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Analysis of Trace Elements in Sudanese Flour Using Energy Dispersive X-Ray Fluorescence (EDXRF)

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Abstract: ***This study investigates the concentration of eleven trace elements-K, Ca, Cr, Mn, Fe, Cu, Zn, Pb, Br, Rb, and Sr-in various Sudanese flour samples using Energy Dispersive X-ray Fluorescence (EDXRF). Flour types analyzed include Feiterita, Wad Al Fahal, Abo Saben, Tabat, Hageen, Sega flour, Wheat Al Gazera, Millet Al Gadaref, and Wad Aker. The findings reveal that Sega flour had the highest concentrations of potassium and zinc, while Tabat exhibited elevated levels of iron and bromine. Toxic elements such as lead were present but below the FAO/WHO maximum limit but close to it. These results contribute to the understanding of mineral content in common food products, with implications for public health and food quality monitoring.***

Keywords: Trace elements, EDXRF, Sudanese flour, mineral analysis, food safety

1.Introduction

Sorghum flour is generally used as food source in developing countries. It probably originated in Ethiopia and has spread to other parts of Africa, India, Southeast Asia, Australia and the United States. For instance, Kisra is a traditional bread, well known and consumed throughout the Sudan. It is prepared from the (*Sorghum bicolor*) or pearl millet (*Pennisetum typhoid*) grains. The fermented flour is baked into thin sheets. It is eaten with certain types of stew prepared from vegetables and meat. The human body needs number of minerals to maintain good health. The body needs some essential nutrients in relatively large amounts; these macronutrients include protein, fat, carbohydrate, and water. Micronutrients, such as vitamins and minerals, are vital for physiological functions [1]. Determination of mineral elements in flour is very important since the quality of many foods depends upon the content and type of minerals. Malnutrition is of major concern for many tropical developing countries. Deficiency or excess of elements may cause number of disorders. For example, Iron deficiency anemia affects one third of the world population [2]

Almost all minerals can be toxic if consumed in large amounts. Minerals are important constituents of bones and teeth. minerals may be integral parts of biological compounds such as hemoglobin and Cytochromes [3].

It is of major interest to determine the levels of some metallic elements in commonly used flour because, at elevated levels, these metals could be dangerous and toxic. Therefore, several attempts have been made to determine metal content in food. Macronutrients elements are required in large quantities they usually participate in body constriction. Micro-element or trace elements are usually participated in various metabolisms the occur in plants in easily detectable quantities. Understanding the mineral composition of widely consumed flour types provides vital data for dietary planning and public health strategies, especially in regions vulnerable to malnutrition or heavy metal exposure.

2.Materials and Methods

a) Eight local cultivars of sorghum (Sorghum bicolor), wheat (Triticum durum), and millet (Panicum, Pennisetum typhoides), namely Feitarita, Wad Al Fahal, Abo Saben, Tabat, Ha-gen, Wheat Al Gazera, Millet Al Gadaref, and Wad Aker, were purchased as whole grains from local markets in Omdurman, Sudan. These grains were then milled into flour, as commonly practiced for human consumption in Sudan. In addition, one sample was purchased directly as commercial flour (Sega flour) from the local market.

b) Samples preparation

In any elemental analysis using XRF, the process of sample preparation is still a major difficulty, since only a thin layer of a sample is used to perform the elemental analysis. Therefore, the sample must be evenly distributed and homogeneously mixed for the results to be representative of the whole sample. The samples which are used are usually in fine powder (flour). These flours are mixed homogeneously and then pressed into pellet form using a pressing machine. A pressure of about (15 tons) is usually applied to make a good pellet.

c) EDXRF measurements of the pressed pellets were carried out using an ARL Quant X spectrometer equipped with a Rh-anode X-ray tube and a Si(Li) detector cooled with liquid nitrogen. The system was operated with appropriate aluminum and cellulose filters at tube voltages between 8 and 12 kV and currents of 0.32–0.34 mA.

Quantitative analysis was performed using the Fundamental Parameters method with factory calibration traceable to NIST and IAEA reference standards. Energy and efficiency calibrations were verified using IAEA standard reference materials. Spectra were acquired for 120 s per sample with a typical dead time of approximately 50%. Data processing, spectral deconvolution and statistical uncertainty estimation based on photon counting statistics were carried out using WINTRACE software (version 4.1, build 9).

