Quantification of fatty acid and mineral levels of selected seeds, nuts, and oils in Northern Ghana

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Abstract The purpose of this study was to identify locally available foods that can be utilized by Northern Ghanaians to improve child growth status. An assortment of seeds, nuts and oils were collected from a local market, packaged in plastic containers, and shipped to the US for all analyses. Fatty acids (FAs) were extracted and derivatized to FA methyl esters prior to quantification by GC/MS. ANOVA were conducted on FA concentrations and Tukey's post hoc test was used to compare FA content. Food grade oils, particularly palm oil and shea butter, contained higher saturated and monounsaturated FAs than seeds or nuts. Soybean, was significantly higher in the essential omega-3 FA alpha-linolenic acid (2.98 mg/g), whereas neri seed (68.4 mg/g) and fermented dawadawa (seed; 56.3 mg/g) had significantly higher amounts of total polyunsaturated FAs than all other foods. Iron levels in soybean (353 mg/kg), neri (282 mg/kg) and fermented dawadawa (165 mg/kg) were also the highest of all foods. Together, these foods may be useful for future intervention to curb stunting and iron-deficiency anemia.

Keywords Fatty acid · Neri · Growth · Ghana · Mineral · Soybean

Abbreviations

AA	Arachidonic acid
ALA	Alpha-linolenic acid
AOAC	Association of analytical communities
BAB	Baobab seed
BHT	Butylated hydroxytoluene
DAW	Dawadawa
DHA	Docosahexaenoic acid
EPA	Eicosapentaenoic acid
EFA	Essential fatty acid
FAME	Fatty acid methyl esters
FA	Fatty acid
FDD	Fermented dawadawa
GC/MS	Gas chromatography mass spectrometry
GLA	Gamma-linolenic acid
HSD	Honest significant difference
LLOQ	Lower limit of quantification
LA	Linoleic acid
MUFA	Monounsaturated fatty acid
NER	Neri
n-3	Omega-3
n-6	Omega-6
PUFA	Polyunsaturated fatty acid
PAL	Palm oil
PKO	Palm kernel oil
PNT	Peanut
RT	Room temperature
SAM	Sesame seed
SIM	Selective ion monitoring
SHB	Shea butter
SOY	Soybean

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Introduction

Although Ghana has achieved its goal of eradicating extreme poverty and hunger according to the Millennium Development Goal 1, uneven wealth distribution and poverty still prevails in the northern sector of the country resulting in lower food consumption and dietary diversity, especially in food insecure households (World Food programme 2012). While the national stunting levels among Ghanaian children below 5 years old is 19%, in Northern Ghana, stunting levels exceed 33% (Ghana Statistical Service Accra 2014). In addition, only 36.6% of Ghanaian children from 6 to 24 months old have fats added to complementary foods (Ghana Statistical Service 2008). Whole blood fatty acids (FAs) are associated with growth and stunting (Jumbe et al. 2016a; Adjepong et al. 2018), and cognition (Jumbe et al. 2016b) in children, hence the availability and inclusion of adequate amounts of FAs in the diet is important. In a Tanzanian population of children, blood levels of essential fatty acids (EFAs) were inversely associated with growth stunting (Jumbe et al. 2016a). Linoleic acid (LA), an omega-6 (n-6) FA, and alpha-linolenic acid (ALA), an omega-3 (n-3) FA, are EFAs which are elongated to form other FAs such as arachidonic acid (AA), eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). EFAs and their long-chain metabolites are important for cognition, growth and immune function (FAO 2010; Huffman et al. 2011). FA intake in African diets are low (Huffman et al. 2011). Specifically, the dietary composition of Ghanaians is mainly starchy roots and cereals with levels of protein and fat below adequate levels. Though the dietary supply meets population energy requirements, the low dietary diversity in the population may be causing a deficiency in proteins and fats (USAID 2009).

