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Amino Acid, Fatty Acid and Mineral Content of Black Finger Millet (*Eleusine coracana*) Cultivated on the Jos Plateau of Nigeria

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ABSTRACT

Finger millet (*Eleusine corocana*) is a staple of some communities living on the Jos Plateau of north-central Nigeria. Having reported in 2003 on the nutrient content of the more-common tan-colored finger millet, we were interested in knowing the content of essential amino acids, fatty acids and minerals and trace elements of a dark, rust-colored finger millet called "black millet" that is also cultivated in the same mountainous savannah of Nigeria. Black finger millet contains 8.71 mg/g dry weight fatty acid and 8.47 g/g dry weight protein. The specific nutrient contents of the three specimens of black millet we analyzed were nearly identical to that of tan finger millet with respect to amino acid and fatty acid content and composition; however, black finger millet contained only half as much iron and one-tenth as much molybdenum as reported previously for the more common variety of finger millet. Nevertheless, black finger millet represents a good source of the essential amino acids (except lysine), the two essential fatty acids (linoleic acid and α-linolenic acid), and the minerals calcium, iron, magnesium, manganese, copper and zinc.

Keywords: cereal, essential fatty acids, finger millet

INTRODUCTION

Finger millet is cultivated in a wide geographical zone ranging from Senegal, Niger, and northern Nigeria in West Africa, across eastern and southern Africa, through the Middle East and into tropical Asia. Finger millet is also known as African millet and black millet. Varieties of the cereal are well-adapted to heat, humidity and tropical conditions, however, some varieties also survive water shortage (Burkill 1985).

In the case of the Jos Plateau in north-central Nigeria, a highland variety of finger millet, *Eleusine coracana*, is cultivated in upland areas where the altitude is between 1,000 and 2,400 meters. In Nigerian languages finger millet is known as *tamba* in Hausa, *chargari* in Fulfulde, and *kpana* in Birom. Hilu and de Wet (1976) examined distribution, linguistic and historical evidence available for finger millet and concluded that *E. coracana* probably originated in the East African Highlands. Additional research seems to confirm this finding and provides evidence that *E. coracana* was likely domesticated in the fourth millennium B.C. in the Sudan-Ethiopian region (Mehra 1991).

Because finger millet is primarily consumed in developing countries it is often referred to as a "crop for the poor" or a "famine food" (Vietmeyer 1996). Despite this, finger millet remains an important food in many of the regions of Africa where it can grow, and it is one of the most nutritious of the cereals. Burkill (1985) cites several studies that have shown this to be the case for communities in Nigeria as well as around Lake Chad and in Central and East Africa. The ability of the crop to grow in water-deficit regions, the storability of the seed for consumption and planting (estimated to be at least ten years) and the resistance of the grain against mold and insects make it a viable emergency food (Burkill 1985).

Previous studies have documented the nutritional value of finger millet: it contains as much protein as rice, is especially rich in two of the essential amino acids (methionine and tryptophan), and contains substantial amounts of the other essential amino acids, except lysine (Malleshi and Klopfenstein 1998; Fernandez *et al*. 2003). It is also a good source of iron and calcium which is especially relevant to populations inhabiting northern Nigeria where the incidences of iron-deficiency anemia in pregnant women (VanderJagt *et al*. 2007) and calcium-deficiency rickets in young children are high (Thacher *et al*. 2000; VanderJagt *et al*. 2001). Finger millet also contains useful amounts of the two polyunsaturated fatty acids that are essential in humans, linoleic acid and α-linolenic acid (Fernandez *et al*. 2003). The body metabolizes linoleic acid and α-linolenic acid into arachidonic acid and docosahexaenoic acid, respectively, which are essential to the normal development of the central nervous system (Birch *et al*. 2007; Jacobson *et al*. 2008).

In a previous study we reported on the amino acid, mineral and fatty acid composition of the dominant tan-coloured strain of *E. corocana* that is grown on the Jos Plateau in Nigeria (Fernandez *et al*. 2003). Recently we collected samples of a rust-colored cultivar of *E. corocana* called "black millet" being grown in rural communities in the vicinity of the city of Jos to investigate the nutrient value of this particular strain of finger millet. This paper reports on the amino acid, mineral and fatty acid content of black millet.