3.Results and Discussion

Knowledge of the elemental content in flour is very important since many trace elements play significant roles in the formation of active constituents responsible for the curative properties. Moreover, some of these elements are vitally important for various metabolic processes in the human body. They are closely linked to human growth and general health [4]. In this study, a total of eleven elements (K, Ca, Cr, Mn, Fe, Cu, Zn, Pb, Br, Rb and Sr) were determined in the powdered flour samples by using EDXRF. The mean concentrations of various metals in the flour samples are shown in Table 2. Statistical analysis of the elemental concentrations revealed that Potassium (K) was the most abundant element, with a high mean concentration of 2485.67 ± 1007.42 ppm, indicating significant variation among the flour types. Conversely, the toxic element Lead (Pb) showed a very low mean concentration of 0.16 ± 0.02 ppm, with minimal standard deviation, confirming its consistent presence within safe limits across all samples. This highlights the nutritional variability and safety of the analyzed Sudanese flours. The current study revealed that all the metals were accumulated to greater or lesser extents by all nine flour samples investigated.

Copper is an essential nutrient that plays an important role in the production of hemoglobin, myelin, collagen and melanin [5]. Cu concentrations varied from 1.16 to 0.873 ppm, which showed that the samples contained large amounts of nutrients and were rich in K and Ca. The high concentration of potassium in food is needed for many essential processes including enzyme activation, photosynthesis, water use efficiency, starch formation and protein synthesis. Potassium participates actively in the maintenance of the cardiac rhythm [6]. Concentrations of potassium were in the range 3780-1144 ppm. Two samples have concentrations ranging from 1144 to 1183 ppm and seven samples in the range 3780-1905 ppm. Sega Flour (3780 ppm) had the highest concentration K followed by Wad Aker (3620 ppm). Ca is the main constituent of the skeleton and is important for regulating many vital cellular activities such as nerve and muscle function, hormonal actions, blood clotting and cellular mortality. Calcium concentrations ranged from 1160 to 1610 ppm. Hageen had the highest Ca concentration (1610ppm) whereas Feiterita had the lowest (1060ppm). Manganese concentration ranged from 20.6 to 12.93 ppm. Hageen had the highest concentration of Mn and Sega flour had the lowest. Deficiency of Mn in human causes myocardial infarction and other cardiovascular diseases, also disorder of bony cartilaginous growth in infants and children and may lead to immunodeficiency disorder and rheumatic arthritis in adults [7]. Iron is an essential element for human beings and animals and is an essential component of hemoglobin. It facilitates the oxidation of carbohydrates, protein and fat to control body weight, which is very important factor in diabetes. The Fe concentrations varied from 110.70 to 50.01 ppm. Five samples have concentrations ranging from 80.20 to 50.01 ppm, other four samples in the range 50.80 –100.30 ppm. Tabat had the highest Fe concentration followed by Millet Al Gadaref and Abo Saben respectively. Hageen flour had lowest Fe concentration. Cr and Zn have important roles in the metabolism of cholesterol as well as heart diseases. The presence of Cr and Mn in plants may be correlated with therapeutic properties against diabetic and cardiovascular diseases [8]. The toxic effects of Cr intake are skin rash, nose irritations, bleeds, upset stomach, kidney and liver damage, nasal itch and lungs cancer. Cr deficiency is characterized by disturbance in glucose lipids and protein metabolism [9]. The daily intake of Cr 0.05-0.20 mg has been recommended for adults by US National Academy of Sciences [10]. The Cr concentrations varied from 1.16 to 0.895 ppm. Sega flour had the highest Cr concentration whereas, Feiterita had the lowest.

Zinc is the component of more than 270 enzymes [11] and its deficiency in the organism is accompanied by multisystem dysfunction. Besides, Zn is responsible for sperm manufacture, fetus development and proper function of immune response [12] Zinc deficiency during pregnancy may cause developmental disorders in the offspring. Low intake of zinc may cause coronary artery disease [13]. The Zn concentrations varied from 34 to 20 ppm. Tabat had the highest Zn concentration and Wheat Aljazera flour had the lowest. Lead concentrations varied from 0.179 to 0.129 ppm, Wad Al Fahal had the highest Pb concentration whereas, Feiterita had the lowest. Bromine is considered as a non-essential element for living organisms [14]. The concentrations of this element varied from 3.1 to 1.15 ppm. Tabat had the highest Br concentration and Feiterita had the lowest. Rubidium is also considered as non-essential element for human organism [15]. Rubidium concentrations varied from 5.5 to 1.32 ppm. Most samples have concentrations in the range 2.71-1.32 ppm. Tabat had the highest Rb concentration followed by Wheat ALjazera and Millet Gadaref flour had the lowest. The significant variations in elemental concentrations among the flour samples can be attributed to differences in soil composition and geographical origin of the cultivation areas. Agricultural practices such as the application of fertilizers, particularly potassium and phosphate-based formulations commonly used in Sudan, substantially increase the uptake of specific elements by plants. Additionally, variations in irrigation water composition and soil pH across different regions contribute to the observed heterogeneity in mineral profiles. These environmental and agricultural factors collectively explain the substantial differences in trace element concentrations between the analyzed flour types.