The prevalence of mineral deficiencies is high in Ghana (Engmann et al. 2008) and approximately half of the 82.1% of children between 6 and 59 months who are anemic in Northern Ghana are thought to be so due to iron-deficiency anemia (Ghana Statistical Service Accra 2014). Mineral deficiencies may also be associated with growth stunting and cognitive impairment (Adu-Afarwuah et al. 2007; Ackatia-Armah et al. 2015) because minerals such as iron and zinc are cofactors needed in FA metabolism. For example, zinc deficiency impairs the conversion of LA to AA and ALA to EPA and DHA (Harris et al. 2009). The evaluation of African seeds and nuts has been conducted in some studies, though the available data is highly variant due to environmental factors such as soil type, agronomic practices and climate (Glew et al. 2006; Sadiq et al. 2012). Geographical differences can directly affect the concentration of minerals in crop plants and, therefore, dietary

mineral content, potentially impairing FA metabolism and leading to growth stunting and cognitive impairment in the population.

The West African food composition table is a nutrient database which publishes an estimation of nutrients such as proteins, carbohydrates, total fat, vitamins, and minerals in food (Stadlmayr et al. 2012). However, there are certain aspects that could be strengthened: (1) The composition table contains the total fat composition of foods with no information on individual FA contents; (2) There is little information on the origin of the foods analyzed; (3) The data represents average values derived from compositional data of 8 countries, not any individual country; and (4) Most of the mineral and vitamin data in the table are based on information obtained from several non-African countries. This study quantified the amount of FAs and minerals in seeds, nuts, and oils available at markets in Northern Ghana to identify locally available foods with nutrient profiles that can be utilized to help curb deficiencies associated with growth stunting and anemia in children from this population.

Materials and methods

Preparation of selected seeds, oils, and nuts in Ghana

Seeds, nuts, and oils (Table 1) were purchased at a local market in Tamale, Northern Ghana. Food abbreviations from Table 1 will be used throughout the manuscript. Oils obtained from the market were transferred to plastic containers as purchased. Local seeds and nuts collected from the market were crushed, freeze-dried using a YK-118 vacuum freeze dryer (True Ten Industrial, Taiwan, China) and stored in plastic containers (Gutierrez et al. 2008; Dulf 2012). All samples were shipped to Michigan State University for FA and mineral analysis. Once received, the samples were purged with high purity nitrogen to prevent FA oxidation and stored at -20°C until analysis 1 week later.

Crude seed oil extraction

All solvents used were high performance liquid chromatography grade and purchased from Sigma-Aldrich (St. Louis, MO) unless otherwise stated. Lipids were extracted from seed and nut material as previously described (Cequer-Sanchez et al. 2008), but modified as specified (Jumbe et al. 2016c). In brief, a total of 400 mg freeze-dried material was incubated for 2 h at RT in 12 mL of a 2:1 (v/v) mixture of chloroform (Avantor Performance

Table 1 Foods analyzed

Food	Abbreviation	General	Description
Baobab seed	BAB	<i>Adansonia sp.</i>	Seeds of an ancient tree, whose fruits possess a velvety shell
Dawadawa	DAW	<i>Parkia sp.</i>	Seeds of a perennial tree, African locust bean plant
Fermented dawadawa	FDD	<i>Parkia sp.</i>	Fermented seeds of the African locust bean plant
Neri seed	NER	<i>Cucumropsis sp.</i>	Climbing vine, flattened seeds
Soybean	SOY	<i>Glycine sp.</i>	A legume, bean seeds
Peanut	PNT	<i>Arachis sp.</i>	A root of a tropical legume
Sesame seed	SAM	<i>Sesamum sp.</i>	Seeds from a domesticated oil seed plant
Shea butter (oil)	SHB	<i>Vitellaria sp.</i>	An ivory-coloured fat extracted from African shea nut
Palm oil	PAL	<i>Elaeis sp.</i>	Crude oil processed locally, red–orange, high in beta carotene
Palm kernel oil	PKO	<i>Elaeis sp.</i>	Oil derived from the kernel of the oil palm

Materials, Inc., Center Valley, PA) and methanol containing 100 µg butylated hydroxytoluene (BHT)/mL (Sigma-Aldrich) to extract lipids. Extracted samples were filtered using lipid-free filters (FGE Healthcare UK Limited, Buckinghamshire, UK) into glass tubes containing 2.5 mL of 0.88% (w/v) aqueous KCl (J.T. Baker, Phillipsburg, NJ) to separate aqueous and organic, lipid containing layers. The tubes were centrifuged and the bottom organic layer was transferred to a new tube and dried under high-purity nitrogen to obtain crude seed and nut oil.