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MATERIALS AND METHODS

Millet specimens

Black millet seeds were obtained in the markets in three villages located on the outskirts of the city of Jos: Sho, Vom and Whos. The millet was dehulled in the traditional manner (i.e., winnowing) and ground into flour using a Krups type 203 stainless-steel mill. The specimens were transported to Albuquerque in cryovials where they were dried to constant weight over calcium chloride desiccant in a vacuum desiccator at room temperature.

Mineral analysis

Triplicate aliquots of approximately 0.25 g of each of the three samples were weighed in 150 mL Phillips beakers and treated with nitric and perchloric acids (4/1, v/v). Beakers were covered and refluxed for 15 h at 150°C on a hotplate. The covers were then removed and the digests were taken to near dryness at the same temperature. Samples were cooled to room temperature and 0.5 mL nitric-perchloric acid and a few drops of distilled water were added. The samples were then transferred quantitatively into graduated centrifuge tubes and brought to a final volume of 10.0 mL. Finally, the solutions were analyzed by ICP-OES for their content of minerals using a Spectro Analytical EOP (end on plasma-axial view) spectrometer using a fixed cross-flow nebulizer and dual spray chamber. Results are expressed as micrograms per g dry weight of original specimen. The coefficient of variation for this method is less than 2%.

Fatty acid analysis

Each sample of millet was analyzed in triplicate. Total lipids were extracted according to the procedure of Folch and colleagues (Folch *et al*. 1957). Briefly, approximately 0.25 g of millet was extracted with 20 mL chloroform: methanol (2:1, v/v) at 4°C for 18 h. The extracted lipids in the chloroform phase were separated from the aqueous phase by adding 4 mL of 0.9% (w/v) NaCl solution. The chloroform phase was evaporated at 25°C using a stream of nitrogen. The crude lipid fraction was then treated with 2 mL of 1% (v/v) sulfuric acid in methanol and 0.5 mL of dimethylsulfoxide for 20 min at 95°C to generate fatty acid methyl esters (Morrison and Smith 1964). The fatty acid methyl esters were extracted into hexane and separated using an Agilent 6890 gas chromatograph equipped with an on-column automatic injector, flame ionization detector, HP-88 capillary column (100 m × 0.25 µm film thickness; Hewlett-Packard, Sunnyvale, CA, USA) and Chemstation software. The operating conditions were as follows: carrier gas, helium; injector temperature, 250°C, detector temperature, 280°C; temperature program, initially at 175°C, raised to 220°C at a rate of 2°C/min, and held at 220°C for 20 min. The fatty acid methyl esters were identified by comparing their retention times to those of known standards donated to us by Nu-Chek (Elysian, MN, USA) and quantified using the principle of internal standardization. The coefficient of variation for the method was less than 4%.

Amino acid analysis

A single sample of each of the three millet specimens was hydrolyzed in 6 N HCl 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 Corporation, City, State, USA) and published methods (Clark *et al*. 1999; Jandik *et al*. 1999). The reproducibility of the method ranged from 0.6-11% for the amino acids reported.

RESULTS

Since the fatty acid compositions of the three different black millet specimens were nearly identical, the compositions were averaged (**Table 1**). The total fatty acid content of black millet was 8.71 mg/g dry weight and the major non-essential fatty acids were oleic acid (18:1n-9)(44.0%) and palmitic acid (16:0)(22.7%). The two fatty acids that are essential in humans, linoleic acid (18:2n-6) and α-linolenic acid (18:3n-3), accounted for 20.2 and 3.74%, respectively, of the fatty acid total. The linoleic acid/α-linolenic acid ratio was 5.4:1, which is within the range of values (10:1 to 5:1) recommended by the World Health Organization (WHO/FAO 1995).

Table 1 Average fatty acid composition (mass %) and content (mg/g dry weight) of three specimens of black finger millet.

Fatty acid	Mass %	Content (mg/g dry weight)
C14:0	0.20 (0.07)*	0.18 (0.05)
C15:1	0.16 (0.01)	0.014 (0.01)
C16:0	22.7 (0.80)	2.02 (0.13)
C16:1n-7	0.18 (0.05)	0.16 (0.003)
C18:0	2.13 (0.19)	0.21 (0.01)
C18:1n-9	44.0 (0.50)	3.93 (0.28)
C18:1n-7	5.13 (0.56)	0.50 (0.04)
C18:2n-6	20.2 (1.81)	1.81 (0.27)
C18:3n-3	3.74 (0.23)	0.34 (0.04)
C20:0	0.20 (0.02)	0.018 (0.01)
C20:1	0.50 (0.13)	0.048 (0.08)

* The number in parentheses indicates one standard deviation.
± The total fatty acid content is 8.71 (0.34) mg/g dry weight.

