Furthering an understanding of West African plant foods

Mineral, fatty acid and protein content of seven cultivated indigenous leafy vegetables of Ghana

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Abstract

Purpose – The main purpose of this paper is to determine the content of amino acids, fatty acids and minerals in seven indigenous leafy vegetables (ILVs) in Ghana.

Design/methodology/approach – Leaves from plants growing near Kumasi were milled to a fine powder, dried to constant weight in a vacuum desiccator, and analyzed for their content of the afore-mentioned nutrients. The plants were: *Hibiscus sabdarifa, Hibiscus cannabinus, Amaranthus cruentus, Corchorus oliforius, Solanum macrocarpon, Xanthomosa sagittifolium* and *Vigna unguiculatus*.

Findings – All seven ILVs contained a large amount of protein (15.5-22.8 percent), which compared favorably to the essential amino acid pattern of a WHO standard. They all contained nutritionally useful amounts of α-linolenic acid and had an omega-6/omega-3 ratio of 0.1-0.9. The seven ILVs contained quantities of calcium, copper, iron, magnesium, manganese, molybdenum and zinc that could contribute significantly to satisfying an individual's need for these elements.

Research limitations/implications – The presence of relatively large amounts of various nutritionally essential macro- and micronutrients in these seven ILVs does not necessarily mean these nutrients are bioavailable. Future research is required to determine the amounts of anti-nutrients (e.g. protease inhibitors, chelators) in these vegetables, and the extent to which their protein, lipid and mineral constituents are digested and/or absorbed.

Originality/value – Since malnutrition (e.g. iron-deficiency anemia, rickets, zinc deficiency, protein-calorie malnutrition) is common in sub-Saharan Africa, the information which is provided should increase awareness among agricultural and public health officials of the nutritional value of seven underappreciated and underutilized ILVs that are indigenous to Ghana and many other parts of Africa.

Keywords Proteins, Minerals, Food products, Ghana, Plants, Africa

Paper type Research paper

Introduction

We were interested in the mineral, fatty acid and protein content of the leaves of seven indigenous leafy vegetables (ILVs) that grow in Ghana, West Africa as well as in learning about the uses of these plants in the communities where they are consumed. The plants analyzed in this study, with local Twi language names in parenthesis, include: *Hibiscus sabdariffa* (bitto), *Hibiscus cannabinus* (berese), *Amaranthus cruentus* (aleefu), *Corchorus olitorius* (ayoyo), *Solanum macrocarpon* (gboma), *Xanthosoma sagittifolium* (nkontomire), and *Vigna unguiculatus* (bento). Indigenous leafy vegetables in general are widely regarded as excellent sources of calcium, iron, zinc

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and many other essential micronutrients. The impetus for investigating the nutritional value of these plant foods is the growing demand for ILVs in Ghana and the significant role they play in the diets of local communities and increasingly in urban communities. As urban centers grow, there is growing demand in cities for these "traditional" plant foods by urban populations for preparation in the home as well as for sale in local restaurants. What had often been thought of as "traditional" or rural foods are now attaining new status in the growing middle class of urban Ghana.

The plants in this study are primarily used as potherbs, meaning they are cooked in a variety of soups that constitute the most common main course of Ghanaian meals. Leaves from the plants are used fresh or may be dried and stored for future use. The leaves are most commonly added to soups that are eaten at meals, which may contain other vegetables or meat. Dokosi (1998) has documented the uses of numerous ILVs in the rural areas of Ghana and when relevant, also highlights medicinal uses of the plants as well.

In the present study, we sought to acquire information regarding the content of protein and essential amino acids, fatty acids, and minerals and trace elements in seven cultivated ILVs in Ghana in order to further our understanding of the potential nutritional benefits of these foods and their role in Ghanaian diets.

Materials and methods

Collection of plants

The Ministry of Food and Agriculture provided a detailed list of vegetable farmers within the Kumasi metropolitan area for us to use as a reference guide. A total of 30 vegetable farmers and fields were randomly selected from the list within a ten mile radius of Kwame Nkrumah University of Science and Technology. The 30 farmers were grouped into cells of five farmers/fields per cell resulting in six cells. These cells were coded and three were randomly selected as the experimental study areas to be used as sample collection sites. This process was taken to avoid bias and prejudicial sampling of the plant specimens. To avoid any uncontrolled environmental stress, all samples were collected in the morning between 8 and 9 o'clock. There were three replicate collections for each plant and each replicate collection and handling was synchronised as a batch collection.

