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Elemental Analysis of Pulses, Spices and Condiments Associated Health Risk

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ABSTRACT

The high rates of industrial growth and rapid urbanization have played role to high level of heavy metals accumulation in soils. Agricultural crops absorb these contaminants, which can be harmful to humans based on the different dietary habits in various parts of the world. The current research evaluated the possible health impact on individual that consume dried legumes in a developing country of small islands that relies on imports of these harvests from large producers. The content of the selected heavy metals, such as Cu, Fe, Si, Mn, Ni, Mg, Ca, Al, Co, Na, Cl, S, C, O, N, K, and B were found in different concentrations in all the analyzed samples was only present in certain legumes. Cu, Fe, Si, Mn, Ni, Mg, Ca, Al, Co, Na, Cl, S, C, O, N, K, and B concentrations ranged from 0.05-1.01, 0.02-0.30, 0.01-1.15, 0.03-0.14, 93, 0.12-0.83, 0.15-2.94, 0.19-0.46, 0.07, 0.01, 0.01-0.87, 0.03-1.08, 39.24-61.65, 34.72-50, 0.60-2.44, 0.52-5.36, and 0.50-1.74 mg/Kg respectively. The concentrations level of Zn, Mn, Cu, and Ni, were found below from World Health Organization (WHO) maximum permissible limit (MPL) level, target hazard quotient (THQ) and the hazard index (HI) values across all the samples, indicating non-carcinogenic risk to consumers.

INTRODUCTION

Heavy metals are commonly found in the both natural and human-made environment and can be deposited in the water, soil, and plants and other components of the environment and therefore they are dangerous to the health of human and well-being [1]. They are recognized as an important contaminants of the international food web, and are becoming a main environmental issue in developing countries. Being non-biodegradable, with long biological half-lives, and having a tendency to bio-accumulate in various human organs, heavy metals have the can cause adverse physiological effects [2]. However the sources of heavy metal exposure are not clearly described, but dietary intake has been considered the main route, with over 90% of the overall exposure accounted by diet, while inhalation and contact with the skin are considered a secondary routes [3]. One significant environmental pollutant is the heavy metals which can have serious impact on human health when it accumulates excessively in foods [4]. These components are naturally occurring and are also emitted into the ecosystems by different man-made activities related to development and industrial processes [5]. Unlike other pollutants, heavy metals are persistent, non-biodegradable and can become accumulative along the food chain, which make heavy metal more hazardous to human health. The exposure can occur mainly via dietary consumption, but inhalation and dermal absorption are also the possible routes. The occurrence of metals in food is different according to sources and routes of contamination, describe as extrinsic and intrinsic factors [6]. Due to their toxicity, excessive levels of heavy metals can cause serious biochemical imbalances in living organisms and cause various acute and chronic health problems, such as polycythemia, kidney dysfunction, cognitive impairment, bone fragility, respiratory disorders, cardiovascular complications, asthma, and various kinds of cancer [7]. Too much utilizations of the fungicides and pesticides chemicals, and growing industrialization rank high amongst the causes of heavy metals accumulation in soils which lead to biological and chemical changes that adversely affect the plant growth, seed germination, and the overall yield of crops. In order to reduce these adverse effects, applying useful microorganisms with multiple growth promoting and stress-resistance properties has become an environmental friendly alternative to synthetic approaches, which also contributes to sustainable agricultural applications [8]. As toxic metals have been considered as major pollutants in the human food chain where these toxic metal build up in specific tissues, their accumulation cause detrimental physiological effects. Some of these metals, such as mercury, cadmium, lead, and arsenic, are highly toxic at very low levels and are non-essential biologically. However, trace minerals like potassium, copper, zinc, and magnesium are important micronutrients and serve as co-factors in enzyme-mediated reactions that promote immunity and cell repair. However, even these metal can cause harmful health consequences when taken in large amounts [9]. Determination of sources and concentration level of heavy metals in food is an important aspect of analytical chemistry. Most countries have a high consumption of cereals, pulses, spices their products. Therefore various studies were concentrated on establishing the trace heavy metals' levels food products that are consumed in high quantities [10]. The pulses has a importance role in ensuring the security of food and nutrition, and improving the fertility of soils, therefore, it is very important to deal with future challenges of global food supply, nutrition, and need of environmental sustainability. Pulse cultivation has brought benefits to farmers by offering both high income potential and less risk due to crop and income diversification. In addition to the ecological advantage of using pulses as a part of crop rotations, their production also provides social and nutritional benefits by meeting the need of protein in diets, decreasing soil degradation, and increasing food production [10]. Pulses, as the legumes of grain, are especially significant in human diet as well as in enriching soils by biological fixation of nitrogen. They are also a significant source of dietary protein that provides 20-25% energy as protein by weight which is 2-3 times higher than staple grains such as rice and wheat. Pulses are a crucial source of energy and protein to millions of people, particularly those that depend on plant-based diets due to economic or cultural factors [11]. Spices are widely used in food and medicines in the entire world. However, researcher has shown that some of the natural spices like pepper and mustard contain significant levels of heavy metals [12]. Spices are essential components in almost every cuisine in the world because they are used to add flavor, palatability, color, and texture [13]. This is one of the critical areas in analytical chemistry because it monitors food sources and heavy metals concentrations. Pulses, spices, cereals, and their by-products are widely eaten locally and internationally, and as a result, researchers across the globe have examined the trace heavy metal content [14]. ED-XRF is one of the fastest, non-destructive, and user-friendly methods of multi-elemental analysis. It has been extensively used in other domains, such as in forensic research, cement manufacturing, mining, archaeology, geology, and food science. ED-XRF does not need multiple sample digestions and frequent calibrations on standard solutions, unlike traditional atomic spectroscopy techniques, which are time consuming, labor intensive, and slow. Moreover, ED-XRF is a sustainable and green technology which ensures reliable multi-element detection and makes the data for analysis efficiently [15].

