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THE MINERAL COMPOSITION OF FLAX, CHIA AND HEMP SEEDS BASED ON X-RAY FLUORESCENCE ANALYSIS

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Abstract

Due to the fact that flax seeds contain the highest amount of essential fatty acids from plants, they are increasingly used as a functional food. Chia seeds are an important source of antioxidants that have beneficial effects on the human body. Hemp seeds are recommended for consumption because they are an excellent source of protein, vitamin E and minerals, and contain all the essential amino acids. The aim of this study is to assess the mineral profile of three types of seeds: flax, chia and hemp. The determination of minerals was made by X-Ray Fluorescence Analyzer. The seeds mineral fingerprints were obtained by using PAST and MVSP programs. The results of the analysis of 12 seeds assortments reveal that these are rich in phytonutrients and minerals (K, Ca, Fe, Mn and Zn). Chia seeds stand out for the highest content of calcium (32.26 g/kg dry weight), while hemp seeds have the greatest content of iron (0.88 g/kg dry weight).

***Key words**: superfoods, XRF, nutrients, mathematical model.*

INTRODUCTION

Flax (*Linum usitatissimum* L.), chia (*Salvia hispanica* L.) and hemp (*Cannabis sativa* L.) are known as superfoods due to their nutritional properties (Barsby et al., 2021; Bordean et al., 2021; Montero et al., 2023, Kraska et al., 2016).
Flaxseeds have an exceptional nutritional value because contains α-linolenic acid, proteins, dietary fiber and phytoestrogens, therefore are used in food industry for obtaining functional foods as breads, cakes, cereal bars (Bhardwaj et al., 2020; Katare et al., 2012; Khalifa et al., 2011).
Chia seeds contains high amounts of ω-3 fatty acids, dietary fibre, gluten free proteins, vitamins, minerals polyphenolic compounds (i.e., gallic and p-coumaric acids), quercetin, kaempferol and antioxidants (da Silva et al., 2017; Ullah et al., 2016).
Cannabis sativa L. is a species in which the level of tetrahydrocannabinol (THC) is very low. EU regulations are limiting the amount of THC in hemp.
The area cultivated with hemp has increased in EU from 20.5 ha in 2015 to 33 ha in 2022 (an increase of 60%). Hemp seeds are an excellent source of protein with good digestibility, vitamin E and minerals, and contain all the essential amino acids (Żuk-Gołaszewska et al., 2018).
Hemp seeds, which are also exceptionally nutritious, are rich in three polyunsaturated fatty acids: alpha-linolenic acid, linoleic acid, and gamma-linolenic acid (Montero et al., 2023).
Hemp is also a good source of antioxidants (bioactive peptides) and phytochemicals (polyphenols and sterols) that are useful in supporting health (Rizzo et al., 2023).
Minerals are essential for the correct functioning of the body, most of them being involved in metabolism, the balance of water in the body and the health of the bone system. All three types of seeds are recognized for their high potassium and calcium content (Barsby et al., 2021).
The aim of this study is to assess the mineral profile of these three types of seeds, using the XRF spectroscopy.
Energy dispersive X-ray fluorescence, called XRF, is a fast, non-destructive method of measuring the elemental composition of a material.

MATERIALS AND METHODS

The study was performed on 12 types of seeds available on the Romanian market, four assortments of each type of seeds:

- flax (S1-S4);
- hemp (S5-S8);
- chia (S9-S12).

In our study we used the nutritional parameters (lipids, carbohydrates, proteins, fibers) mentioned on the labels of the seeds assortments.

Determination of samples mineral profiles was made by X-Ray Fluorescence using Hitachi X-MET8000 portable Spectrometer.

In order to analyze the mineral content, the samples were dried until constant weight, and then grounded.

The results are expressed in ppm (mg/kg dry weight).

The graphical fingerprints of the seeds based on mineral composition were obtained using PAST (Hammer et al., 2001) and MVSP programs.

