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Full Length Research Paper

Antioxidants, minerals and bioactive compounds in tropical staples

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In light of reported micronutrient deficiencies and declining overall food quality, nine staple foods were assessed for minerals, antioxidants and some bioactive constituents. Minerals were assessed by atomic absorption spectrophotometry, antioxidants by the DPPH radical scavenging method, polyphenols, flavonoids and IP6 by standard methods. Iron and zinc concentrations were highest in dasheen samples; yellow yam and dasheen recorded highest calcium values; while the highest copper concentrations were recorded in potato and water yam samples. Water yam and dasheen samples recorded significantly higher antioxidant activities compared to other samples (95.83 ± 0.21 and 93.41 ± 0.60% DPPH inhibition respectively). St. Vincent yam, water yam and pumpkin displayed significantly higher flavonoid content than other samples with values of 390.65 ± 40.63, 410.52 ± 20.22 and 345.23 ± 15.81 CE/100 mg respectively. IP6 concentrations in dasheen (2925.67 ± 175.33 µg/g) and St. Vincent yam (2900 ± 100.67 µg/g) were significantly higher than other crops.This is a comprehensive study of minerals, antioxidants and bioactives in important tropical staples. The data is important to policymakers in food and nutraceutical industries. Results argue well for increased consumption of staples high in minerals and bioactives owing to their positive effects on inflammatory disorders and overall health.

Keywords: Food, phytates, health, minerals, antioxidants.

INTRODUCTION

Tuber crops along with other staples are commonly consumed in Africa, the Caribbean region and in other West Indian populations throughout the world. Some of these tuber crops include various cultivars of yams, potatoes, sweet potatoes, cocoyam and dasheen (taro). In addition to tubers, other staples including pumpkin, banana and breadfruit may also be added to the diet in order to supplement the carbohydrate portions. These staples are high in carbohydrates, calcium and vitamin C, but low in protein (FAO, 1990; Arinathan *et al*., 2009).

Research have identified roots, tuber crops and other starchy foods as important components of the diet accounting for 40 percent of the food eaten by half the population of sub-Saharan Africa, and are important staples to about 1 billion people in the developing world (Diouf, 1995). In the Caribbean, tubers and other starchy foods are both nutritionally and economically important. Locally, yam exports have experienced overall increases in production attaining an export value of US $18,000,000 in 2007 which reflects 5% of local production (Beckford *et al*., 2011). Other staples, including pumpkin and breadfruit contribute significantly to overall exports with earnings of over US $5,500,000 in 2010 (STATIN, 2011). There is therefore unlimited potential for local and regional economic growth via increased production and export of roots, tubers and other staples.

There are Caribbean guidelines for the dietary management of metabolic diseases including diabetes mellitus and coronary heart disease risk reduction based

Abbreviations

CE: Catechin equivalents, DPPH: 2,2-diphenyl-1-picrylhydrazyl, FAO: Food and Agriculture Organization
IP6: Inositol Hexaphosphate, Nm: Nanometre, RDA: Recommended daily allowance, SEM: Standard Error of the Mean, SPSS: Statistical Programme for the Social Sciences, STATIN: Statistical Institute of Jamaica

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on different food groups consumed with the main dietary staples being ‘ground provisions’ as well as grains and cereals (Caribbean Food and Nutrition Institute, 1994). In addition to micronutrients, it is important to assess the antioxidant activity of foods since it tells the extent to which they are able to nullify the effects of free radicals. Free radicals are independently existing atoms or molecules that have one or more unpaired electrons and are thought to play key roles in initiation of many inflammatory and metabolic diseases (Williams *et al*., 2006).

In light of associations between dietary habits and increased incidences of metabolic disorders in the western world, tubers and other staples have been studied in order to unravel any such associations and by extension, any positive association between their consumption and overall health. This research is aimed at assessing the concentrations of some essential minerals, bioactive compounds as well as overall antioxidant activities of economically important tubers and other commonly consumed staple foods from the southern region of Jamaica. This area is recognized as the main food producing region and is situated in the mining belt owing to high soil mineral content. The impact of the findings on health and well being of consumers as well as for improved food security cannot be overstated.

METHODOLOGY

Chemicals and Reagents

All chemicals and reagents were purchased from Sigma-Aldrich Co. (MO, USA) and were of analytical grade.