MATERIALS AND METHOD

Collection of Samples

The Samples were purchased from Local market district Peshawar, KP, Pakistan. The Samples were washed, cleaned and chopped into pieces and dried at 40 °C in thermostatically controlled oven until they attained a constant weight. The samples were then crushed into powder, using mechanical grinding machine, so as to enhance effective contact of solvent with sites on the plant materials.

Energy dispersive X-ray fluorescence (ED-XRF) analysis

The prepared samples of spices, pulses, and condiments were taken to the Centralized Resource Laboratory (CRL) of the University of Peshawar for analysis. Quantification of elements was carried out on an energy-dispersive X-ray fluorescence spectrometer (EDX-7000, Na-U, and Shimadzu, Japan) using loose powder method and the used standard was Al-Cu. Each sample of powdered material of paddy soil, marble, and rice plants (1 gram) in triplicate was placed on a thin film manufactured with polypropylene inside a 10 mL polypropylene cup and then inserted into the EDX-7000 system. The spectrometer was equipped with Rhodium (Rh) target X-ray tube and high-resolution silicon drift detector (SDD) which was run by PCEDX-Navi software at a maximum 50 kV and 1000 mA. The measurements were conducted in air-base environment and the elemental composition was done by a 10mm collimator with 60s of acquisition time [16].

RESULTS

Cu, Fe, Si, Mn, Ni, Mg, Ca, Al, Co, Na, Cl, S, C, O, N, K, and B were found in different concentrations in all the analyzed samples. Cu, Fe, Si, Mn, Ni, Mg, Ca, Al, Co, Na, Cl, S, C, O, N, K, and B concentrations ranged from 0.05-1.01, 0.02-0.30, 0.01-1.15, 0.03-0.14, 93, 0.12-0.83, 0.15-2.94, 0.19-0.46, 0.07, 0.01, 0.01-0.87, 0.03-1.08, 39.24-61.65, 34.72-50, 0.60-2.44, 0.52-5.36, and 0.50-1.74 mg/Kg respectively.

