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Amino Acid, Fatty Acid, and Mineral Composition of 24 Indigenous Plants of Burkina Faso[1]

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The leaves, seeds, flowers, and fruit of many indigenous plants are staples of populations who inhabit the Sahel region of Africa. They serve to supplement the nutrients provided by cereals such as millet and sorghum. However, there is a lack of comprehensive compositional data regarding the nutrient content of these indigenous plants. In this report, we present nutritional data for 24 plant materials collected in Burkina Faso, including their content of amino acids, fatty acids, and minerals. Three plants contained 20 to 37% protein (on a dry weight basis): *Vigna sp., Hibiscus esculentus,* and *Parkiia biglobosa.* Relative to a WHO protein standard, three plants scored relatively high: *Voadzeiia subterranea, Pennisetum americanum,* and *Bixa orellana.* Plants which contained large amounts of the essential fatty acids linoleic or α-linolenic acid were *Vigna sp., Hibiscus esculentus* seeds, *Parkiia biglobosa* seeds, and *Vitex doniana* fruit. Three plants were rich in iron: *Adansonia digitata, Bixa orellana,* and *Xylopia sp.* The fruit and seeds of *Hibiscus esculentus* were an excellent source of zinc. The plant foods with the highest calcium content were *Adansonia digitata* leaves, *Hibiscus sp.,* and *Bombax costatum.* These data show that in terms of both quality and quantity there are numerous spontaneous desert plants that can serve as significant sources of essential amino acids, essential fatty acids and trace minerals for populations living in the western Sahel.

INTRODUCTION

The significance of wild plants in the nutrition of human populations of the Sahel is increasing for several reasons. First, because the region continues to be visited by drought and other weather-related calamities, such as floods, which reduce the yields of traditional grain staples (e.g., millet, maize, and sorghum). Since 1980, 13 of 41 African countries experienced declines in yields for cereals, and 15 saw declines for tubers and root crops (Paarlberg, 1996). Second, world grain markets have tightened in recent years and world grain reserves are approaching their lowest levels in 20 years. The most severe problems are in Africa where unstable governments, poor economic growth, and degradation of the rural environment are threatening to increase malnutrition in the decades ahead. The result is that populations living in the Sahel

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will likely soon be facing food shortages that will compel them to turn with increasing urgency to indigenous, wild plants as staples.

We recently reported on the nutritional composition of baobab leaf (*Adansonia digitata sp.*) (Yazzie *et al.*, 1994) and the seeds of *Boscia senegalensis* (Kim *et al.*, 1997) procured in northern Nigeria and the Republic of Niger, respectively. In those studies we determined the amino acid, fatty acid, and mineral content of these two plants which serve as food supplements in the western Sahel, particularly during times of famine. Smith and colleagues (1996) have also reported on the nutritional compositions and uses of wild foods common to Burkina Faso and Niger. Despite these and other published works (Salih *et al.*, 1991) describing the chemical and nutritional composition of ''spontaneous'' or wild plants, as these indigenous staples are called, overall, information in this area is fragmentary and a comprehensive knowledge of the nutritional value of such foods in the Sahel is lacking. We therefore collected 24 indigenous edible plant specimens from Burkina Faso and analyzed them for their content of amino acids, fatty acids, and minerals.

MATERIALS AND METHODS

Source of Plant Specimens

The plants analyzed in this study were collected May–November, 1993, in southern Burkina Faso within a circle 60 kilometers in radius centered in Zabre. A total of 24 plant specimens representing 16 species were collected for nutritional analysis (Table 1). The research was conducted in two southern provinces, Boulgou and Nahouri, and plant specimens were gathered from regions surrounding the villages of Gassougou, Zabre, Zion-Youka, and Zoaga. Geographically speaking, the area is a flat plain bisected by several rivers. Local soils were poor and lateritic and the general vegetation was classified as intermittent grassland. We previously reported (Smith *et al.*, 1996) that wild edible plants comprised 21% of the total diet throughout the study area and that most wild bush foods were obtained from forested areas within 8–10 kilometers from the villages. Respondents in 1993 informed us that they commonly walked to the forested areas to search for edible wild foods, a round trip that sometimes exceeded 20 kilometers.

Standard botanical field collection methodology was used (Humphry *et al.*, 1993). All foods collected were common to all the sites. Specific samples were obtained with the aid of interpreters and field guides. Multiple specimens of edible portions of each type were collected. Most samples obtained averaged 25 g. Fresh leaves were dried and pressed. Fruits and vegetables were dried inside a thatched-roof hut in a darkened space (Smith *et al.*, 1996).

To minimize problems caused by insect infestation, some samples were treated with insecticide before leaving Burkina Faso. Upon their return to the United States, all specimens were stored in an industrial freezer at −20°C until analyses were performed. Before analysis, samples were inspected for nonplant materials and any visible dirt and insect parts were removed. Genus and species were confirmed by comparison with herbarium reference materials housed in the capital city, Niamey. Composites of the various plant specimens were ground to a fine powder in a stainless steel mill and dried to constant weight in a vacuum oven at 25°C. A sample composite of each specimen was analyzed and all results are expressed on the basis of dry weight.

