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Evaluation of the Mineral Composition of Chia (*Salvia Hispanica* L.) Seeds from Selected Areas in Kenya

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Abstract

Chia (*Salvia hispanica* L.) seeds are gaining popularity among consumers and food processors, particularly in food fortification. Consequently, there has been an increased need to determine the mineral composition of chia seeds cultivated in different regions to ascertain their potential in various food applications. In this study, 20 chia seeds samples obtained from farmers practicing commercial farming of chia seeds in selected areas in Kenya during the two main chia seed planting seasons (April-August 2019) and (September-December 2019) were analyzed for their mineral content using Atomic Absorption Spectrophotometry (AAS). Values of sodium and potassium were determined using a Flame photometer using sodium chloride (NaCl) and potassium chloride (KCl) as the standards, while phosphorus was determined using the Vanodo-molybdate method. Chia seeds samples studied revealed the most predominant minerals as phosphorus (531 to 889 mg/100g), calcium (478 to 589 mg/100g), potassium (343 to 526 mg/100g) and, magnesium (322 to 440 mg/100g). The general linear model (GLM) used to determine the coefficient of variation on all chia seed growing sites showed that calcium, iron, and magnesium are the best-performing chia minerals in Kenya and hence should be the minerals of interest in food fortification using chia seeds.

Keywords: chia, elements, fortification, minerals, performance, seeds

1. Introduction

Chia (*Salvia hispanica* L.) is a herbaceous plant that has been known and cultivated since pre-Hispanic times and is native to Mexico and Central America (Ullah et al., 2016). Chia seeds are an excellent source of macro and micro-nutrients that are vital to human health. In terms of its composition, the chia seed is composed of proteins (15–25%), fats (30–33%), carbohydrates (26–41%), high dietary fiber (18–30%), ash (4-5%), minerals, vitamins, and dry matter (90–93%) (Ixtaina, Nolasco & Tomàs, 2008). The most significant minerals in chia include; calcium (631 mg/100g), potassium (407 mg/100g), magnesium (335 mg/100g), iron (7.72 mg/100g) and zinc (4.58 mg/100g) (USDA, 2018). Studies by (Ullah et al., 2016) reported that macronutrients in chia seeds are composed of; phosphorus 860 mg/100g, calcium 631 mg/100g, potassium 407 mg/100g, and magnesium 335 mg/100g. The microelements in chia seeds are selenium 55.2 μg/100 g, sodium 16 mg/100 g, iron 7.72 mg/100 g, manganese 2.72 mg/100 g, zinc 4.58 mg/100 g, copper 0.924 mg/100 g and molybdenum 0.2 μg/100 g. Chia seeds' phosphorous, calcium, and potassium content is greater than that of other crops such as wheat, rice, oats, and corn (Beltran-Orozco and Romero, 2003). Chia seeds have been reported to contain six times more calcium, eleven times more phosphorus, and four times more potassium than 100g of milk (Suri, Passi & Goyat, 2016).

With minerals performing a wide range of functions such as being a building material for bones, regulating the body's water balance, and influencing nerve and muscle function; there has been increased emphasis on the importance of dietary minerals in disease prevention hence the utilization of chia seeds which are rich in minerals in various food applications such as food fortification (Weyh, Krüger, Peeling & Castell, 2022). However, despite the increased consumption and utilization of chia seeds in Kenya, limited information on the mineral content of chia seeds grown in Kenya has been reported (FAO, 2020). Therefore, this study's objective was to evaluate the mineral composition of chia seeds from selected areas in Kenya to identify minerals of interest in food fortification.