The plant samples collected represented the stage of development that would normally be harvested for consumption, typically young leaves between two and three weeks old. Batch samples were bulked for each plant type and for each site, and 15 kg per batch were cleansed and seperately dried in solar dryers at the KNUST Biochemistry Annex for five days. Dried sample collections per batch as described were seperately collected, ground to a smooth powder and sealed in sanitary vials brought from the USA. Phytosanitary certification was obtained from the proper authorities in Ghana and the samples were carried back to the USA for analysis. All three sets of analyses were performed in triplicate and results are reported as the mean value/g dry weight, plus or minus one standard deviation.

Lipid extraction and fatty acid analysis

Prior to lipid extraction, powdered specimens of leafy vegetables were vacuum dried using an Eyela centrifugal evaporator CVE-1000 (Tokyo, Japan) for 12 hours. Total lipids were extracted according to a modification of the method previously described by Folch *et al.* (1957). Briefly, approximately 1 g of sample were extracted overnight at 4°C with 20mL of chloroform/methanol (2:1, v/v). The extracted lipids in the chloroform

phase were separated from the aqueous phase after shaking with 4mL of 0.9 percent (w/v) NaCl solution and concentrated under a stream of by nitrogen. The lipids were then reconstituted to 5mL with chloroform.

To prepare fatty acid methyl esters, 0.1mL of the chloroform solution of the lipid sample was evaporated under a stream of nitrogen, and then treated with 14 percent (w/v) BF_3 (Morrison and Smith, 1964) in methanol for 20 minutes at 95°C. The fatty acid methyl esters were extracted into hexane, and separated and quantified using an Agilent 6890 gas chromatograph (GC) equipped with a flame-ionization detector and a fused-silica capillary column (Omegawax; 30m × 0.32 mm, i.d., film thickness 0.25μm, Supelco, Bellefonte, Pennsylvania, USA). Helium was used as the carrier gas. The injector was set at 205°C, and the detector at 240°C. The temperature of oven was initially 120°C, and then raised to 205°C at a rate of 4°C/min and held for 20 minutes. The fatty acid peaks were identified by comparing their retention times to fatty acid methyl ester standards (mixture RL-461, Nu-Chek-Prep, Inc., Elysian, Minnesota). Quantification was made using the technique of internal standardization with triheptadecanoin (Sigma, St Louis, Missouri, USA).

Mineral analysis

Samples (0.2 g) of the dried, powdered plant were weighed into 125mL Phillips beakers and digested with 15mL concentrated nitric acid and 1mL perchloric acid. The samples were covered with watch glasses, allowed to stand for one hour at room temperature, and then placed on a hotplate. The temperature was increased at a rate of 50°C/15 min to 150°C after which the samples were refluxed for 24 h. The watch-glass covers were removed and the samples were brought to near dryness at the 150°C. The samples were cooled to room temperature and brought to 10.0mL with 4 percent nitric acid/1 percent perchloric acid. Samples were analyzed for their metal content by ICP-OES as described elsewhere (Fernandez *et al.*, 2003).

Amino acid analysis

A total of 20 mg of dried, milled leaf of each sample were hydrolyzed in 6N HCl containing 0.1 percent (w/v) phenol at 110°C for 24 hours *in vaccuo*, and the resultant amino acids were separated and quantified using the Dionex BioLC Chromatographic System configured for AAA-Direct analysis according to the manufacturer's instructions (Dionex) and published methods (Clark *et al.*, 1999; Jandick *et al.*, 1999). For the determination of methionine and cysteine, samples were oxidized with performic acid (Hirs, 1967) prior to acid hydrolysis. The reproducibility of the method ranged from 0.6-11 percent for the amino acids reported. Tryptophan was not measured.

Results

Comments regarding ethnobotanical considerations

During July-August 2008 a total of 90 farmers in the Greater Accra, Ashanti and Eastern Regions of Ghana were interviewed regarding the cultivation, preference and marketing of the seven indigenous leafy vegetables cited in this study. All seven of the plants were rated highly by the farmers as desirable plant foods in their communities and with regard to their potential for consumption at home as well as for sale in the market.

