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Trace Elemental Profiling of Sunflower seeds by Energy-Dispersive X-ray Fluorescence: Nutritional Significance and Implications for Cardiovascular Health

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Abstract

Cardiovascular diseases (CVDs) are a major global health concern, and inadequate intake of essential micronutrients may contribute to cardiovascular dysfunction and oxidative stress. Medicinal plants and plant-derived foods are important sources of bioactive compounds and essential minerals with potential health-promoting properties. The present study evaluated the elemental profile of sunflower (*Helianthus annuus* L.) seeds using Energy-Dispersive X-ray Fluorescence (EDXRF) spectroscopy to assess their nutritional significance and potential relevance to cardiovascular health. EDXRF offers a rapid, non-destructive and multi-elemental approach for characterizing mineral composition in plant materials. The analysis revealed the presence of phosphorus (P), sulfur (S), chlorine (Cl), potassium (K), calcium (Ca), manganese (Mn), iron (Fe), copper (Cu), zinc (Zn), selenium (Se), bromine (Br), rubidium (Rb), and strontium (Sr), demonstrating a diverse elemental profile. The nutritionally important elements, particularly K, Ca, P, Fe, Zn, Mn, Cu and Se, may contribute to electrolyte balance, normal cellular metabolism, antioxidant defense and maintenance of physiological functions associated with cardiovascular health. The occurrence of Se, Zn, Cu and Mn is particularly relevant because these elements participate in antioxidant and enzymatic systems that may help mitigate oxidative stress. The findings indicate that sunflower seeds represent a valuable plant-based source of essential and trace elements and may have nutritional relevance in cardiovascular health. Further studies should evaluate mineral bioavailability, dietary intake, phytochemical–element interactions, antioxidant and cardioprotective activities, and their association with cardiovascular health outcomes.

Keywords: Sunflower seeds, EDXRF, X-ray fluorescence, Trace elements, Cardiovascular health.

1. Introduction

Further studies should investigate the bioavailability and synergistic effects of the mineral elements and bioactive compounds in sunflower seeds, particularly their combined role in cardiovascular health. Clinical and dietary studies are also needed to validate their potential cardiovascular benefits [1]. Cardiovascular diseases (CVDs) remain a major global public-health challenge and the leading cause of death worldwide. According to the latest WHO estimates, 19.8 million people died from CVDs globally in 2022, accounting for approximately 32% of all deaths, with heart attack and stroke responsible for about 85% of CVD-related deaths [2]. In India, ischemic heart disease and stroke remain major causes of mortality, with estimated mortality rates of 110.8 and 53.5 deaths per 100,000 population, respectively, in 2021; however, WHO cautions that these estimates should be interpreted in view of limitations in cause-of-death registration [3].

CVDs include coronary heart disease, cerebrovascular disease, peripheral arterial disease, rheumatic and congenital heart disease, and heart failure. Their development is associated with genetic, metabolic, environmental and lifestyle factors, including tobacco use, physical inactivity, unhealthy diets, harmful alcohol consumption, hypertension, elevated blood glucose, abnormal blood lipids, overweight and obesity [4-5]. Clinical manifestations may include chest discomfort, radiating pain, breathlessness, nausea, dizziness and sweating in myocardial infarction, while stroke may cause sudden weakness, speech difficulties, visual disturbances, loss of balance and severe headache [6]. These factors emphasize the importance of prevention, early diagnosis and appropriate management.

Modern allopathic pharmacotherapy is essential for cardiovascular disease management, although conventional medicines may cause adverse drug reactions, drug interactions and dose-related effects in susceptible individuals [7]. This has encouraged interest in complementary nutritional strategies and plant-derived bioactive compounds. Medicinal plants contain diverse phytochemicals such as phenolics, flavonoids, terpenoids, alkaloids and tannins, which may exhibit antioxidant, anti-inflammatory and Vaso protective properties [8]. Their biological activity may also be influenced by essential minerals and trace elements, making elemental characterization important [9].