TABLE 1

Latin and Common Names of Plant Species Analyzed in the Present Report

Latin	English	French	Local language:term
Adansonia digitata	Baobab	Baobab	Djerma: Foku
Bixa orellana	Annatto	Rocou	Bissa: Tomati-enshee
Bombax costatum	Kapok	Kapokier rouge	Bissa: Karayah
Butyrospermum parkii	Shea nut	Karité	Bissa: Kourou Koussaré: Tanma
Carissa edulis	African plum	Prunier	Bissa: Dougourah
Hibiscus esculentus	Okra	Gombo	Bissa: Kugay
Hibiscus sabdarifa	Sorrel	Oseille	Bissa: Sununkru Gourensi: Bare-see Koussare: Beet
Lannea microcarpa	African grape	Raisin	Koussare: Sisibah
Manihot esculanta	Manioc/cassava	?	?
Parkii biglobosa	Flour tree	Niere	Bissa: Kariah
Pennisetum americanum	Millet	Mil	Bissa: Yiryah Djerma: Yiryah Moré: Kajori
Sclerocarya birrea	Yellow plum	Prunier	Bissa: Sorah Koussaré: Nobray
Sorghum vulgaris	Sorghum	Sorgho	Bissa: Beniyhah Djerma: Nahmo
Tamarindus indica	Tamarind	Tamarinier	Bissa: Fer Djerma: Bozay Moré: Pusah
Vigna sp.	Bean	Haricot	Bissa: Saylay Gourensi: Benko
Vitex doniana	African olive	Prunier noir	Bissa: Komm
Voadzeiia subterranea	Bambara groundnut	?	Bissa: Yiriyah Koussaré: Sumengah
Xylopea aethiopia	Soursop	?	Bissa: Simunyah
Xylopea sp.	Soursop	?	Bissa: Monsuriyah

Amino Acid Analysis

Individual weighed samples were placed in 2-ml ampoules containing internal standard (norleucine) and 0.25 ml 6 *N* HCl. The ampoules were flushed with nitrogen, evacuated, sealed, and placed in the oven for 20 h at 110°C. After hydrolysis, the acid was removed in a vacuum. The samples were redissolved in 0.4 ml of 1 m*M* HCl and a 20-μl aliquot was taken for derivitization. Samples for the determination

of cysteine were first oxidized with performic acid (Hirs, 1967) for 18 h at room temperature. Performic acid was removed in a vacuum and the samples were hydrolyzed as described above. The tryptophan content was determined in a separate analysis. The samples were hydrolyzed in polypropylene tubes in 4.2 *M* KOH containing 1% (w/v) thiodiglycol (Hugli and Moore, 1972) for 18 h at 110°C. After hydrolysis, the KOH was neutralized with 4.2 *M* perchloric acid. The supernatant was removed and adjusted to pH 3 with dilute acetic acid, and a 50-μl aliquot was used for derivitization. Quantitation was achieved using a Pierce standard H amino acid calibration mixture that was supplemented with tryptophan.

The amino acid analyses were performed using the Pico-Tag system (Waters, Milford, MA). After hydrolysis, aliquots were dried, mixed with 10 μl of ethanol: water: triethylamine (2:2:1), dried again, and reacted with 20 μl phenylisothiocyanate reagent (Cohen and Strydom, 1988) (ethanol: water: triethylamine: phenylisothiocyanate, 7:1:1:1) for 20 min at room temperature. Excess reagent was removed with the aid of a vacuum. Derivatized samples were dissolved in 0.1 ml of 0.14 *M* sodium acetate that had been adjusted to pH 6.4 with acetic acid. A 10-μl aliquot was injected onto the column. Tryptophan was analyzed on a Waters C18 column (3.9 $\times$ 300 mm) using the conditions described by Buzzigoli *et al.* (1990). It was necessary to use this column in order to achieve complete resolution of tryptophan and ornithine. Ornithine is produced by alkaline hydrolysis of arginine. Analysis of the other amino acids was carried out using a Waters C18 column (3.9 $\times$ 150 mm) with gradient conditions described elsewhere (Bidlingmeyer *et al.*, 1984). A sample of egg white lysozyme, in duplicate, served as the control protein.

Mineral Analysis

Three replicate aliquots (50–500 mg) from each of the dried plant specimens were weighed and then wet-ashed by refluxing overnight at 150°C with 15 ml of concentrated HNO_3 and 2.0 ml of 70% $HClO_4$. The samples were taken to dryness at 120°C and the residues dissolved in 10 ml of 4.0% 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-Ashas described by Yazzie *et al.*, 1994). The samples were quantified against standard solutions of known concentration that were analyzed concurrently.

