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Nutrient Content of Four Edible Wild Plants from West Africa

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Abstract. Non-cereal plant foods in the Western Sahel of Africa contribute significantly to the diets of local residents, especially during periods of grain shortages. In this paper, we analyze four such plant foods including *diyan kwakwa* (nut of coconut palm, *Cocos nucifera* L.), *muricin giginya* (young shoot of *Borassus aethiopum*), *tsamiya biri* (fruit of the tree, *Tamarindus indica*), and *yari* (a mixture of lichens, mainly *Rimelia reticulate)* that grows on ebony trees (*Diospyros mespiliformis*). They were analyzed for their content of amino acids, fatty acids, and minerals. Although *diyan kwakwa* contained the highest protein content (27.1%), its protein quality fell below the WHO standard in 3 of 8 essential amino acid categories. *Yari* and *muricin giginya* contained moderate levels of good quality protein. Only *diyan kwakwa* contained calorically significant amount of total fatty acid (24.7%); however, none of the plants contained useful amounts of the essential fatty acids, linoleic acid, or α-linolenic acid. All four plants contained useful amounts of zinc (>12 μg/g dry weight), while *yari* contained the most calcium (14.7 mg/g dry weight) and iron (1.41 mg/g), and *diyan kwakwa* the most copper. All the four plant foods contained lesser amounts of magnesium, molybdenum, or selenium. These data indicate that the four plants contain useful amounts of various essential nutrients that could supplement the diets of populations inhabiting the Western Sahel.

Key words: Amino acid, *Borassus aethiopum*, *Cocos nucifera* L., *Diospyros mespilformis*, Fatty acids, Minerals, Niger, *Tamarindus indica*, Lichens

Introduction

Edible plants contribute significantly to the nutrition of inhabitants of rural areas of the Sahel region of West Africa. Although these plants are consumed by people throughout the year, in fresh and dried forms, reliance on these foods increases during periods of grain shortage. Millet, which is harvested in September and October, is the staple grain for most Nigeriens. In many regions of Niger, however, granaries often become exhausted months before the next season's crops are harvested. This results in a "hungry season" during which people must purchase grains at elevated prices. Recent studies suggest that consumption of many different wild edible plant foods provides nutritional benefits [1–12].

In previous studies of plant foods, we have used various terms including, "wild plant foods," "famine foods," and "non-cultivated plant foods." However, recent field interviews conducted in rural Niger during the summer of 2004 confirm that some of the "wild" plant foods consumed in Niger are now cultivated. Therefore, we have adopted the term "plant" food to describe the wide range of edible plants, both collected and cultivated, that are consumed in the Sahel region of West Africa.

In July 2004, we identified and collected several edible plants in Niger that are consumed by the local population. As part of an ongoing project aimed at educating rural communities regarding the nutritional benefits of consuming specific plant foods, we analyzed the following four plant foods for their content of amino acids, fatty acids, and minerals: *diyan kwakwa* (nut of the coconut palm, *Cocos nucifera* L.), *muricin giginya* (young shoot of *Borassus aethiopum*), *tsamiya biri* (fruit of the tree, *Tamarindus indica*), and *yari* (a mixture of lichens, mainly *Rimelia reticulate*) that grows on ebony trees (*Diospyros mespiliformis)*. Dried specimens of these plant foods were collected in Kasuwar Dole, the central market in the town of Zinder, located in south-central Niger.

The nuts, young shoots, and seeds of *diyan kwakwa*, *muricin giginya*, and *tsamiya biri* respectively, are consumed as snack foods and individuals typically eat a small handful of the food. *Yari* is a mixture of lichens that is ground and added to sauces as a flavor enhancer. It is typically used in small amounts with a tablespoon or less being added to the sauce prepared for the evening meal. The present study was undertaken to quantify the various nutritionally relevant amino acids, fatty acids, and trace minerals in the four non-cultivated edible plants cited above.

