW compared with 10 to 20 mEq in yellow-fleshed potato. Among tubers, total flavonoids vary from 2.2 mg catechin equivalent (CE)/100 g FW in cassava to 71 mg in taro (Table 3). Starchy fruits are poorer in total flavonoids than tubers, with the exception of mature green plantain which supplies 40.2 to 95.0 mg CE/100 g FW.

Potatoes provide globally more vitamin C than the tropical raw materials studied here (Table 3), but *D. cayenensis* and cassava are in the range of potato and contain 14.4 and 20.6 mg vitamin C/100 g FW, respectively. Potatoes only contain traces of carotenoids, unless they are colored-fleshed (Table 3). Among noncolored-fleshed tubers, sweet potato, *Dioscorea dumetorum* and cassava have the highest content in total carotenoids and provitamin A carotenoids. As an example, they provide up to 145.4, 297.9, and 679 µg of provitamin A carotenoids/100 g FW, respectively (Table 3). Enhancing the consumption of cassava and sweet potato will allow to meet human requirements for vitamin A. The contents in 9-*cis*-β-carotene and lutein are also shown in Table 3. The vitamin A activity of 9-*cis*-β-carotene was shown to be 38% of that of all-*trans*-β-carotene (Davey et al., 2009). On the contrary, the *in vitro* antioxidant activity of 9-*cis*-β-carotene is higher than that of all-*trans*-carotenoid isomers (Ekesa, Mirroir, Blomme, Van den Bergh, & Davey, 2013). This difference may be due to the more pronounced reactivity of *cis* isomers as compared to *trans* ones. In noncolored fleshed tubers, cassava exhibits the highest content in 9-*cis*-β-carotene, up to 189.1 g/100 g FW (Table 3). This indicates that the antioxidant activity of cassava might be partially due to this compound. In sweet potato, the color of orange-fleshed tuber is partially linked to lutein and zeaxanthin (Sateesh & Solomon, 2019). So, the orange color does not always correlate with provitamin A activity (Price et al., 2018). In noncolored fleshed root and tuber crops, the lutein content is generally low, with the exception of cocoyam and *D. bulbifera,* which provide 19.1 and 67.9 µg of lutein/100 g FW, respectively (Table 3).

As far as fruits are concerned, dessert bananas are in the range of potato for total phenolic content, except for an orange-fleshed one, called red banana, which is richer and contains up to 161 mEq/100 g FW (Passo Tsamo et al., 2014). The total phenolic content of cooking bananas, either plantain (AAB) or nonplantain (ABB), is generally higher than that of dessert bananas and varies from 38 to 198 mEq/100 g FW (Table 3). Some starchy fruits can be a good source of vitamin C, as compared to root and tuber crops. Some varieties of dessert banana as well as breadfruit and jackfruit pulps supply about 9.9 to 14.8 mg of vitamin C/100 g FW. Ripe dessert bananas, plantain, and jackfruit pulp are of nutritional interest for their carotenoids supply (Table 3). They contain 25 to 84 g/100 g FW of provitamin A carotenoids, which is somewhat lower than the provitamin A carotenoids supplied by cassava, sweet potato, and some yam species. Mature green starchy fruits contain a higher level of lutein than most of noncolored-fleshed root and tuber crops, amounting 6 to 40 g/100 g FW.

3. ANTIOXIDANT ACTIVITY AND ITS COMPONENTS

Table 4 indicates the antioxidant activities of starchy resources using DPPH or ABTS assays. Both methods are based on the deactivation of free radicals via electron transfer. ABTS allows the determination of antioxidant activity of compounds that are either hydrophilic or lipophilic, contrary to DPPH. The correlation between DPPH and ABTS is generally high and, as an example, was found to be 0.94 in jackfruit pulp in Mexico (Ruiz-Montanez et al., 2015).

In Table 4, tubers and fruits are ranked from the highest to the lowest antioxidant activities, which vary greatly (Table 4). The percentage of oxidation inhibition for DPPH is in the range of 95.8 in *D. alata* to 12.2 in the pulp of mature-green jackfruit in noncolored-fleshed fruits. Starchy fruits and tubers can be ranked according to their antioxidant activities, on the basis of the percentage of oxidation inhibition when using DPPH assay (Table 4). Among tubers, *D. alata*, taro, and sweet potato have the highest antioxidant activity, whereas cocoyam has the lowest. In fruits, it is shown that the pulp of plantain and dessert bananas exhibits the highest percentage of oxidation inhibition and breadfruit has the lowest.