Methylation of oils to FAMES, neutralization, and FAME isolation

The extracted oils and samples initially collected as oils were suspended in chloroform:methanol (2:1 v/v, 100 µg BHT/mL) to obtain a final lipid concentration of 20 mg/mL. The resuspended oils were prepared for methylation as previously described (Cequier-Sanchez et al. 2008). In brief, 100 µL of lipid extract solution was transferred to clean 16 × 100 mm Teflon-lined screw-capped glass tubes. To each sample, 200 µg of the internal standard, Stearic acid *d*35 (Sigma-Aldrich, Lot #TP1700 V) suspended in chloroform, was added. The resultant mixture was dried under high-purity nitrogen at RT. The samples were methylated with 2% acidified methanol as previously described to produce fatty acid methyl esters (FAMES) (Agren et al. 1992; Pickens et al. 2015). The mixture was neutralized and isolated as previously described (Gurzell et al. 2014) and FAMES were extracted with hexane and dried down.

FAME identification, analysis, and data processing

FAMES were suspended in isooctane and quantified using a dual stage quadrupole GC/MS (Thermo Scien-

tific, Waltham, MA) equipped with a DB-23, 30-m column (0.25 mm id; Agilent Technologies, Santa Clara, CA) using helium as a carrier gas. GC/MS temperature profile and selective ion monitoring (SIM) were performed as previously described (Jumbe et al. 2016c). Identification and quantification of individual FAMES were done with standard FAME mixture (Part# CRM47885; Lot# LC06601 V; Supelco, Bellefonte, PA) and standard curves were prepared as previously described (Jumbe et al. 2016c). Detected FAME concentrations below the lower limit of quantification (LLOQ) are defined for each FA in Tables 2, 3 and 4. DHA, EPA, and linoelaidic acid were below the LLOQ in all samples analyzed and were excluded from the tables. FAME peak integration and quantification was performed using TargetLynx V4.1 (Waters, Milford, MA) based on the FAME standard's retention time and SIM ions and ratios. The concentrations of resuspended FAMES were normalized to the amount of food-grade oil (i.e. palm oil) or crude seed oil and total seed or nut material for samples (i.e. neri seed).

Mineral analysis

Freeze-dried seed and nut samples were analyzed for their mineral content. The samples DAW, FDD, NER, SAM, SOY, PNT and BAB were analyzed by a commercial laboratory using official AOAC methodology. The minerals analyzed were zinc, iron, potassium, phosphorus, sodium, magnesium, manganese and calcium. Identification and quantification of minerals was performed by inductively coupled plasma emission spectroscopy using the improved AOAC official method 984.27 (Poitevin et al. 2009; Jajda et al. 2015).

Table 2 Saturated fatty acids expressed in mg FA/g crude oil, mg FA/g nut or mg FA/g seed (Mean $\pm$ SD)