Lipid Extraction and Fatty Acid Analysis

One batch of each sample was ground to a powder and dried under vacuum to a constant weight. To each specimen 0.1 mg of an internal standard (nonadecanoic acid) was added. The powder was extracted with chloroform/methanol (2:1, v/v) as described elsewhere (Chamberlin *et al.*, 1993) and the solid, nonlipid material was removed by filtration. The total weight of the extracted lipid was determined gravimetrically after solvent removal in a stream of nitrogen. The samples were then redissolved in dry chloroform/methanol (19:1, v/v) and clarified by centrifugation. A 0.1-ml aliquot was withdrawn for transmethylation using 0.3 ml of 14% BF_3 in methanol in a 2-ml Teflon-lined screw-cap vial which was heated in a boiling water bath for 15 min. After cooling and addition of 0.3 ml of water, 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 GC/MS. A Hewlett–Packard Gas

Chromatograph (5890 Series II) with the Mass Selective Detector 5972A in scan mode was used to separate and quantify fatty acids. Aliquots (1 to 2 μl) of the hexane extract were injected in splitless mode onto a DB-225 column (30 m $\times$ 0.25 mm I.D., 0.24 μm). The injector temperature was 250°C, detector at 280°C, oven at 70°C for 1 min, then 70–180°C at 20°C per min, 180–220°C at 3°C per min, 220°C for 15 min. The carrier gas was helium and the flow rate was 32 cm/s. Electronic pressure control in the constant flow mode was used. The internal standard nonadecanoic acid was used for quantitation of fatty acids. Fatty acid calibration standards and nonadecanoic acid were procured from Alltech, Deerfield, IL. Solvents were purchased from EM Science, Gibbstown, NJ.

RESULTS

Protein Content and Amino Acid Composition

The amino acid content of each of the 24 plants we studied is summarized in Table 2. The plant that contained the most protein on a dry weight basis was *Vigna sp.* (37.8 g/100 g). Two of the plant specimens contained 20–23% protein, namely the seeds of *Hibiscus esculentus* (23.0%) and *Parkiia biglobosa* (20.9%). *Manihot esculanta* contained the lowest amount of protein (0.090 g/100 g). The following plant foods contained 10–20% protein: *Adansonia digitata* leaves and seeds, *Bixa orellana* seeds, *Hibiscus esculentus* fruit, *Pennisetum americanum, Sorghum vulgaris, Tamarindus indica* seed, *Voadezeiia subterranea,* and *Xylopia sp.*

In order to assess the nutritional quality of the protein in those plant specimens that contained greater than 10% protein on a dry weight basis, we compared the amino acid composition of each of these specimens to that of a World Health Organization standard protein (WHO, 1973). As shown in Table 3, according to the WHO reference protein, the highest quality plant proteins were those of *Voadzeiia subterranea, Pennisetum americanum,* and *Bixa orellana;* each of these scored at or above the score of the WHO standard for 6 of 8 amino acids or amino acid pairs. Four other plant proteins were rated ''good'' in that they scored as well or better than the WHO standard protein in 5 of 8 categories: *Parkiia biglobosa* seeds, *Adansonia digitata* leaves and seeds, and *Vigna sp.* Noteworthy is the fact that none of the plants listed in Table 3 had a tryptophan content, expressed as a percentage of total amino acids, that met the WHO standard. In contrast, five of the plants on that list had a combined methionine and cysteine content which exceeded that of the WHO standard.

Lipid and Fatty Acid Analyses

The fatty acid composition of the plants is given in Table 4. Fat comprised more than 20% of the dry weight of seven of the plant specimens: *Butyrospermum parkii* (22.5%), *Lannea microcarpa* (25.5%), *Xylopea aethiopia* (32.5%), *Hibiscus sabdarifa* flowers (26.0%), *Parkiia biglibosa* (26.0%), the sticky raw membrane of *Tamarindus indica* (46.0%), and *Vignia sp.* (24.0%). Eight other plant materials contained 10–20% lipid: *Adansonia digitata* pod, *Bixa orellana* seeds, *Pennisetum americanum, Sclerocarya birrea* fruit and seeds, *Vitex doniana, Voadzeiia,* and *Xylopia sp.*

In terms of specific fatty acids, we were most interested in linoleic acid and α-linolenic acid because both are essential for humans. While all plant specimens contained significant percentages of linoleic acid, the ones that contained the highest absolute amounts of this

TABLE 2

Amino Acid Composition of the Crude Protein Fraction of Indigenous Plant Foods of Burkina Faso