Materials and Methods

Collection of Plant Foods

Dried plant samples of the following were obtained from the central market in the town of Zinder: the nut of *Cocos nucifera,* L., the young shoot of *Borassus aethiopum*, the fruit of *Tamarindus indica*, and *yari*. Because the plants collected for this study are not readily available or difficult to find in Niger, the plants are imported from Nigeria. All samples of the plants analyzed in this study were purchased

in July 2004 from vendors in the Zinder market, Kasuwar Dole. Vendors estimated that in all cases the plants had been imported from Nigeria in dried form within the previous 4 months. The purchased samples were sealed in individual plastic bags for transport to the United States. The *yari* contained a mixture of four species of lichen, the most abundant being *Rimelia reticulate* (Tayl.) Hale & Fletcher. Only small amounts of the following three species were present in the lichen scraped from the tree bark: *Rimelia cetrata* (Ach.) Hale & Fletcher, *Pyrixine* sp., *and Bulbothrix* sp.

Amino Acid Analysis

Duplicate specimens of each plant were ground to a fine powder with the aid of a stainless steel mill and dried under vacuum at room temperature until a constant weight was reached. Each sample was analyzed in duplicate. Each specimen (5–9 mg) was weighed and placed in 2-ml ampoules, to which the internal standard (norleucine) and 0.45 ml of 6 *N* HCl were added. Norleucine was used as internal standard because it is an amino acid not commonly found in proteins. The ampoules were evacuated, sealed, and placed in an oven for 24 hr at 110 °C. After hydrolysis, 20 μl aliquots of the hydrolysates were dried, mixed with 10 μl of redry solution (ethanol:water: triethylamine, 2:2:1), dried again, and finally derivatized with 20 μl phenylisothiocyanate reagent (ethanol:water: triethylamine:phenylisothiocyanate, 7:1:1:1) for 20 min at room temperature [13]. Excess reagent was removed with the aid of a vacuum at room temperature. Derivatized samples were dissolved in 0.1 ml of 0.14 *M* sodium acetate that had been adjusted to pH 6.4 with dilute acetic acid. A 20 μl aliquot was injected onto the column. Quantitation of amino acids was performed using a Waters C18 column (3.9 mm × 150 mm) with gradient conditions as described elsewhere [14]. Derivatized amino acids were eluted from the column with increasing concentrations of acetonitrile. The eluate was monitored at 254 nm and the areas under the peaks were used to calculate the concentrations of the unknowns using a Pierce Standard H amino acid calibration mixture (Rockford, IL). Norleucine was the internal standard used in all amino acid determinations. A sample of eggwhite lysozyme, analysed in duplicate, served as the control protein.

Samples intended for the determination of cysteine were first oxidized with performic acid (80% formic acid and 30% hydrogen peroxide, 9:1) for 18 hr at room temperature [15]. The oxidizing reagent was removed with the aid of an evaporative centrifuge and the samples were hydrolyzed with 6 *N* HCl as described above.

The tryptophan content was determined in a separate analysis. The weighed samples were placed in polypropylene tubes and after the addition of the internal standard (norleucine) they were hydrolyzed in 4.67 *M* KOH containing 1% (w/v) thiodiglycol for 18 hr at 110 °C [16]. After hydrolysis, the KOH was neutralized with 4.2 *M* perchloric acid, and the supernatant was adjusted to pH 3.0 with acetic acid. A 20 μl aliquot of the hydrolyzed specimen was subjected to derivatization as described above. The solution of amino acid standards was supplemented with tryptophan. Quality control assurance for the tryptophan determination was obtained by demonstrating that the method yielded the correct number of tryptophan residues for egg-white lysozyme. Tryptophan analysis was performed using a Waters C18 reversed-phase column (3.9 mm × 150 mm) (Waters, Milford, MA) and the solvents and gradient conditions were as described by Hariharan et al. [17]. Use of this elution protocol was necessary in order to adequately separate tryptophan from ornithine that results from the alkaline hydrolysis of arginine.

Fatty Acid Analysis

Two dried specimens were extracted with chloroform:methanol (2:1, v/v) and the solid, non-lipid material was removed by filtration. The total extracted lipid material was recovered after solvent removal in a stream of nitrogen. The samples were then redissolved in anhydrous chloroform:methanol (19:1, v/v) and clarified by centrifugation at 10,000 × *g* for 10 min. Transmethylation was performed using 14% (w/v) boron trifluoride (BF_3) in methanol [18]. Fifty nanograms of heptadecanoic acid (internal standard) and 1 ml aliquot of each sample were transferred to a 15 ml Teflon-lined screw-cap tube. After removal of solvent by nitrogen gassing, the sample was mixed with 0.5 ml of BF_3 reagent, placed in a warm bath at 100 °C for 30 min and cooled. After the addition of saline solution, the transmethylated fatty acids were extracted into hexane. A calibration mixture of fatty acid standards was processed in parallel.

