Determination of Essential Elemental Concentration Profile in Ghanaian Shea (*Vitellaria Paradoxa* L) Fruit Pulp using Instrumental Neutron Activation Analysis

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ABSTRACT

Studies have shown that the Shea (*Vitellaria paradoxa* L) tree is an important ecological, nutritional and socio-economic resource for upgrading the standard of living of the indigenous population in the Sub-Saharan region of Ghana. However, little is known about the essential elements concentration profile of the widely-consumed fruit pulp of this tree. The aim of this study therefore was to ascertain the essential elements present in the Shea fruit pulps as well as other contaminants using the well-established Instrumental Neutron Activation Analytical Technique. All fresh Shea fruit pulps samples contain high concentrations of K, Ca and Mg with the rest being Cl Na, Zn, Cr, Co, Cu and Fe which were also found in significant amounts. Sb and As were found in traces in some of the samples. This data is paramount in the estimation of essential minerals dietary intake for humans as well as the evaluation of their exposure to toxic elements.

Keywords: Shea fruits; activation analysis; relative method; Elemental analysis; Ghana.

1 INTRODUCTION

FRUITS form an integral part of food needed to meet the mineral requirements of the human body. They are noted to contain a wide variety of complex phytochemicals and secondary metabolites that protect the human body from various biotic and abiotic stresses, diseases and help develop defense mechanisms for fighting various ailments by boosting the immune system [1]. The consumption of fruits which are abound with minerals, vitamins, enzymes and are easily digestible, have a tradition of being a natural staple of human diets since ancient times [2]. Hence, aside been used as a dietary supplement, fruits have a central role in health care by increasing lifespan and improving general well-being of humans.

One of such fruits is the Shea (*Vitellaria paradoxa* L) fruit. The Shea tree is one of the most predominant trees in northern Ghana. It is an important multipurpose tree, which plays important ecological and socio-economic role, and is the principal source of income for the indigenous population in the Sahel region [3]. The Shea tree, locally termed “the African wonder”, is synonymous to crude oil in the oil industry because every part of this plant has a useful purpose.

For instance, the pulp which could be removed by fermentation can be processed into juice [4]. The wood, which is termite-resistant, is used as building poles. The kernels in the nuts are processed into butter or oil. This butter/oil aside being widely used for cooking African foods and traditional medicines, is used in factories to produce baking fat, margarine, chocolate, cocoa butter substitutes, various moistening beauty and pharmaceutical products. Also, the unsaponifiable components are used to cure third degree burned victims [5]. The hard shells of the nuts are used as native mosquito repellent materials for combating malaria. An edible caterpillar [4] which feeds only *Vitellaria paradoxa* leaves is dried and sold in the markets of some countries. The flowers are prepared into edible fritters. The roots are used as chewing sticks. Infusion of the bark is used to neutralize the venom of splitting cobra. Sap from the barks is an invaluable raw material in the gum and rubber industry [6].

However, most research work related to this plant targets only the economic important nuts and its products [7], [8], [9], [10]. Even though, the nutritional importance of many trace elements is well established [11] and their concentrations in fruits widely studied in developing countries [12], not much however, is known about these essential elements present in the Ghanaian Shea fruit. These elements are extensively studied because; first, at optimal levels they play important roles in biochemical, metabolic, catabolic and enzymatic reactions in the living cells of human beings; secondly, deficiency causes diseases; whereas thirdly, excessive intake of some of these elements may adversely affect the human biomedical function [9], [13], [14]. Moreover, due to the general lack of an ingenious way of packaging and handling of Shea fruit, it is necessary to check the elemental content for toxic elemental (As, Sb) contaminants levels in an ever-increasing industrialized and ecological polluted environment.

Since the essential elements, which constitute a minute fraction, are being considered “inorganic switches” in an ever-evolving complex biological systems coupled with the possible masking of major elemental constituents, a highly sensitive, selective and reliable instrumental method is necessary to...
collect precise and accurate data [15], [16], [17]. Aside the requirements mentioned above, Instrumental Neutron Activation Analysis (INAA), has advantages of being freedom from reagent blanks corrections, good detection limit (ppm to ppb), rare interferences, seldom matrix and offers easy sample preparation [18]. Hence, it was the method of choice for this analysis. The determination of essential elemental concentration profile in Ghanaian Shea (*Vitellaria paradoxa* L) fruit pulp is therefore, justified.