Samples

Samples selected for analyses: Water yam (*Dioscorea alata*), St. Vincent yam (*Dioscorea alata*), cocoyam (*Xanthosoma sp.*), sweet potato (*Ipomoea batatas*), potato (*Solanum tuberosum*), dasheen (*Colocasia esculenta*), yellow yam (*Dioscorea cayenensis*), breadfruit (*Artocarpus altilis*) and pumpkin (*Cucurbita moschata*). Fresh matured samples were collected from several farms in the parishes of Clarendon and St. Elizabeth, southern Jamaica. They were kept at 4°C and were washed, peeled, diced and oven dried (40°C) to constant weight. Samples were then crushed in a laboratory mill (GE motors and Industrial Systems), mesh size 0.2 mm and frozen for further use. All samples were assessed in quadruplets.

Analytical Methods

Calcium, copper, zinc and iron were determined by standard atomic absorption spectrophotometeric methods (AOAC, 2000). Samples were ashed, acid digested and taken to solution in deionized water. A nitrous oxide/acetylene mixture was used and minerals were assessed at the following wavelengths; calcium 422.7 nm, iron 248.3 nm, zinc 213.9 nm and copper 327.7 nm. In assessing calcium and zinc, 0.7 nm slit width was used while 0.2 nm was used for assessing iron and copper. When determining calcium content, a solution of lanthanum chloride was added to all samples and to reference samples to attain a 0.5% La^{3+} concentration. The accuracy of the analytical method was confirmed through a series of certified analyses of reference materials. Appropriate spikes were added to specific samples for recovery determination. Samples were read using a Unicam 939 atomic absorption spectrophotometer equipped with background correction lamps.

Total phenolics were assessed by a modification of the Folin-Ciocalteu assay method as described by Prasad *et al*. (2010). Assays for 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity were carried out by previously described methods (Matkowski *et al*., 2008). IC50 values were then determined from the equation of the graph of the percentage inhibition against extract concentration for each plant sample. Flavonoids were assessed by the aluminum chloride colorimetric assay as previously reported (Marinova *et al*., 2005) and expressed as catechin equivalents (CE). IP6 was determined by a modified colorimetric procedure following ion exchange purification as previously described (Siddhuraju and Becker, 2001).

Statistical analyses

Results were expressed as means ± SEM. SPSS version 16.0 was used for one way Analysis of variance tests to assess significant difference among samples. Duncan’s Multiple Range Test was used to test for significant difference among the means and a cutoff p value <0.05 was taken as significant (Sokal and Rolf, 1969; 1994).

RESULTS AND DISCUSSION

Minerals

Food security and food quality are of concern to governments of developed and developing countries. One factor contributing to overall food quality is the amount and availability of essential minerals, some of which were assessed in this study. Assessing the calcium content of different foods is important since this macronutrient plays critical roles in skeletal development, neuromuscular function etc. with its deficiency resulting in muscle spasms, cramps and eventually osteoporosis (Andre *et al*., 2007). In addition to traditional dairy sources, the staple food samples assessed in this study

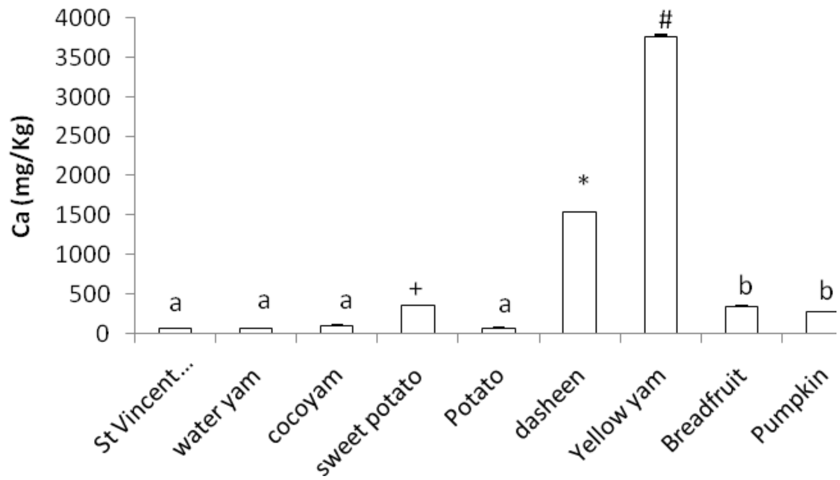

Figure 1 Calcium concentrations in commonly eaten food samples in the Caribbean. Columns with different assigned superscripts are significantly different, (P<0.05), n=4. Yellow Yam samples recorded calcium concentrations that were significantly higher than all other samples. Dasheen and Sweet potato also had appreciable calcium concentrations.