Aliquots of the hexane phase were analyzed by gas chromatography. Fatty acids were separated and quantified using a Hewlett-Packard gas chromatograph (5890 Series II) equipped with a flame-ionization detector. One or two microliter aliquots of the hexane phase were injected in split-mode onto a fused-silica capillary column (Omegawax; 30 m × 0.32 mm I.D., Supleco, Bellefonte, PA). The injector temperature was set at 200 °C, detector at 230 °C, oven at 120 °C initially, then 120–205 °C at 4 °C per min, and 205 °C for 18 min. The carrier gas was helium and the flow rate was approximately 50 cm/sec. Electronic pressure control in the constant flow mode was used. The internal standard (heptadecanoic acid, C17:0) and calibration standards (NuCheck, Elysian, MN) were used for quantitation of fatty acids in the lipid extracts. The fatty acids reported represent the average of three determinations.

Table 1. The amino acid content of four plant foods of Niger (mg/g dry weight)

Amino acid	*Diyan kwakwa*	*Muricin giginya*	*Tsamyia biri*	*Yari*
Alanine	12.4 (1.17)	5.04 (0.11)	6.20 (0.39)	3.42 (0.18)
Arginine	42.1 (2.40)	17.4 (0.79)	8.74 (0.79)	3.71 (0.29)
Aspartic acid	23.3 (1.82)	77.6 (1.21)	12.0 (0.93)	4.20 (0.44)
Cysteine	2.11 (0.21)	1.02 (0.14)	1.35 (0.22)	1.09 (0.07)
Glutamic acid	50.3 (3.13)	7.38 (0.11)	16.7 (1.70)	6.73 (0.48)
Glycine	12.1 (1.48)	1.87 (0.03)	5.15 (0.47)	2.72 (0.17)
Histidine	5.21 (0.47)	4.28 (0.30)	3.37 (0.37)	1.07 (0.11)
Isoleucine	10.8 (0.90)	1.71 (0.12)	5.20 (0.54)	2.44 (0.16)
Leucine	20.0 (1.49)	2.98 (0.09)	8.89 (0.91)	3.91 (0.18)
Lysine	11.9 (1.08)	6.31 (0.24)	8.22 (0.77)	2.28 (0.17)
Methionine	3.15 (0.33)	0.85 (0.04)	2.48 (0.37)	1.35 (0.14)
Phenylalanine	13.5 (0.81)	1.72 (0.18)	4.78 (0.40)	2.60 (0.16)
Proline	11.3 (1.30)	3.41 (0.18)	7.61 (0.53)	3.43 (0.12)
Serine	14.8 (1.36)	11.1 (0.91)	6.88 (0.45)	3.59 (0.23)
Threonine	11.1 (1.35)	3.52 (0.30)	6.05 (0.55)	3.40 (0.22)
Tryptophan	2.14 (0.34)	1.82 (0.02)	1.04 (0.09)	1.70 (0.15)
Tyrosine	9.04 (0.61)	3.21 (0.20)	4.34 (0.54)	2.09 (0.25)
Valine	15.8 (1.29)	3.23 (0.07)	6.97 (0.69)	3.40 (0.22)
Total(mg/g)	271	154	116	53.1

Note. The number in parenthesis represents the difference between two determinations.

Mineral Analysis

Three replicate aliquots (50–500 mg) from each of the dried, powdered plant specimens were weighed, then wet-ashed by refluxing overnight with 15 ml of concentrated HNO_3 and 2.0 ml of 70% $HClO_4$ at 150 °C. The samples were dried at 120 °C and the residues were dissolved in 10 ml of 4.0 *N* HNO_3–1% $HClO_4$ solution. The mineral content of each sample solution was determined by inductively coupled argon plasma atomic emission spectroscopy (ICP-AES, Jarrel-Ash) as described elsewhere [1, 2]. The mineral contents of the samples were quantified against standard solutions of known concentrations which were analyzed concurrently.