2. Materials and methodology

2.1 Sampling and Study Design

Twenty chia seeds samples of the mixed variety (black and white chia seeds) were obtained from commercial farmers from Kivaa, Njoro, Ol-kalou, Mweiga, Nanyuki, Siaya, Busia, Nyahururu, Embu and Mwea. Truncation sampling was carried out considering those farmers already practicing commercial farming of chia in Kenya with a seasonal yield of more than 20kgs of chia seeds. Ten commercial farmers were identified from each of the above-mentioned regions, and a homogenous sample was obtained to represent each region. Based on the current chia farming practice, the two main seasons of chia planting in Kenya were considered where chia farmers plant chia from April- July (2019) and August- November (2019). An analytical experimental design was used to quantify the relationship between different variables

2.2 Mineral Analysis

The methods of (AOAC, 2012), were used. The chia seeds were ground into a fine powder using a 1500W Smart Touch Combo Blender: Model NBT-0815. One gram of ground chia seeds sample was digested with nitric/perchloric/sulphuric acid mixture in the ratio 9:2:1 respectively and then filtered using Whatman filter paper no. 42. The filtrate was made up to mark in a 50ml volumetric flask and the filtered solution was loaded to an Atomic Absorption Spectrophotometer (ZEEnit 700P, Analytik Jena, Germany). The standard curves for sodium, potassium, calcium, magnesium, zinc, copper, and manganese were prepared from the following analytical grade standards (KCl, $CaCl_2$, $MgSO_4$, $NaCl_2$, $ZnCl_2$, Cu solution, and Manganese solution) from Sigma Aldrich, USA. Sodium and potassium values were determined by a Flame photometer using sodium chloride and potassium chloride (Sigma Aldrich, USA) as the standards, while phosphorus was determined calorimetrically using the Vanodo-molybdate method as described by (Prakash & Kumar, 2007).

2.3 Statistical Analysis

All analyses were carried out in triplicate. The data were subjected to statistical analysis using the IBM Statistical Package of Social Science (SPSS-V20) The variability among the samples was done using One Way Analysis of Variance (ANOVA). The means were separated using Duncan multiple range test because the data was not normally distributed and the significance of the differences was established at $p<0.05$. Data obtained for the mineral elements were used to conduct a General Linear Model to evaluate the relationship between the sampled areas in Kenya, mineral elements, and the chia planting seasons to identify the dominant mineral contributors to the observed variations.

3. Results and Discussion

The mineral composition of chia seeds from selected areas in Kenya analyzed for the first chia planting season (April-Aug 2019) and for the second chia planting season (Sep-Dec 2019) are shown in Table 1 and Table 2.

Table 1. Macro elements (mg/100g) of chia seeds from selected areas in Kenya for the first (April-Aug 2019) and second chia planting season (Sep-Dec 2019)

	K	**Ca**	**Mg**	**P**
Mwea 1	513.00 ±0.00^{n}	511.00 ±0.00^{e}	383.64 ±0.02^{l}	587.36 ±0.03^{b}
Mwea 2	526.50 ±0.05^{o}	517.70 ±0.07^{i}	434.84 ±0.54^{o}	833.38 ±0.26^{k}
Kivaa 1	398.00 ±0.00^{d}	517.33 ±0.05i	343.09 ±0.76^{d}	663.62 ±0.28^{d}
Kivaa 2	394.00 ±0.00^{c}	589.00 ±0.00^{o}	363.00 ±0.38^{h}	732.05 ±0.28^{g}
Embu 1	484.50 ±0.07^{j}	478.67 ±0.05^{a}	373.96 ±0.16^{j}	636.27 ±0.04^{c}
Embu 2	484.00 ±0.01^{j}	514.60 ±0.06^{fg}	440.67 ±0.40^{p}	738.62 ±0.02^{h}
Nyahururu 1	467.50 ±0.07^{j}	531.67 ±0.07^{k}	322.17 ±0.15^{a}	889.02 ±0.17^{o}
Nyahururu 2	445.50 ±0.07^{h}	513.33 ±0.07^{fg}	383.32 ±0.09^{l}	813.21 ±0.81^{j}
Busia 1	449.00 ±0.00^{i}	538.67 ±0.06^{m}	364.10 ±0.05^{h}	868.14 ±0.99^{n}
Busia 2	449.20 ±0.01^{i}	497.00 ±0.00^{b}	360.33 ±0.03^{g}	685.17 ±0.54^{e}
Siaya 1	414.50 ±0.07^{e}	544.00 ±0.00^{n}	338.05 ±0.01^{c}	635.13 ±0.70^{c}
Siaya 2	414.00 ±0.03^{e}	507.00 ±0.00^{c}	370.67 ±0.53^{i}	888.36 ±0.07^{o}
Nanyuki 1	491.00 ±0.00^{k}	518.00 ±0.00^{i}	401.00 ±0.05^{n}	785.20 ±0.59^{i}
Nanyuki 2	490.00 ±0.00^{k}	517.70 ±0.06^{i}	406.86 ±0.77^{b}	533.24 ±0.61^{a}
Mweiga 1	426.00 ±0.00^{i}	516.00 ±0.00^{h}	398.48 ±0.04^{m}	736.96 ±0.75^{h}
Mweiga 2	427.50 ±0.00^{i}	515.00 ±0.00^{fg}	354.34 ±0.27^{f}	704.80 ±0.18^{f}
Ol-kalou 1	366.00 ±0.01^{b}	511.00 ±0.00^{e}	323.03 ±0.61^{a}	837.87 ±0.17^{l}
Ol-kalou 2	343.00 ±0.00^{a}	507.67 ±0.06^{c}	376.65 ±0.14^{k}	707.25 ±0.71^{f}
Njoro 1	448.50 ±0.00^{i}	514.33 ±0.07^{f}	376.04 ±0.06^{k}	531.63 ±0.16^{a}
Njoro 2	448.00 ±0.01^{i}	509.67 ±0.05^{d}	350.57 ±0.64^{e}	833.98 ±0.34^{k}