	Total protein	ASP	GLU	SER	GLY	HIS	ARG	THR	ALA	PRO
				(mg/g dry wt)						
Adansonia digitata (leaf)	103	12.9	11.4	4.55	5.57	2.18	7.07	3.65	6.58	6.76
Adansonia digitata (monkey bread pod)	27	2.96	3.94	1.18	1.21	0.42	2.28	0.65	2.21	2.35
Adansonia digitata (seeds)	196	21.1	48.9	11.4	10.4	5.05	2.21	6.98	10.6	9.55
Bixa orellana (seeds)	106	9.73	17.8	5.19	4.93	2.74	7.49	4.53	7.87	7.46
Bombax costatum	78	16.9	10.2	3.03	2.97	2.21	7.63	1.64	4.37	3.81
Butyrospermum parkii	42	5.90	5.66	1.92	1.85	1.06	3.23	1.83	2.60	4.18
Carissa edulis (fruit)	48	12.4	5.62	2.07	3.38	0.97	2.75	1.49	1.95	2.59
Hibiscus esculentus (fruit)	172	30.2	30.7	5.86	5.59	3.71	15.3	4.13	7.89	24.5
Hibiscus esculentus (seeds)	230	27.6	40.8	11.8	13.3	6.15	22.1	7.84	10.5	9.95
Hibiscus sabdarifa (dried flowers)	60	10.5	8.85	2.65	2.47	1.19	4.48	2.36	3.46	5.82
Lannea microcarpa	41	3.67	4.44	1.74	1.59	0.97	2.91	1.58	2.26	9.47
Manihot esculanta	9.0	1.42	2.11	0.29	0.28	0.12	0.68	0.36	0.68	0.35
Parkiia biglobosa (yellow powder & seed)	209	21.4	39.7	10.9	11.4	6.20	13.2	6.22	11.6	11.9
Pennisetum americanum	119	10.4	23.0	5.73	3.59	2.05	5.30	4.80	9.70	7.88
Sclerocarya birrea (fruit)	36	3.77	4.52	1.91	1.98	0.80	2.12	1.45	2.66	3.28
Sclerocarya birrea (seed)	56	5.17	13.1	2.64	2.68	1.22	6.76	1.79	2.53	2.57
Sorghum vulgaris	114	8.63	20.6	5.50	3.83	2.34	5.37	4.25	10.7	8.82
Tamarindus indica (seed)	173	18.0	28.2	9.53	16.7	5.54	16.6	5.20	6.52	8.46
Tamarindus indica (sticky raw membrane)	50	4.01	3.95	2.19	1.74	1.35	1.95	1.99	2.03	15.3
Vigna sp.	378	42.8	67.6	20.3	16.6	11.3	28.3	14.9	16.8	21.4
Vitex doniana	22	2.64	2.93	1.45	1.32	0.46	1.53	1.07	1.36	1.65
Voadzeiia subterranea	186	21.4	32.9	10.9	7.62	7.02	13.2	7.47	8.29	9.59
Xylopea aethiopia	84	9.65	11.5	5.03	4.39	1.76	8.17	3.78	5.31	5.48
Xylopia sp.	145	18.2	23.4	8.78	6.87	2.25	7.25	5.49	9.83	14.6

essential fatty acid, on a mass basis (mg of fatty acid/g dry weight), were *Vigna sp.* (8.07), followed by *Hibiscus esculentus* flowers (4.83), *Parkiia biglobosa* seeds (4.75), *Bixa orellana* seeds (2.86), and *Voadziia subterranea* (2.17). The following plant materials contained between 1 and 2 mg/g dry weight linoleic acid: *Adansonia digitata* seeds, *Butyrospermum parkii* seeds, *Pennisetum americanum*, and *Tamarindus indica* seeds. Surprisingly, *Vitex doniana* was devoid of linoleic and α-linolenic acids.

TABLE 2—*Continued*

	Total protein	TYR	VAL	MET	ILE	LEU	PHE	LYS	CYS	TRP
				(mg/g dry wt)						
Adansonia digitata (leaf)	103	4.15	6.55	1.04	5.46	8.75	6.02	6.11	2.11	2.05
Adansonia digitata (monkey bread pod)	27	1.06	1.62	0.14	1.37	2.06	1.09	1.63	1.37	0.18
Adansonia digitata (seeds)	196	5.59	11.6	2.29	8.27	14.0	10.3	11.2	3.60	2.81
Bixa orellana (seeds)	106	3.69	6.13	1.48	4.26	9.65	4.62	4.45	2.61	1.32
Bombax costatum	78	2.09	3.90	0.78	3.40	4.87	3.07	3.46	2.34	1.17
Butyrospermum parkii	42	1.31	2.25	0.08	1.97	3.21	1.58	1.85	0.92	0.48
Carissa edulis (fruit)	48	1.62	2.22	0.43	1.86	2.43	1.49	1.84	2.38	0.43
Hibiscus esculentus (fruit)	172	3.98	7.14	1.34	5.35	8.45	5.65	6.62	2.65	2.81
Hibiscus esculentus (seeds)	230	9.05	12.4	3.31	7.90	14.9	10.0	13.1	4.80	4.99
Hibiscus sabdarifa (dried flowers)	60	1.44	3.33	0.65	2.70	4.21	2.32	2.77	0.87	0.45
Lannea microcarpa	41	1.05	2.08	0.43	1.69	2.63	1.60	1.63	0.92	0.48
Manihot esculanta	9.0	0.21	0.41	0.01	0.44	0.57	0.27	0.42	0.24	0.02
Parkiia biglobosa (yellow powder & seed)	209	7.76	11.2	1.55	9.71	16.3	10.5	14.7	2.47	2.52
Pennisetum americanum	119	3.83	7.03	2.05	5.54	12.4	6.12	3.19	3.15	3.26
Sclerocarya birrea (fruit)	36	1.32	2.17	0.51	1.83	2.74	1.60	1.57	0.97	0.52
Sclerocarya birrea (seed)	56	1.47	3.03	0.68	2.53	3.78	2.37	1.29	1.95	0.83
Sorghum vulgaris	114	3.86	6.07	1.90	4.60	14.8	5.67	2.77	2.44	1.87
Tamarindus indica (seed)	173	9.53	7.14	1.40	6.69	10.9	7.11	10.5	3.52	1.78
Tamarindus indica (sticky raw membrane)	50	1.83	2.21	0.27	2.00	2.96	2.76	1.75	1.20	0.38
Vigna sp.	378	14.2	18.9	4.66	17.4	28.4	20.0	23.8	4.49	6.25
Vitex doniana	22	0.82	1.26	0.17	1.11	1.71	1.03	0.38	0.74	0.26
Voadzeiia subterranea	186	6.90	9.23	1.92	7.51	13.8	9.99	13.6	2.51	2.17
Xylopea aethiopia	84	3.31	4.90	1.01	3.34	6.01	3.61	3.75	1.83	1.14
Xylopia sp.	145	8.42	7.78	2.04	5.02	13.7	6.37	2.64	2.48	0.07