Results

Amino Acid Content

The protein content of the four plants, estimated by summing the content of individual amino acids, ranged from a high of 27.1% in *diyan kwakwa* to a low of 5.31% in *yari* (Table 1). In order to arrive at a measure of the quality of the plant proteins, the percentages of the essential amino acids in each of the four plant foods were compared with those of an "ideal protein" standard established by the World Health Organization [19] (Table 2). Unfortunately, *diyan kwakwa* with the highest protein content fell short of the WHO standard in 3 of 8 categories, namely lysine (76%), methionine plus cysteine (80%), and tryptophan (73%). The plant food whose protein scored the lowest relative to the WHO standard was *muricin giginya*; for only 1 of 8 categories (tryptophan) did *muricin giginya* compare favorably to the WHO standard. The essential amino acid percentages of the other two plant foods exceeded those of the "ideal protein" except for tryptophan (82%) in *tsamiya biri* and lysine in *yari* (74%). Noteworthy are the large amounts of arginine and glutamic acid in *diyan kwakwa* (Table 1).

Fatty Acid Content

The fatty acid compositions of the four plant foods are expressed on a dry weight basis in Table 3. Fatty acids accounted for nearly one-fourth of the dry weight of *diyan kwakwa* (Table 3). In contrast, each of the other three plants contained less than 1% fatty acid: *muricin giginya* (0.25%), *tsamiya biri* (0.96%), and *yari* (0.25%). The intermediate chain-length fatty acids lauric acid (12:0) and myristic acid (14:0) together represented 66.7% of the fatty acid total in *diyan kwakwa*, with oleic acid (18:1$n-9$) contributing another 15.4% to the fatty acid total. With regard to the two essential fatty acids, on an absolute basis, *diyan kwakwa* contained very little linoleic acid (18:2$n-6$)(5.8 mg/g dry

Table 2. The essential amino acid composition of four plant foods from Niger compared to the WHO "ideal protein"

	Diyan kwakwa		*Muricin giginya*		*Tsamiya biri*		*Yari*	
Amino acid	% of total amino acid	(% amino acid)/ [(ideal)] × 100	% of total amino acid	(% amino acid)/ [(ideal)] × 100	% of total amino acid	(% amino acid)/ [(ideal)] × 100	% of total amino acid	(% amino acid)/ [(ideal)] × 100
Isoleucine	4.0	143	1.1	39	4.5	160	4.6	164
Leucine	7.4	112	1.9	29	7.6	115	7.2	109
Lysine	4.4	76	4.2	73	7.1	123	4.3	74
Methionine + cysteine	2.0	80	1.2	48	3.3	132	4.6	184
Phenylalanine + tyrosine	8.3	132	3.2	51	7.9	125	8.8	140
Threonine	4.1	121	2.3	68	5.2	153	6.4	189
Tryptophan	0.8	73	1.2	109	0.90	82	3.2	291
Valine	5.8	165	2.1	60	6.0	172	6.4	183

Table 3. Total lipid and fatty acid content of four snack foods from Niger

	(μg/g dry weight)			
Fatty acid	*Diyan kwakwa*	*Muricin giginya*	*Tsamiya biri*	*Yari*
10:0	2.86 (0.1)	ND	ND	ND
12:0	116.8 (2.0)	0.01 (0)	0.01 (0)	0.01 (0.01)
14:0	49.6 (0.7)	0.01 (0)	0.01 (0)	0.02 (0)
14:1	0.20 (0.01)	ND	ND	ND
15:0	0.07 (0.01)	0.01 (0)	0.01 (0)	0.01 (0)
16:0	25.0 (0.45)	0.65 (0.02)	1.80 (0.08)	0.25 (0.01)
16:1$n-7$	0.08 (0.01)	ND	0.12 (0.01)	0.01 (0)
18:0	6.72 (0.13)	0.06 (0)	0.70 (0.04)	0.09 (0.01)
18:1$n-9$	38.1 (0.89)	0.63 (0.02)	2.29 (0.1)	0.30 (0.04)
18:1$n-7$	0.63 (0.02)	0.03 (0)	0.55 (0.02)	0.69 (0.04)
18:2$n-6$	5.85 (0.19)	0.57 (0.02)	3.42 (0.16)	0.72 (0.04)
18:3$n-6$	0.13 (0.06)	0.01 (0)	ND	0.07 (0.08)
18:3$n-3$	ND	0.09 (0.01)	0.21 (0.01)	0.08 (0)
20:0	0.34 (0.01)	0.01 (0)	0.07 (0.01)	0.01 (0)
20:1	0.24 (0.01)	0.01 (0)	0.02 (0)	0.01 (0.01)
20:2$n-6$	ND	ND	0.01 (0)	0.01 (0)
20:3$n-6$	ND	ND	ND	0.18 (0)
20:4$n-6$	ND	ND	ND	ND
20:5$n-3$	ND	ND	ND	ND
22:0	0.13 (0.01)	0.01 (0)	0.03 (0)	0.04 (0)
22:1	0.17 (0)	ND	0.01 (0)	0.01 (0)
24:0	0.17 (0.01)	0.03 (0)	0.03 (0)	0.05 (0)
24:1	ND	0.58 (0.13)	0.20 (0.06)	ND
Total lipid (mg/g dry weight)	247	2.7	9.4	2.5