Values in a column with different letters are significantly different to $p < 0.05$

Data are means ± standard deviation (n = 3).

1-First chia planting season (April-August 2019); 2-Second chia planting season (September-December 2019).

Table 2. Microelements (mg/100 g) of chia seeds from selected areas in Kenya for the first (April-Aug 2019) and second chia planting season (Sep-Dec 2019)

	Zn	**Na**	**Cu**	**Mn**	**Fe**
Mwea 1	5.24 ±0.07^{cd}	20.96 ±0.00^{i}	0.85 ±0.07^{c}	3.44 ±0.21^{abc}	7.49 ±0.00^{d}
Mwea 2	2.98 ±0.00^{a}	14.87 ±0.00^{b}	1.39 ±0.00^{fg}	3.47 ±0.28^{abc}	7.05 ±0.06^{a}
Kivaa 1	2.74 ±0.21^{a}	19.96 ±0.01^{h}	0.80 ±0.00^{bc}	2.90 ±0.00^{a}	7.49 ±0.00^{d}
Kivaa 2	3.69 ±0.00^{abc}	17.95 ±0.01^{f}	1.15 ±0.07^{de}	3.59 ±0.56^{abcd}	7.83 ±0.02^{g}
Embu 1	3.18 ±0.01^{ab}	16.91 ±0.03^{d}	0.70 ±0.00^{b}	3.98 ±0.00^{cdef}	9.05 ±0.02^{m}
Embu 2	2.50 ±0.01^{a}	17.97 ±0.01^{f}	1.40 ±0.00^{fg}	3.20 ±0.14^{ab}	7.79 ±0.00^{fg}
Nyahururu 1	3.78 ±0.00^{abc}	15.93 ±0.00^{c}	0.45 ±007^{a}	3.59 ±0.42^{abcd}	7.18 ±0.00^{b}
Nyahururu 2	4.99 ±0.02^{bcd}	17.97 ±0.00^{f}	1.30 ±0.00^{c}	3.96 ±0.14^{bcd}	7.47 ±0.00^{d}
Busia 1	2.78 ±0.00^{a}	13.98 ±0.00^{a}	1.30 ±0.14ef	3.99 ±0.00^{cdef}	7.59 ±0.00^{e}
Busia 2	3.48 ±0.00^{abc}	17.92 ±0.01^{f}	1.20 ±0.00^{de}	3.48 ±0.43^{abc}	7.78 ±0.01^{f}
Siaya 1	3.59 ±0.00^{abc}	15.93 ±0.01^{c}	1.20 ±0.14^{de}	5.42 ±0.21^{h}	7.58 ±0.02^{e}
Siaya 2	4.08 ±0.02^{abc}	17.42 ±0.70^{e}	1.29 ±0.00^{e}	4.43 ±0.49^{efg}	7.76 ±0.04^{f}
Nanyuki 1	2.48 ±0.01^{a}	17.90 ±0.00^{f}	1.09 ±0.13^{d}	4.23 ±0.21^{defg}	7.77 ±0.03^{f}
Nanyuki 2	2.96 ±0.04^{a}	17.95 ±0.00^{f}	1.29 ±0.00^{e}	3.39 ±0.42^{abc}	7.89 ±0.00^{i}
Mweiga 1	2.49 ±0.00^{a}	13.96 ±0.02^{a}	1.20 ±0.00^{de}	4.29 ±0.29^{defg}	7.48 ±0.01^{d}
Mweiga 2	3.37 ±0.00^{ab}	17.86 ±0.06^{f}	1.20 ±0.00^{de}	3.58 ±0.43^{abcd}	8.95 ±0.03^{l}
Ol-kalou 1	3.58 ±0.20^{abc}	18.87 ±0.04^{g}	0.80 ±0.00^{bc}	4.77 ±0.27^{g}	7.89 ±0.01^{i}
Ol-kalou 2	3.77 ±0.00^{abc}	16.86 ±0.00^{d}	1.29 ±0.00^{e}	4.57 ±0.21^{fg}	7.62 ±0.00^{e}
Njoro 1	5.87 ±0.03^{d}	13.89 ±0.01a	0.70 ±0.00^{b}	3.77 ±0.28^{bcde}	8.21 ±0.00^{k}
Njoro 2	3.90 ±0.01^{abc}	15.91 ±0.01^{c}	0.90 ±0.01^{c}	3.73 ±0.21^{bcde}	7.56 ±0.02^{f}