RESULTS AND DISCUSSIONS

In Table 1 are presented the nutritional parameters of seeds samples, as they are mentioned on the products labels, expressed in g/100 g product.

Lipids content is high for all seed samples ranging between 30.2-50 g/100 g.

The protein highest content corresponds to the S8 sample (hemp seeds) (34.0 g/100 g) and the lowest to the S3 sample (flax seeds) (15.2 g/100 g).

Table 1. Nutritional parameter of seeds samples

Seeds samples	Lipids (g/100 g)	Carbohydrates (g/100 g)	Proteins (g/100 g)	Fibers (g/100 g)
S1	42.0	29	18	24.2
S2	42.1	1.5	18.2	27.3
S3	41.0	10.4	15.2	26.9
S4	30.9	0.0	24.4	38.6
S5	50.0	4.7	30.0	7.75
S6	30.2	3.4	20.0	33.9
S7	41.0	11.0	30.0	9.3
S8	48.0	3.1	34.0	6.0
S9	31.0	5.0	20.0	36.0
S10	31.0	42.0	17.0	34.0
S11	31.1	4.9	20.4	31.8
S12	30.8	43.8	15.6	37.7

The highest value of the fibers content corresponds to the S4 assortment (flax seeds) (38.6 g/100 g) and the lowest to the S8 assortment (hemp seeds) (6.0 g/100 g).

All the seeds taken in our study have high nutritional values due to the fact that they are rich in proteins and fibers (Table 1).

In Table 2 are presented literature data regarding flax, hemp and chia seeds minerals content.

Table 2. Mineral's content of seeds (Literature data)

Element	Flax seeds (Range)	Hemp seeds (Range)	Chia seeds (Range)
K (g/kg)	5.8 - 19.2 (Kluza-Wieloch et al., 2020) (Khan et al., 2010)	4.63 - 28.2 (Mihoc et al., 2012)	4.07 - 7.67 (Kulczyński et al., 2019) (Barsby et al., 2021)
Ca (g/kg)	1.38 - 2.36 (Barsby et al., 2021) (Katare et al., 2012)	0.7 - 9.55 (USDA, 2016) (Mihoc et al., 2012)	4.56 - 6.71 (Kulczyński et al., 2019) (Vera-Cespedes et al, 2023)
Fe (g/kg)	0.02 - 0.24 (Kraska et al., 2016) (Khalifa et al., 2011)	0.001- 2.4 (Callaway et al., 2004) (Mihoc et al., 2012)	0.07 - 0.145 (USDA, 2016) (Barsby et al., 2021)
Mn (g/kg)	0.015 - 0.04 (Kluza-Wieloch et al., 2020) (Kraska et al., 2016)	0.06 - 0.11 (Mihoc et al., 2012)	0.027 - 0.059 (Kulczyński et al., 2019) (Vera-Cespedes et al., 2023)
Zn (mg/kg)	43.7 - 78 (Barsby et al., 2021) (Kluza-Wieloch et al., 2020)	42 - 94 (Mihoc et al, 2012)	46 - 52 (Kulczyński et al., 2019) (Vera-Cespedes et al., 2023)
Cu (mg/kg)	2.31 - 25.6 (Khan et al., 2010) (Kluza-Wieloch et al., 2020)	10 -12.2 (Mihoc et al., 2012) (Barsby et al., 2021)	9 - 17.7 (Kulczyński et al., 2019) (Barsby et al., 2021)
Ni (mg/kg)	1.2 (Barsby et al., 2021)	53.2 (Barsby et al., 2021)	1.8 (Barsby et al., 2021)

In Table 3 are presented the minerals content of flax, hemp and chia seeds, analyzed in the laboratory by FRX method.

We observe that chia seeds stand out for the highest calcium content (32.26 g/kg dry weight) and hemp seeds for the highest iron content (0.88 g/kg dry weight).