Note. The values indicated in the table represent mean (SD); ND, not detected (<0.005 mg/g dry weight).

weight) and no detectable amount of α-linolenic acid (18:3$n-3$). The other three plant food contained only 0.5–3.4 mg/g dry weight linoleic acid and 0.08–0.20 mg/g dry weight α-linolenic acid.

Mineral Content

Calcium. As shown in Table 4, *yari,* which is used as a flavoring agent, was the only plant food that contained greater than 15 mg/g dry weight calcium. *Diyan kwakwa* and *tsamiya biri* contained between 1 and 2 mg/g calcium. *Muricin giginya* contained relatively little calcium (0.196 mg/g).

Copper. Diyan kwakwa had the highest copper content (11.7 μg/g dry weight), but the other three plant foods contained between 4.54 and 9.09 μg/g copper.

Iron. The iron content of *diyan kwakwa*, *muricin giginya*, and *tsamiya biri* was extraordinarily low (14.8–31.7 μg/g dry weight); however, *yari* contained an exceptionally large amount of iron (1,410 μg/g).

Magnesium. Compared to many other edible plants of Niger that we analyzed previously and which contained 4–14 mg/g dry weight magnesuium [6], the magnesium content of all four plant foods in the present study was relatively low (0.482–1.62 mg/g).

Manganese. Except for *muricin giginya* which contained very little manganese (5.93 μg/g dry weight), the other three plant foods contained quantities of manganese that were within the range of values we estimated for many other edible plants of Niger.

Molybdenum and Selenium. The molybdenum (0.05–0.27 μg/g dry weight) and selenium (0–1.85 μg/g dry weight) contents of all four plant foods in this study were much lower than values reported for a number of other edible plants of Niger [4–7, 10, 11].

Zinc. The zinc content of the four plants ranged from 12.1 to 19.0 μg/g dry weight. These values are considerably higher than the content of many other plant foods of Niger that we have analyzed [4–7, 10, 11].

Table 4. The mineral content of four snack foods from Niger

Mineral	(μg/g dry weight)			
	Diyan kwakwa	*Muricin giginya*	*Tsamiya biri*	*Yari*
Aluminum, Al	10.3 (1.2)	14.6 (1.5)	18.4 (5.89)	2,250
Arsenic, As	0.32 (0.08)	ND	ND	0.33
Barium, Ba	0.09 (0.01)	0.38 (0.03)	2.0 (0.16)	135
Beryllium, Be		ND	ND	0.12
Calcium, Ca	1,470 (96.2)	196 (20.5)	1,899 (48.6)	15,700
Cadmium, Cd	ND	ND	ND	0.19
Cobalt, Co	ND	ND	0.07 (0.01)	1.09
Chromium, Cr	2.80 (0.13)	2.22 (0.07)	2.94 (1.3)	4.36
Copper, Cu	11.7 (0.52)	4.54 (0.17)	9.09 (0.08)	5.80
Iron, Fe	24 (0.55)	14.8 (0.39)	31.7 (1.34)	1,410
Potassium, K	2,570 (87.4)	6,860 (289)	6,547 (766)	2,760
Lanthanum, La	ND	ND	ND	2.93
Lithium, Li	ND	ND	ND	1.07
Magnesium, Mg	1,620 (11.5)	482 (41.3)	1,153 (5.77)	917
Manganese, Mn	64.4 (4.2)	5.93 (0.6)	215 (11.9)	69.8
Molybdenum, Mo	0.1 (0.01)	0.27 (0.02)	0.1 (0.02)	0.05
Sodium, Na	59.7 (10.2)	83.1 (13.8)	62.1 (16.8)	202
Nickel, Ni	0.7 (0.5)	0.21 (0.01)	1.29 (0.02)	1.95
Phosphorus, P	3,430 (86.6)	2,730 (215)	1,220 (55.7)	634
Lead, Pb	ND	0.1 (0.01)	0.1 (0.03)	2.52
Selenium, Se	1.47 (0.06)	1.85 (0.12)	0.03 (0.07)	ND
Strontium, Sr	4.84 (0.19)	0.96 (0.08)	2.75 (0.25)	106
Titanium, Ti	ND	0.12 (0.02)	0.154 (0.04)	45.9
Thallium, Tl	ND	ND	0.18 (0.04)	ND
Vanadium, V	ND	ND	ND	3.13
Yttrium, Y	ND	ND	ND	1.56
Zinc, Zn	19.0 (0.71)	12.1 (1.36)	13.2 (0.22)	15.6
Zirconium, Zr	ND	0.11 (0.02)	0.1 (0.04)	0.99