Values in a column with different letters are significantly different to $p < 0.05$

Data are means ± standard deviation (n = 3).

1-First chia planting season (April-August 2019); 2-Second chia planting season (September-December 2019).

In this study, chia seeds revealed potassium levels (366 – 513 mg/100g), calcium (478 - 544 mg/100g), magnesium (322 - 401 mg/100g), phosphorus (531 - 889 mg/100g) for the first chia planting season and potassium (343– 526 mg/100g), calcium (497 – 589 mg/100g), magnesium (363 – 440 mg/100g) and phosphorus (533 - 888 mg/100g) in the second chia planting season (Table 1). Concerning the micronutrients evaluated in the first chia planting season, chia seeds showed the following levels; zinc (2.48 – 5.47 mg/100 g), copper (0.45 – 1.30 mg/100 g), manganese (2.9 – 5.42 mg/100 g), iron (7.08 – 9.05 mg/100 g) and sodium (13.89 – 20.96 mg/100 g). From the second chia planting season (Table 2), the following mineral contents were observed for chia seeds obtained from selected areas in Kenya. Sodium (14.87 -17.97 mg/100 g), zinc (2.50– 4.99 mg/100 g), copper (0.90– 1.40 mg/100 g), manganese (3.20– 4.57 mg/100 g), and iron (7.05– 8.95 mg/100 g).