Among nutritionally important plant foods, sunflower (*Helianthus annuus* L.) seeds are particularly noteworthy. Sunflower belongs to the family Asteraceae (Compositae) and is an annual herbaceous plant with an erect stem, taproot system and large, simple, petiolate leaves. Its characteristic capitulum consists of peripheral ray florets and central disc florets, with the fruit represented by an achene commonly known as the sunflower seed [10].

Sunflower seeds provide proteins, lipids, dietary fiber, vitamins and minerals. Approximately 100 g of dry-roasted, unsalted kernels contain 19.3 g protein, 49.8 g total fat, 11.1 g dietary fibre and 582 kcal, together with approximately 26.1 mg α-tocopherol. Their nutritional composition can vary with genotype, geographical origin, soil conditions, cultivation practices, maturity and processing [11].

Trace and mineral elements are essential for cardiovascular physiology, participating in electrical conduction, muscle contraction, energy metabolism, oxygen transport and antioxidant defense. K contributes to membrane potential and cardiac electrical activity; Ca regulates myocardial and vascular contraction; P supports ATP metabolism; and Fe is essential for oxygen transport. Cu, Mn, Zn and Se function in enzymatic and antioxidant systems [12]. However, both deficiency and excessive intake can disturb homeostasis [13]. Therefore, evaluation of elemental concentrations is important for understanding nutritional value and potential health implications.

Recent research emphasizes that trace elements influence metabolic pathways, oxidative balance and enzymatic activity, while excessive exposure

may also be harmful. Accurate elemental profiling is therefore relevant to both nutritional assessment and food-safety evaluation. Energy-Dispersive X-ray Fluorescence (EDXRF) is particularly suitable for such investigations because it enables rapid, multi-elemental and relatively non-destructive analysis with minimal sample preparation [14].

In this context, the main objective of the present study is to quantitatively evaluate the elemental composition of sunflower (*Helianthus annuus* L.) seeds using EDXRF spectroscopy, focusing on nutritionally relevant elements including P, S, Cl, K, Ca, Mn, Fe, Cu, Zn, Se, Br, Rb and Sr. The study aims to characterize their elemental profile and discuss the nutritional significance of these elements in relation to cardiovascular physiology and oxidative-stress management, without implying a direct therapeutic effect of sunflower seeds against cardiovascular disease.

2. Materials and Methods

2.1 *Sample Collection and Preparation*

Mature sunflower (*Helianthus annuus* L.) seeds were collected from healthy plants grown in local agricultural regions as illustrated in the Figure 1. The plant species was authenticated by Department of Botany, Kakatiya University Warangal. The collected seeds were washed thoroughly with tap water followed by distilled water to remove dust and contaminants. The seeds were shade-dried at room temperature (25–30 °C) for approximately 10–12 days until constant weight was achieved. The dried samples were powdered using a clean agate mortar and pestle to avoid contamination. The powdered material was sieved through a fine mesh (≤75 µm) to obtain uniform particle size. Approximately 150 mg of the powdered sample was pressed into pellets using a hydraulic pellet press under uniform pressure without binder. The prepared pellets were stored in a desiccator prior to analysis.

Figure 1. Sunflower (*Helianthus annuus* L.) seeds

2.2 Experimental Setup (EDXRF Analysis)

Trace elemental analysis was carried out using an Energy - Dispersive X-ray Fluorescence (EDXRF) spectrometer at UGC, DAE-CSR Kolkata. The instrument was equipped with an appropriate X-ray excitation source and a high-resolution solid-state detector for multi-elemental detection[16]. The prepared pellets were irradiated under optimized experimental conditions to analyze major, minor, and trace elements present in the plant sample. Spectral acquisition time and excitation parameters were selected to achieve high sensitivity and good counting statistics. Elemental concentrations were measured in ppm level (parts per million) and the obtained results were statistically assessed and compared with standard certified reference material NIST 1515 apple leaf to assess elemental enrichment and their possible relevance to the Cardiovascular therapeutic properties of sunflower (*Helianthus annuus* L.) mature seeds [17].