Figure 1

Pearson Correlation among macro nutrients

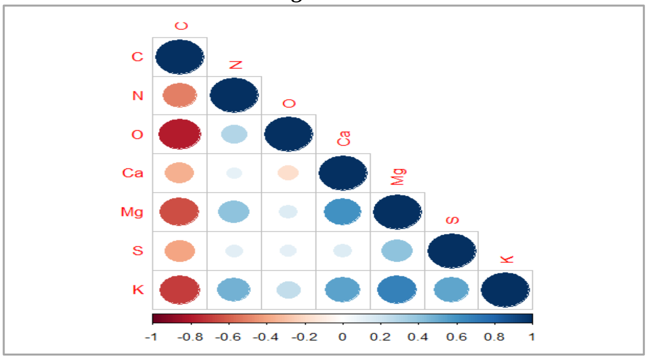

Figure 2

Pearson correlation among micro nutrients

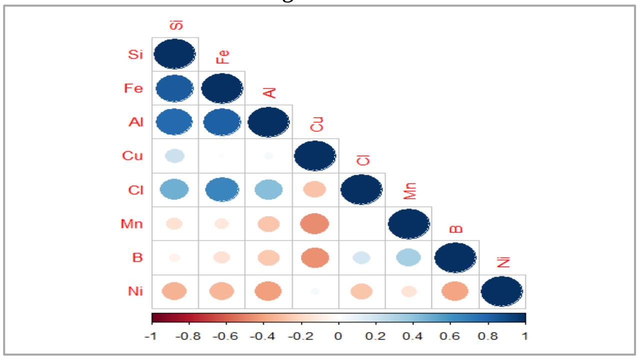

Table 1
Elemental Analysis of Pulses, Spices and Crodomints

S.No	Samples	Ca	S	K	Si	Mg	Fe	Al	Cu	Cl	Mn	B	C	N	O	Ni
1	*Saigon cinnamon*	1.64	0.33	3.40	0.39	0.75	0.14	0.19	0.23	0.72	-	0.50	43.90	1.66	45.60	0.01
2	*Curcuma longa*	-	1.08	3.69	0.29	0.53	-	-	0.09	0.16	-	1.74	43.98	1.44	46.81	-
3	*Piper nigurm*	-	0.03	2.88	0.09	0.50	0.06	-	-	0.31	0.05	0.16	48.95	1.57	45.17	0.02
4	*Amonum subulatum*	-	-	2.28	0.37	0.38	0.07	-	0.05	0.21	0.14	1.22	43.12	1.15	50.93	-
5	*Myristica fragrans*	0.32	-	0.62	0.04	0.15	0.08	-	0.43	0.05	-	0.88	61.65	0.60	34.72	-
6	*Trigonella foenum graecum*	0.62	0.03	1.01	0.16	0.14	0.08	-	0.15	0.01	0.03	0.90	56.48	1.00	39.33	0.02
7	*Rabdosia rugosa*	0.92	-	0.52	0.95	0.25	0.21	0.46	0.68	0.00	-	-	48.48	0.73	46.64	-
8	*Cinnamomum zeylanicum breyn*	1.33	0.22	2.98	0.23	0.40	0.02	-	0.65	-	-	-	46.25	1.51	46.17	0.02
9	*Cinnamomum tamala*	2.94	0.25	5.36	1.15	0.83	0.30	0.29	0.69	0.52	-	-	39.24	2.01	45.63	-
10	*Cumrnun cyminim L.*	2.29	0.35	1.79	1.04	0.72	0.26	0.34	0.21	0.87	-	1.01	46.77	1.10	42.54	-
11	*Lens culinaris*	-	0.13	1.09	0.01	0.16	-	-	1'01	0.05	-	0.29	49.15	-	47.55	-
12	*Vigna aconitifolia*	-	0.13	2.03	0.29	0.24	0.05	-	0.64	0.07	-	-	46.63	2.44	46.44	0.07
13	*Macrotyloma uniflorum*	-	0.09	1.19	0.80	0.76	0.05	-	0.85	0.07	-	0.63	45.90	1.98	46.81	0.02
14	*Vigna aconitifolia*	0.15	0.07	0.91	0.50	0.16	0.09	0.32	0.20	0.07	-	-	48.36	1.58	47.46	-
15	*Phaseolus vulgaris*	-	0.04	1.36	0.04	0.12	0.04	-	0.27	0.04	-	-	48.48	1.82	47.58	0.07

The elemental analysis of selected pulses and condiments revealed the presence of both macro- and microelements in varying concentrations. Among the macronutrients, calcium (Ca) content ranged from 0.15 to 2.94mg/kg, showed maximum amount in *Cinnamomum tamala* and the minimum in *Vigna aconitifolia*. Potassium (K), an essential electrolyte, was found in all samples (0.52–5.36 mg/kg), with *Cinnamomum tamala* again exhibiting the highest levels. Magnesium (Mg) ranged between 0.12 and 0.83 mg/kg, showing maximum values in *Cinnamomum tamala*. Sulfur (S) was most abundant in *Curcuma longa* (1.08 mg/kg), indicating its importance in sulfur-containing phytochemicals such as curcuminoids. Silicon (Si) varied from 0.01 to 1.15 mg/kg, the maximum being in *Cinnamomum tamala*.