According to (Kulczynski et al., 2019) and (Guru et al., 2016), chia seeds have been reported to contain potassium in the range of 407-726 mg/100g. Calcium values similar to the present study have been observed in chia seeds grown in Brazil revealing calcium levels of 480mg/100g (Pereira et al., 2017). According to (USDA, 2015), chia seeds have been reported to have calcium levels of 631mg/100g. The magnesium values obtained in this study compare with values reported for magnesium levels in chia seeds to be ranging from 335-449 (mg/100g) (Nieman et al., 2012). In addition, some of the magnesium levels reported for chia seeds grown in selected areas in Kenya fall within those reported for chia seeds grown in different areas in Brazil in the range of 330 to 350 mg/100g (Pereira et al., 2017; Kulczynski et al., 2019). The phosphorus content of chia seeds has also been reported to be 799.2 mg/100g (Bolaños, Marchevsky & Camiña, 2016). Additionally, according to (USDA, 2011), the phosphorus content of chia seeds has been reported as 860 mg/100g. Concerning zinc levels (Silva et al., 2017), reported that chia seeds from different regions in Brazil had a zinc content between 3.65% to 3.76%. Some of the areas sampled from this study agree with previous studies that have revealed chia seeds to contain zinc levels between 4.2% and 5.9%. Additionally, based on (USDA, 2011) chia seeds have been reported to contain 4.58% of zinc. Other researchers have reported that chia seeds contain a copper content (mg/100g) of 2.26 (Bolaños, Marchevsky & Camiña, 2016). Additionally, further studies have revealed that chia seeds have a copper content ranging between 1.8 to 2.1 mg/100g (Baretto et al., 2016). According to (Pająk et al., 2018), chia seeds have a manganese content of 3.44mg/100g while (Bolaños, Marchevsky & Camiña, 2016), reported that chia seeds contain a manganese content of 3.0 mg/100g. Other findings have also indicated that chia seeds have an iron content ranging from 6.8 to 8.9 mg/100g (Baretto et al., 2016; Silva et al., 2017), also revealed that chia seeds obtained from two different regions contain an iron content of 7.69 mg/100g and 9.39mg/100g. From these results, different selected areas revealed different concentrations of both the macro-nutrients and micro-nutrients evaluated. These differences are linked to the fact that the availability of mineral nutrients to plants from the soil is influenced by various soil management practices such as drainage, organic matter content, acidity, cultivation, and the application of chemical fertilizers. In our case, during sampling, it was identified that different farmers use different agronomic practices and thus the lack of use of standard agronomic practices could result in the variations observed. In an overall view, it was observed that the second chia planting season (September-December 2019) showed relatively higher amounts of the analyzed elements (Table 1 and Table 2) as compared to the first chia planting season. This observation could be attributed to the second chia planting season being characterized by warmer temperatures as compared to the first chia planting season which is characterized by increased amounts of rainfall and long cloudy durations. Previous studies have reported that increased light durations and higher temperatures favor the absorption of mineral nutrients by leaves (Reich & Oleksyn, 2004).

In this study, significant differences ($p<0.05$) in the mineral content were observed among the various regions in the first chia planting season as well as between both chia planting seasons. The observed significant differences could be linked to the chia seeds being from different ecosystems. Previous studies have indicated that different ecosystems have variable significant effects on the nutritional composition of chia seeds. Specific environmental factors that have been shown to influence the composition of chia seeds include light, temperature, soil composition, and type/variety of seed (Ayerza & Coates, 2004). In other studies, it has been indicated that genetics strongly influence the contents of macronutrients such as phosphorus, potassium, and magnesium as well as some micronutrients such as copper, manganese, and iron (Szostak et al., 2020). Additionally, it has been previously reported that genetic and environmental factors affect the accumulation of calcium, potassium, iron, zinc, and copper in common bean seeds (Ribeiro et al., 2012).

The evaluated minerals from chia seeds obtained from selected areas in Kenya showed significant differences ($p<0.05$) within the selected areas and between the two chia planting seasons. The percentage coefficient of variation obtained using GLM (Table 3) showed calcium, iron, and magnesium as the dominant contributors to the variation observed regarding different sampling areas, different mineral compositions, and the two chia planting seasons.

Table 3. Mineral Variation in Kenya (First and second chia planting season): Percentage Coefficient of variation for minerals in selected areas

Mineral	% Coefficient of variation
Ca	4.08
Fe	6.20
Mg	8.60
Na	11.16
P	15.04
Mn	16.18
K	25.19
Cu	25.54
Zn	30.27

4. Conclusion

The mineral elements of chia seeds from selected areas vary based on the chia planting season as well as the region they are grown in. Predominantly, chia seeds revealed increased amounts of the macro-elements phosphorus, calcium, potassium, and magnesium and the micro-elements sodium and iron. Overall, the second chia planting season had higher levels of the evaluated mineral elements as compared to the first chia planting season. From the coefficient of variation only calcium, iron, and magnesium can be selected for use in fortification as they are adequate in all the selected areas in Kenya. With chia seeds farming in Kenya being on the rise, additional studies should be conducted to determine the effect of agroecological zones on the mineral composition of chia seeds.

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Conflict of Interest

The authors declare no conflict of interest

Informed Consent Statement

Not applicable

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