Table 3. Mineral content of seeds analyzed in the laboratory

Element	Flax	Hemp	Chia
	Range	Range	Range
K (g/kg)	26.3 - 35.9	26.57 - 36.67	21.85 - 27.25
Ca (g/kg)	8.85 - 11.7	2.79 -3.9	23.71 - 32.26
Fe (g/kg)	0.49 - 0.64	0.67 - 0.88	0.46 - 0.52
Mn (g/kg)	0.12 - 0.22	0.4 - 0.46	0.38 - 0.55
Ba (g/kg)	0.122 - 0.13	0 - 0.15	0 - 0.158
Zn (g/kg)	0.215 - 0.27	0.23 - 0.45	0.16 - 0.25
Sr (mg/kg)	12 - 23	0 - 40	65 - 137
Cu (mg/kg)	74 - 86	62 - 88	74 - 94
Rb (mg/kg)	8 - 14	7 - 26	22 - 43
Ni (mg/kg)	0 - 23	0 - 23	0 - 27

Correlation between experimental laboratory and literature data

Using the average data of the mineral content presented in Tables 2 and 3 and applying linear correlation r, we can observe that the literature data show a strong positive correlation with the laboratory data for flax seeds (0.92522) and chia seeds (0.87914) and a positive low correlation for hemp seeds.

Figures 1, 2 and 3 show the correlation between the mineral content quantified in laboratory for flax, hemp and chia seeds and the literature data.

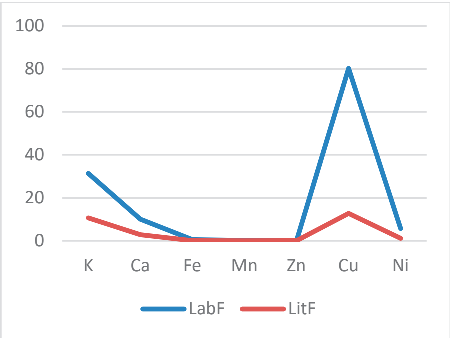

Figure 1. Graphical representation of values of flax seeds mineral contents obtained in the laboratory and those available in literature

(Legend: LabF = Flax mineral content analysed in the lab; LitF = Literature data for flax seed mineral content)

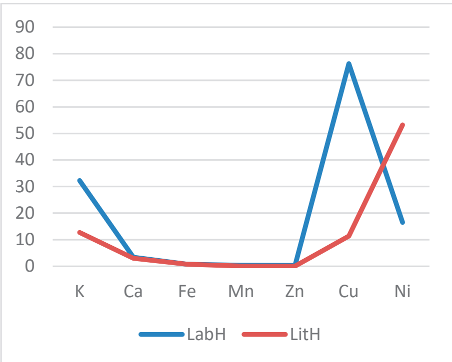

Figure 2. Graphical representation of values of hemp seeds mineral contents obtained in the laboratory and those available in literature

(Legend: LabH = Hemp mineral content analysed in the lab; LitH = Literature data for hemp seed mineral content)

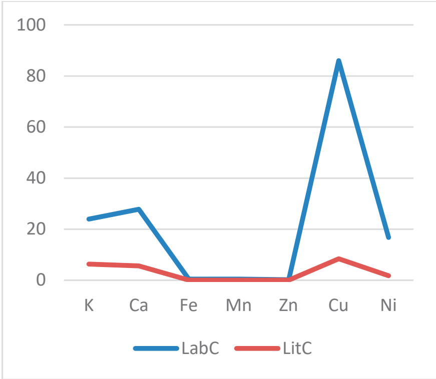

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Figure 3. Graphical representation of values of chia seeds mineral contents obtained in the laboratory and those available in literature

(Legend: LabC = Chia mineral content analysed in the lab; LitC = Literature data for chia seed mineral content)

The Figure 4 provides a graphical representation of how the data points (in this case, the seed samples) are grouped into clusters based on their similarities.