Sample ID	Sample Type	Myristic C14:0	Palmitic C16:0	Stearic C18:0	Arachidic C20:0	Lignoceric C24:0	Total Saturated FAs
Baobab seed	Seed	0.15 $\pm$ 0.02 ^B	12.0 $\pm$ 1.44 ^B	3.28 $\pm$ 0.42 ^D	0.77 $\pm$ 0.10 ^D	0.17 $\pm$ 0.03 ^E	16.4 $\pm$ 1.93 ^C
Dawadawa	Seed	< LLOQ	5.15 $\pm$ 1.09 ^B	8.28 $\pm$ 1.44 ^{CD}	2.74 $\pm$ 0.87 ^C	1.09 $\pm$ 0.24 ^C	17.3 $\pm$ 1.43 ^C
Fermented dawadawa	Seed	< LLOQ	14.7 $\pm$ 1.85 ^B	21.9 $\pm$ 2.88 ^{BC}	5.49 $\pm$ 0.73 ^B	2.42 $\pm$ 0.36 ^A	44.5 $\pm$ 5.79 ^C
Neri seed	Seed	< LLOQ	24.4 $\pm$ 1.04 ^B	13.0 $\pm$ 1.22 ^{CD}	0.78 $\pm$ 0.05 ^D	0.19 $\pm$ 0.01 ^E	38.4 $\pm$ 1.87 ^C
Soybean	Seed	0.05 $\pm$ 0.03 ^B	4.53 $\pm$ 0.22 ^B	1.49 $\pm$ 0.21 ^D	0.19 $\pm$ 0.07 ^D	0.10 $\pm$ 0.02 ^E	6.36 $\pm$ 0.32 ^C
Peanut	Nut	< LLOQ	19.4 $\pm$ 0.46 ^B	6.03 $\pm$ 0.26 ^D	2.50 $\pm$ 0.06 ^C	1.97 $\pm$ 0.08 ^B	29.9 $\pm$ 0.72 ^C
Sesame seed	Seed	< LLOQ	16.3 $\pm$ 3.86 ^B	10.4 $\pm$ 2.12 ^{CD}	0.99 $\pm$ 0.21 ^D	0.15 $\pm$ 0.01 ^E	27.8 $\pm$ 6.18 ^C
Shea butter	Oil	< LLOQ	20.7 $\pm$ 0.29 ^B	314 $\pm$ 14.83 ^A	8.20 $\pm$ 0.28 ^A	0.64 $\pm$ 0.03 ^D	343 $\pm$ 15.1 ^A
Palm oil	Oil	6.16 $\pm$ 1.26 ^B	293 $\pm$ 56.5 ^A	28.7 $\pm$ 5.48 ^B	2.24 $\pm$ 0.36 ^C	0.70 $\pm$ 0.05 ^{CD}	331 $\pm$ 63.7 ^A
Palm kernel oil	Oil	82.8 $\pm$ 3.97 ^A	54.2 $\pm$ 2.82 ^B	15.2 $\pm$ 0.96 ^{BCD}	< LLOQ	< LLOQ	153 $\pm$ 7.82 ^B
<i>p</i> value		< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

^{A,B,C,D,E}Denote Tukey HSD comparison at 0.05 significance level. Any value stated as < LLOQ was either below the limit of quantification, or below the lowest point on the standard curve. LLOQ, lower limit of quantification

Table 3 Monounsaturated fatty acids expressed in mg FA/g crude oil, nut or mg FA/g seed (Mean $\pm$ SD)

Sample ID	Sample Type	Palmitoleic C16:1	Oleic C18:1	Eicosenoic C20:1	Total MUFAs
Baobab seed	Seed	0.25 $\pm$ 0.25 ^B	15.2 $\pm$ 1.62 ^{CD}	0.20 $\pm$ 0.03 ^D	15.6 $\pm$ 1.68 ^{CDE}
Dawadawa	Seed	0.03 $\pm$ 0.01 ^C	9.20 $\pm$ 2.35 ^D	0.43 $\pm$ 0.12 ^D	9.68 $\pm$ 2.21 ^E
Fermented dawadawa	Seed	< LLOQ	24.8 $\pm$ 2.75 ^{CD}	0.97 $\pm$ 0.14 ^C	25.9 $\pm$ 2.90 ^{CDE}
Neri seed	Seed	0.11 $\pm$ 0.01 ^{BC}	12.6 $\pm$ 1.05 ^{CD}	0.28 $\pm$ 0.02 ^D	13.0 $\pm$ 1.05 ^{CDE}
Soybean	Seed	0.04 $\pm$ 0.02 ^C	11.8 $\pm$ 2.53 ^D	0.19 $\pm$ 0.05 ^D	12.1 $\pm$ 2.47 ^{DE}
Peanut	Nut	< LLOQ	55.0 $\pm$ 6.91 ^{BCD}	2.28 $\pm$ 0.09 ^A	57.3 $\pm$ 6.99 ^{BCD}
Sesame seed	Seed	0.15 $\pm$ 0.04 ^{BC}	58.7 $\pm$ 14.0 ^{BC}	0.49 $\pm$ 0.05 ^D	59.3 $\pm$ 13.9 ^{BC}
Shea butter (oil)	Oil	< LLOQ	292 $\pm$ 11.0 ^A	2.20 $\pm$ 0.09 ^A	294 $\pm$ 11.0 ^A
Palm oil	Oil	0.68 $\pm$ 0.15 ^A	247 $\pm$ 46.7 ^A	1.57 $\pm$ 0.29 ^B	249 $\pm$ 47.2 ^A
Palm kernel oil	Oil	< LLOQ	91.5 $\pm$ 0.82 ^B	0.85 $\pm$ 0.03 ^C	92.4 $\pm$ 0.80 ^B
<i>p</i> value		< 0.0001	< 0.0001	< 0.0001	< 0.0001