can be utilized as important sources of calcium to the diet. Figure 1 shows that calcium concentrations in yellow yam samples were significantly higher than in other samples assessed. These values are also noticeably higher than recorded elsewhere (Omoruyi *et al*., 2007; Akin-Idowu *et al*., 2009). Dasheen samples also had appreciable levels of calcium with levels being significantly higher than all other samples studied except for yellow yam. These values are slightly higher than recorded elsewhere (Ndabikunze *et al*., 2011). As a result of high calcium content of both dasheen and yellow yam samples, only 200g of either sample is needed to supply the recommended daily allowance of 800-1200 mg for calcium. In addition to having high calcium concentrations, previous studies indicate that after these samples are processed, a significant portion of the calcium is still retained and available for intestinal absorption (Dilworth *et al*., 2007). This is important as low mineral bioavailability in some tuber crops is an important factor militating against their increased consumption. Some of these variations in mineral concentrations of samples assessed may be attributed to variations in cultivars grown in different regions as well as differences in cultivation methods. These variations in mineral concentrations that may be attributed to different farming methods need to be further studied.

Lower calcium levels were recorded for breadfruit samples in this study compared to literature (Oladunjoye *et al*., 2010), however, samples of pumpkin recorded noticeably higher calcium concentrations than reported elsewhere (Hussain *et al*., 2010). This again indicates that variations in cultivar and geographical location may impact calcium concentrations in foods. All other samples assessed in this study apart from those mentioned above, reported significantly lower calcium concentrations with over 1 Kg of sample needed to supply the recommended daily allowance for calcium.

Samples of dasheen and St. Vincent yam recorded significantly higher iron concentrations compared to all other crops assessed as demonstrated in figure 2. Our research however shows that *Dioscorea alata* comprising St. Vincent and water yam samples had lower iron concentrations (<15 mg/Kg) than reported in literature (Baah, 2009). These two samples as well as dasheen samples recorded the highest IP6 concentrations compared to other crops, suggesting that iron availability from these samples may be compromised as a result of the high affinity of phytates for iron. Iron bioavailability from these foods may however be increased by consuming them along with foods high in ascorbic acid which enhances iron absorption (Bello *et al*., 2008; Akin-Idowu *et al*., 2009). The issue of iron bioavailability from foods is of importance as in addition to anaemia, iron deficiency is implicated in impaired cognitive development in children (Lozoff *et al*., 2006).

Other samples assessed did not exhibit significant variations in iron. With respect to nutritional value, consumption of 1 Kg of all samples except sweet potato, yellow yam and breadfruit is sufficient to satisfy USA and UK recommended daily iron intake values of 15 mg and 14 mg respectively. The concentrations of iron observed in yellow yam samples were found to be twice as high as values reported in literature, however, literature values for cocoyam were higher than values recorded for these samples (Akin-Idowu *et al*., 2009; Ndabikunze *et al*., 2011. Iron concentration in potato samples were in line with reported values (Burgos *et al*., 2007) while sweet potato iron concentrations were lower than recorded elsewhere (Tidemann-Andersen, 2011). Iron concentrations in breadfruit samples were also lower than