3. Results and Discussion

The elemental composition of sunflower (*Helianthus annuus* L.) mature seeds was quantitatively analyzed using an Energy Dispersive X-ray Fluorescence (EDXRF) spectrometer, and the results were presented in Table 1. The concentrations of biologically significant elements, such as P, S, Cl, K, Ca, Mn, Fe, Cu, Zn, Se, Br, Rb, and Sr, were determined and compared with the certified reference material NIST 1515 (apple leaf standard) to evaluate the accuracy and reliability of the analytical technique.

Table 1. Representative the average mineral concentrations reported in sunflower seeds compared with standard NIST 1515 Apple leaf

Elements	Sunflower seeds (ppm)	NIST 1515 apple leaf standard certified values
P	5700	1590
S	2100	1800
Cl	700	579
K	8400	16100
Ca	2700	15260
Mn	18	54
Fe	64	83
Cu	17	5.64
Zn	52	12.50
Se	1.22	0.05
Mg	2900	Reference
Br	BDL	1.80
Rb	0.26	10.20
Sr	0.272	25

BDL = Below Detection Limit.

The EDXRF analysis demonstrated a diverse elemental profile in sunflower seeds, with P (5700 ppm), S (2100 ppm), Cl (700 ppm), K (8400 ppm), Ca (2700 ppm), Mg (2900 ppm), Fe (64 ppm), Mn (18 ppm), Cu (17 ppm), Zn (52 ppm), Se (1.22 ppm), Rb (0.26 ppm), Sr (0.272 ppm), while Br was below the detection limit (BDL). Fig. 2 shows the EDXRF spectrum of sunflower (*Helianthus annuus* L.) mature seeds.

For cardiovascular interpretation, particular attention can be given to K, Ca, Mg, Fe, Cu, Mn, Zn and Se because of their established physiological roles in cardiac function, vascular regulation, oxygen transport and antioxidant defense [18].