^{A,B,C,D,E}Denote Tukey HSD comparison at 0.05 significance level. Any value stated as < LLOQ was either below the limit of quantification, or below the lowest point on the standard curve. LLOQ, lower limit of quantification

Statistical analyses

All samples were analyzed in triplicate for fatty acid analysis. Mean FA composition of the seeds, nuts, and food-grade oils are reported as the concentration of each FA in mg per gram of food sample in Tables 2, 3 and 4. Parametric one-way ANOVA was conducted for each FA and overall *p* values are given. Concentration values below the LLOQ were excluded from all analyses. Tukey's honest significant difference (HSD) post hoc test was used for multiple comparisons of significant models. Single samples of seeds and nuts were analyzed for mineral analyses and reported in mg mineral per kg sample. Statistical analyses were conducted using R (R version 3.3.0).

Results

Fatty acid analysis

Food-grade oils were more abundant in saturated fats than seeds or nuts (Table 2). PAL was significantly higher in palmitic acid than other nuts and oil studies (293.1 mg/g; *p* < 0.001). SHB was highest in stearic acid content (313.8 mg/g; *p* < 0.001). PKO contained the highest amount of myristic acid (82.8 mg/g; *p* < 0.001). Food-grade oils were more abundant in MUFAs compared to seeds or nuts as well (Table 3). SHB (292.0 mg/g) and PAL (246.5 mg/g) were significantly higher in oleic acid than all other foods (*p* < 0.001). The PUFAs considered in

Table 4 Polyunsaturated fatty acids expressed in mg FA/g crude oil, mg FA/g nut or mg FA/g seed (Mean $\pm$ SD)

Sample ID	Sample Type	α -Linolenic (ALA) C18:3n3	Linoleic C18:2n6	Docosadienoic C22:2	Total PUFAs
Baobab seed	Seed	0.14 $\pm$ 0.02 ^C	7.41 $\pm$ 0.89 ^D	0.38 $\pm$ 0.04	7.93 $\pm$ 0.96 ^F
Dawadawa	Seed	0.34 $\pm$ 0.05 ^C	20.8 $\pm$ 4.15 ^D	< LLOQ	21.1 $\pm$ 4.10 ^{EF}
Fermented dawadawa	Seed	0.94 $\pm$ 0.03 ^{BC}	55.3 $\pm$ 8.38 ^{AB}	< LLOQ	56.3 $\pm$ 8.40 ^{AB}
Neri seed	Seed	0.20 $\pm$ 0.01 ^C	68.2 $\pm$ 3.78 ^A	< LLOQ	68.4 $\pm$ 3.78 ^A
Soybean	Seed	2.98 $\pm$ 0.85 ^A	20.3 $\pm$ 2.68 ^D	< LLOQ	23.3 $\pm$ 3.46 ^{DE}
Peanut	Nut	0.11 $\pm$ 0.02 ^C	37.5 $\pm$ 4.75 ^C	< LLOQ	37.7 $\pm$ 4.75 ^{CD}
Sesame seed	Seed	0.48 $\pm$ 0.01 ^C	47.2 $\pm$ 10.8 ^{BC}	< LLOQ	47.7 $\pm$ 10.8 ^{BC}
Shea butter	Oil	0.82 $\pm$ 0.09 ^C	39.5 $\pm$ 1.47 ^C	< LLOQ	40.3 $\pm$ 1.56 ^C
Palm oil	Oil	1.79 $\pm$ 0.31 ^B	47.3 $\pm$ 3.79 ^{BC}	< LLOQ	49.0 $\pm$ 3.76 ^{BC}
Palm kernel oil	Oil	< LLOQ	15.3 $\pm$ 1.01 ^D	< LLOQ	15.3 $\pm$ 1.01 ^{EF}
<i>p</i> value		< 0.0001	< 0.0001	–	< 0.0001

