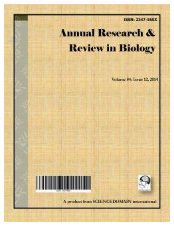

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Assessment of Essential Minerals from Almond Fruits of *Terminalia catappa* Cultivated in Côte d'Ivoire

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Authors' contributions

This work was carried out in collaboration between all authors. Author DTE designed the study, wrote the protocol, fitted the data and wrote the first draft of the manuscript. Author KNY performed the statistical analysis, checked the first draft of the manuscript for submission and revised the manuscript. Authors CA and SD managed the literature and assisted the experiments implementation. Author BGHM expertized the results interpretations. All authors read and approved the submitted manuscript.

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ABSTRACT

Aims: To assess the minerals nutrients in the almonds of *Terminalia catappa* from Côte d'Ivoire and their daily contributions in adult people's diet.
Study Design: The almonds of *Terminalia catappa* extracted from the dry fruits harvested in

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different regions of Ivory Coast. The concentration of the minerals was determined and their contribution to cover the requirements required in the diet.

Place and Duration of Study: The dried fruits of *Terminalia catappa* were collected in the regions of tonkpi (Man and Danane) and Guemon (Duékoué) of the Côte d'Ivoire, from October to December 2015.

Methodology: The dry fruits of *Terminalia catappa* were opened using nutcracker. The extracted almonds were dried at 50°C for 48 h in an oven (MEMMERT, Germany). After cooling, they were crushed (Magimix Crusher) before being stored in sealed polyethylene bags and then stored in a desiccator before analysis (essential minerals content).

Results: The results show the presence of K, P, Mg, Ca, Na, S, Fe, Zn, Cu, Mn. Potassium and phosphorus have the highest concentrations with respective contents of 1398.4±23.25 and 587.60±14.60 mg/100 g. Also, 100 g of almond samples contain 220.67±14.10 mg of magnesium, 176.80±9.71 mg of calcium, and 67.07±1.66 mg of sulfur and 32±1.74 mg of sodium. Essential trace elements concentration ranged between 0.96±0.96 mg / 100 g (Zn) and 13.60±10.74 mg/100 g (Cu). The consumption of almond by an Ivorian adult of 70 kg is 1 g/day; which provides the organism quantities of macroelements ranging between 0.320±0.01 mg/day (Na) and 13.98±0.23 mg/day (K), whereas the contributions in trace elements oscillate between 0,01±0.00 mg/day (Zn) and 0,14 ±0.00 mg/day (Cu).

Conclusion: This study revealed that the almonds of *Terminalia catappa* are good source of essential minerals. The contribution determined from the estimated intake showed that the almonds are able to cover the essential mineral requirements required in the human diet.

Keywords: Almonds; essential minerals; daily intakes; Terminalia catappa; Côte d'Ivoire.

1. INTRODUCTION

Terminalia catappa belongs to the Combretaceae family, native to Southern Asia. Produced from fruits or almond nuts, it was introduced in Côte d'Ivoire thanks to colonization, through urban ornamentation [1]. *Terminalia catappa* can reach 8 m at the adult stage and its fruit turns yellow at maturity. This plant has being the subject of much research on the therapeutic and phytochemical properties of leaves. Masuda et al. [2] reported that leaf extracts of *Terminalia catappa* possess anti-carcinogenic and antioxidant activities. Lin et al. [3] and Wang et al. [4] showed that the leaves of *Terminalia catappa* have antioxidant and anti-inflammatory activities. Téotia and Singh [5] and Nagappa et al. [6] also highlighted their inhibitory action on elevated blood glucose levels. According to Chen et al. [7], Ratnasooriya et al. [8] and Ko et al. [9], this plant contains protective substances of the liver muscle and of fortification of the immune system.

The fresh almonds of this plant have a delicious taste and are consumed by children. Biego et al. [10] indicated that the almonds of *Terminalia catappa* can be eaten as an aperitif in more or less salty forms. Researchers have shown that these almonds are rich in minerals as potassium magnesium, calcium, phosphorous, sodium, and iron in appreciable proportions [11,12]. Minerals constitute 4% of the human body, brought by food (consumed food and drinking water); they perform many functions in the body. These include muscle contraction, oxygen transport, conduction of nerve impulses, acid / base balance of blood, maintenance of fluid intake, blood coagulation, proper immune function or normal heart rate. Their absence in food is the cause of certain disorders such as anemia (due to lack of iron or zinc and copper) and goitre (due to iodine deficiency) [13].