Total phenolics and total flavonoids are generally considered to be the main contributors to antioxidant activity, as shown in banana, jackfruit, and sweet potato (Alothman et al., 2009; Barreto, Benassi, & Mercadante, 2009; Rumbaoa et al., 2009). The correlation between DPPH or ABTS and total phenolics was shown to be about 0.9 in various tropical fruit and root crops (Barreto et al., 2009), 0.83 in sweet potato (Rumbaoa et al., 2009), and 0.77 in yam (Cornago, Rumbaoa, & Geronimo, 2011). The correlation between ABTS and total flavonoids is also high, about 0.86 in the pulp of tropical crops from Brazil (Barreto et al., 2009), in good agreement with the findings in Chinese yam (*D. opposita*) (Chen et al., 2017). Among phenolics, flavonoids may thus have a high antioxidant activity. However, in some cases, the correlation

Table 4–Antioxidant activity of the edible part of starchy fruits and tubers produced in tropical and subtropical areas.

		Antioxidant activity DPPH			
		(% inhibition)	EC50[a]	ABTS (µm ET/mL)	Authors
Tubers pulp	*Dioscorea alata*	95.8	5.6 - 65.5		Cornago et al., 2011; Dilworth et al., 2012
	Taro *Colocasia antiquorum*	93.4	0.50		Dilworth et al., 2012
	Sweet potato *Ipomea batatas*	28.0 - 88.5 92.0; 92.6	0.8 - 1.58 24.7; 10.3; 3.7		Dilworth et al., 2012; Shih et al., 2009; Rumbaoa et al., 2009
	Cassava *Manihot esculenta*	44.4			Omar et al., 2012
	Potato *Solanum tuberosum*	20.5	1.25		Dilworth et al., 2012
	Dioscorea cayenensis-rotundata	13.6	3.13		Dilworth et al., 2012
	Dioscorea esculenta	12.0 to 57.0			
	Cocoyam *Xanthosoma sagitifolium*	12.6	2.90		Dilworth et al., 2012
Fruit pulp	Cooking banana plantain *(Musa paradisiaca)*	61.1 to 74.4			Sulaiman et al., 2011
	Dessert banana *Musa* sp.	56.5	4		Alothman et al., 2009; Sulaiman et al., 2011
	Cooking banana Nonplantain	52.7 (MG)-39.6 (R)	3 - 22		Khawas et al., 2014
	Jackfruit pulp *Artocarpus heterophyllus*	12.2 (MG)19.7 (R)		9.1 (MG) - 10.3 (R)	Ruiz-Montanez et al., 2015
	Bread fruit *Artocarpus altilis*	10.6	2.8		Dilworth et al., 2012

ABTS, 2,2'-azino-bis(3-ethylbenzothiazolin-6-sulphonic acid) used to measure radical-scavenging activity; DPPH, 2,2-diphenyl-1-picrylhydrazyle (µmoles of Trolox equivalent.100 g^{-1} of FW) used to measure radical-scavenging activity.
[a]EC50 value is the sample concentration (mg/mL or mg/mg sample) at 50% activity.

between DPPH and total phenolic content dropped to 0.02 in Malaysian bananas (Sulaiman et al., 2011). This low correlation suggests that other components contribute to antioxidant activity, with interrelated synergistic and antagonistic effects. The contribution of ascorbic acid to antioxidant activity is much lower than that of phenolics in starchy food. It has been estimated to 2% in jackfruit (Isabelle et al., 2010). As far as carotenoids are concerned, β-carotene was recorded to contribute to 3% to 53% of total antioxidant activity in sweet potatoes with varying flesh colors (Teow et al., 2007). However, the contribution of those lipophilic constituents to antioxidant activities is not easy to rate. As DPPH and ABTS have no similarity with the radicals involved in lipid peroxidation, these methods cannot be used to effectively evaluate lipophilic micronutrients.