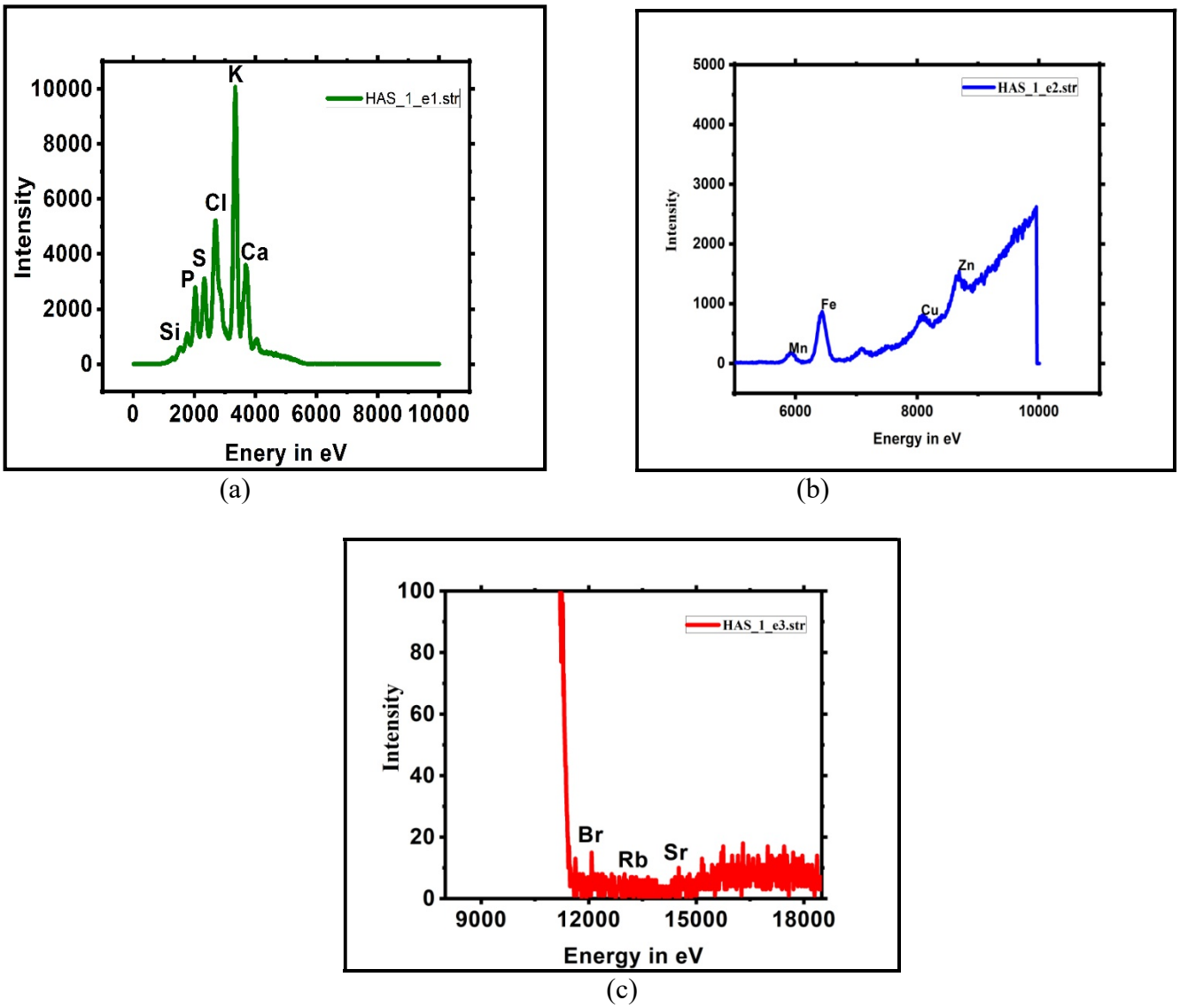
Potassium (K) was the most abundant element detected in the sunflower seeds at 8400 ppm (0.84%). Potassium is particularly relevant to cardiovascular health because it contributes to membrane potential, cardiac electrical activity and regulation of blood pressure [19]. The high potassium concentration observed in the present sunflower-seed sample suggests a potentially valuable dietary contribution to potassium intake [20]. WHO recommends increasing potassium intake from food to help reduce blood pressure and cardiovascular risk, particularly because potassium can counterbalance some of the adverse effects of high sodium intake on blood pressure. However, the measured concentration in seeds should not be interpreted as evidence of a direct cardioprotective effect, since actual dietary contribution depends on serving size, bioavailability and overall dietary intake [21].

Calcium (Ca) and magnesium (Mg) were detected at 2700 and 2900 ppm, respectively. Both minerals are physiologically important for cardiovascular function. Calcium is essential for myocardial contraction and vascular smooth-muscle function, whereas magnesium participates in ATP-dependent reactions, neuromuscular regulation and cardiac electrophysiology [22].

The presence of these elements therefore adds to the nutritional significance of sunflower seeds. Nevertheless, their cardiovascular effects depend on maintaining physiological homeostasis, and the EDXRF concentrations alone cannot establish their bioavailability or clinical effect.

Phosphorus (P) was present at 5700 ppm, representing one of the major mineral constituents of the analyzed seeds. Phosphorus is essential for ATP production, phospholipid metabolism and cellular energy transfer, all of which are fundamental to myocardial metabolism [23]. However, phosphorus is not generally considered a cardiovascular-protective element simply on the basis of high dietary concentration; therefore, its presence should primarily be interpreted as evidence of the mineral nutritional density of sunflower seeds.