By far the richest source of α-linolenic acid was *Vigna sp.* (1.19 mg/g dry weight). All of the other plants, except for *Vitex doniana* fruit, *Carissa edulis, Manihot esculanta,* and *Lannea microcarpa,* contained between 0.025 and 0.23 mg/g dry weight α-linoleic acid.

Mineral Analyses

The mineral content of the plants is summarized in Table 5.

Iron. The three plants with the highest iron content were the leaves of *Adansonia*

TABLE 3

Comparison of the Content of Selected Essential Amino Acids of 12 Food Plants§ with That of the WHO Ideal Pattern

PLANT SPECIMEN	ILE	LEU	VAL	PHE+ TYR	LYS	THR	MET+ CYS	TRP	SCORE*
				(% of total amino acids)					
WHO standard**	4.0	7.0	5.0	6.0	5.5	4.0	3.5	4.0	- - -
Bixa orellana (seeds)	4.0	9.1	5.8	7.8	4.2	4.3	3.9	1.2	6/8
Pernnisetum americanus	4.7	10.5	5.9	8.4	2.7	4.0	4.4	2.7	6/8
Voadzeiia subterranea	4.0	7.5	5.0	9.1	7.3	4.0	2.4	1.2	6/8
Adansonia digitata (leaves)	5.3	8.5	6.4	9.9	5.9	3.5	3.0	2.0	5/8
Adansonia digitata (seeds)	4.2	7.1	5.9	8.1	5.7	3.6	3.0	1.4	5/8
Parkiia biglobosa	4.7	7.9	5.5	8.9	7.2	3.0	2.0	1.2	5/8
Vigna sp.	4.6	7.5	5.0	9.0	6.3	3.9	2.4	1.7	5/8
Hibiscus esculentus (seeds)	3.4	6.5	5.4	8.3	5.7	3.4	3.5	2.1	4/8
Sorghum vulgaris	4.0	13.0	5.3	8.4	2.4	3.7	3.8	1.6	3/8
Tamarindus indica (seeds)	3.9	6.3	4.1	9.6	6.1	3.0	4.9	1.0	3/8
Xylopia sp.	3.5	9.5	5.4	10.2	1.8	3.8	3.1	1.4	3/8
Hibiscus esculentus (fruit)	3.1	4.9	4.2	5.6	3.8	2.4	2.3	1.6	0/6

§The twelve plant specimens that contained 10% or more protein (on a dry weight basis) were selected from 24 that were analyzed in the present study (see Table 1).

* The number of amino acids ≥ the standard.

**This patterns is based on the essential amino acid needs of the preschool child; WHO/FAO Report: energy and Protein Requirements. WHO Technical Report Series, No. 522. Geneva, World Health Organization, 1973.