Table 2 Mineral content (µg/g dry weight) of black finger millet.

Mineral	1 (Sho)≠	2 (Vom)	3 (Whos)	Average
Calcium	2990 (62)≠	3710 (87)	5320 (140)	4010
Chromium	1.06 (0.04)	1.94 (0.12)	3.69 (0.03)	2.23
Copper	7.69 (0.25)	7.90 (0.09)	6.83 (0.09)	7.47
Iron	82.3 (3.1)	260 (37)	203 (30)	182
Potassium	6180 (151)	5710 (55)	4320 (54)	5410
Magnesium	1830 (64)	1730 (34)	1670 (29)	1740
Manganese	233 (8)	392 (6)	250 (2)	292
Molybdenum	0.16 (0.01)	0.21 (0.02)	ND	0.15
Sodium	151 (18)	151 (15)	143 (4)	148
Phosphorus	3250 (79)	2790 (22)	2230 (83)	2760
Zinc	29.3 (1.1)	26.8 (0.3)	25.3 (0.5)	27.1

ND, not detected (<0.10 µg/g dry weight).
≠ The number in parenthesis indicates one standard deviation.
*The name in parenthesis indicates the village where the black finger millet was purchased.

With regard to minerals and trace metals and relative to most other cereals, the black millet specimens contained large amounts of calcium, iron and manganese (**Table 2**) and significant amounts of several other essential minerals, including copper, potassium, magnesium and zinc. However, the amounts of chromium and molybdenum in black millet were only one-half and one-tenth, respectively, of the corresponding values we reported previously for the more common tan-colored finger millet cultivated on the Jos Plateau (Fernandez *et al*. 2003). Furthermore, whereas we found measurable levels of selenium in the pwana samples we analyzed in 2003, the amount of selenium in all three of the black millet specimens analyzed in the present study was below the limit of detection of the method (<0.3 ug/g dry weight).

Both the amino acid content and percentage composition of black millet (**Table 3**) were nearly identical to those of the more common variety of tan-coloured finger millet grown on the Jos Plateau (Fernandez *et al*. 2003). For example, amino acids accounted for 8.47% of the solids in black millet versus 6.89% of the dry weight of tan-coloured *E. coracana*. Furthermore, the proportions of the essential amino acids methionine (plus cysteine), threonine, isoleucine, phenylalanine (plus tyrosine) and leucine in black millet were equal to or exceeded the proportions of these same amino acids in a WHO protein standard (**Table 4**). On the other hand, as we found in our previous study of the more common tan-colored variety of finger millet, the proportion of the essential amino acid lysine in black millet was only 49% that of the WHO protein standard (WHO 1985). Due to cost considerations, tryptophan was not determined in the present study.

Table 3 Amino acid composition (mg/100 mg dry weight) of three different specimens of black finger millet.

Amino acid	1 (Sho)*	2 (Vom)	3 (Whos)	Mean ± 1 S.D.[≠]
Cysteine	0.216	0.179	0.161	0.185 (0.017)
Aspartic acid	0.598	0.490	0.467	0.518 (0.053)
Threonine	0.392	0.304	0.294	0.330 (0.038)
Serine	0.512	0.386	0.372	0.423 (0.060)
Glutamic acid	2.66	1.85	1.81	2.11 (0.035)
Proline	0.730	0.535	0.542	0.602 (0.078)
Glycine	0.325	0.295	0.266	0.295 (0.017
Alanine	0.675	0.514	0.506	0.565 (0.067)
Valine	0.705	0.516	0.497	0.573 (0.083)
Methionine	0.356	0.303	0.276	0.337 (0.028
Isoleucine	0.496	0.359	0.351	0.402 (0.053)
Leucine	1.11	0.781	0.763	0.881 (0.130)
Tyrosine	0.134	0.089	0.079	1.01 (0.022)
Phenylalanine	0.558	4.403	0.381	0.447 (0.057)
Histidine	0.269	0.210	0.196	0.225 (0.022)
Lysine	0.243	0.224	0.195	0.221 (0.017)
Arginine	0.321	0.293	0.237	0.284 (0.020)
Total:	10.3	7.73	7.39	8.47 (1.20)

[≠]S.D., Standard deviation.
*The name in parentheses indicates the village where the black finger millet was purchased.