The influence of intrinsic and extrinsic factors on total phenolic content, total carotenoid, and antioxidant activity is also documented in this paper. Vitamin C is not taken into consideration due to its low contribution to antioxidant activity.

4. INFLUENCE OF INTRINSIC FACTORS SUCH AS GENOTYPE AND TISSUE ON PHENOLIC AND CAROTENOID CONTENTS

Genotype is a main source of variability in the micronutrient content in starchy resources as reported in sweet potato, yam, and banana (Nadia et al., 2015; Shih, Kuo, & Chiang, 2009; Singh, Pal Singh, Kaur, & Singh, 2016). In yam, species influence total phenolic content. *D. cayenensis* is often reported to be low in total phenolic content, whereas *D. alata* seems to be the richest in this compound (Table 3). Within a species, the variability in total phenolics is as marked as from one species to another. In *D. alata*, total phenolic content was recorded to be almost six times higher in purple variety than in a noncolored one. In sweet potato, in yellow and purple varieties, total phenolics amounts 2.2 and 5.2 times more than in the white-fleshed variety, respectively (Table 3). A concomitant increase in antioxidant activity was observed. DPPH inhibition at 50 mg/mL was recorded to be 93% in purple-fleshed varieties and 88% white-fleshed one (Rumbaoa et al., 2009). In purple varieties of sweet potato, anthocyanins contribute up to 25% of the antioxidant activity of the flesh (Philpott, Gould, Markham, Lewthwaite, & Ferguson, 2003). *In Musa*, within dessert and nonplantain cooking bananas, the total phenolic content is highly related to the genotype (A compared with AB) (Passo Tsamo et al., 2014). Plantain (AAB) is reported to be the richest in total phenolics, in the range of 37 mEq to 154 mEq/100 g FW (Passo Tsamo et al., 2014).

Recent interest has dealt with the phenolic profile of tropical starchy fruits, roots, and tubers (Champagne, Hilbert, Legendre, & Lebot, 2011; Lebot et al., 2018a; Passo Tsamo et al., 2015; Ramos-Escudero, Santos-Buelga, Perez-Alonso, Yanez, & Duenas, 2010). There are wide inter- and intraspecific variations in phenolic profiles (Champagne et al., 2011; Lebot et al., 2018a). As an example, it has been reported that most phenolic acids in sweet potato are chlorogenic, caffeic, and 3,5-dicaffeoylquinic acids, whereas no phenolic acid was found in cocoyam. These differences based on genotype indicate that biosynthetic pathways change from one species to another. Purple-fleshed root and tuber crops have the most complex phenolic profile as they contain anthocyanins. Twelve different anthocyanins have been identified in purple-fleshed yam (*D. trifida*) and sweet potato (Ramos-Escudero et al., 2010; Xu et al., 2014). Most anthocyanins in these plant foods are acylated, which goes together with a higher antioxidant activity than nonacylated anthocyanins (Luo, Zhou, Yang, Wang, & Zhang, 2018). So, the highest antioxidant activity of purple-fleshed yam and sweet potato might be related to the structure of anthocyanins they contain. However, most studies on the

phenolic profile have dealt with HPLC or HP-TLC techniques (Champagne et al., 2011; Lebot et al. 2018a; Nadia et al., 2015). So, individual phenols have been tentatively identified. More work is needed using mass spectrometry and nuclear magnetic resonance techniques for formal identification and a more accurate quantification.