TABLE 4

Total Lipid and Fatty Acid Content of Indigenous Plant Foods of Burkina Faso

PLANT	TOTAL LIPID	FATTY ACID CONTENT							
		14:0	16:0	16:1	18:0	18:1n-9	18:2n-6	18:3n-6	20:0
	(mg/g dry wt)	(mg/g dry wt)							
Adansonia digitata (leaves)	55	Tr	0.24	0.011	0.035	0.058	0.10	0.081	Tr
Adansonia digitata (fruit)	155	Tr	0.15	ND	Tr	ND	0.023	0.15	ND
Adansonia digitata (seeds)	90	Tr	1.43	0.018	0.16	2.14	1.38	0.016	Tr
Bixa orellana (seeds)	175	Tr	1.54	0.015	2.56	4.49	2.86	0.13	0.012
Bombax costatum	25	Tr	0.20	ND	0.024	0.10	0.12	0.025	Tr
Butyrospermum parkii (seeds)	225	Tr	1.11	ND	3.38	7.69	1.06	0.030	0.011
Carissa edulis (fruit)	30	Tr	0.032	ND	0.018	0.043	0.059	ND	Tr
Hibiscus esculentus (flower)	190	Tr	6.54	0.063	0.65	3.47	4.83	0.033	0.047
Hibiscus esculentus (fruit)	40	Tr	0.26	ND	0.032	0.061	0.19	0.032	0.011
Hibiscus sabdarifa (flower)	260	Tr	0.20	ND	0.019	0.034	0.14	0.075	Tr
Lannea microcarpa	255	Tr	0.23	0.015	0.040	0.12	0.13	0.031	Tr
Manihot esculanta	7.5	ND	Tr	ND	ND	0.037	0.018	ND	ND
Parkiia biglobosa (seeds)	260	Tr	2.11	Tr	2.05	1.83	4.75	0.090	0.40
Pennisetum americanum	115	Tr	0.88	Tr	0.21	1.11	1.87	0.17	0.40
Sclerocarya birrea (seeds)	195	0.030	2.06	0.019	1.08	6.26	0.46	0.033	0.058
Sclerocarya birrea (fruit)	135	0.040	0.33	0.031	0.037	0.32	0.12	0.16	0.017
Sorghum vulgaris	75	Tr	0.61	0.019	0.065	1.11	1.75	0.061	Tr
Tamarindus indica (membrane)	460	Tr	0.095	ND	Tr	0.11	0.014	0.061	ND
Tamarindus indica (seeds)	75	Tr	0.54	ND	0.17	1.07	1.65	0.014	0.064
Vigna sp.	240	Tr	2.52	0.011	0.75	3.65	8.07	1.19	0.048
Vitex doniana	150	Tr	0.057	ND	0.040	ND	ND	ND	Tr
Voadzeiia subterranea	105	Tr	1.31	ND	0.43	1.27	2.17	0.15	0.13
Xylopea aethiopia	325	Tr	1.11	Tr	0.22	1.70	1.07	0.11	0.14
Xylopia sp.	170	0.025	1.12	0.011	0.15	0.22	0.84	0.23	ND

ND, not detected (< 0.005 mg/g dry weight)

digitata (155 μg/g), the seeds of *Bixa orellana* (589 μg/g), and *Xylopia sp.* (113 μg/g). The iron content of all other plant specimens ranged from a low of 10.5 μg/g (*Carissa edulis*) to 66.1 μg/g (*Vigna sp.*).

Zinc. The richest sources of zinc were the fruit and seeds of *Hibiscus esculentus* (approx. 80 μg/g). More than half a dozen plants contained less than detectable levels of zinc (<10 μg/g).

Calcium. The plants with the lowest calcium content were *Xylopia sp.* (<10 μg/

TABLE 5

Mineral Content of Indigenous Plant Foods of Burkina Faso (μg/g Dry Weight)

PLANT	Fe	Cu	Ca	Mg	Mn	Zn	Mo	Na	P
Adansonia digitata (leaves)	155	11.6	20,000	5490	31.0	18.7	ND	1630	3020
Adansonia digitata (fruit)	17	ND	3410	2090	ND	10.4	ND	54.6	733
Adansonia digitata (seeds)	18.3	ND	3950	3520	10.6	25.7	ND	19.4	6140
Bixa orellana (seeds)	589	ND	759	2040	31.1	51.4	ND	161	4480
Bombax costatum	40.8	ND	13,500	4730	35.0	16.1	ND	42.2	2180
Butyrospermum parkii (seeds)	14.6	ND	820	841	ND	13.6	ND	ND	587
Carissa edulis (fruit)	10.5	ND	3730	399	10.3	ND	ND	21.9	859
Hibiscus esculentus (flower)	43.6	11.6	1590	4510	23.2	62.2	38.7	172	7950
Hibiscus sabdarifa (flower)	61.4	ND	11,300	3090	100	27.1	ND	38.3	1630
Hibiscus esculentus (fruit)	55.3	12.1	10,000	7540	49.2	81.5	43.4	39.8	8020
Lannea microcarpa	16.6	ND	6440	2420	14.3	ND	ND	ND	1670
Manihot esculanta	49.0	ND	566	739	ND	ND	ND	49.9	820
Parkiia biglobosa (seeds)	42.3	ND	4590	2910	37.6	35.0	ND	16.9	2750
Pennisetum americanum	35.8	ND	203	1220	14.8	29.5	ND	14.1	3050
Sclerocarya birrea (seeds)	27.8	ND	1560	1930	ND	26.5	ND	11.9	2120
Sclerocarya birrea (fruit)	24.9	ND	4810	3100	ND	ND	ND	15.2	2640
Sorghum vulgaris	35.0	ND	202	1520	24.5	25.2	ND	ND	3030
Tamarindus indica (membrane)	13.9	ND	1830	1580	ND	ND	39.9	ND	1000
Tamarindus indica (seeds)	26.7	11.6	1850	1960	ND	26.3	13.9	ND	2280
Vigna sp.	66.1	ND	3890	2290	29.1	ND	17.5	ND	4220
Vitex doniana	19.1	ND	1390	1240	11.4	ND	ND	ND	957
Voadzeiia subterranea	21.5	ND	635	1830	10.4	20.3	ND	ND	2510
Xylopea aethiopia	52.0	15.2	3850	2170	112	ND	ND	65.6	1060
Xylopia sp.	113	20.0	ND	2160	114	25.9	ND	1180	1670