In Africa, specifically in Côte d'Ivoire, the malnutrition generally affects children from 0 to 5 years of age [14]. This malnutrition concerns got worse by the military conflicts between 2002 and 2010, especially in the western Côte d'Ivoire, particularly the Guemon region with 39.8% resurgence rate [15]. From the western Ivorian populations, meals are based on rice and cassava which generally display lower minerals traits. For addressing the diet minerals deficiency, it is important to find in the close area other foods that could be richer in these nutrients and available in plantations or forests such as the almonds of *Terminalia catappa*. The exploitation of dried from *Terminalia catappa* can increase the revenue of the producers, contributing to the reduction of poverty. In this study, we evaluated the content of essential minerals and the contributions of almonds consumption in the mineral daily requirements from almonds fruits of *Terminalia catappa* cultivated in Côte d'Ivoire.

2. MATERIALS AND METHODS

2.1 Plant Material

The plant material consisted of dried ripe fruits from *T. catappa* collected from different regions of Côte d'Ivoire.

2.2 Sampling

The dried fruits of *T. catappa* were collected October to December in the regions of tonkpi (Man, Danane) and Guemon (Duékoué) of the Côte d'Ivoire from producers. In each city, 3 suppliers were considered. At these last, 60 kg of dried fruits were collected. Thus, a total of 540 kg of dried fruit of *T. catappa* was collected, escorted and crushed in the laboratory for analysis.

2.3 Treatment of Dried Fruits of *T. catappa*

The treatment diagram of the fruits of *T. catappa* is detailed in Fig. 1. The dried fruits of *T. catappa* were opened using nutcracker. The extracted almonds were dried at 50°C. for 48 h in an oven (MEMMERT, Germany). After cooling, they were crushed (Magimix Crusher) before being stored in sealed polyethylene bags and then stored in a desiccator before analysis.

2.4 Determination of Minerals

2.4.1 Mineralization of samples

The method of determination of ashes was described by AOAC [16] that consisted to incinerate a sample to 550°C until the obtaining of white ash. Thus, 5 g of dry matter were introduced in a capsule of incineration. The capsule was placed in muffle furnace (PYROLABO, France) and incinerated to 550°C during 24 h. After calcinations and cooling in desiccator, the white ashes were collected for analysis.

2.4.2 Operative conditions of the energy dispersive spectrophotometer (EDS)

The apparatus used for minerals determination was an energy dispersive spectrophotometer coupled to scanning electron microscope (SEM). This device to variable pressure (MEB FEG Supra 40Vp Zeiss) was equipped of an X-ray detector (Oxford instruments) bound to a flat shape of EDS microanalyser (Inca cool dry, without liquid nitrogen).