Hibiscus sabdariffa is cultivated most commonly, during the six month-long dry season, and is very popular as a potherb in the northern regions of Ghana. *Hibiscus cannabinus* is used in a similar manner but is known to have poor storability. It is

typically produced for consumption in the home and not for sale at market. *Amaranthus cruentus* is cultivated at all times during the year and is most commonly consumed in a soup consisting of tomatoes, onions and ground pumpkin seeds (egusi). While the leaves of *Amaranthus cruentus* are good-tasting, farmers indicated that is does not store well for long periods of time (typically eaten within two months of harvesting) and has a stable but relatively low market value. *Corchorus olitorius*, while cultivated, is also found growing wild, and as with the other ILVs, the leaves are cooked in a soup that contains other vegetables as well. Leaves of *Corchorus oliforius* are highly desirable in many communities because of their flavor, but have a low but stable market value. The poor storability of *Corchorus oliforius* is a limitation as farmers indicated that the plant must be consumed within several days of harvest.

Solanium macrocarpon is most often collected by residents in its non-cultivated form, but is also known to be cultivated in home gardens. The leaves of this plant are less desirable in terms of taste and have only minimal market value compared to the other plants in this study.

Conversely, *Xanthosoma sagittifolium*, is a highly marketable and popular ILV used in home-prepared soups and as an ingredient in food served in many restaurants. The leaves are highly perishable and thus costly in the market during the dry season. Although *Vigna unguiculatus* is valued more because of the desirability of the plant's beans, the leaves of the plant are also used to prepare soups. Because of their slightly bitter taste, the leaves of *Xanthosoma sagittifolium* are less commonly sought than other plant foods in this study and have little market value.

Thus, ILVs represent a potential income-earning opportunity for farmers in Ghana. Proximity to large urban centers such as Accra and Kumasi is an important factor in decisions about whether to cultivate ILVs. Furthermore, the market for ILVs in Ghana may be enhanced if scientific nutritional data suggests that eating such foods provides nutritional benefits.

Fatty acid content and composition

On a dry-weight basis, fatty acids accounted for 0.5-1.1 percent of the total dry weight of the specimens (see Table I). Except for the leaves of *Xanthosoma sagittifolium* and *Vigna unguiculatus*, saturated fatty acids (mainly palmitic acid and stearic acid) represented 20 percent or less of the fatty acid total; in *Xanthosoma sagittifolium* and *Vigna unguiculatus*, saturated fatty acids accounted for 30-35 percent of the total. Noteworthy was the finding that the essential omega-3 fatty acid α-linolenic acid was the most abundant fatty acid in all seven of the plant foods. Furthermore, the omega-6/omega-3 ratio for all seven green leafy vegetables was less than 1/1. An omega-6/omega-3 ratio less than 2/1 is considered healthful (Simopoulos *et al.*, 1999; Simopoulos 2002).

Amino acid content and composition

As indicated in Table II, the protein content of the seven green leafy vegetables, estimated by summating the individual amino acids, was substantial, ranging from 15.5 percent (*Hibiscus cannabinus*) to 22.8 percent (*Xanthosoma sagittifolium*). To assess the quality of the protein in the seven kinds of leaves, we compared their proportions of essential amino acid (except tryptophan) to the proportions of these same amino acids in a WHO protein standard (World Health Organization, 1985).

Table I.
Fatty acid composition (percent ± 1 SD) composition of seven cultivated green leafy vegetables in Ghana

