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Non-cultivated Plant Foods in West Africa: Nutritional Analysis of the Leaves of Three Indigenous Leafy Vegetables in Ghana

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ABSTRACT

Although non-cultivated indigenous leafy vegetables (ILVs) are widely consumed in Ghana and other parts of sub-Saharan Africa, particularly during periods of food scarcity, much remains to be learned about their content of essential nutrients. We collected the leaves of *Cleome gynandra*, *Fleurya aestuans* and *Solanum nigrum* growing near Kumasi and compared them in terms of their content of essential amino acids, fatty acids, and minerals and trace elements. All three plant foods contained (on a dry-weight basis) 21.6-26% protein whose essential amino acid pattern, except for the methionine/cysteine pair, compared favorably with a World Health Organization standard protein. Although fatty acids accounted for only 0.5-1.1% of the dry weight of the ILVs, the proportion of the essential omega-3 fatty acid α-linolenic acid was high (24.3-58.2%) in all three plants, and the omega-6/omega-3 ratio was a healthful 0.1 and 0.4, respectively for *C. gynandra* and *S. nigrum*, respectively. The leaves of the three ILVs contained nutritionally significant amounts of calcium, copper, iron, magnesium, manganese, molybdenum and zinc, but were devoid of detectable selenium. These results indicate that *C. gynandra*, *F. aestuans* and *S. nigrum*, which are widely regarded by the inhabitants of sub-Saharan Africa as 'famine foods', actually represent excellent potential sources of many different nutrients that are essential in humans.

Keywords: α-linolenic acid, amino acids, *Cleome gynandra*, fatty acids, *Fleurya aestuans*, minerals, *Solanum nigrum*

INTRODUCTION

We sought to further our understanding of the role and importance of non-cultivated plant foods in West African communities by analyzing the mineral, fatty acid and protein content of the leaves of three indigenous leafy vegetables (ILVs) from Ghana in West Africa. During field work conducted during June-August 2008, data were also collected regarding the use and consumption patterns of these plant foods.

The plants included in this study, with local Twi language name in parenthesis, include: *Cleome gynandra* (tete), *Fleurya aestuans* Mig. (bhonho) and *Solanum nigrum* (bachinia). The common names of the plants in English are cat's whiskers, nettle weed, and black nightshade, respectively. Our interest in investigating the use and nutritional value of these plants is based on the fact that although Ghana is an agriculturally-productive region of West Africa, it is common for people in rural communities to consume ILVs as part of their diet, either as food or medicine. Furthermore, with growth of urban centers there is increasing demand in cities such as Kumasi and Accra for some of these "traditional" plant foods by urban populations for preparation in the home as well as for sale in local restaurants. Kumasi is 250 km northwest of the capital city Accra and has a population of over 1.5 million people.

C. gynandra is found throughout tropical Africa. Mnzava and Chigumira (2004) have provided a comprehensive review of the various uses of the plant in different world regions. In Africa and Asia, the leaves, young shoots and sometimes the flowers of the plant are consumed as a side dish, relish or in a soup. In addition to its use as a food, Mnzava and Chigumira also highlight the medicinal properties of the plant. Examples of its medicinal use include consumption of the leaves by mothers before and after childbirth, for treatment of blood loss, and for treatment of anemia. While the plant is readily available for collection in its non-cultivated form, there is evidence that as quality seed becomes available more extensive cultivation of the plant is occurring in Africa. Since *C. gynandra* is a desirable food in many locales in tropical Africa, and as knowledge about the plant's cultivation is enhanced, it has the potential to develop into a regularly cultivated plant food. In Ghana, leaves from the plant are added to soups where the plant is a valued potherb. While available in the wild, the plant is also seeded in crop fields in the Volta Region where burning of plant materials is a common practice (Dokosi 1998). Examples of medicinal uses of *C. gynandra* in Ghana include treatment for constipation and ear infections.

In contrast to *C. gynandra*, *F. aestuans* is a common weed that grows throughout the tropics, but it is not very popular as a food. Medicinal uses of the plant in Africa include treatment for eye infections, swelling, wounds, burns, and gonorrhoea (Dokosi 1998). In Ghana, the plant is used in preparing soup for women after childbirth to ensure good health, thus reflecting the local population's perception that the plant has nutritional value. Medicinal applications of *F. aestuans* in Ghana include using the leaves of the plant to make a poultice to treat scorpion stings. Also, the leaves are used to make a soup with palm nuts that is consumed to treat stomach ailments and irregular menstruation (Dokosi 1998).