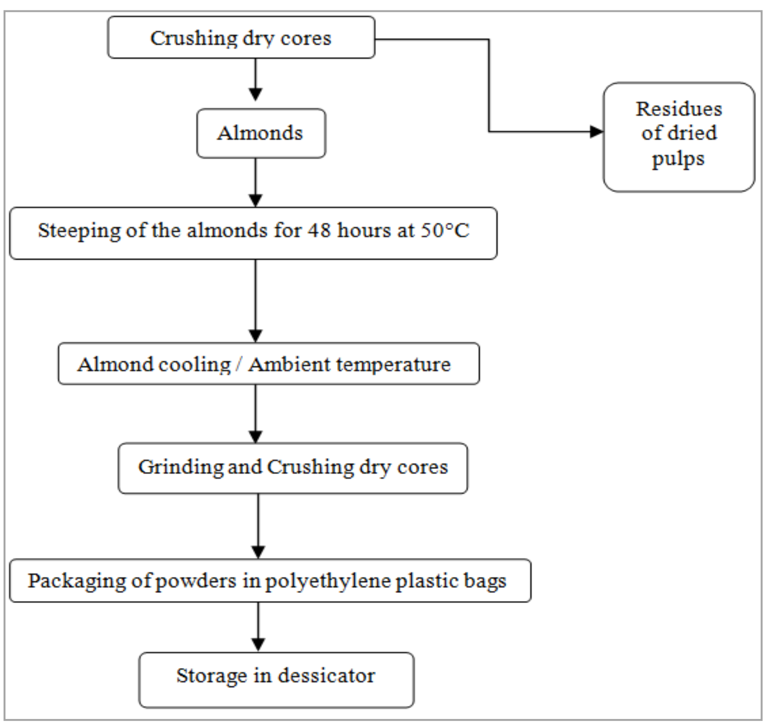

Fig. 1. Diagram for obtaining almond powder from *Terminalia catappa*

The operative conditions of the EDS-SEM were the following:

- Enlargement: 10x to 1000000x;
- Resolution: 2 nm;
- Variable voltage: 0.1 KeV à 30 KeV;
- Acquirement of the elementary chemical composition: enlargement, 50x; borer diameter, 30 nm and 120 nm; borer energy, 20 KeV and 25 KeV; work distance (WD), 8.5 mm.

The chemical composition has been done on 3 different zone then data have been transferred on an Excel file. An average and a standard deviation (SD) have been determined.

2.4.3 Validation test of the minerals determination method

Validation has been achieved according to the method of AFNOR [17,18]. This procedure consists of studies of the linearity, the repeatability, the reproducibility, the extraction yields, detection limits and quantification limits. The linearity of 10 mineral elements has been tested between 25% and 125% with the help of 5 points of standardization (25%, 50%, 75%, 100% and 125%). The tests of repeatability and reproducibility have been achieved with standards of the different mineral to a concentration of 25%. Thirty tests have been achieved respectively for the tests of repeatability and reproducibility. Additions of 5% of the standards have been achieved for the determination of the extraction yields of the minerals. Ten distinct tests have been achieved for the addition measured.

2.5 Contributions Estimated in Essential Elements at the Consumer

The contributions in mineral elements have been estimated according to the method of the Codex Alimentarius that takes into account the concentrations in minerals recovered in the food and the daily consumption of an adult individual of 70 kg of this food [19]. These quantities of foods are given by World Health organization studies [19]. The contribution of this food in daily requirement has been calculated also from the values of daily recommended intakes [20].

Estimated Daily Intake (EDI) = C × Q
Contribution (%) = (EDI × 100)/DRI
C: mineral concentration measured
Q: food daily consumption
DRI: Daily Recommended Intake

2.6 Statistical Analysis

The data was statistically processed using SPSS (SPSS 22.0 for Windows). The analysis consisted of an analysis of variance according to the mineral content, and then the averages were classified by the Newman Keuls test at 5%. The homogeneity of the results was estimated on the basis of the standard deviations and the coefficients of variation.

3. RESULTS AND DISCUSSION

3.1 Validation Results

The results of the validation tests are presented in the Table 1. The square of the correlation coefficient (R^2) is 0.999 for different minerals studied. The variations coefficients for the repeatability and reproducibility tests determined are consisted respectively between 1.0±0.06% and 1.8±0.95% and between 2.3±0.93% and 4.7±0.32%. These results translate a stability and a satisfy precision of microanalysis technics. The percentages of additions measured out are consisted between 97.3±0.84% and 99.5±0.17%. The method is reliable and exact.

3.2 Mineral Concentrations Recovered in Almonds of *Terminalia catappa*

The results indicate the presence of Ca, K, Na, Mg, P , S, Cu, Fe, Mn, and Zn. Table 2 shows the minerals with statistically different grades in the samples ($P < 0.001$). Potassium represents the important macro element in the almond of *T. catappa*, with an average grade of 1398.4±23.25 mg / 100 g. It is followed by phosphorus with a content of 587.6±14.60 mg/100 g. Magnesium, calcium and sulfur recorded concentrations of 220.67±14.10, 176.80 ±9.71 and 67.07 ±1.66 mg/100 g, respectively. Sodium (Na) is the least abundant macro element, with an average content of 32±1.74 mg/100 g of almond powder of *T. catappa.* Concerning trace elements, the contents vary statistically ($p < 0.001$) from 0.96±0.06 to 13.60 ±10.74 mg/100 g. Among them, copper provides the highest concentration (average at 13.60±10.74 mg/100 g). Iron and manganese have respective concentrations of 7.66 ±0.22 and 6.84±0.20 mg/100 g, whereas zinc is only 0.96±0.06 mg/100 g (Table 2).