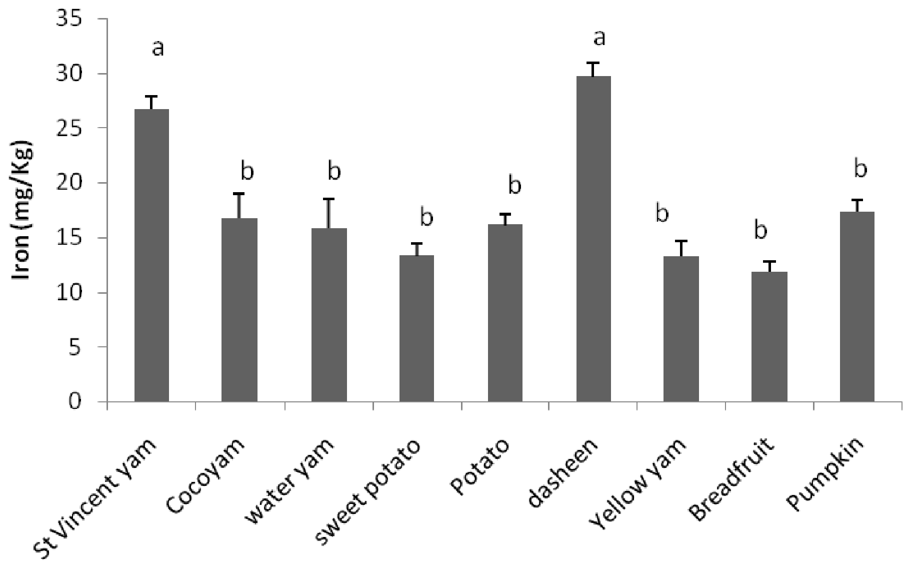

Figure 2 Iron concentrations in commonly eaten food samples in the Caribbean. Columns with different assigned superscripts are significantly different (P<0.05), n=4. Iron concentrations in dasheen and St. Vincent yam samples were significantly higher than all other samples assessed. All other samples displayed similar iron concentrations.

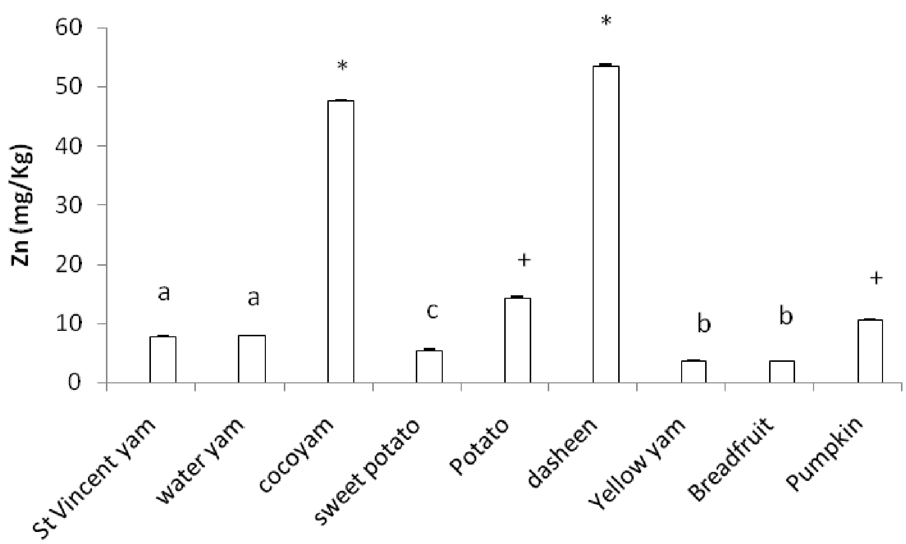

Figure 3 Zinc levels in commonly eaten staple foods. Columns with different assigned superscripts are significantly different, (P<0.05), n=4. Zinc concentration in cocoyam and zinc samples were significantly higher than values recorded for other samples. Conversely the lowest zinc concentrations were recorded in sweet potato samples.

recorded elsewhere (Oladunjoye *et al.*, 2010). Assimilation of minerals by crops grown in areas of varying soil mineral contents need to be further assessed as the samples assessed in this study did not record significantly higher iron content compared to similar crops grown elsewhere.

Figure 3 shows that zinc concentrations in locally grown cocoyam and dasheen samples were significantly higher than all other samples analysed and also values higher than reported in literature (Ndabikunze *et al.*, 2011). Zinc plays critical roles in neuronal development, maintenance of epithelial structures, immune cell func-