Total carotenoid content is also dependent on the species and variety (Singh et al., 2016). In yam, the carotenoid content was the highest in *D. dumentorum*; *D. esculenta* and *D. bulbifera* were the poorest in this compound (Table 3). Yellow varieties of *D. dumetorum* contain 12 and 20 times more provitamin A carotenoids than *D. alata* and *D. cayenensis*, respectively. However, the low content in β-carotene of 7.7 g/100 g FW in yellow yam (*D. cayenensis*) grown in Nigeria suggests that the color of the flesh is not only linked to β-carotene (Adepoju et al., 2018). Other carotenoids and flavonoids might also contribute to the color of the flesh. Varieties with high carotenoid contents have been reported in sweet potato, jackfruit, and plantain (Table 3). OFSP draws particular interest for nutrition as it provides both high levels of total phenolics and total carotenoids (Sateesh & Solomon, 2019). These compounds amount 365 mg and 191 g/100 g FW, respectively, which is 3.5 and 2.7 times higher than yellow-fleshed sweet potato. Concerning the carotenoid profile, in Taïwan, OFSP contains 8.6 times more β-carotene than yellow-fleshed sweet potato (Shih et al., 2009). A DPPH oxidation inhibition of 92% was found in OFSP, which is promoted in different countries in Africa. In *Musa*, the yellow-orange pulp of plantain varieties (AAB) provided about twice more total carotenoids and provitamin A carotenoids than the dessert ones (AAA and AA) and the nonplantain cooking banana (ABB) (Davey et al., 2009; Ekesa et al., 2012, 2013), with the exception of red AAA banana (Lokesh, Divya, Puthusseri, Manjunatha, & Neelwarne, 2014). In plantain, the provitamin A carotenoids are generally in the range of 27 to 84 g/100 g FW (Table 3), which represented more than 87% of total carotenoids (Ekesa et al., 2013). It is noteworthy that in yellow-fleshed jackfruit and *D. dumetorum*, which is the richest *Dioscoracae* species in carotenoids, the corresponding figures are 36% and 52% of total carotenoids, respectively (De Faria et al., 2009; Ferede, Maziya-Dixon, Alamu, & Asiedu, 2010). In Burundi, four orange-fleshed plantain varieties (AAB) were selected as they were much richer in carotenoids than the average of their subgroup. These varieties contain from 1,098 to 4,680 μg of provitamin A carotenoids.100 g^{-1} FW. Ekesa et al. (2015) recommend the promotion and adoption of these varieties introduced from Ghana and the Pacific region, in replacement of local varieties, to improve vitamin A content of the diet. Either due to anthocyanins or carotenoids, coloration thus often goes together with a higher antioxidant activity, as shown in red and purple potato (Lachman et al., 2013).

Modern agriculture has successfully produced high-yield crops, but it has enormously narrowed the number of commercial crops available and led to a dramatic loss of biodiversity. Biodiversity is still important in tropical areas, but it is also threatened. As an example, *D. bulbifera* is about to disappear in some regions of Africa. Its bulbils are used for medicinal purposes in Africa and India, but this resource is overexploited (Ikiriza et al., 2019). The introduction or promotion of varieties rich in micronutrients can have a positive impact on micronutrients deficiencies and the health of inhabitants of tropical regions. In the United States and Japan, orange- and purple-fleshed sweet potatoes are promoted for their nutraceutical value (Sateesh & Solomon, 2019). To enhance this promotion, a wide range of processed products, including juices, bread, cookies, and porridge, have been developed using these varieties. Most breeding programs deal with the resistance to biotic and abiotic stress (pathogens, drought, and so on) and rarely evaluate the nutritional quality traits of the selected varieties. Micronutrient supply could also be increased by selective breeding taking into account micronutrient content. However, more research is needed to determine the stability of the genotypes for the quality traits whatever the environment. If there are interactions between the genotype and the environment, they will slow down the selection progress (Dia et al., 2016). The heritability of quality traits must also be measured. Moreover, over the years, selection has induced the loss of undesirable compounds, such as cyanogenic glycosides in cassava, oxalates, phytates, and saponins (dioscin and gracillin) in yam. As a result, Lebot et al. (2018b) found neither dioscin nor gracillin in 550 varieties of *D. alata*, either in local varieties or hybrids. Catechin, which is related to browning susceptibility and therefore to low market value, was not detected either. It is concluded that in Nigeria, India, and Vanuatu, yam varieties were selected, over the years, for low contents in saponins and catechins on the basis of visual evaluation. The challenge in breeding programs will be to select varieties resistant/tolerant to stresses with high content of favorable micronutrients and low content of antinutritional compounds.