Table 1. Tests results of mineral analytic validation by MEB/SDE

Minerals	Standard lines		Repeatability	Reproducibility	Ext yield (%)	LOD (µg/kg)	LOQ (µg/kg)
	Equation	R^2	RSD (%)			RSD (%)	
K	Y=3838+3821x	1	1.3±0.04	4.7±0.32	98.4±1.51	581±0.04	796±0.09
P	Y=1742+2667x	0.99	1.4±0.11	3.7±1.22	99.4±0.66	334±0.21	467±0.88
S	Y=-332+4958x	1	1.0±0.06	2.8±0.07	97.6±0.92	667±0.52	947±0.001
Ca	Y=5287+6581x	1	1.5±0.43	2.3±0.93	97.3±0.84	514±0.15	704±0.47
Na	Y=147+2083x	0.99	1.2±0.05	3.4±0.48	98.8±0.33	261±0.74	365±0.07
Mg	Y=237+1452x	0.99	1.1±0.21	3.1±1.44	97.9±0.68	426±0.11	635±0.19
Fe	Y=-88+2285x	0.99	1.4±0.07	3.6±0.01	99.5±0.17	107±0.32	149±0.55
Cu	Y=6951+1953x	0.99	1.8±0.95	2.5±0.03	98.8±0.43	104±0.05	146±0.63
Mn	Y=74454+3659x	1	1.2±1.01	2.9±0.77	99.0±0.78	337±0.81	488±0.60
Zn	Y=-523+4365x	0.99	1.3±0.51	3.2±0.96	98.3±0.03	281±0.58	396±0.29

R^2, Coefficient of determination of standard lines, RSD, Relative standard deviation, LOD, Limit of determination, LOQ, Limit of quantification

Table 2. Averages and statistical data of the mineral elements of fruit almonds of *T. catappa* produced in Côte d'Ivoire

Minerals	Contents (mg /100 g)	RSD	F	P
Calcium (Ca)	176.80±9.7^{d}	5.5		
Potassium (K)	1398.40±23.25^{a}	1.62		
Sodium (Na)	32.00±1.7^{f}	5.45		
Phosphorus (P)	587.60±14.60^{b}	2.49		
Magnesium (Mg)	220.67±14.10^{c}	6.4	4483.54	<0.001
Sulfur (S)	67.07±1.66^{e}	2.48		
Copper (Cu)	13.60±10.47^{f}	78.97		
Iron (Fe)	7.66 ±0.22	82.81		
Zinc (Zn)	0.96±0.06^{h}	86.81		
Manganese (Mn)	6.84±0.20^{g}	86.51		

Means ± standard deviations with the same lowercase letters are statistically identical at 5% significance. F, Value of the statistical Ficher test, P, Probability value of the statistical test; RSD, Relative standard deviation

3.3 Estimated Contributions in Essential Mineral at Ivorian Adult

The intakes of mineral elements estimated for the average daily consumption of 1 g of almond of *T. catappa* for an adult Ivorian is presented in Table 3. Among the macroelements, potassium recorded the highest estimated intake at 13.98±0.23 mg/day, followed by phosphorus at 5.87±0.14 mg/day. However, magnesium, calcium and sodium have respective low estimated intakes of 2.20 ± 0.14, 1.77 ± 0.99 and 0.32±0.01 mg. Estimated intakes of trace elements fluctuate between 0.67±0.01 and 0.01 ±0.00 mg/day. Thus the sulfur indicates a value of 0.67±0.01 mg/day; while copper, iron, manganese and zinc have respective estimated intakes of 0.14±0.10, 0.07±0.00, 0.07±0.00 and 0.01±0.00 mg/day.