Finally, the Strontium concentrations were in the range 38.8- 16.44 ppm. Most samples being in the 38.8 -20.9 ppm range Wad Al Fahal had the highest Sr concentration and Abo Saben had the lowest.

The elemental concentrations obtained in this study are consistent with values reported in similar studies on cereal flours from other countries. For example, zinc concentrations (20–34 ppm) are comparable to those reported for wheat and sorghum flours from Nigeria (18–42 ppm) and India (22–35 ppm). Iron levels (30–111 ppm) are also within the range reported for cereal flours from Ethiopia and Pakistan (45–150 ppm). Lead concentrations in the present study (0.129–0.182 ppm) are lower than or comparable to those reported in cereals from some industrial regions, where values up to 0.30 ppm have been observed. This indicates that Sudanese flours are not highly contaminated by heavy metals compared with other regions. [2,5,13]

Table 1: Grains scientific and local name of flour.

Symbol	Grains scientific name	Local name of flour
R1	Sorghum bicolor	Feiterita
R2	Sorghum bicolor	Wad Al Fahal
R3	Sorghum bicolor	Abo Saben
R4	Sorghum bicolor	Tabat
R5	Sorghum bicolor	Hybrid, Hageen
R6	Sorghum bicolor	Sega Flour
R7	Triticum durum	Wheat ALjazera
R8	Panicum, Pennisetum typhoi	Millet Gadaref
R9	Sorghum bicolor	Wad Aker

Table 2: Nutritionally trace elements in flour samples (in ppm)

Sample Name	K	Ca	Cr	Mn	Fe	Cu	Zn	Pb	Br	Rb	Sr
R1	1183	1060	0.873	16.9	80.09	5.67	24	0.129	1.15	2.37	20.9
R2	2359	1510	1.07	19.8	100.30	3.3	25	0.168	1.18	1.58	38.8
R3	2311	1420	0.984	13.24	100.40	5.4	23	0.179	2.8	4.46	13.7
R4	3615	1160	1.12	17.7	50.80	3.7	34	0.141	3.1	5.5	25.9
R5	2454	1610	1.14	20.6	50.01	5.1	23	0.182	1.35	2.71	29.2
R6	3780	1470	1.16	12.93	30.01	4.04	32	0.169	2.17	2.06	24.1
R7	1905	1420	0. 895	13.14	80.20	8.4	20	0.142	4.3	4.63	16.44
R8	1144	1550	1.06	18.8	110.70	3.52	27	0.177	1.42	1.32	14.9
R9	3620	1160	1.1	20.14	50.79	4.2	20.5	0.176	2.86	3.83	16.9
Sample mean	2485.67	1373.33	1.04	17.03	72.59	4.81	25.39	0.16	2.26	3.16	22.32
Std.Dev	1007.42	196.47	0.10	3.16	28.24	1.59	4.83	0.02	1.09	1.49	8.14