Trace elements were also detected, with iron (Fe) between 0.02 to 0.30 mg/kg, copper (Cu) from 0.05 to 1.01 mg/kg, and manganese (Mn) from 0.03 to 0.14 mg/kg. Notably, *Lens culinaris* exhibited the maximum Cu concentration (1.01 mg/kg), while *Amomum subulatum* contained the highest Mn (0.14 mg/kg). Boron (B), an essential micronutrient for metabolic regulation, showed considerable variation (0.50–1.74 mg/kg), being most abundant in *Curcuma longa*. Aluminum (Al), a non-essential element with potential toxicity, was identified in all samples (0.19–0.46 mg/kg), with the utmost concentration in *Rabdosia rugosa*. Nickel (Ni) was found only in limited samples such as *Piper nigrum*, *Vigna aconitifolia*, and *Phaseolus vulgaris*, with concentrations between 0.01–0.07 mg/kg. Cobalt (Co) was not broadly detected, but *Piper nigrum* showed traces (0.02 mg/kg).

In addition to minerals, organic elemental composition dominated, with carbon (C) ranging from 39.24% (*Cinnamomum tamala*) to 61.65% (*Myristica fragrans*), nitrogen (N) from 0.60–2.44%, and oxygen (O) between 34.72–50.93%. These findings highlight that pulses such as *Lens culinaris*, *Phaseolus vulgaris*, and *Vigna aconitifolia* are rich in proteins (due to higher nitrogen content) and carbohydrates (reflected in carbon and oxygen), whereas condiments like *Cinnamomum tamala* and *Curcuma longa* are richer in mineral diversity. The results collectively suggest that both pulses and condiments serve as essential dietary sources of macro- and microelements, although the occurrence of non-essential metals such as Al and Ni necessitates monitoring to avoid potential health risks.

The table 1 shows the elemental analysis of various pulses, spices, and condiments, including the concentrations of essential macro-elements (Ca, K, Mg, S, Si) and trace/heavy elements (Fe, Al, Cu, Ni, Mn, Cl, B) along with major organic elements (C, N, O). According to the World Health Organization (WHO) and FAO guidelines, essential elements such as calcium, potassium, magnesium, and iron are beneficial when present in moderate amounts, as they are required for normal physiological functions. Fe levels reported in the samples (0.05–0.36%) are within acceptable ranges for plant-derived foods and contribute positively to dietary intake. Similarly, Ca (0.32–3.36%) and K (0.93–4.08%) are in safe limits and support bone health and electrolyte balance. Trace elements like Cu (0.09–0.85%) and Mn (up to 0.29%) are present in permissible concentrations, as WHO limits Cu intake to <10 mg/day and Mn to <12 mg/day through food sources. Importantly, potentially toxic elements such as Ni and Al are detected only in trace amounts (Ni up to 0.07%, Al up to 0.40%), which remain within WHO safety limits (Ni <1.5 mg/day, Al <2 mg/kg body weight/day). The absence of highly toxic heavy metals such as Pb, Cd, Hg, and As in this dataset is notable, further confirming that these samples are safe for consumption. Thus, the elemental concentrations reported in the table fall within the WHO permissible limits and indicate that these spices, pulses, and condiments are safe dietary sources of both macro- and micro-elements [17, 18, 19].

Authors' contributions

Muhammad Adnan[1]* and Muhammad Idrees[1]* contributed to the conceptualization, study design, and supervision of the research. Fahad Zada[1] & Muhammad Anis[1] carried out the experimental work and data collection & assisted in data analysis, interpretation, and validation & contributed to the literature review, writing, and editing of the manuscript. All authors read and approved the final manuscript.

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