Note. There was only enough plant material to support a single determination; values in this table represent mean (SD); ND, not detected. The following elements were not detected: Ag, Sb, Te (silver, antimony, tellurium).

Discussion

The overall conclusion of this study is that each of the four plant foods from Niger that we analyzed contains significant quantities of one or more nutrients that are essential to man. We found that *diyan kwakwa* contained 2.7% protein (on a dry weight basis), which is only about one-half the protein content of coconut reported elsewhere [20]. Although *diyan kwakwa* could contribute a significant quantity of amino acid to one's diet, the protein it contains falls 20–27% short of the percentages of tryptophan, methionine/cysteine, and lysine in the WHO "ideal protein" [19] (Table 2). In contrast, the amino acid composition of coconut published elsewhere (20) reported percentages of tryptophan and methionine/cysteine that did meet the WHO standard. The remarkably high content of arginine and glutamic acid we observed in coconut protein (Table 1) has also been noted by other investigators [21]. Nevertheless, our findings indicate that useful amounts of reasonably good quality protein are provided by *diyan kwakwa*. Although *tsamiya biri* contains potentially useful amounts of protein, the proteins in *Tamarindus indica* fruit have been shown to be poorly digested and utilized by rats [22]. On the other hand, the proteins in coconut meat are extensively digested and efficiently utilized by mammals [23].

The fatty acids a plant food contains can satisfy at least two important nutritional functions, first as a source of calories, and second, as a source of nutritionally essential fatty acids which, by definition, humans cannot synthesize. As has been documented by other investigators [20, 24, 25], lauric acid (12:0) accounted for about 50% of the fatty acid total in *dayan kwakwa*, the solid endosperm of coconut. In terms of energy that could be derived from fatty acids, of the four plants we analyzed, *diyan kwakwa* was the only one that could provide significant calories to a child or adult. For example, if an individual were to consume 20 g dry weight of nuts, they would be taking in 5 g of oxidizable fatty acid; at 9 kcal/g of fatty acid, this corresponds to 45 kcal of energy, or only about 5% of the total daily energy requirement of an adult in the hot, arid zone of West Africa [26]. According to this estimate, it appears that *diyan kwakwa* could contribute only modestly to satisfying the energy needs of the local population where the plant grows. The fat content of the *Cocos nucifera,* L., we analyzed in the present study

was only about one-half that of similar analyses of coconut reported elsewhere [20].

With regard to the two essential fatty acids, neither *diyan kwakwa* nor the other three plants contained nutritionally significant amounts of linoleic acid or α-linolenic acid. *Diyan kwakwa* contained only 5.85 mg/g dry weight of linoleic acid (18:2$n-6$) (Table 3), a finding which is in good agreement with the value of 7.06 mg/g dry weight reported elsewhere [20]. The recommended daily intake of linoleic acid is 3% of total calories [27], or about 0.03 $\times$ 1700 kcal/day or 50 kcal/day of linoleic acid; this corresponds to 50 kcal/day divided by 9 kcal/g for fat, or 5.6 g of linoleic acid per day. If one consumed the equivalent of 20 g dry weight per day of *diyan kwakwa*, they would take in about 0.12 g of linoleic acid, which corresponds to only a small fraction of the daily requirement of this essential fatty acid. The recommended daily intake of α-linolenic acid is one-sixth that of linoleic acid, or about 1.0 g. By similar reasoning, the amount of α-linolenic acid in 20 g of any of the four plant foods analyzed in this study would provide less than 5% of the daily requirement of this essential fatty acid.