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In tropical Africa, *S. nigrum* is generally consumed during times when other foods are scarce or as medicinal treatment. Like *F. aestuans*, this plant is not a preferred food. The plant is a weed that grows wild in fields as well as other locations, although it is occasionaly cultivated. Jansen (2008) has recently highlighted the significant medicinal uses of *S. nigrum* in Africa and Asia which include treatment for the following conditions: itching, burns, cuts, skin diseases, heart disease, fever and eye disease. The leaves of *S. nigrum*, which are consumed during times of food scarcity, are bitter tasting. Thus, human consumption of the leaves usually reflects a lack of availability of other preferred foods. Before consumption the leaves are usually boiled several times to remove toxins. Dokosi (1998) has highlighted the medicinal value of *S. nigrum* in Ghana. Available in local markets, the leaves of *S. nigrum* are boiled in soup and may be used to treat jaundice, in addition to being used as a purgative and diuretic (Dokosi 1998). In the Volta Region of Ghana, a poultice made from the leaves is applied externally to treat Guinea worm.

MATERIALS AND METHODS

Collection and handling of plant specimens

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. Thirty vegetable farmers and fields were randomly selected from the list within a 10 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 2-3 weeks old. Batch samples collected were bulked for each plant type and for each site, and 15 kg per batch was 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 United States. Phytosanitary certification was obtained from the proper authorities in Ghana and the samples were carried back to the United States 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 h. Total lipids were extracted according to a modification of the method previously described by Folch *et al*. (1957). Briefly, approximately 1 g of sample was extracted overnight at 4°C with 20 mL of chloroform/methanol (2: 1, v/v). The extracted lipids in the chloroform phase were separated from the aqueous phase by shaking with 4 mL of 0.9% (w/v) NaCl solution, collected and evaporated by nitrogen. The lipids were then reconstituted with 5 mL of chloroform.

To prepare fatty acid methyl esters, 0.1 mL of the chloroform solution of the sample was evaporated under a stream of nitrogen, and then treated with 14% BF_3 (w/v) in methanol for 20 min at 95°C (Morrison and Smith 1964). The fatty acid methyl esters were extracted with 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; 30 m × 0.32 mm, i.d., film thickness 0.25 µm, Supelco, Bellefonte, PA, USA). Helium was used as the carrier gas. The temperature of the injector was 205°C, and that of detector 240°C. The temperature of the oven was initially 120°C, and raised to 205°C at a rate of 4°C/min and held for 20 min. The fatty acid peaks were identified by comparing their retention times to those of standards (mixture RL-461, Nu-Chek-Prep, Inc., Elysian, MN, USA). The quantification was determined by using the technique of internal standardization with triheptadecanoin, (Sigma, St. Louis, MO).

Mineral analysis

Samples (0.02 g) of the dried, powdered plant were weighed into 125 mL Phillips beakers and digested with 15 mL concentrated nitric acid and 1 mL perchloric acid. The samples were covered with watch glasses, allowed to stand for 1h at room temperature, and then placed on a hot plate. The temperature was increased at 50°C/15 min to 150°C where the samples were refluxed for 24 h. The watch-glass covers were removed and the samples were brought to near dryness at 150°C. The samples were cooled to room temperature and brought to 10.0 mL with 4% nitric acid: 1% perchloric acid. Samples were analyzed for their metal content by ICP-OES as described elsewhere (Fernandez *et al*. 2003).

Amino acid analysis

Twenty milligrams of dried, milled leaf were hydrolyzed in 6 N HCl containing 0.1% (w/v) phenol at 110°C for 24 h *in vacuo*, 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 Corp. Technical Note 50) and published methods (Clarke *et al*. 1999; Jandik *et al*. 1999). For determination of methionine and cysteine, samples were oxidized with performic acid (Hirs 1964) prior to acid hydrolysis. The reproducibility of the method ranged from 0.6-11% for the amino acids reported. Tryptophan was not measured.