ND, not detected (<10.0 mg/g dry weight)

g), *Pennisetum americanum* (203 μg/g), and *Sorghum vulgaris* (202 μg/g). The richest source of calcium was the leaves of *Adansonia digitata* (20 mg/g). For all the other plants analyzed, the calcium content ranged from 566 μg/g (*Manihot esculanta*) to 13.5 mg/g (*Bombax costatum*).

Copper. Most plant materials had a copper content below the level of detection ($<$10 μg/g). Six plants had copper values in the 10–20 μg/g range: *Adansonia digitata* leaves, *Hibiscus esculentus* seeds, *Hibiscus sabdarifa* flowers, *Tamarindus indica* seeds, *Xylopia aethiopia,* and *Xylopia sp.*

Magnesium. With the exception of *Butyrospermum parkii, Manihot esculanta,* and *Carissa edulis* which contained 399–841 μg/g magnesium, all the other plant specimens had magnesium contents in the 1.0–7.5 mg/g range.

Manganese. Three plants had manganese contents in the 100–123 μg/g range: *Hibiscus sabdarifa* flowers, *Xylopia aethiopia,* and *Xylopia sp.*

Other minerals. Selenium was not detected in any of the plants. However, levels of molybdenum in the range of 13.9–43.4 μg/g were detected in four of the plant specimens: *Hibiscus esculentus* fruit and seeds, *Parkiia biglobosa* seeds, and *Tamarindus indica* seeds. One of the plants, namely *Xylopia sp.,* contained a large amount of cadmium (2.05 mg/g). Noteworthy is the high sodium content of *Adansonia digitata* leaves (1.63 mg/g) and *Xylopia sp.* (1.18 mg/g). The following metals were not present at detectable levels ($<$10 μg/g): silver, arsenic, beryllium, cobalt, chromium, potassium, and lanthanum.

DISCUSSION

Awareness of the significant contributions that wild indigenous plants make to the diets of sub-Saharan populations is increasing (Grivetti, 1978, 1979; Ogle and Grivetti, 1985; Humphry *et al.,* 1993; Smith and Grivetti, 1994). However, knowledge of the nutritional content of these plants is far from complete. The present study represents an attempt to close this knowledge gap.

One of the not-so-surprising findings of our study was that, in general, few of the plants appear to be well endowed with all of the essential nutrients for which analyses were performed. For example, while the seeds of *Adansonia digitata* contained significant amounts of the essential fatty acids, linoleic acid and α-linolenic acid and nearly 20% of a crude protein whose amino acid composition compared favorably with that of the WHO reference protein (WHO, 1973), their content of certain trace minerals such as iron and zinc was relatively low. Another example which conforms to this generalization is *Hibiscus esculentus* seed. The lipid content of the seed was high (19%) and the most abundant fatty acid in this lipid was the nutritionally essential linoleic acid. The seeds also contained reasonable amounts of calcium, iron, copper, magnesium, and manganese. However, the abundant (23% dry weight) protein of *Hibuscus esculentus* seed was moderately deficient in threonine, leucine, isoleucine, and tryptophan (Table 3).

Based on the nutritional analyses we conducted, the oil seeds of *Bixa orellana* are an exception to the generalization stated in the previous paragraph: they contain more than 10% protein that is of reasonable quality (Table 3), abundant lipid (17.5%), which is composed of significant amounts of linoleic and α-linolenic acids, and with the exception of zinc, moderate quantities of most of the trace minerals. Likewise, the seeds of *Parkiia biglobosa* contain large amounts of protein (20.9%) and lipid (26.0%) that can contribute significant quantities of essential amino acids and fatty acids to the diet.

The results of the mineral analyses we performed on some of the same plants analyzed by Smith and coworkers (1996) are in general agreement with their findings. For example, the iron value we report for baobab leaves (155 μg/g) is within the range of values reported by Smith *et al.* (1996) which were 117–278 μg/g. Since the methods used by Smith and coworkers and ourselves to digest the plant materials and quantify minerals were different, it should not be surprising to find examples of modest

discrepancy between the values we obtained and they reported. For example, the leaves of *Adansonia digitata* contain relatively large amounts of magnesium and manganese. We concur, too, with their findings that the dried calyx of *Bombax costatum* contains high concentrations of copper, magnesium, manganese, zinc, and iron. Smith and coworkers (1996) emphasized the importance of *Xylopia sp.* as a source of zinc for pregnant women and neonates. Our data on mineral composition are in accord with their data in that we found that *Xylopia sp.* contains large quantities of zinc, iron, magnesium, manganese, and copper. In contrast, however, whereas Smith and coworkers reported high concentrations of copper in the seeds of *Sclerocarya birrea,* we did not find detectable levels of this mineral in either the fleshy fruit or the oily seed of *Sclerocarya birrea* (Table 5). It is noteworthy that trace minerals are important not only for human nutrition, but for plant nutrition as well. Mineral-efficient varieties of plants are more drought resistant and require less irrigation (Bouis, 1996).