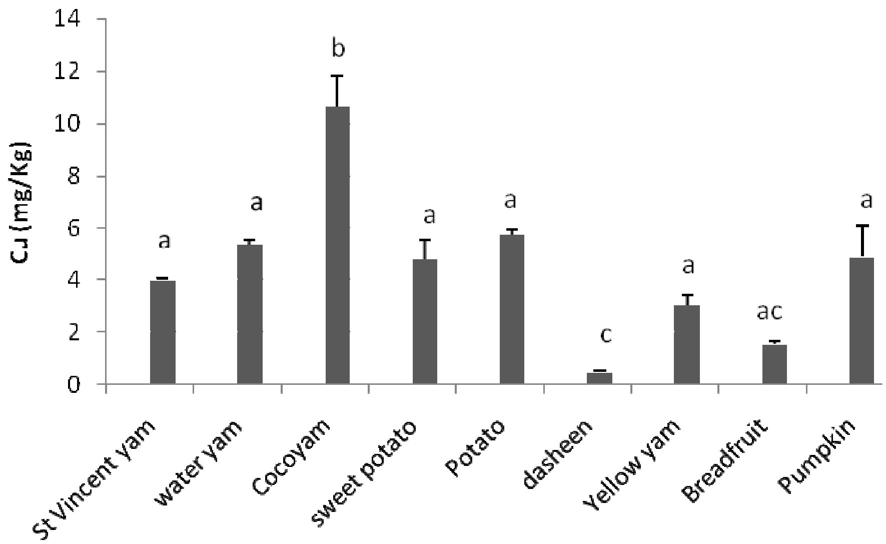

Figure 4 Copper levels in commonly eaten Staple foods. Columns with different assigned superscripts are significantly different, ($P<0.05$), n=4. Cocoyam recorded highest copper concentrations while the lowest concentrations were recorded in dasheen samples.

tioning, and its deficiency is thought to be an independent risk factor for coronary heart disease (Soinio *et al.*, 2007; Haase and Rink, 2009). It is important to note that the high affinity of IP6 for zinc may result in its reduced availability in zinc-deficient diets (Dilworth *et al.*, 2004). It is therefore suggested that once diets high in fibre and IP_6 are consumed, adequate zinc supplementation is necessary. This is of special interest as zinc availability may be a major health issue worldwide since approximately 20% of the world's population is thought to be zinc deficient (Hotz and Brown, 2004). From a nutritional standpoint, cocoyam and dasheen are good source of zinc as only 250 g of either sample is needed to satisfy the recommended daily allowance for zinc (11 mg for men and 8 mg for women). These tubers therefore have the potential of playing important roles in improving zinc status of the region's population. Further studies involving *in vivo* assessments of zinc availability are needed.

Appreciable levels of zinc are also found in pumpkin, St. Vincent and water yam samples with daily consumption of 500 g of these and other staples needed to satisfy the nutritional requirements for this micronutrient. Zinc concentration in yellow yam and *Dioscorea alata* cultivars were however lower than recorded in literature (Baah *et al.*, 2009; Akin-Idowu *et al.*, 2009). Further literature survey showed that sweet potato samples recorded higher zinc concentrations compared to literature (Courtney *et al.*, 2008) while values for potato and breadfruit were comparable (Ekin, 2011; Jones *et al.*, 2011).

Copper is an essential mineral that plays critical roles in numerous metabolic processes throughout the body. It is transported bound to caeruloplasmin which has oxidase activity and thereby facilitates the early stages of haemopoiesis by incorporating ferric iron into transferrin (Soetan *et al.*, 2010). Copper deficiency results in the affected individuals presenting with anemia, neutropenia, bone abnormalities and are at increased risk of cardiovascular diseases (Ma and Betts, 2000). Figure 4 indicates that copper concentrations in cocoyam samples are significantly higher than all other samples assessed in this study, with levels also higher than those recorded elsewhere (Ndabikunze *et al.*, 2011). All yam samples along with sweet potato, potato and pumpkin recorded similar copper concentrations with 500 g of these samples required to satisfy US RDA (2 mg). Dasheen samples recorded the lowest copper concentration of 0.45 ± 0.05 mg/Kg. Apart from cocoyam samples, copper concentrations in the other food samples assessed were lower than literature values (Alimor and Akalezi, 2010; Baah *et al.*, 2009; Ekin, 2011). The variations seen in mineral composition of tubers may be attributed to numerous factors including climate variations, soil type, elevation, crop variety among other factors (FAO, 1990). Data from this study however corroborate results from previous studies confirming that tubers and other staples are in general good sources of essential minerals with high bio-availabilities in most instances (Dilworth *et al.*, 2007). Data from this research shows that consumption of these tubers by specific groups vulnerable to mineral deficiencies e.g. children and the elderly, should be encouraged.