A,B,C,D,E,F Denote Tukey HSD comparison at 0.05 significance level. Any value stated as < LLOQ was either below the limit of quantification, or below the lowest point on the standard curve. LLOQ, lower limit of quantification

this study include ALA (C18:3n3), LA (C18:2n6) and docosadienoic (C22:2) acid (Table 4). SOY was significantly higher in ALA (2.98 mg/g; $p < 0.01$) than all other foods. NER was significantly higher in LA (68.2 mg/g; $p < 0.01$) than all foods except FDD ($p = 0.13$).

Minerals

Iron levels in SOY (353 mg/kg), NER (282 mg/kg) and FDD (165 mg/kg) were highest, while FDD (55.0 mg/kg), SAM (51.0 mg/kg), and SOY (45.0 mg/kg) contained higher levels of zinc than other nuts and oils (Table 5). Calcium was highest in SAM (8767 mg/kg), FDD (4500 mg/kg) and SOY (3223 mg/kg). Samples had a range of phosphorus (2980 mg/kg to 5500 mg/kg) and potassium (3007 mg/kg to 15,733 mg/kg) values, but relatively similar amounts of sodium (< 300 mg/kg) and copper (9.10 mg/kg to 18.8 mg/kg).

Discussion

This study reports the FAs and select micro- and macrominerals found in a selection of seeds, nuts and oils in Northern Ghana. Fatty acids and minerals are important dietary components required for optimal human growth and development and are key in cell membrane formation and proper development of brain and nerve cells, cell differentiation, and metabolism (Ross et al. 2013; Kang et al. 2014). Northern Ghanaians experience food inadequacies for approximately 5 months every year, resulting in low availability of rice and cereals, as well as legumes and groundnuts such as SOY and PNT (Quaye 2008). SOY is considered an oilseed due to its high fat content, approximately 18% of its dry volume (Adu-Afarwuah et al. 2007; van Ee 2009). Therefore, lack of SOY availability can further lower nutritional diversity as SOY had the highest ALA and iron content of all foods analyzed. It was observed during an intervention in Eastern Ghana that supplements boosted with micronutrients, ALA, and LA resulted in significantly higher growth than supplements

Table 5 Mineral levels of seeds and nuts expressed as mg/kg seed or nut

Sample ID	Calcium	Copper	Iron	Magnesium	Manganese	Phosphorus	Potassium	Sodium	Zinc
BAB	2070	9.10	120	3700	13.9	5500	12,000	< 197	30.2
DAW	5100	10.0	127	3257	73.7	2980	11,867	301	40.3
FDD	4500	18.5	165	3240	145	4000	3007	< 200	55.0
NER	490	13.1	282	2127	22.2	4633	3500	< 200	34.3
SOY	3223	11.43	353	2410	79.0	4733	15,733	< 194	44.7
PNT	553	9.87	30.0	1987	16.0	3400	6900	< 194	30.6
SAM	8767	18.8	111	2587	23.6	4767	4400	< 197	51.3

only boosted with micronutrients (Adu-Afarwuah et al. 2007). While the authors proposed ALA as growth-promoting, recent research on blood FA levels of stunted children in Northern Ghana indicates EFA deficiency itself is low in the population and that n-6 PUFAs, which are downstream products of the EFA LA, are inversely associated with stunting in children from Northern Ghana (Adjepong et al. 2018). This may be a result of altered FA metabolism due to low overall PUFA availability (Fumagalli et al. 2015). NER and FDD had the highest LA content of all foods analyzed and as homegrown, locally available products, can be explored as cheap supplement ingredients to boost n-6 PUFAs and combat growth stunting.