The nutritional analysis of the indigenous edible plants of the Sahel by chemical means informs one only of the potential value of these foods to those populations who rely upon them as staples or supplements to their diet. The next step is to assess the bioavailability of the essential nutrients in these plants; such studies are contemplated. These studies will focus on the digestibility of the proteins and lipids in these plants and on the possible presence of antinutrients, such as metal chelators (e.g., phytates, oxalates) and protease inhibitors.

REFERENCES

Bindlingmeyer, B. A., Cohen, S. A., and Tarvin, T. L. (1984). Rapid analysis of amino acids using precolumn derivitization. *J. Chromatogr.* **336,** 93–104.

Bouis, H. (1996). Enrichment of food staples through plant breeding: A new strategy for fighting micronutrient malnutrition. *Nutr. Rev.* **54,** 131–137.

Buzzigoli, G., Lanzone, L., Ciorciaro, D., Fascerra, S., Cerri, M., Scandroglio, A., Coldani, R., and Ferrannini, E. (1990). Characterization of a reversed-phase high performance liquid chromatographic system for determination of blood amino acids. *J. Chromatogr.* **507,** 85–93.

Chamberlain, J., Nelson, G., and Milton, K. (1993). Fatty acid profiles of major food sources of howler monkeys (*Aloutta palliata*) in the neotropics. *Experientia* **49,** 820–823.

Cohen, S. A., and Strydom, D. J. (1988). Amino acid analysis utilizing phenylisothiocyanate derivatives. *Anal. Biochem.* **174,** 1–16.

Grivetti, L. E. (1978). Nutritional success in a semi-arid land: examination of Tswana agropastoralists of the eastern Kalahari, Botswana. *Am. J. Clin. Nutr.* **31,** 1204–1220.

Grivetti, L. E. (1979). Kalahari agro-pastoral-hunter-gatherers. The Tswana example. *Ecol. Food Nutr.* **7,** 235–256.

Hirs, C. W. H. (1967). Performic acid oxidation. *Methods Enzymol.* **11,** 197–199.

Hugli, T. E., and Moore, S. (1972). Determination of the tryptophan content of proteins by ion exchange chromatography of alkaline hydrolysates. *J. Biol. Chem.* **247,** 2828–2834.

Humphry, C. M., Clegg, M. S., Keen, C. L., and Grivetti, L. E. (1993). Food diversity and drought survival. The Hausa example. *Int. J. Food Sci. Nutr.* **44,** 1–16.

Kim, T. R., Pastuszyn, A., VanderJagt, D. J., Glew, R. S., Millson, M., and Glew, R. H. (1997). The nutritional composition of *Boscia senegalensis* (Anza, Dilo) in the Republic of Niger. *J. Food Comp. Anal.* **10,** 73–81.

Morrison, W. R., and Smith, L. M. (1964). Preparation of fatty acid methyl esters and dimethylacetals from lipids with boron fluoride-methanol. *J. Lipid Res.* **5,** 600–608.

Ogle, B. M., and Grivetti, L. E. (1985). Legacy of the chameleon: edible wild plants in the Kingdom of Zwaziland, Southern Africa. A cultural, ecological and nutritional study. Part IV-nutritional analysis and conclusions. *Ecol. Food Nutr.* **17,** 41–64.

Paarlberg, R. L. (1996). Rice bowls and dust bowls. *Foreign Affairs* **75,** 127–132.

Salih, O. M., Nour, A. M., and Harper, D. B. (1991). Chemical and nutritional composition of two famine food sources used in Sudan: Mukheit (*Boscia senegalensis*) and Maikah (*Dobera roxburghi*). *J. Sci. Food Agric.* **57,** 367–377.

Smith, G. C., Clegg, M. S., Keen, C. L., and Grivetti, L. E. (1996). Mineral values of selected plant foods common to southern Burkina Faso and to Niamey, Niger, West Africa. *Int. J. Food Sci. Nutr.* **47,** 41–53.

Smith, G. C., and Grivetti, L. E. (1994). Cultural use of edible wild plants in Burkina Faso, West Africa. *FASEB J.* **8,** A183.

WHO/FAO. Energy and Protein Requirements. WHO Technical Report Series, No. 522. Geneva, World Health Organization, 1973.

Yazzie, D., VanderJagt, D. J., Pastuszyn, A., Okolo, A., and Glew, R. H. (1994). The amino acid and mineral content of Baobab (*Adansonia digitata L.*) leaves. *J. Food Comp. Anal.* **7,** 189–193.