It is known that total phenolic content highly varies with the tissue. In sweet potato, leaves were the richest in phenolic acids and antioxidant activity, skin of root was intermediate, and the flesh of root was the poorest. In breadfruit, jackfruit, and banana, whatever the genotype (A, AB, and AAB), peels were also twice to three times higher in total phenolics than pulps (Bramont et al., 2018; Passo Tsamo et al., 2014, 2015). Banana peel must also be considered as a better source of α- and β-carotene than the pulp (Pereira & Maraschin, 2015). This suggests that the wastes of fruit and tubers could be of interest as a source of natural antioxidants.

The distribution in total phenolics may also be modified in a given tissue. In yam (*Dioscorea rotundata*), a spatial distribution of total phenolic content in the pulp was highlighted, as it was the highest in the head and middle sections of the tuber together with more marked browning (Graham-Acquaah, Ayernor, Bediako-Amoa, Saalia, & Afoakwa, 2014). This spatial distribution may be due to the fact that the head and then the middle part of this tuber crop are the eldest and the pool of polyphenols is generally formed early in the development of plants (Khawas et al., 2014).

5. INFLUENCE OF EXTRINSIC FACTORS

5.1 Preharvest conditions: year of plantation, agricultural practices, and stage of harvest

It is often said that the micronutrient composition of roots and tubers depends on location, soil type, and agricultural practices (Chandrasekara & Kumar, 2016). However, there is little evidence of the influence of preharvest conditions on the phenolic and carotenoid contents of these crops.

In The Philippines, white-fleshed *D. esculenta* was reported to be 2.5 times richer in total polyphenols and to exhibit higher DPPH activity in the Highlands than in the Lowlands (Cornago et al., 2011). In banana, a single assay suggests that mature-green Cavendish banana exhibits a higher total phenolic content when harvested in the dry season rather than in the wet one (Bruno Bonnet et al., 2013). Moreover, in potato, total carotenoids increased by 10% in a warmer and drier year, as compared to a colder year (Hamouz, Pazderu, Lachman, Cepl, & Kotikova, 2016).

As far as agricultural practices are concerned, two manures with different supplies in K element were used to grow Boutou variety

of yam. The manure, which was the highest in K element, induced a 11% and a 64% rise in vitamin C and total polyphenol contents, respectively (Njoh Ellong, Billard, Pétro, Adenet, & Rochefort, 2015). In cassava, organic fertilizer (vegetable waste vermicompost), as compared to a mineral-base fertilizer, resulted in a higher antioxidant activity together with a 30% increase in total phenolics and total flavonoids (Omar et al., 2012). These data suggest that organic fertilization may have favorable effects on micronutrient content in starchy roots and tubers. More work is still needed to rate accurately the effects of soil, climate, and agricultural practices on phenolic and carotenoid contents and antioxidant activity. No clear conclusion can be drawn on the effect of the date of harvest on phenolic content in yam (*D. dumetorum*) (Abiodun & Akinoso, 2014). According to these authors, this parameter did not significantly change in yellow varieties harvested 7 to 10 months after being planted, whereas in white varieties it was at a peak when harvested at the 9th month. In culinary banana (ABB), the pool of total phenolics is high at the very early stage of development and declines by 70% between 20 and 80 days post flowering (Khawas et al., 2014).

5.2 Postharvest conditions: stage of ripening, storage conditions, and processing

With regard to fruit ripening at ambient temperature, in bananas, including plantain, it is generally acknowledged that the total phenolic content of the pulp increases from the mature green stage to the yellow with green ends stage and then declines (Bugaud, Alter, Daribo, & Brillouet, 2009; Passo Tsamo et al., 2014). In Eastern Africa, total carotenoid content was twice to three times higher between these two stages in dessert bananas (AA) and plantain (AAB). This increase in carotenoids during ripening was due to enhanced carotenogenesis, which goes on even after harvest (Ekesa et al., 2015). Enhanced carotenogenesis during ripening at ambient temperature might be variety dependent and affect only varieties rich in carotenoids. In India, no change was found in carotenoids in Cavendish variety between two stages of ripening, whereas there was a significant increase in the orange-fleshed red banana (Lokesh et al., 2014). In jackfruit, total carotenoids were also shown to rise between the mature green and the ripe stages and a 61% increase in antioxidant activity was observed (Table 3) (Englberger et al., 2014; Ruiz-Montanez et al., 2015). Synthetic pathways leading to increased carotenogenesis have to be studied in ripening starchy fruits. Whatever, further studies are needed to establish the optimum stage of harvest or stage of ripening in starchy tropical resources, to maximize micronutrient content.