From the standpoint of those trace minerals that are critical to human health, overall, of the four plant foods analyzed in the present study, *yari* is the one that theoretically could provide nutritionally useful amounts of most of them, including calcium, copper, iron, magnesium, manganese, selenium, and zinc (Table 4). *Yari* appears to be especially rich in calcium and iron. Calcium is important for bone growth and muscle and neurologic function, whereas iron is a component of hemoglobin, myoglobin, and the cytochrome pigments of the respiratory chain of mitochondria. However, it would take 10 g (dry weight) of *yari to* contribute about 160 mg of calcium to the diet, or about one-sixth of the daily recommended allowance for a child or adult, and 10 g (dry weight) of *yari* to satisfy an adult's daily iron requirement. These estimates are, however, only theoretical and not of practical significance since *yari* is used only as a condiment. Thus, it is improbable that *yari* would ever be consumed in quantities sufficient to contribute significantly to satisfying the daily nutrient requirements of the populations who inhabit the Western Sahel. Furthermore, one must keep in mind that such estimates depend very much on the bioavailability of calcium and iron in *yari.* The amounts of calcium, copper, iron, magnesium, molybdenum, selenium, and zinc in the *tsamiya biri* we analyzed in this study are similar to those reported elsewhere for *Tamarindus indica* fruit [25]. In the present study, while the amounts of copper, magnesium, manganese, selenium, and zinc we report for *diyan kwakwa* are in general similar to the values reported elsewhere [25], we found only one-fifth as much calcium in the coconut endosperm compared to what has been reported by others.

Copper is an essential component of numerous enzymes that catalyze oxidation–reduction reactions and is required for collagen synthesis and iron mobilization. The divalent cations magnesium and manganese are cofactors for many enzymes. Molybdenum is a cofactor for xanthine oxidase and aldehyde oxidase and selenium plays a key role in the glutathione peroxidase reaction. *Diyan kwakwa* and *tsamiya biri* both contain potentially useful amounts of magnesium, manganese, and selenium, but low amounts of molybdenum.

Differences between the values we report for the amino acid, fatty acid, and mineral content of coconut and the corresponding values reported by others could be due to differences in strains, the stage of maturity at which the seeds were harvested, and growing conditions.

Although the data contained in this report can provide nutritionists and public health officials in West Africa with a basis for recommending which local plant foods ought to be incorporated into the diets of the populations who have access to them, one must keep in mind the need for information regarding the bioavailability of specific nutrients in these foods. Although the four plants we analyzed contained impressive quantities of certain important nutrients, the amounts the body might actually absorb may be low due to the presence of antinutrients (e.g., protease inhibitors, chelating agents). Furthermore, the presence of toxic substances could seriously reduce the usefulness of these non-cultivated plant foods. Seeds, for example, often contain antinutrients such as lectins and protease inhibitors that are deleterious to humans and which must be removed or inactivated by exhaustive washing or heat-treatment prior to their consumption [22].

References

1. Humphry CM, Clegg MS, Keen CL, Grivetti LE (1993) Food diversity and drought survival. The Hausa example. Int J Food Sci Nutr 44: 1–16.
2. Yazzie D, VanderJagt DJ, Pastuszyn A, Okolo A, Glew RH (1994) The amino acid and mineral content of baobab. (*Adansonia digitata* L.). J Food Comp Anal 7: 183–193.
3. Nordeide MB, Hatloy A, Folling M, Lied E, Oshaug A (1996) Nutrient composition and nutritional importance of green leaves and wild food resources in an agricultural district, Koutiala, in southern Mali. Int J Food Sci Nutr 47: 455–468.
4. Glew RH, VanderJagt DJ, Lockett C, Grivetti L, Smith G, Pastuszyn A, Millson M (1997) Amino acid, fatty acid, and mineral composition of 24 indigenous plants of Burkina Faso. J Food Comp Anal 10: 205–217.
5. Kim T, Pastuszyn A, VanderJagt DJ, Glew RS, Millson M, Glew RH (1997) The nutritional composition of seeds from *Boscia senegalensis* (dilo) from the Republic of Niger. J Food Comp Anal 10: 73–81.
6. Freiberger C, VanderJagt D, Pastuszyn A, Mounkaila G, Millson M, Glew RH (1998) Nutrient content of the edible leaves of seven plants from Niger. Plant Foods Hum Nutr 53: 57–69.
7. Sena L, VanderJagt D, Rivera C, Tsin A, Muhamadu I, Mahamadou O, Millson M, Pastuszyn A, Glew RH (1998) Analysis of the nutritional components of eight famine foods of the Republic of Niger. Plant Foods Hum Nutr 52: 17–30.