Fatty acid	*Hibiscus sabdariffa*	*Hibiscus cannabinus*	*Amaranthus cruentus*	*Corchorus olitorius*	*Solanum macrocarpon*	*Xanthomosa sagittifolium*	*Vigna unguiculatus*
14:0	1.99 (0.12)	1.62 (0.30)	1.91 (0.09)	2.12 (0.56)	1.60 (0.45)	1.67 (0.21)	3.22 (0.32)
14:1	ND	ND	ND	0.24 (0.02)	0.28 (0.01)	ND	ND
15:0	ND	0.21 (0.0)	ND	ND	ND	ND	0.43 (0.04)
16:0	16.8 (0.14)	18.7 (0.04)	22.4 (0.05)	20.2 (0.3)	20.7 (0.01)	24.1 (0.3)	29.2 (0.8)
16:1n-7	0.27 (0.02)	0.22 (0.0)	0.27 (0.03)	0.33 (0.01)	0.23 (0.02)	0.32 (0.3)	0.43 (0.04)
18:0	3.03 (0.04)	3.07 (0.02)	2.77 (0.01)	2.51 (0.02)	5.04 (0.02)	5.67 (0.11)	4.56 (0.15)
18:1n-9	3.10 (0.02)	2.80 (0.04)	3.24 (0.01)	2.98 (0.04)	1.37 (0.02)	4.26 (0.07)	1.90 (0.36)
18:1n-7	0.42 (0.0)	0.28 (0.0)	0.34 (0.03)	0.43 (0.01)	0.27 (0.01)	0.28 (0.01)	0.40 (0.01)
18:2n-6	14.9 (0.04)	13.2 (0.01)	17.2 (0.05)	13.6 (0.1)	21.4 (0.1)	22.4 (0.2)	7.18 (0.11)
18:3n-3	58.0 (2.0)	58.6 (0.7)	50.1 (0.6)	55.8 (0.9)	44.6 (0.7)	34.5 (0.6)	50.4 (0.3)
20:0	0.75 (0.03)	0.61 (0.01)	0.37 (0.01)	0.50 (0.0)	1.15 (0.02)	3.27 (0.28)	0.87 (0.04)
20:1	ND	ND	ND	0.39 (0.01)	ND	0.65 (0.01)	ND
20:2n-6	ND	ND	ND	ND	ND	0.43 (0.02)	ND
22:0	0.72 (0.04)	0.54 (0.01)	0.74 (0.02)	0.75 (0.01)	1.28 (0.03)	1.65 (0.03)	1.30 (0.03)
22:1	ND	ND	0.47 (0.04)	0.27 (0.23)	0.26 (0.23)	0.55 (0.04)	0.48 (0.41)
24:0	ND	0.35 (0.61)	ND	ND	ND	1.18 (1.05)	ND
Unknown	ND	ND	ND	ND	1.81 (0.02)	ND	ND
Total (mg/g dry weight)	10.9 (0.05)	10.7 (0.04)	8.60 (0.20)	9.00 (0.10)	9.50 (0.06)	7.60 (0.05)	4.81 (0.01)

Note: ND, not detected

Amino acid	*Hibiscus sabdariffa*	*Hibiscus cannabinus*	*Amaranthus cruentus*	*Corchorus olitorius*	*Solanum macrocarpon*	*Xanthamosa sagittifolium*	*Vigna unguiculatus*
	Content (Mean ± 1 SD)						
Aspartic	27.9 (1.5)	16.8 (0.7)	21.0 (0.7)	27.6 (1.3)	34.9 (0.8)	18.9 (0.9)	31.4 (2.6)
Threonine	8.56 (0.33)	7.92 (0.28)	8.78 (0.24)	10.8 (0.50)	7.91 (0.25)	7.54 (0.34)	10.6 (0.8)
Serine	8.33 (0.69)	6.55 (0.22)	8.98 (0.25)	9.44 (0.38)	7.70 (0.21)	7.62 (0.37)	9.23 (0.61)
Glutamic	22.3 (0.6)	19.9 (0.8)	34.7 (1.2)	29.2 (0.8)	34.9 (0.9)	33.6 (1.8)	26.9 (1.9)
Glycine	9.48 (0.37)	8.73 (0.35)	11.5 (0.3)	12.8 (0.6)	10.7 (0.3)	9.68 (0.38)	12.5 (0.8)
Alanine	11.0 (0.6)	10.7 (0.5)	13.2 (0.4)	14.4 (0.7)	11.8 (0.4)	12.6 (0.5)	15.4 (1.0)
Valine	11.5 (0.3)	10.6 (0.4)	13.2 (0.4)	15.1 (0.7)	12.7 (0.4)	12.3 (0.6)	15.5 (1.0)
Isoleucine	8.62 (0.30)	7.99 (0.33)	10.1 (0.3)	11.5 (0.6)	8.86 (0.27)	8.71 (0.37)	11.2 (0.7)
Leucine	15.0 (0.6)	13.8 (0.6)	16.6 (0.5)	20.0 (0.8)	14.0 (2.2)	13.9 (0.6)	19.3 (1.3)
Tyrosine	1.63 (0.41)	1.74 (0.17)	5.32 (0.16)	6.55 (0.75)	6.03 (0.21)	4.70 (0.18)	5.26 (0.41)
Phenylalanine	11.1 (0.5)	9.65 (0.39)	11.4 (0.4)	14.4 (0.7)	13.3 (0.4)	9.72 (0.43)	15.0 (0.9)
Histidine	4.26 (0.76)	4.06 (0.14)	4.75 (0.17)	5.90 (0.29)	5.44 (0.18)	4.58 (0.23)	4.87 (0.28)
Lysine	12.0 (0.5)	10.9 (0.4)	13.1 (0.4)	14.3 (0.7)	12.8 (0.4)	10.4 (1.0)	12.7 (0.8)
Arginine	9.92 (0.30)	8.48 (0.93)	11.0 (0.3)	13.4 (0.6)	11.9 (0.4)	9.70 (0.34)	11.4 (0.8)
Cysteine	2.37 (0.11)	2.33 (0.10)	3.54 (0.13)	3.09 (0.17)	3.85 (0.12)	2.68 (0.11)	2.97 (0.13)
Proline	11.5 (0.5)	14.0 (0.4)	9.62 (0.30)	17.8 (0.9)	21.6 (0.6)	7.78 (0.32)	15.5 (0.8)
Methionine	1.04 (0.06)	0.84 (0.05)	0.84 (0.09)	1.17 (0.12)	0.95 (0.09)	0.87 (0.05)	0.85 (0.02)
Total (%)	176 (7)	155 (6)	198 (6)	228 (11)	216 (7)	228 (11)	221 (12)