RESULTS

Ethnobotanical considerations

Ninety farmers from the Greater Accra, Ashanti and Eastern Regions of Ghana were interviewed to provide ethnobotanical information regarding the plants collected and analyzed in this study. Farmers confirmed that two of the plants, *S. nigrum* and *F. aestuans*, are hardship foods. As for *S. nigrum*, farmers described it as a wild and rarely cultivated plant food. Cultivation of *S. nigrum*, when it does occur, usually takes place in a home garden. As a food, the plant is used in times of necessity, not because of preference. In addition, the farmers interviewed indicated that the plant has little market value. *F. aestuans* is a non-cultivated food plant that is typically found and collected in the vicinity of dump sites. Leaves from the plant are added to soups, but only during times of severe food shortage, which often occurs following a crop failure. Historically the plant has served as a "famine food" in the region and has no market value. *C. gynandra* occurs in a non-cultivated form but may also be semi-cultivated and found in home gardens. Although the plant has little market value, it is considered a desirable and good-tasting potherb in many communities in Ghana.

As interviews in the field have illustrated, the plants in this study share similar characteristics. They are typically non-cultivated, difficult to store, and have little or no market value, which results in low incentive to cultivate them as plant foods. The plants do, however, play a significant role in the diet so that they are often relied upon during times of food scarcity. For this reason it is useful to investigate the mineral, fatty acid and protein content of the plant foods to understand their potential nutritional value in local communities during such periods of hardship.

Fatty acid composition

The fatty acid content and composition of the three plants are summarized in **Table 1**. As is true for green leafy vege-

Table 1 Fatty acid composition (mass %) of three indigenous leafy vegetables.

Fatty acid	*Cleome gynandra*	*Fleurya aestuans*	*Solanum nigrum*
14:0	2.27 (0.33)*	4.52 (0.13)	2.00 (0.10)
14:1	0.14 (0.12)	0.14 (0.25)	0.24 (0.03)
15:0	0.14 (0.11)	0.55 (0.03)	ND
16:0	22.1 (0.4)	36.1 (0.4)	16.8 (0.1)
16:1n-7	0.53 (0.07)	0.54 (0.06)	0.19 (0.01)
18:0	3.31 (0.21)	3.58 (0.05)	4.24 (0.02)
18:n-9	1.52 (0.40)	2.33 (0.02)	2.17 (0.02)
18:1n-7	0.24 (0.21)	0.77 (0.02)	0.27 (0)
18:2n-6	7.80 (0.22)	22.8 (0.3)	19.0 (0.2)
18:3n-3	58.2 (1.0)	24.3 (0.7)	46.7 (0.1)
20:0	1.03 (0.03)	1.11 (0.03)	1.14 (0.03)
20:1	ND	ND	0.18 (0.02)
22:0	1.91 (0.01)	2.36 (0.04)	0.98 (0.15)
22:1	0.52 (0.36)	0.94 (0.04)	0.37 (0.04)
24:0	0.28 (0.49)	ND	ND
Unknown	ND	ND	5.78 (0.07)
Total (mg/g dry weight)	9.50 (0.55)	5.00 (0.17)	11.3 (0.11)

ND, not detected.
*Each value is the mean (± 1 standard deviation) for triplicate determinations.

tables in general, fatty acids contributed <2% to the dry weight of the leaves of *C. gynandra*, *F. aestuans* and *S. nigrum*. *C. gynandra* and *S. nigrum* leaves each contained about 1% fatty acid whereas *F. aestuans* contained only 0.5% fatty acid. Noteworthy features of the fatty acid profiles of the leaves of *C. gynandra* and *S. nigrum* were their high percentage of the essential omega-3 fatty acid, α-linolenic acid (58.2 and 46.7%, respectively) and low percentage of total saturated fatty acids (i.e., 25-30%). Furthermore, the linoleic acid/α-linolenic acid ratio for all three vegetables was very low (0.1-0.9) and within a range that is widely regarded as healthful (WHO 1995; Simopoulos *et al*. 1999; Simopoulos 2002).

Amino acid composition

All three green leafy vegetables contained substantial amounts of protein that ranged from 21.6% (*C. gynandra*) to 26.0% (*S. nigrum*) (**Table 2**). Except for the sulfur amino acids methionine and cysteine, the three plants compared favorably with a World Health Organization protein standard (WHO 1985) (**Table 3**). However, with regard to methionine plus cysteine, the WHO score for *S. nigrum* was only 60 and slightly higher for plants *C. gynandra* (71) and *F. aestuans* (77). Nevertheless, overall, these data indicate that *C. gynandra*, *F. aestuans*, and *S. nigrum* are good sources of protein of generally satisfactory quality.