Due to their high moisture content and the lack of knowledge about optimal postharvest conditions, there are large postharvest losses in starchy fruit, root, and tuber crops. In Brazil, banana loss in postharvest is assumed to be about 70% (Clerici & Carvalho-Silva, 2011). In West Africa, the postharvest loss in yam is reported to be about 40% (Sanginga & Mbabu, 2015). It is thus of the upmost importance to establish storage and processing conditions that maximize the polyphenol and carotenoid contents as well as the antioxidant potential of the crops.

Storage length and temperature cause shifts in total phenolic contents and antioxidant activity. Less is known on the influence of storage on carotenoid content, which is controversial and might be dependent on the variety. In dessert banana, carotenoids were found to be negatively affected by 15 days' storage at 13 °C in the variety Prata, whereas they did not significantly change in Cavendish (De Vasconcelos Facundo, Gurak, Zerlotti Mercadante, Lajolo, & Cordenunsi, 2015). Optimal temperature and duration of storage should be more accurately determined for species and varieties of interest for their health benefits.

In the tropics, the current use of starchy resources is often limited by the poor storage properties of the fresh fruit and to a lesser extent of tubers. The potential of these valuable resources might be maximized by processing into different food products with a better shelf-life. The effect of processing on micronutrients has thus to be questioned.

The influence of processing on total phenolics and carotenoids depends on the type of process and its duration. In *D. alata*, boiling and deep-frying led to a 60% to 70% decline in total phenolic content, as compared to the raw tuber, and to a marked reduction in DPPH value (Liu & Lin, 2009). In Nigeria, the optimum boiling duration was found to be 30 min for *D. alata*. After boiling during 30 min, a moderate 35% loss in total phenolics and total flavonoids was recorded, whereas antinutrients, such as alkaloid and saponin, were reduced by 50% (Ezeocha & Ojimelukwe, 2012), which coincides with the results obtained in *D. cayenensis* (Adepoju et al., 2018). The decrease in phenolics during processing might be due to both structural changes in phenols and the activity of oxidative enzymes, such as polyphenol oxidase. These enzymes might be only partially inactivated by heat treatment. In the Caribbean, Njoh Ellong et al. (2015) found a residual 56% activity in polyphenol oxidase in cooked *D. alata*. The negative effect of boiling may also be due to the leaching of water-soluble phenols in the water (Adegunwa, Alamu, & Fasanya, 2012). Steaming and microwaving are thus the best cooking methods to preserve phenolics in plant foods. These findings confirm that the peel has a protective influence and limits the losses in phenolics during processing, as also reported in unripe and ripe plantain and purple-fleshed potatoes (Ebun & Santosh, 2011; Tian et al., 2016).

With regard to carotenoids, in OFSP, all-*trans*-β-carotene were lower after boiling than after microwaving and steaming (Bengtsson, Larsson Alminger, & Svanberg, 2009). In peeled banana and plantain, the highest 58% loss in total carotenoids is due to deep-frying, which caused a more important decline than steaming and roasting (Ekesa et al., 2013). This overall adverse effect of boiling and deep-frying, on micronutrients, conducted to the development of new methods of cooking. In *D. opposita*, air-drying at temperatures of 40 and 60 °C resulted in a higher retention of total soluble polyphenols and total flavones than air-drying at 80 °C. Pretreatment, such as blanching at 100 °C for 1 min, also induced a 39% rise in total flavone content due to a tremendous inhibition of polyphenol oxidase. Blanching therefore led to a 27% increase in antioxidant activity (Chen et al., 2017). In sweet potato, microwaving induced no change in total phenolic content nor in antioxidant activity, as compared to the raw tuber, whereas air-frying even improved the antioxidant capacity (Tian et al., 2016). Extrusion also has a favorable effect on total phenolic content, which was increased by 28%, in yellow or OFSPs in comparison with freeze-drying. Despite a concomitant 57% decline in β-carotene content, extrusion led to a significantly higher antioxidant activity (Shih et al., 2009).