Table II.
Amino acid content (mg/g) of seven cultivated green leafy vegetables in Ghana

Xanthosoma sagittifolium scored below 100 in five of seven categories. The sulfur amino acid (cysteine plus methionine) score of each of the seven vegetables was very low (46-63 percent). However, with regard to the other essential amino acids – isoleucine, leucine, lysine, threonine, valine and phenylanine plus tyrosine – *Hibiscus sabdariffa*, Hibiscus *cannabinus*, Amaranthus *cruentus*, Corchorus *olitorius*, Solanum *macrocarpon* and *Vigna unguiculatus* all had amino acid scores greater than 100 (see Table III). Thus, in terms of protein content and pattern of amino acids relative to the WHO standard, six of the seven vegetables contained substantial amounts of relatively high-quality protein.

Mineral and trace element content

In general, the seven green leafy vegetables differed considerably in terms of their content of various minerals and trace elements that are essential in humans (see Table IV). For example, the calcium content of *Vigna unguiculatus* was 32,800μg/g dry compared to *Xanthosoma sagittifolium*, which contained only about one-third as much calcium (9,360μg/g dry weight). On the other hand, *Xanthosoma sagittifolium* contained nearly three times as much copper as *Vigna unguiculatus*. The magnesium content of the seven plant foods ranged from a low of 1,210μg/g dry weight in *Amaranthus cruentus* to a high of 5,190μg/g dry weight in *Solanum macrocarpon*. The iron content of all but *Xanthosoma sagittifolium* was in the range 153-275μg/g dry weight. *Xanthosoma sagittifolium* contained the smallest amount of manganese (27.9μg/g dry weight and *Amaranthμus cruentus* the most (126μg/g dry weight). Most of the plants contained similar amounts of potassium, phosphorous and zinc. None of the vegetables contained a detectable level of selenium, a component of glutathione peroxidase and thus a critical element in the body's antioxidant defense system. As for non-nutrient elements, all of the plants contained significant quantities of strontium and low but measurable amounts of lead.

Discussion

Collectively, the seven plants we describe herein represent a sampling of ILVs in Ghana that are increasing in value in urban centers because of their desirability for consumption by large segments of their population and increasing economic value. As demand for these plants continues to grow, cultivators in rural areas of the country have begun considering cultivating some of the plants on their land to diversify their cultivars.

The main finding of this study was that, with the exception of *Xanthosoma sagittifolium*, which was inferior to the other six plants, the ILVs we investigated appear to contain nutritionally useful amounts of good-quality protein, α-linolenic acid, and many essential minerals.

The protein in a typical serving of plant *Hibiscus sabdariffa*, Hibiscus *cannabinus*, Amaranthus *cruentus*, Corchorus *olitorius*, Solanum *macrocarpon* or *Vigna unguiculatus* could contribute significantly to satisfying the daily needs of an adult for all of the essential amino acids, except the sulfur amino acids methionine and cysteine. For example, consumption of about 80 g of fresh *Xanthonsoma sagittifolium* (20 g dry weight) would provide about 5 g of protein, which compares with a recommended daily intake of 42 g of protein for an adult (World Health Organization, 2007). Noteworthy is the fact that all seven of the plants contained less-than-ideal