Mineral and trace-element content

Macronutrients. *F. aestuans* had the most calcium (Ca); however, the leaves of all three species contained large quantities of this mineral (**Table 4**). The amounts of iron (Fe), manganese (Mn), phosphorus (P), potassium (K) and sodium were similar in all three leafy vegetables. *F. aestuans* had 2 to 3 times more magnesium (Mg) than *C. gynandra* and *S. nigrum*. The molybdenum content varied widely among the three plants, from a low of 2.04 μg/g for *F. aestuans* to a high of 9.46 μg/g for *C. gynandra*. *S. nigrum* is rich in zinc (Zn). Remarkably, none of the plants contained selenium (Se), a nutritionally important element that plays a central role in the body's antioxidant defense system against harmful free radicals.

Measurable levels of the potentially toxic aluminum, lead and strontium were present in all of the green leafy vegetable specimens.

Table 2 Amino acid composition (mg/g dry weight) of three wild indigenous leafy vegetables.

Amino acid	*Cleome gynandra*	*Fleurya aestuans*	*Solanum nigrum*
Alanine	20.9 (0.5)*	16.3 (0.8)	16.6 (0.5)
Arginine	14.7 (0.1)	13.5 (0.6)	13.0 (0.5)
Aspartate	28.4 (0.4)	30.6 (0.2)	36.7 (1.0)
Cysteine	4.04 (0.11)	3.47 (0.19)	4.25 (0.19)
Glutamate	37.1 (0.8)	29.3 (1.3)	33.8 (1.1)
Glycine	14.7 (0.2)	13.9 (0.7)	14.5 (0.5)
Histidine	5.19 (0.10)	5.03 (0.22)	6.51 (0.21)
Isoleucine	13.4	11.0 (0.5)	13.2 (0.4)
Leucine	22.3 (0.4)	21.3 (0.8)	22.0 (0.7)
Lysine	15.5 (0.20)	13.6 (0.6)	17.0 (0.6)
Methionine	1.27 (0.13)	2.70 (0.12)	1.32 (0.05)
Phenylalanin	15.7 (0.3)	13.8 (0.7)	15.3 (0.5)
Proline	22.7 (0.5)	11.4 (0.5)	20.7 (0.8)
Serine	11.5 (0.1)	10.6 (0.4)	10.4 (0.4)
Threonine	13.0 (0.1)	12.0 (0.6)	11.2 (0.4)
Tyrosine	6.42 (0.08)	6.67 (0.37)	5.77 (0.30)
Valine	17.6 (0.3)	14.6 (0.7)	17.5 (0.6)
Total (mg/g dry weight)	216 (4)	227 (6)	260 (8)

* Each value is the mean (± 1 standard deviation) for triplicate determinations.

Table 3 Comparison of the essential amino acid composition of three indigenous leafy vegetables with the WHO ideal: sample/ideal x 100.

Amino acid	*Cleome gynandra*	*Fleurya aestuans*	*Solanum nigrum*
Isoleucine	155	122	127
Leucine	147	134	121
Lysine	131	109	118
Methionine and cysteine	71	77	60
Phenylalanine and tyrosine	170	150	135
Threonine	150	133	108
Valine	164	128	134

Table 4 Mineral and trace element content (mg/g dry weight) of three indigenous leafy vegetables.

Element	*Cleome gynandra*	*Fleurya aestuans*	*Solanum nigrum*
Ca	37400 (404)*	68400 (1250)	23800 (265)
Co	0.119 (0.0134)	0.221 (0.015)	0.15 (0.01)
Cr	1.82 (0.67)	5.29 (0.40)	1.09 (0.02)
Cu	8.02 (0.12)	12.1 (0.31)	6.61 (0.11)
Fe	214 (2)	295 (10)	330 (2)
K	20900 (321)	18900 (113)	22000 (58)
Mg	4190 (44)	12,400 (265)	5050 (50)
Mn	37.5 (0.1)	33.6 (0.6)	39.3 (0.31)
Mo	9.46 (0.16)	2.04 (0.01)	2.55 (0.02)
Na	782 (7)	603 (8)	472 (7)
P	7090 (53)	4800 (35)	6650 (68)
Pb	0.65 (0.11)	0.49 (0.07)	6.48 (0.12)
Se	ND	ND	ND
Sr	85.1 (0.7)	152 (0.7)	39.2 (0.3)
Zn	34.3 (0.5)	37.8 (0.4)	209 (6)

ND, not detected (<0.43)
* Each value is the mean (± 1 standard deviation) for triplicate determinations.