Table 1 Flavonoids, IP6 and total phenolics in commonly eaten staples

Samples	IP6 [a]	Flavonoids [b]	Total phenolics [c]
St. Vincent yam	2900.33 ± 100.67[a]	390.65 ± 40.63[a]	16.03 ± 0.79[a]
Water yam	1666.67 ± 191.66[b]	410.52 ± 20.22[a]	13.10 ± 1.03[a]
Cocoyam	1329.67 ± 54.16[bc]	145.31 ± 5.61[b]	9.39 ± 0.68[b]
Sweet Potato	2000.23 ± 200.67[b]	165.34 ± 5.81[b]	4.37 ± 0.27[c]
Potato	762.50 ± 129.67[cd]	85.21 ± 4.32[c]	18.26 ± 1.35[a]
Dasheen	2925.67 ± 175.33[a]	71.50 ± 3.06[c]	13.89 ± 1.58[a]
Yellow Yam	750.20 ± 25.10[c]	150.67 ± 30.34[b]	3.43 ± 0.19[c]
Breadfruit	591.50 ± 133.51[cd]	160.26 ± 30.86[b]	3.42 ± 0.19[c]
Pumpkin	358.30 ± 22.60[d]	345.23 ± 15.81[a]	15.99 ± 0.86[a]

Values are expressed as mean ± SEM where n=4. Values in the same column with different letter subscripts are significantly different ($p<0.05$). [a]Expressed as µg/g dry weight (dw), [b]Expressed as CE/100 mg, [c]Expressed as mg/100mg.

IP6

IP6 concentrations recorded for St. Vincent and dasheen samples were significantly higher than other samples assessed with values of 2900.33 and 2925.67 µg/g respectively (table 1). These values were also higher than reported in literature (Philipy *et al*., 2003; Wanasundera and Ravindran *et al*., 2004). Conversely, the lowest IP6 concentrations were recorded in samples of breadfruit and pumpkin. While IP6 has mineral chelating properties, it is a potent hypoglycaemic compound and is shown to reduce total serum cholesterol as well as the incidences of multiple types of carcinomas (Dilworth *et al*., 2004; Lee *et al.,* 2006; Vucenik and Shamsuddin, 2006). Previous concerns regarding the mineral-chelating properties of IP_6 were down played in light of the beneficial properties elucidated by new research. IP_6 is recommended as a supplement and is found to be useful in treating some metabolic disorders including diabetes mellitus, hyperlipidaemias and endothelial dysfunction (Nascimiento *et al*., 2006; Lee *et al*., 2007). The IP_6 content of St. Vincent yam, water yam, cocoyam, dasheen and sweet potato samples can therefore be exploited in the development of nutraceuticals useful in treating various metabolic disorders related to carbohydrate and lipid metabolism. For micronutrient compromised individuals, consumption of mineral-sufficient diets is therefore recommended for IP6 to be most effective. However, it must also be noted that the natural form of the compound already exists as a sodium salt hence the mineral binding capacity may be less than originally thought.

Antioxidant activity

The DPPH assay is used as an indication of the free radical scavenging activity of various samples and as such may identify potentially beneficial antioxidant components. In this assay, the activity of various plant samples may be compared to ascorbic acid which is a know antioxidant. Ascorbic acid is a known free radical scavenger shown here by the low IC50 value which is similar to that reported elsewhere (Sultana *et al*., 2010). Table 2 shows the percentage inhibition of a 500 µg/mL methanol extract of the plant samples compared to ascorbic acid and the corresponding IC50 values. Results indicate that water yam and dasheen displayed the highest percentage inhibition of DPPH of all the samples (95.83 ± 0.21 and 93.41 ± 0.60% respectively). These percentage are comparable to that of ascorbic acid (97.42 ± 0.41%) and significantly higher than percentage inhibition for all other samples assessed. Consequently, these samples recorded the lowest IC50 values of all the samples with values similar to that of ascorbic acid (0.018 mg/mL). Low IC50 values indicate that a small amount of sample is required to produce 50% inhibition hence highlighting the potency of these samples as free radical scavengers. The other yam cultivars assessed gave high IC50 values indicating they had greatly reduced antioxidant activity compared to water yam.