Amino acid(s)	*Hibiscus sabdariffa*	*Hibiscus cannabinus*	*Amaranthus cruentus*	*Corchorus olitorius*	*Solanum macrocarpon*	*Xanthomosa sagittifolium*	*Vigna unguiculatas*
Isoleucine	122	130	127	125	103	95	127
Leucine	121	127	120	126	93	87	124
Lysine	123	127	120	115	107	84	106
Methionine and cysteine	54	60	63	54	63	46	49
Phenylalanine and tyrosine	120	123	140	153	148	105	153
Threonine	123	128	110	118	85	83	120
Valine	130	136	134	132	118	108	140

Table III.
The essential amino acid scores of seven cultivated green leafy vegetables in Ghana relative to the WHO ideal (11): score = sample/ideal x 100

Table IV.
Mineral and trace element content (micrograms/g dry weight) of seven cultivated green leafy vegetables in Ghana

Element	*Hibiscus sabdariffa*	*Hibiscus cannabinus*	*Amaranthus cruentus*	*Corchorus olitorius*	*Solanum macro*	*Xanthomosa sagittifolium*	*Vigna unguiculatus*
Ca	18,100 (603)	14,200 (208)	31,900 (265)	14,100 (153)	22,300 (503)	9,360 (203)	32,800 (351)
Co	0.11 (0)	0.23 (0.01)	0.12 (0.01)	0.10 (0.02)	0.13 (0.01)	0.06 (0)	0.09 (0.01)
Cr	0.93 (0.07)	0.78 (0.07)	2.25 (0.26)	1.70 (0.08)	1.18 (0.01)	0.65 (0.02)	0.86 (0.03)
Cu	5.29 (0.05)	8.63 (0.17)	7.50 (0.14)	6.66 (0.10)	14.1 (0.23)	16.3 (0.29)	5.63 (0.11)
Fe	170 (4)	153 (2)	270 (11)	275 (5)	206 (4)	84.4 (0.7)	190 (3)
K	12,100 (115)	13,900 (58)	24,000 (656)	22,000 (300)	26,100 (872)	23,700 (351)	15,600 (252)
Mg	3,220 (51)	2,650 (6)	1,210 (173)	4,080 (46)	5,190 (76)	2,080 (35)	4,970 (29)
Mn	35.3 (0.2)	60.2 (0.6)	126 (4.2)	44.3 (0.4)	66.4 (1.2)	27.9 (0.3)	68.9 (0.6)
Mo	1.85 (0.04)	1.18 (0.02)	1.87 (0.03)	0.59 (0.01)	1.71 (0.03)	1.96 (0.01)	0.66 (0.01)
Na	235 (5)	272 (29)	484 (9)	305 (12)	353 (15)	411 (50)	332 (7)
P	3,950 (17)	3,040 (0)	6,270 (44)	5,530 (12)	4,220 (1,810)	5,090 (95)	6100 (46)
Pb	0.48 (0.05)	0.37 (0.11)	0.34 (0.02)	1.06 (0.34)	0.84 (0.38)	0.33 (0.03)	0.32 (0.01)
Se	ND	ND	ND	ND	ND	ND	ND
Sr	40.6 (0.6)	32.3 (0.6)	66.5 (0.4)	37.4 (0.4)	41.3 (0.9)	10.9 (0.4)	60.8 (0.1)
Zn	25.5 (0.5)	23.6 (0.2)	42.7 (0.3)	38.8 (0.6)	59.5 (1.2)	72.4 (1.4)	63.4 (0.8)

Note: ND, not detected. The values reported represent the mean ± 1 standard deviation of three determinations

proportions of cysteine plus methionine relative to the WHO standard protein (World Health Organization, 1985). Plant proteins in general and especially those derived from legumes, tend to be low in methionine and cysteine (McCarty *et al.*, 2009). Exacerbating this problem is the fact that the digestibility of plant proteins is lower than that of animal proteins (Saunders *et al.*, 1973; Pirie, 1978; McCarty *et al.*, 2009). In light of the low scores of all seven plants for the sulfur amino acid pair relative to the WHO standard protein (see Table III), the diets of populations who rely extensively on any of these indigenous leafy vegetables would have to be complemented with some other protein source that could provide these essential amino acids.

The seven plants reported in the current study are readily and widely available in Kumasi because they are grown in family gardens and local farms.