DISCUSSION

The main goal of this study was to determine the content of certain essential nutrients including amino acids, fatty acids, and minerals and trace elements in three indigenous leafy vegetables that are consumed by many people in Ghana and other parts of Africa during periods of food scarcity. Overall, the data presented herein support the conclusion that any one of these vegetables represents a useful dietary source of the two essential fatty acids (linoleic acid, α-linolenic acid), all of the essential amino acids except the sulfur amino acids methionine plus cysteine (tryptophan was not determined), and most of the essential minerals and trace elements, except Se.

With regard to minerals and trace elements, *F. aestuans* was the richest source of Ca, chromium, copper, Fe and Mg. Akubugwo and colleagues (2007, 2008) reported values for the P content of *S. nigrum* grown in Nigeria that agree with our data; however, their values for Ca, Mg and Zn are less than that we obtained in the present study for *S. nigrum*. Differences in soil and the use of fertilizers could account for differences in the content of certain minerals in *S. nigrum* grown in Ghana and Nigeria. Comparing the data in the present report with that of Chweya and Mnzava (1997), it appears that whereas leaves of *C. gynandra* grown in Ghana contain about the same quantities of K, Mg, Na, Fe, and Zn as that grown in Kenya, leaves of *C. gynandra* from Ghana contain several-fold more calcium but only one-third as much copper as its counterpart in Kenya.

As for fatty acids, although all three of the plants reported herein contained only a small amount of fatty acid (0.5-1.1% of dry weight), the two essential fatty acids accounted for nearly half or more of the total. Therefore, the three plant foods could contribute useful amounts of these critical fatty acids to the diet. Noteworthy, too, was the remarkably low linoleic acid/α-linolenic acid ratio (0.1-0.9)(**Table 1**) we found for *C. gynandra*, *F. aestuans*, and *S. nigrum*. In a study of the fatty acid profiles of *S. nigrum* leaves and several other green leafy vegetables in Australia, Liu and coworkers (2007) reported that α-linolenic acid was the predominant fatty acid. Van der Walt and colleagues (2008) reported that three dark leafy vegetables grown in South Africa were low in fat (1.6-2.9% of dry weight) and that α-linolenic acid accounted for more than half of the fatty acid total. These investigators proposed that these vegetables with their characteristic high linoleic acid/α-linolenic acid ratio could have anti-inflammatory effects in those who consume them. An omega-6/omega-3 ratio >4/1 is common in most Western diets and is associated with an increased risk of certain diseases, including cardiovascular disease, breast cancer, and inflammatory and autoimmune diseases (Simopoulos *et al*. 1999; Simopoulos 2002). The oleic acid content of all three of the plants was remarkably low (approximately 4%) and saturated fatty acids accounted for only about one-quarter of the fatty acid total.

As for protein quantity and quality, all three plant foods contained substantial amounts (21.6-26% of dry weight) of relatively high-quality protein. Of the essential amino acids, the proportion of only the methionine-cysteine pair fell significantly below the WHO standard. There is agreement between our estimate and that of Chweya and Mnzava (1997) of the protein content of *Cleome gynandra* leaves.

The substantial amounts of essential fatty acids, minerals and trace elements, and amino acids in the three green leafy vegetables we document herein indicate that they represent potential valuable and important sources of critical nutrients in the diets of populations living in sub-Saharan Africa. Information regarding the protein content, amino acid composition and mineral and trace element content of edible plants indicate only their healthful potential. Since antinutrients in plants, such as protease inhibitors, and metal chelators, such as phytates and tannins, can decrease the bioavailability of amino acids and minerals and trace elements, respectively, further studies are required to assess the extent to which the full nutritional value of these essential nutrients is realized.

In addition, future studies should address the possible effects of potentially toxic metabolites in the three plant foods on human nutrition, in particular alkaloids, terpenoids, saponins, steroids and glycosides. For example, *S. nigrum* (Schmidt *et al*. 2004; Afolayan and Jomoh 2008; Li *et al*. 2008) and *C. gynandra* (Narendhirakannan *et al*. 2007) both contain these biologically-active substances.

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