8. Smith G, Glegg M, Keen C, Grivetti L (1996) Mineral values of selected foods common to southern Burkina Faso and Naimey, Niger. Int J Food Sci Nutr 47: 41–53.
9. VanderJagt D, Freiberger C, Vu H, Mounkaila G, Glew RS, Glew RH (2000) The trypsin inhibitor content of 61 wild plant foods of Niger. Plant Foods Hum Nutr 55: 335–346.
10. Cook J, VanderJagt D, Pastuszyn A, Mounkaila G, Glew RS, Millson M, Glew RH (2000) Nutrient and chemical composition of 13 wild edible plant foods of Niger. J Food Comp Anal 13: 83–92.
11. Cook J, VanderJagt D, Pastuszyn A, Mounkaila G, Glew RS, Glew RH (1998) Nutrient content of two indigenous plants of the Western Sahel: *Balanites aegyptiaca* and *Maerua crassifolia*. J Food Comp Anal 11: 221–230.
12. Glew RS, VanderJagt DJ, Huang Y-S, Chuang L-T, Bosse R, Glew RH (2004) Nutritional analysis of the edible pit of *Sclerocarya birrea* in the Republic of Niger. J Food Comp Anal 17: 99–111.
13. Cohen SA, Strydom DJ (1988) Amino acid analysis utilizing phenylisothiocyanate derivatives. Anal Biochem 174: 1–16.
14. Bidlingmeyer BA, Cohen SA, Tarvin TL (1984) Rapid analysis of amino acids using pre-column derivatization. J Chromatogr 336: 93–104.
15. Hirs CWH (1967) Performic acid oxidation. Methods Enzymol 11: 197–199.
16. Hugli TE, Moore S (1972) Determination of the tryptophan content of proteins by ion exchange chromatography of alkaline hydrolysates. J Biol Chem 247: 2828–2834.
17. Hariharan M, Sundar N, VanNoord T (1993) Systematic approach to the development of plasma amino acid analysis by high-performance liquid chromatography with ultraviolet detection with precolumn derivatization using phenylisothiocyanate. J Chromatogr 621: 15–22.
18. Morrison WR, Smith LM (1964) Preparation of fatty acid methyl esters and dimethylacetals from lipids with boron trifluoride-methanol. J Lipid Res 5: 600–608.
19. WHO (1985) WHO/FAO Report: Energy and Protein Requirements. WHO Technical Report Series No. 724. Geneva: World Health Organization.
20. United States Department of Agricultural Research Service, Nutrient Data Laboratory, Nutrient Database for Standard Reference, Release 17, 2004. Available at http://www.nal.usda.gov/fnic/foodcomp.
21. Rasyid F, Manullang M, Hansen PMT (1992) Isolation and characterization of coconut protein. Food Hydrocolloids 6: 310–314.
22. Grant G, More LJ, McKenzie NH, Dorward PM, Buchan WC, Telek L, Puszatal A (1995) Nutritional and hemagglutination properties of several tropical seeds. J Agric Sci 124: 437–445.
23. Mepba HD, Achinewhu SC (2003) Effects of food processing on protein nutritive quality of coconut *Cocos nucifera* products. Plant Foods Hum Nutr 58: 15–25.
24. Laureles LR, Rodriguez FA, Reano CE, Santos GA, Laurena AC, Mendoza EMT (2002) Variability of fatty acid and triacylglycerol composition of the oil of coconut hybrids and their parentals. J Agric Food Chem 50: 1581–1586.
25. Food Intake Analysis System, Version 3.99, University of Texas, Houston Health Sciences Center, Houston, TX, 1999.
26. Glew RH, Williams M, Conn CA, Cadena SM, Crossey M, Okolo SN, VanderJagt DJ (2001) Cardiovascular disease risk factors and diet of Fulani pastoralists of northern Nigeria. Am J Clin Nutr 74: 730–736.
27. National Academy of Sciences. Dietary reference intakes for energy, carbohydrate, fiber, ash, fat, fatty acids, cholesterol, protein, and amino acids (macronutrients). Washington, DC: National Academics Press, 2002, pp 335–342.