If we apply the Cluster analysis based on Paired group algorithm and correlation as similarity measure, we observe that the correlation coefficient is high (0.8633).

The correlation coefficient indicates the strength and direction of the relationship between the variables being compared. A high correlation coefficient suggests a strong positive linear relationship between the paired groups.

Based on the formed clusters chia seeds (green, S9-S12) presents a different profile compared to hemp (blue, S5-S8) and flax (red, S1-S4) (Figure 4).

This observation suggests that there are significant differences between the characteristics or attributes of these seed types. Based on the results we can observe that chia seeds have distinct characteristics that set them apart from both hemp and flax seeds.

This could be valuable information for further research, product development, or market positioning in areas such as nutrition, agriculture, or food science.

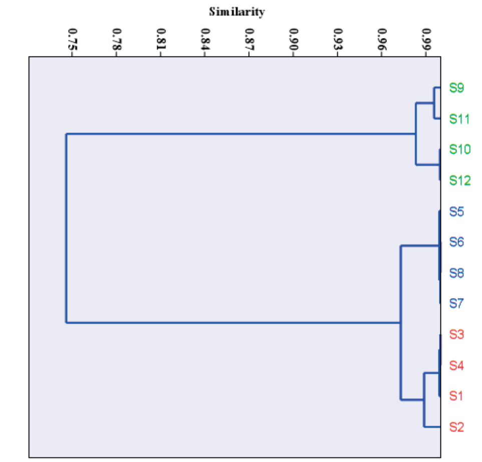

Figure 4. Cluster analysis

Legend: red color = Flax seeds (S1-S4), blue color = hemp seeds (S5-S8), green color = chia seeds (S9-S12)

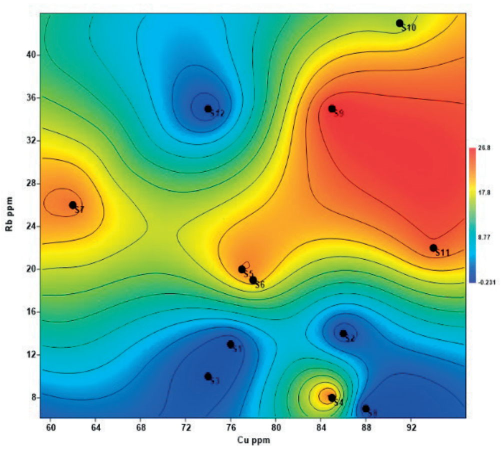

Figure 5. The spatial interpolation

Legend: Flax seeds (S1-S4), Hemp seeds (S5-S8), Chia seeds (S9-S12)

The spatial interpolation is presented in Figure 5. The rubidium content is highest in chia seeds, and based on the spatial interpolation, we can group the samples after the geographical origin criteria.

So, the first group with the assumed same origin is formed by S4, S5, S6, S7 samples; the second group by S1, S2, S3, S8, S12 samples and the third group by S9 and S11 samples, which is correlated with the origins of seed samples mentioned on the labels. This suggests that the samples within each group share similarities in terms of their origin or characteristics that led to their clustering together. Figure 5 provides a visual representation of the spatial distribution of the seed samples, allowing for a better understanding of their geographical patterns and relationships based on the clustering analysis results.

Figure 6 shows a graphical representation of a General Linear Model (GLM) applied to pairs of minerals: potassium (K) and calcium (Ca), strontium (Sr) and manganese (Mn), and copper (Cu) and rubidium (Rb) and provides insights into the relationships between different mineral pairs (potassium and calcium, strontium and manganese, copper and rubidium) across various seed types, highlighting potential patterns or interactions in mineral uptake or utilization within the seeds.

Potassium (K) and Calcium (Ca) Relationship: the observation suggests an inverse relationship between potassium (K) and calcium (Ca) content, particularly noticeable in chia seeds. As the potassium content increases, the calcium content decreases. The trend is more prominent in chia seeds compared to other seed types (flax and hemp). This inverse relationship suggests that there might be some form of competition or antagonistic interaction between potassium and calcium uptake or utilization in the seeds, leading to a negative correlation between their concentrations.