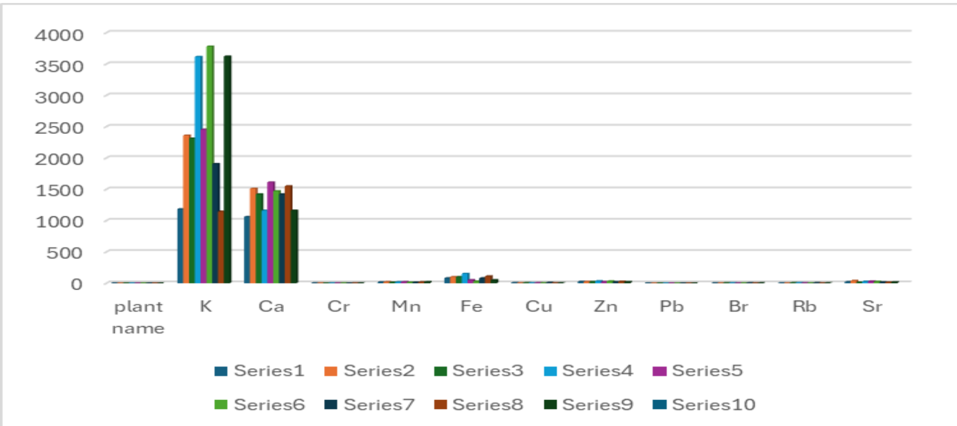

Figure 1: Nutritionally trace elements content in flour samples

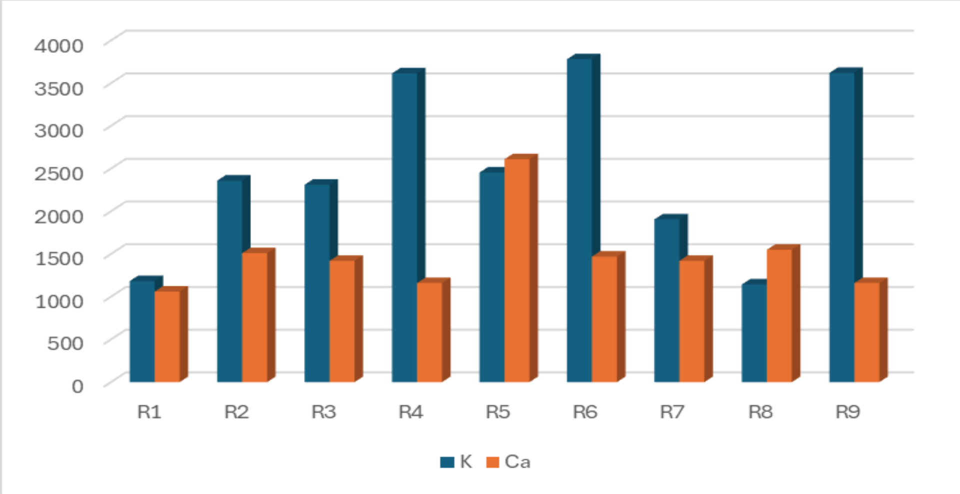

Figure 2: Nutritionally essential macro-elements content in flour samples (in ppm).

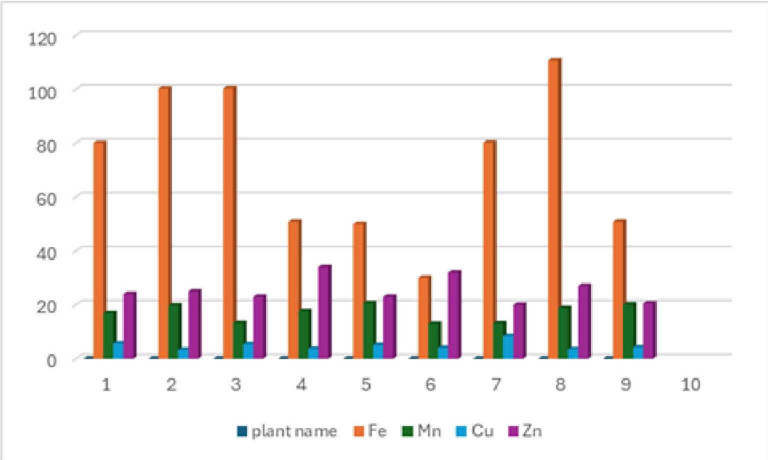

Figure 3: Nutritionally essential micro-elements content in flour samples (in ppm).

4.Conclusion

The application of EDXRF in this study successfully quantified essential and toxic elements in commonly consumed Sudanese flours. Potassium emerged as the most abundant nutrient, while toxic metals like lead were present in low concentrations, suggesting limited risk. These results support the use of XRF as a reliable technique for nutritional monitoring and could aid in shaping public health guidelines and quality standards for food products.

Comparison of the measured elemental concentrations with the FAO/WHO Codex Alimentarius limits showed that all detected heavy and trace elements, including lead, zinc, copper, iron, manganese and chromium, were within the internationally permissible safety levels. The highest recorded lead concentration (0.182 ppm) was below the FAO/WHO maximum limit of 0.20 ppm for cereals. Therefore, the analyzed Sudanese flour samples can be considered safe for human consumption with respect to trace and heavy metal contamination. [16]

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