The determined contributions are presented in Table 4. These values indicate that with the exception of sodium (with 0, 01%) and of zinc (0, 1%), the contributions are all superior to the 0, 1% of the almonds of *T. catappa* in the daily general food. Also, the cover of the needs to copper even culminates to 12, 5%.

Table 3. Estimated daily mineral intake resulting from consumption of 1 g almond of *T. catappa* from the Ivorian adult people

Minerals	Estimated intake (mg/day)
Potassium (K)	13.98 ± 0.23
Phosphorus (P)	5.88±0.14
Calcium (Ca)	1.77±0.09
Sodium (Na)	0.32±0.01
Magnesium (Mg)	2.2±0.14
Sulfur (S)	0.67±0.01
Copper (Cu)	0.147±0.01
Iron (Fe)	0.07±0.00
Zinc (Zn)	0.01±0.00
Manganese (Mn)	0.07±0.00

4. DISCUSSION

The R^2 determination coefficients got from the calibrations tests were close to 1, forecasting a quasi-linear estimation of the mineral nutrients according to their concentration from in the meals. Also, the lower coefficients of variation (<5%) resulting from reproducibility and repeatability translate quite stability of the EDS method used, which is as fitted as the full amount of each mineral nutrient is revealed, as shown by the weak extraction defaults below 2.7% from the added minerals. Thus, these characteristics highlight the reliability and precision of the outcomes in the minerals contents determination using the EDS method.

Table 4. Minerals intake recommendations (mg / day) and contribution of *T. catappa* almonds (%) in their recovery

Minerals	RDI (mg/day)	Estimated contribution (%)
Potassium	2000	0.7 ±0.00
Phosphorus	700	0.83±0.00
Calcium	800	0.22 ±0.00
Sodium	2500	0.01 ±0.00
Magnesium	375	0.6±0.00
Copper	1	12.8±10
Iron	14	0.5±0.00
Zinc	10	0.1±0.00
Manganese	2	3.5±0.00

RDI: Recommended daily intake

Minerals are very important in human diet because of their various functions in the body. They serve as cofactors for physiological factors and many metabolic functions.

The highest contents of potassium, phosphorus, magnesium and calcium in almonds are due to the fact that fruits at the terminal parts of the plant are the preferred locus of mineral accumulation [21].

Thus in almonds the potassium concentration (1398.40±23.25 mg/100 g) is lower than that (1718.2mg/100 g) reported by Ladele et al. [22]. However, this content remains higher than those indicated (42.17 and 30.36 mg/100 g) respectively by Olatidoye et al. [23] and Udotong et al. [24]. This content (1398.40±23.25 mg/100 g) could cover 70% of the RDA (2000 mg/day); this shows the richness of the almonds of *T. catappa.* The potassium, the predominant mineral of the almonds studied, intervenes in the functioning of the heart and in the regulation of the osmotic pressure through the $Na+/K^+$ pump. It also contributes to the maintenance of the acid-base balance of the organism [25].

Concerning phosphorus Mbah et al. [26] and Udotong et al. [24] founded less than 50 mg in 100g almonds of *T. catappa*; while our studies revealed a content of nearly 600 mg/100 g, when Agatemor et al. [27] report an average of 2200 mg/100 g. Then, the consumption of almonds (100 g/day) could cover 83.93% of the RDA (700 mg). Thus, almonds could be recommended for human diet. Phosphorus has an important energy role through its presence in the molecules of adenosine monophosphate, diphosphate and triphosphate (AMP, ADP and ATP); and also contributes to maintaining the acid-base balance of body fluids [28].

Udotong et al. [24] reported less than 50 mg/100 g of magnesium and calcium in almonds while Ladele et al. [22] reported levels of about 729.09 mg/100g that are higher than ours. The consumption of almonds could cover 58.84% and 22.1% respectly of the RDA of Mg (357 mg/day) and Ca (800 mg/day). Magnesium is involved in protein biosynthesis, release of energy, relaxation of muscle fibers and reduces the risk of cardiovascular disease [29,30]. Then the valorization of the consumption of almonds of *T. catappa* could decrease the risks of cardiovascular disease. Calcium is one of the major components of teeth and bone tissue. In addition, it is involved in muscle function and blood coagulation [29]. Its deficiency would cause rickets, bone pain and muscle weakness.