Table 4 Comparison of the amino acid composition of black finger millet to the WHO standard.

Amino acid	WHO Ideal* (% of total)	Black finger millet[≠] (% of total)	Black finger millet x100 WHO Standard
Isoleucine	4.0	4.8	120
Leucine	7.0	10.4	149
Lysine	5.5	2.6	47
Methonine plus cysteine	3.5	6.2	177
Phenylalanine plus tyrosine	6.0	6.7	112
Threonine	4.0	3.9	98
Valine	5.0	6.8	136

*WHO (1985).
[≠] The mean value from **Table 3**.

DISCUSSION

Since cereals in general, and finger millet in particular, are such important components of the diets of the people of the Jos Plateau, we wanted to assess the nutritional quality of a strain of *E. corocana* called 'black millet' that is cultivated and consumed in certain communities on the high savannah of north-central Nigeria. In general, the composition of black millet with regard to amino acids, minerals and trace elements and fatty acids agreed closely with the data we obtained several years ago when we analyzed the more common tan-colored variety of finger millet (Fernandez *et al*. 2003), especially with regard to essential amino acids and fatty acids. Thus, black millet appears to be an excellent source of the two essential fatty acids, linoleic acid and α-linolenic acid, all of the essential amino acids except lysine, and many of nutritionally important minerals and trace elements, including calcium, iron, molybdenum, magnesium and copper. However, the black millet we analyzed in the present study contained significantly less chromium, molybdenum and selenium than tan-coloured *E. corocana* grown on the Jos Plateau. Such discordance between the two strains of finger millet black versus tan-coloured could be due to genetic differences or may reflect differences in the soil conditions between the sites where the two strains of millet were grown (Vadivoo *et al*. 1998). Finger millet will grow on a variety of soils and it is widely recognized that soil and climate can impact the nutrient composition of cereals, including millet (Vietmeyer 1996).

The nutrient content of black finger millet reported herein should help correct the scientific neglect of finger millet and the false impression of some that it is a "poor person's" crop or a "famine food" (Vietmeyer 1996), and promote a resurgence of the cultivation of this hardy, productive, tasty and nutritious cereal which thrives in a wide range of conditions and environments. The high calcium content of finger millet offers a means of preventing and treating calcium-deficiency rickets in Plateau State and the surrounding states where the incidence of the disease is high (Thacher *et al*. 2000; VanderJagt *et al*. 2001). Similarly, based on its high iron content, it would seem that more widespread consumption of finger millet would also be beneficial to pregnant and lactating women living in communities where iron-deficiency anemia is common (VanderJagt *et al*. 2007). Noteworthy, too, is the fact that finger millet is also a good source of zinc, a trace element that is required for a healthy immune system (Hirano *et al*. 2008).

We have confirmed our previous observation (Fernandez *et al*. 2003) and that of others (Malleshi *et al*. 1998) that *E. corcorana* grown on the Jos Plateau is deficient in lysine; in that study and this one we have shown that black millet and the more common tan-colored variety both contain only half the proportion of lysine recommended by the WHO. This means that wherever finger millet is the staple, the diet should be supplemented with a food such as soya beans which is a good source of lysine.

The question of the bioavailability of minerals such as iron, calcium and other divalent cations in finger millet is relevant since the deep rust colour of 'black millet' could be due to the presence of large amounts of tannins which are strong metal chelators that could retard the absorption of metals from the small intestine. In this regard, Antony and Chandra (1998) have shown that fermenting finger millet reduced its tannin content as well as the content of other antinutrients (e.g., trypsin inhibitor, phytates, phenolics).

Future studies should include testing the hypothesis that increasing the consumption of finger millet in northern Nigeria would reduce the incidence of iron-deficiency anemia in pregnant women and rickets in young children.

CONCLUSION

The amino acid, fatty acid and mineral content of black finger millet cultivated on the Jos Plateau of Nigeria was similar to that of tan finger millet in the same locale, except that black finger millet contains significantly less iron (50%) and molybdenum (10%). Black finger millet is a good source of essential amino acids (except lysine), essential fatty acids and many minerals.

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