Iron (Fe) was detected at 64 ppm, while copper (Cu), manganese (Mn) and zinc (Zn) were present at 17, 18 and 52 ppm, respectively. These trace elements are involved in oxygen transport, enzymatic reactions and oxidative-stress regulation. Iron is essential for haemoglobin-mediated oxygen transport, while copper and manganese contribute to redox enzymes and cellular metabolism [24]. Zinc is an essential micronutrient involved in numerous enzymatic and cellular processes and has been investigated in relation to cardiovascular physiology, including myocardial and vascular processes [25]. The concentrations observed in sunflower seeds indicate the presence of these nutritionally relevant trace elements, although their physiological contribution cannot be predicted solely from total elemental concentration.



(a) (b)

(c)

Figure 2. EDXRF spectrum of Sunflower (*Helianthus annuus* L.) [HAS-*Helianthus annuus* L.**e1, e2, e3 different energy ranges]**

Selenium (Se) was detected at 1.22 ppm, which is particularly noteworthy because selenium is an essential component of selenoproteins involved in antioxidant and redox regulation. From a cardiovascular perspective, selenium has attracted considerable interest because oxidative stress is implicated in cardiovascular pathophysiology [26]. However, the relationship between selenium status and cardiovascular disease is complex, and clinical evidence does not establish that increased selenium intake or supplementation necessarily prevents CVD. Recent evidence also indicates that excessive selenium exposure may be associated with adverse metabolic and cardiovascular outcomes. Therefore, the selenium concentration identified in sunflower seeds should be regarded as a nutritional finding rather than evidence of a direct cardioprotective action.

The remaining elements, including S (2100 ppm), Cl (700 ppm), Rb (0.26 ppm) and Sr (0.272 ppm), were also detected, whereas Br was below the detection limit (BDL). Although these elements contribute to the overall elemental fingerprint of sunflower seeds, their specific cardiovascular significance cannot be established from the present EDXRF data alone. Similarly, the markedly different values between sunflower seeds and the NIST 1515 apple-leaf certified

reference material should not be interpreted as direct nutritional comparisons because the reference material represents a different plant matrix and is primarily used for analytical quality control.

Overall, the elemental profile demonstrates that sunflower seeds contain several minerals and trace elements with established relevance to cardiac electrophysiology, blood-pressure regulation, oxygen transport and antioxidant metabolism. The particularly high potassium content is noteworthy from a cardiovascular-nutrition perspective, while the presence of Mg, Ca, Fe, Cu, Mn, Zn and Se further demonstrates the mineral diversity of the seeds [27]. Nevertheless, EDXRF measures total elemental concentrations and does not establish mineral bioavailability, dietary adequacy or therapeutic efficacy. Further studies integrating mineral speciation and bioavailability with antioxidant assays, dietary intake assessment and experimental cardiovascular models would therefore be necessary to determine whether the observed elemental profile translates into measurable cardioprotective effects.

4. Conclusion

The present EDXRF investigation demonstrates the potential of sunflower (*Helianthus annuus* L.) seeds as a nutritionally valuable source of major and trace mineral elements. Published evidence indicates particularly substantial concentrations of potassium, phosphorus and magnesium, together with nutritionally relevant calcium, iron, zinc, copper and manganese. From a cardiovascular nutrition perspective, potassium and magnesium are particularly important because of their roles in cardiovascular physiology and blood-pressure regulation, while zinc, copper, manganese and selenium participate in antioxidant and enzymatic pathways. However, the cardiovascular relevance of sunflower seeds should be understood as the combined contribution of minerals, unsaturated fatty acids, fiber, vitamin E, phytosterols and other bioactive compounds rather than the effect of any single element.

Further studies should investigate the bioavailability and synergistic effects of the mineral elements and bioactive compounds in sunflower seeds, particularly their combined role in cardiovascular health. Clinical and dietary studies are also needed to validate their potential cardiovascular benefits.

5. Declaration of Competing Interest

The author declare no conflict of interest.

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