The present studies mentioned 32.00±1.7 mg/100 g of sodium comparable to the 27 mg/100 g indicated by Udotong et al. [24] but lower than the 58.4 mg/100 g reported by Amata et al. [31]. This content (32.00±1.7 mg/100g) could not cover the RDA (2500 mg/day). Sodium provides a good transmembrane electrical gradient between extracellular and intracellular media and participates in the absorption of glucose and amino acids [32].

Concerning trace elements (Cu, Fe, Mn, Zn) detected in almond powders of *T. catappa*, copper is the most abundant (13.6±10.74 mg/100 g). This content is higher than that (4.63 mg/100 g) reported by Ladele et al. [22]. This content (13.6±10.74 mg/100 g) could cover the RDA (1 mg/day). Indeed, copper is involved in bone mineralization, neurotransmitter regulation, immunity, iron metabolism and in the oxidative metabolism of glucose [33,34,35].

Iron is important for the working of the organism that its deficiency poses real problems of public health. It serves as a carrier of oxygen to the tissues from the lungs by red blood cell hemoglobin, as a transport medium for electrons within cells, and as an integrated part of important enzyme systems in various tissues

[36]. Indeed, Iron is an important constituent of hemoglobin in the red blood corpuscles. Its absence is the cause of anemia in the body. Its concentration (7.66 ±0.22 mg/100 g) in the almonds studied is comparable to that (6.38 mg/100 g) indicated by Olatidoye et al. [23]. This content (7.66 ±0.22 mg/100g) could cover 76.60% of the RDA (10 mg/day). Increased consumption of almonds especially in children could reduce the risk of anemia.

Ladele et al. [22] indicated a manganese content of 4.25 mg/100 g in almonds, while our present studies revealed 6.84±0.20 mg/100 g. In case of insufficient manganese in food, the consumption of almonds as aperitif could cover the RDA (2 mg/day). The blood contains 20 mg to 28 mg of manganese which perform many functions in the body. Among which manganese activates many enzymatic systems by limiting the action of free radicals and therefore prevents aging of cells.

The present studies indicate zinc as the least abundant trace elements with 0.96 ±0.06 mg/100 g. This content (0.96±0.06 mg/100 g) corroborates the 1.0 mg /100 g indicated by Mbah et al. [11], on the other hand greater than that (0.5 mg / 100 g) underlined by Agatemor et al. [27] for the same biological material. This content could cover 9.60% the RDA (10 mg/day). Zinc just like iron is very important for the functioning of the body. It plays an important role in the immune system which affects a large number of cells involved in humoral immunity [37].

This variability in mineral content in the almonds of *T. catappa* observed by the various authors and our study could be related to the pedological differences of the cultivation zones and the periods of fruit harvest [11].

Although there is much research in human nutrition, bibliographic data on the estimation of essential mineral nutrient intakes are still very scarce. According to OMS [17], the daily consumption of almonds of *Terminalia catappa* is around 1 g for an average food intake of 1018.1 g. In this case, almonds represent a proportion of 0.1% of the daily diet of the populations. With the exception of sodium (0.01%) and zinc (0.1%), these contributions are all higher than 0.1% of the almonds of *T. catappa* in the daily general diet. Coverage of copper requirements is even at 12.5%. This testifies to the mineral richness of *T. catappa* almonds. The study revealed that almonds of *T. catappa* are a rich source of essential minerals (potassium, phosphorus, magnesium and calcium). The study also showed the consumption of almonds of *T. catappa* will be cover the essential mineral requirements required in the human diet.

5. CONCLUSION

This study revealed the richness of minerals essential to the organism in the almonds of *Terminalia catappa*. In addition, it revealed that the daily amount of kernel consumed (1 g) is very low compared to the amount (1018.1 g / d) of food ingested by an adult. Although consumed in small quantities, the contribution determined from the estimated intake showed that the almonds are able to cover the essential mineral requirements required in the diet. Thus, from this study, we could consider the design of foods made from almonds; encourage the sale of almonds by producers to increase their profit in order to reduce poverty in their environment.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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