### 2 MATERIALS AND METHODS

#### 2.1 Sampling

Individual fresh Shea fruits pulps (*Vitellaria paradoxa* L) variety were randomly obtained, from local farmers, from most districts in the Upper East Region of Ghana where the Shea tree is wildly distributed as shown by the sampling points in Fig., 1. The region is located on the North-East corner of Ghana between latitudes 10º 30´ to 11º North and longitudes 0º to 1º 30´ West within the White Volta River Basin. About 3 kg of fresh edible fruits were sampled from each administrative district. The samples were thoroughly hand-rinsed with distilled water, shaken to remove any excess water and then gently blotted with a paper towel. The samples were wrapped with clean polyethylene, frozen and then placed into clean polyethylene containers for transportation to the Ghana Research Reactor-1 Centre at the National Nuclear Research Institute of Ghana Atomic Energy Commission.

#### 2.2 Sample and Standards Preparation

The samples were further washed with de-ionized water before peeling the pulps using a stainless steel knife at the Centre. Each category of samples was freeze-dried for 48–72 hours using a Christ LMC-1 freeze dryer, milled into fine powder and then homogenized for analysis. Aliquots (between 200mg and 250 mg) of the homogenized samples were weighed onto clean polyethylene films wrapped and heat sealed. Ten replicates of these samples from each district were prepared. Also, 3 replicates each of two biological Standard Reference Materials (SRMs) obtained from the U.S. National Institute of Standard and Technology (NIST), namely Oyster Tissue (SRM 1566b) and Apple leaves (SRM 1515), were also prepared for analysis as comparator standards in the relative method. All standards and samples were located in polyethylene vials, stack with cotton in order to maintain reproducible geometry and heat sealed for irradiation.

#### 2.3 Irradiation and Counting

Samples and standards were transferred into the inner (No. 2) irradiation sites of Ghana's Miniature Neutron Source Reactor (MNSR) via pneumatic transfer system at a pressure of 0.6 Mpa. The stability, homogeneity, and reproducibility of the Ghana's MNSR neutron flux for neutron activation analysis have previously been reported [19]. Counting of all the samples was done a distance of 7.2 cm on top of the gamma-ray spectroscopic detector.

Fig. 1. Location of study areas and administrative districts in Upper East Region, Ghana
3 RESULTS AND DISCUSSION

It is an irrefutable fact that though the single ($k_0$ – INAA) comparator method is considered to be the most highly optimized and economic version of the INAA, it is very complex in its formulation and implementation [20], [21]. Paradoxically, the $k_0$ – INAA community are still suspicious about the reliability of $k_0$ – values of some isotopes [22], [23]. Thus to completely avoid the complexities posed by the use of nuclear constants, irradiation site parameters and several correction factors, the relative comparator method of INAA was used in our work for the determination of essential elements as well as toxic elements in all the samples. A detail study about the applicability of this method in our laboratory has previously been presented [24]. Also, validation of the relative comparator method at Ghana’s MNSR has been described, discussed and compared with various different matrix reference materials by various authors over the years in published literature [25], [26], [27], [28].

The distinct energy signatures from the neutron – capture reaction of the various radioisotopes of interest as well as their half-lives [20], [29] are presented in Table 1. A careful assessment of Table 1 shows that the characteristic half – lives of all the elements studied varied by a wide spectrum. Therefore, in order to reduce high background activities posed by some elements resulting in masking of other elements of interest and for obtaining; better counting statistics, improved signal to noise ratio of the gamma – ray spectrum and, higher precision and specificity at much lower detection limits of the gamma – ray spectroscopic system, all the elements were critically categorized into three main optimized irradiations schemes.

Table 1. Nuclear data of nuclides determined in this work.