Numerous studies have analyzed the effects of micronutrient supplementation on growth in children [reviewed by (Rivera et al. 2003)] especially the role of iron. Anemic children benefit the most from iron supplementation with doses as low as 10 mg/day resulting in improved growth status in as quickly as 12 weeks. One possible reason may be the role of iron as a cofactor in FA metabolism (Harris et al. 2009). Therefore, intake of iron with FAs such as LA may promote growth in individuals more efficiently than either alone. Of the foods analyzed, NER was one of the best sources of LA and iron. SAM had the highest content of calcium, a primary bone-forming mineral. However, the bioavailability of these minerals in foods can be impaired by high phytate levels, the storage form of elemental phosphorus. Since all foods analyzed contain phosphorus, wet processing methods such as soaking in water, boiling, fermentation and/or germination treatments may reduce phytic acid levels, increasing the bioavailability of nutrients (Mahesh et al. 2015). The food preparers in these communities can be taught such techniques to achieve full nutritional benefits of the available foods. Unfortunately, SAM is a cash crop and is relatively expensive because a bulk of what is produced is sold for income and not for domestic consumption, and NER is not commonly consumed compared to other foods that are available in Northern Ghanaian markets such as PNT. The local communities can be educated on the nutritional benefits of feeding SAM and NER to their children, increasing household consumption of the important growth nutrients they contain.

Northern Ghana is known to have poor soil quality. Additionally, the largely impoverished region suffers from lack of hybrid seeds and large-scale farming machinery, improper food storage habits, and incomplete knowledge of modern farming techniques, all of which contribute to lower and less nutritious agricultural yields (Quaye 2008). For example, much of the PAL, a common cooking oil, produced in Ghana does not meet criteria for international export due to long storage times resulting in high free FA

content (Osei-Amponsah et al. 2012). Similarly, according to the USDA National Nutrient Database, mature soybean seeds (USDA #16108) contain 11.26 g PUFA for every 100 g seed, whereas SOY analyzed in this study contains an average of just 2.33 g PUFA/100 g seed. This trend is consistent for SAM as well: 21.77 g PUFA/100 g seed (USDA #12023) versus a mean of 4.77 g PUFA/100 g seed in Northern Ghana (US Department of Agriculture 2015). Clearly, there is need for intervention to increase education and improve farming practices as Northern Ghana is largely a rural area, and agricultural occupations are the most common jobs (Quaye 2008). This would also result in higher nutrient diversity in foods helping reduce the above average child growth stunting levels in Northern Ghana.

To our knowledge, this study is the first to extensively characterize the fatty acid and mineral composition of local seeds, nuts, and oils in Northern Ghana. This study reveals the potential of FDD and NER from Northern Ghana to increase dietary PUFA and mineral intake in the population. Additionally, the mineral composition of NER, SAM, and FDD in the West African Food Composition table is incomplete and our study adds to that body of knowledge. Increased dietary consumption of some of the foods identified in this study has the potential to combat growth stunting in children, which can have profound effects not only socially, but also economically. In fact, the median benefit–cost ratio for investing in the reduction of stunting is estimated at 14.6 for African countries in which stunting is considered prevalent (Quaye 2008). Despite these strengths, we acknowledge that this study has limitations. First, the data from this study cannot be generalized to the entire population in Northern Ghana, hence future studies should investigate FA and mineral profiles from several markets in Northern Ghana. Moreover, the foods reported on were collected from markets rather than household collections, and there may exist variation between what is consumed in households compared to that obtained from the market. Another limitation of this study is that we do not have a complete knowledge regarding the processing methods of food-grade oils in Ghana. Additionally, the cooking time for the various foods analyzed is different, and the cooking time of oils are known to affect their nutritional quality. Future studies should investigate the impact of local cooking methods on FA degradation and measure antioxidant vitamins that may protect PUFA oxidation during cooking and processing.

Conclusion

In conclusion, NER may be further incorporated into diets and dietary supplements to potentially prevent stunting and cognitive impairment in Northern Ghana as it is a locally

available source of n-6 FAs and iron whereas higher domestic consumption of SAM may improve calcium intake. It is known that certain FA and mineral deficiencies are associated with stunting, anemia and cognitive impairment. Future studies should explore the incorporation of these food in the diets of children in Northern Ghana to reduce the prevalence of iron-deficiency anemia and stunting. Additionally, the nutrient content of foods reported here (i.e. SOY and SAM) greatly differ from those found in the USDA food database. Therefore, future studies should characterize the nutrient profile of local foods rather than assuming values based on general databases and food composition tables prior to considering malnutrition interventions.

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