Although water yam and St. Vincent yam belong to the same species, they did not exhibit similar antioxidant activities as it required 40 times more St. Vincent sample to achieve the same 50% inhibition. This seems to be the first comprehensive assessment of antioxidant activities of these staple foods and comparisons show that except

Table 2 Percentage inhibition of DPPH at 500 µg/ml and IC50 values of the methanolic extracts of tubers and other food samples compared to ascorbic acid

Sample	% DPPH Inhibition[a]	IC50 +
Ascorbic acid	97.42 ± 0.41[c]	0.018
St. Vincent yam	18.90 ± 0.56 [b]	1.390
Water yam	95.83 ± 0.21[c]	0.041
Cocoyam	12.59 ± 0.66 [a]	2.895
Sweet potato	28.01 ± 1.34[e]	1.579
Potato	20.47 ± 1.38[b]	1 .249
Dasheen	93.41 ± 0.60[c]	0.504
Yellow yam	13.55 ± 0.52[a]	3.127
Breadfruit	10.59 ± 1.76[ad]	2.790
Pumpkin	7.92 ± 0.52[d]	5.519

The % DPPH inhibition represents the mean ± SD. +IC50 values were calculated based on duplicate analysis of each plant sample and represented as mg/mL. Values in the same column with different letter subscripts are significantly different $p<0.05$. Values are expressed as mean ± SEM where n=4.

for a few tuber samples, their antioxidant activities are lower than values obtained for condiments and spices commonly consumed in the Caribbean (Williams *et al*., 2006).

The high values for antioxidant activity recorded for water yam may be attributed to high levels of phenols and flavonoids, however this correlation was not observed in St. Vincent Yam and pumpkin samples which also have high levels of these compounds but did not record high antioxidant activities. Also, the antioxidant activities for dasheen differed significantly from potato even though both samples had statistically similar levels of phenols and flavonoids. This indicates that in addition to flavonoids and phenols, there are other compounds contributing to the overall antioxidant activity of the food samples e.g. phenylpropanoids and anthocyanins (Spina *et al*., 2008). The levels of these compounds in these food samples need to be further elucidated. Since bioactive compounds differ for each sample, it also suggests that not all phenolic compounds and flavonoids have similar antioxidant activity. Antioxidant activity may also be affected by sample storage conditions since this may affect structure and interactions between individual antioxidants. This was alluded to by Marimuthu *et al*. (2008) who showed that ethanolic fractions of plant samples with similar phenol contents varied in antioxidant activity. Apart from pumpkin samples, other food samples analysed with low flavonoid and polyphenolic content also displayed low antioxidant activity. We can therefore assume that in these specific samples, there is a direct correlation between antioxidant activity and levels of flavonoids and polyphenols.

CONCLUSIONS

In light of the paucity of information surrounding the nutraceutical value of tubers and other staple foods, this research adds valuable data to the literature being the first concise study of antioxidant activities, minerals and bioactive components of a group of economically important tubers and other staple crops commonly consumed in many countries throughout the tropics. This study shows that staple food crops grown in the southern mining region of Jamaica are rich in essential minerals with most values higher than those reported in literature. This is also the first literature confirmation that daily consumption of 500 g of dasheen will satisfy minimum recommended daily allowance for calcium, iron, zinc and copper. This bears some significance as production and consumption of this and other tubers have decreased over the years in favour of other imported staples. In addition to essential minerals, some staple foods assessed in this study are high in bioactive compounds and also exhibit high antioxidant activities.

Data from this study are valuable to food industry interests who aim to develop and market value-added nutraceutical products from staples crops. Results from this study can also serve as positive indicators for increased production of these and other staple crops for the local and export markets once similar proximate assessments are carried out. This will lead to stimulation of the local agricultural sector which has fallen as one of the top contributors to regional economies in recent years.

Further studies are now geared at assessing the *in vivo* effects of food samples that are high in antioxidants and bioactive compounds. This will provide more applicable information to overall health and wellbeing as opposed to data on antioxidant activity and bioactive components of foods only. Further research should also entail methodologies involved in improving nutrient content, bioactive compounds and antioxidant activities of these and other staple crops. Research on staples grown in other geographical areas is also needed for comparison since biological and geographical variations may influence the concentrations of bioactive compounds and minerals assessed in this study.

Disclosures

The authors declare no conflict of interest.

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