With regard to the ability of these plants to contribute to satisfying one's mineral requirements, take calcium and iron as examples. The recommended daily intakes of calcium and iron for an adult male are 1,000 mg and 10 mg, respectively. From the data in Table IV, one can estimate that 20 g dry weight of *Vigna unguiculatus* would provide more than 600 mg of calcium and 4 mg of iron. Clearly, most of the green leafy vegetables in the present study represent impressive sources of protein and minerals.

The same can be said for the ability of these indigenous green leafy vegetables to provide the human diet with the essential fatty acid α-linolenic acid. The daily recommended intake of α-linolenic acid for an adult is about 1 g (Spaaij and Pijls, 2004)). 20 g (dry weight) of *Hibiscus cannabinus* contain 0.13 mg of α-linolenic acid. Although the quantity of α-linolenic acid in the leaves of the seven plants we analyzed in the present study represents only 10-15 percent of the daily requirement for an adult, the fatty acid profiles of all of these leaf species is advantageous vis-à-vis human nutrition because the ratio of linoleic acid/α-linolenic acid in each instance was less than 1/1. To put this low ratio in perspective, consider that the linolenic acid/α-linolenic acid ratio in most western diets is $>$ 5/1 and commonly in the range of 10/1 to 20/1. A high linoleic acid/α-linolenic acid ratio is widely regarded as pro-inflammatory and generally unhealthful, especially with regard to cardiovascular disease and certain cancers (9,10).

The amounts of certain nutrients in the leaves of *Hibiscus sabdarifa* gathered in Ghana are similar to values reported for the corresponding vegetable obtained in the Republic of Niger (Spaaij and Pijls, 2004; Freiberger *et al.*, 1998). For example, the protein content of *Hibiscus sabdarifa* leaves gathered in the Republic of Niger and Nigeria was in the range 16.9-22.8 percent; however, the methionine plus cysteine content of *Hibiscus sabdarifa* leaves from Ghana was only about half that of the same species from the Republic of Niger. In all other respects, the amino acid compositions of the proteins from the two countries were similar. Although the total amount of fatty acid in *Hibiscus sabdarifa* leaf grown in Ghana was only about one-half that of the same green leafy vegetable from the Republic of Niger (Freiberger *et al.*, 1998; Sena *et al.*, 1998), the fatty acid profiles (expressed on a fatty acid-percentage basis) were similar in that α-linolenic acid was the most abundant fatty acid in both sets of specimens and the omega-6/omega-3 ratio was well below 1/1.

As for minerals and trace elements, leaves of *Hibiscus sabdarifa* grown in Ghana and those obtained in the Republic of Niger contained similar amounts of calcium and magnesium (Freiberger *et al.*, 1998; Sena *et al.*, 1998; however, the leaves of *Hibiscus*

sabdarifa gathered in Ghana contained only half or less as much iron, copper, manganese and zinc than those from the Republic of Niger.

Relative to nutrient content data reported by Ndlovu and Afolayan (Ndlovu and Afolayan, 2008) for *Corchorus olitorius* grown in South Africa, the leaves of this same species that we collected in Ghana contained about 30 percent more protein, half as much lipid, one-third as much calcium but similar amounts of zinc and iron.

The literature is lacking with respect to reports of the nutrient content of *Hibiscus canabinus* and *Amaranthus cruentus* against which we might compare the results we obtained in the present study.

In light of the high incidence of iron-deficiency anemia (Agyei-Frempong *et al.*, 2001), calcium-deficiency rickets (Thacher *et al.*, 1999), and deficiencies of zinc and other micronutrients in Ghana and many other regions of sub-Saharan Africa (Lutter and Rivera, 2003; Adu-Afarwuah *et al.*, 2008), the information in this study should serve to underscore the value of certain readily available and economically accessible, but heretofore underappreciated, green leafy vegetables which could contribute to the prevention of these and many other health problems that affect vulnerable populations (e.g. infants and young children, pregnant and lactating women).

A limitation of the present study is that we did not investigate the content of anti-nutrients such as protease inhibitors (e.g. trypsin inhibitor), metal chelating substances (e.g. phytate, tannins) and fiber that can reduce protein digestibility (Pirie, 1978). In addition, we did not use *in vitro* protease-based methods to assess the digestibility of the proteins in the seven Ghanaian plants, nor did we measure the bioavailability of the amino acids in these proteins. Bioavailability studies in general must be performed in order to obtain a more complete picture of the actual value of the nutrient data provided in the current report. The bioavailability of proteins and minerals and trace elements will be the focus of future studies.

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