Moreover, favorable results of traditional cooking methods on total phenolic content and antioxidant activity have been reported in boiled or steamed cassava (Shih et al., 2009; Silva de Lima et al., 2017). These results might be due to the fact that polyphenols and polysaccharides are less bonded after processing, resulting in higher extractable polyphenol content. The discrepancies between authors about the effect of processing on the phenolic content might also be related to differences in the phenolic composition of

starchy resources, as reported in plantain and *D. dumetorum* (Passo Tsamo et al., 2015; Salawu, Ajiboye, Akindahunsi, & Bolignon, 2017). In boiled peeled plantain, ferulic acid increased by 33% due to the release from its conjugated form, whereas a maximum 60% loss in flavonols was recorded (Passo Tsamo et al., 2015). In addition, a release of carotenoids after cooking has been found in sweet potato and is probably linked to cell-wall rupture (Bengtsson, Brackmann, Enejder, Larsson Alminger, & Svanberg, 2010). In any case, these data about the influence of processing suggest that micronutrient content might either be under or overestimated when using data from raw fruits or tubers (Faller & Fialho, 2009b).

5.3 Bioaccessibility of polyphenols and carotenoids

Processing has also been shown to modify the bioaccessibility of total phenolics in cassava and of β-carotene in sweet potato (Bengtsson et al., 2009; Silva de Lima et al., 2017). Bioaccessibility of micronutrients is defined as the percentage of compounds that is released from the food matrix after digestion and is available for absorption (Haminiuk et al., 2012). The *in vitro* bioaccessibility of phenolics in steamed or boiled cassava was found to be around 74% (Silva de Lima et al., 2017), which is much higher than the 48% reported in fruits and vegetables grown in temperate areas (Haminiuk et al., 2012). In white-fleshed *D. dumetorum*, it has been reported that although boiling induced on average a 30% decrease in total phenolic and flavonoid contents and a 75% decline in DPPH, *in vitro* digestion had favorable effects on these compounds. *In vitro* digestion of the boiled tuber led to a 100% rise in the total phenolic and flavonoid contents (Salawu et al., 2017). It is suggested that cooking releases bound phenolics from starch and fiber, so that they are more easily available after cell wall disruption caused by digestive enzymes (Zhou & Khang, 2019). In regard with carotenoids, *in vitro* bioaccessibility of β-carotene in processed foods was found to be in the range of 24% to 41% in OFSP (Bengtsson et al., 2009) and between 10% and 32% in cooking bananas (AAA and AAB) (Ekesa et al., 2012). Due to the scarce data available on the bioaccessibility of total phenolics and carotenoids in starchy food in the tropics, further work is needed to measure the bioaccessibility of those compounds in relation to processing.

6. CONCLUSION

Starchy fruits and tubers are important staple foods in the tropics. As far as food security and food biodiversity are concerned, it is of the upmost importance to promote local foods to meet energy and micronutrients needs. Food-based strategies are to be established to avoid shortage of starchy plant derived food either by alternating the consumption of various resources in relation to their seasonal availability (Ekesa et al., 2015) or by developing optimal storage conditions and processing. Phenolic and carotenoid contents highly depend on the species and variety. The promotion of the richest varieties might thus be taken into consideration. The few studies available about the influence of the year of plantation, the manure or organic fertilization, suggest that preharvest conditions are susceptible to induce shifts in the total phenolic content of starchy foods. More studies are needed on the influence of cold storage to preserve total phenolics and carotenoids or delay their losses in postharvest. Traditional domestic cooking was rated in terms of consequences on micronutrient content. It has been shown that it generally has adverse effects on total phenolic and carotenoid contents and favorable effects on the decline in antinutritional compounds. New cooking methods should lead to a rise in the retention of micronutrients. Further researches are needed on the phenolic composition of tropical fruits and tubers as some phenolic compounds have higher scavenging ability than others. Moreover, a few recent studies have dealt with the bioaccessibility of phenolics and carotenoids in cassava, yam, and cooking banana. Further knowledge is required on the bioaccessibility of micronutriments in tropical starchy fruits and tubers in relation to the type of processing.

ACKNOWLEDGMENTS

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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