<table>
<thead>
<tr>
<th>Element</th>
<th>Target Isotope</th>
<th>Product Isotope</th>
<th>Half live</th>
<th>$\gamma$-Ray, keV</th>
</tr>
</thead>
<tbody>
<tr>
<td>As</td>
<td>$^{75}$As</td>
<td>$^{76}$As</td>
<td>26.4 d</td>
<td>559</td>
</tr>
<tr>
<td>Ca</td>
<td>$^{46}$Ca</td>
<td>$^{47}$Ca</td>
<td>4.356 d</td>
<td>1292</td>
</tr>
<tr>
<td>Cl</td>
<td>$^{37}$Cl</td>
<td>$^{38}$Cl</td>
<td>37.24 m</td>
<td>1642.7</td>
</tr>
<tr>
<td>Co</td>
<td>$^{59}$Co</td>
<td>$^{60}$Co</td>
<td>5.271 y</td>
<td>1173</td>
</tr>
<tr>
<td>Cr</td>
<td>$^{50}$Cr</td>
<td>$^{51}$Cr</td>
<td>27.7 d</td>
<td>1332.5</td>
</tr>
<tr>
<td>Cu</td>
<td>$^{65}$Cu</td>
<td>$^{66}$Cu</td>
<td>5.088 m</td>
<td>1039.2</td>
</tr>
<tr>
<td>Fe</td>
<td>$^{58}$Fe</td>
<td>$^{59}$Fe</td>
<td>44.50 d</td>
<td>1099.3</td>
</tr>
<tr>
<td>K</td>
<td>$^{41}$K</td>
<td>$^{42}$K</td>
<td>12.36 h</td>
<td>1524.6</td>
</tr>
<tr>
<td>Mg</td>
<td>$^{26}$Mg</td>
<td>$^{27}$Mg</td>
<td>9.46 m</td>
<td>843.8</td>
</tr>
<tr>
<td>Na</td>
<td>$^{23}$Na</td>
<td>$^{24}$Na</td>
<td>15.03 h</td>
<td>1368</td>
</tr>
<tr>
<td>Sb</td>
<td>$^{126}$Sb</td>
<td>$^{128}$Sb</td>
<td>2.70 d</td>
<td>564.2</td>
</tr>
<tr>
<td>Zn</td>
<td>$^{64}$Zn</td>
<td>$^{65}$Zn</td>
<td>244.3 d</td>
<td>1115</td>
</tr>
</tbody>
</table>

Thus to enhance the sensitivities of each element determined by INAA method; short irradiation schemes were employed for Mg, Cu and Cl with Na, As and K using the medium irradiation scheme and the rest (Ca, Co, Cr, Fe, Sb, Zn) using the long irradiation scheme.

The distinct energy signatures from the neutron – capture reaction of the various radioisotopes of interest as well as their half-lives [20], [29] are presented in Table 1. A careful assessment of Table 1 shows that the characteristic half – lives of all the elements studied varied by a wide spectrum. Therefore, in order to reduce high background activities posed by some elements resulting in masking of other elements of interest and for obtaining; better counting statistics, improved signal to noise ratio of the gamma – ray spectrum and, higher precision and specificity at much lower detection limits of the gamma – ray spectroscopic system, all the elements were critically categorized into three main optimized irradiations schemes.
Significant differences between the means of the results were determined by using the Tukey HSD test. A criterion of $p \leq 0.05$ was considered to be significant. Even though the concentrations of essential elements were mostly varied amongst the various samples as depicted in Table 2, nevertheless it is evident that Vitellaria paradoxa L. variety fruit pulps are endowed with a rich variety of various complex pharmacological bioavailable phytochemicals that could protect against several chronic diseases when consumed [30].

The concentration of major essential elements (Ca, K, Mg and Na) is in the range of 9 – 37 mg/10g. These values are relatively high compared to similar fruit pulps analyzed in Uganda by Okullo et al., [31]. However, similar results were obtained in Nigeria by Adepoju [32]. Aside the major essential elements, CI recorded the highest concentration (106.0 – 334.5 µg/g) in the Shea fruit pulps from all sampling points. The increasing order of this observed element in the various sampling points was TAN < KAN < BAW < BUL < BON < BOM < BAM < GAT. Other observed essential elements of substantial concentrations in all samples were Zn, Fe and Cu. A perusal of Table 2 shows that, in all sampling areas; As, Sb and Co recorded the lowest concentration in the ranges of 0.106 – 0.312 µg/g, 0.656 – 1.990 µg/g and 1.08 – 3.02 µg/g respectively. Sb, As and elements such as Pb, Hg, Cd are said to have toxicological effects, hence they are classified among the most dangerous groups of anthropogenic environmental pollutants [18].

Thus the low concentrations of As and Sb re-affirms the popular belief that natural products are safe for consumption [33]. A careful scrutiny of Table 2 again shows that no particular sampling point recorded highest values of all elements studied. We have no explanation to this observation yet. However, the variation in elemental concentration of the same Shea fruit pulp species can mainly be attributed to the differences in the mineral composition of the soil and climatological conditions in which the plants are grown [34].

Other factors could be due to contamination during the harvesting and handling of the fruit pulps. The accountability of the different elements present and their concentration levels in terms of their physiological, pharmacological, nutritional and biochemical roles may be a search light for physicians and dieticians / nutritionist. Hence, it is not discussed in the study.

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