Strontium (Sr) and Manganese (Mn) Relationship: the observation indicates a positive relationship between strontium (Sr) and manganese (Mn) content in chia and hemp seeds. As the content of strontium increases, the content of manganese also increases for these seed types. This trend is not observed in flax seeds, signifying that the relationship between strontium and manganese may vary among different seed types. The positive correlation between strontium and manganese suggests a potential association or similar uptake mechanisms for these minerals in chia and hemp seeds.

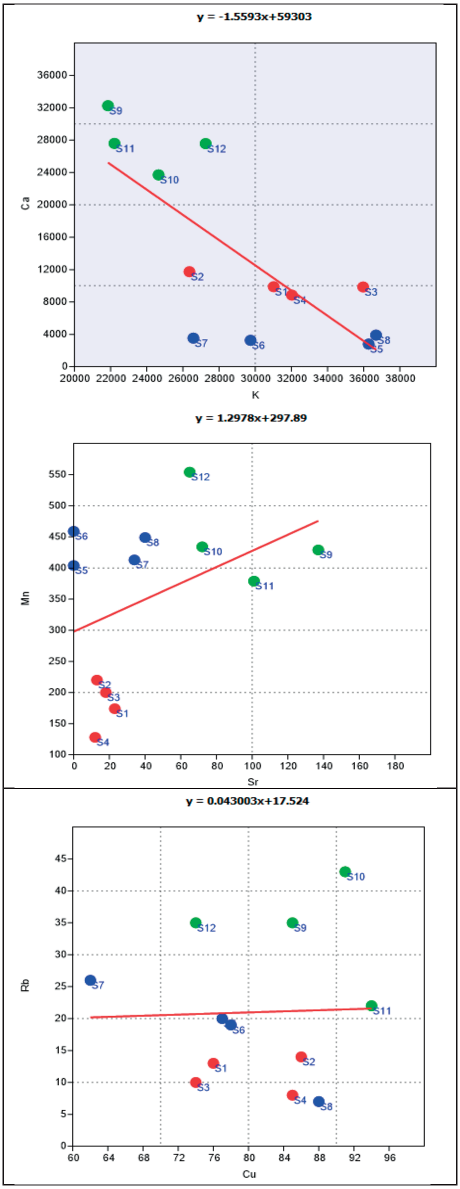

Figure 6. Representation of GLM (General linear model for K and Ca, Sr and Mn, Cu and Rb)

Legend: Red color = Flax seeds (S1-S4), Blue color = hemp seeds (S5-S8), green color = chia seeds (S9-S12)

Copper (Cu) and Rubidium (Rb) Relationship: the observation notes a slight increase in rubidium (Rb) content with increasing copper (Cu) content for all types of seeds. This suggests a positive correlation between copper and rubidium content across all seed types (flax, hemp, and chia). The slight increase in rubidium content with increasing copper content indicates a potential relationship or shared uptake pathways between these two minerals in the seeds.

Due to the various content of minerals of the investigated seeds, we have tried to identify the percent of minerals in case of associating different quantities of seeds (Figure 7).

Each seed type contributes varying amounts of minerals, and understanding these contributions can help in creating seed mixtures tailored to specific mineral needs.

Figure 7 visually represents the contribution of minerals from different seed mixtures and provides valuable information for consumers to make informed choices about seed mixtures based on their specific mineral needs, utilizing the unique mineral contributions of each seed type. It shows the percentage or proportion of various minerals contributed by each type of seed in different seed mixtures. The information suggests that consumers can choose seed mixtures based on their desired mineral content. For example: If a consumer needs a high content of potassium, they can choose a seed mixture with specific proportions of flax, hemp, and chia seeds to meet their requirements. Similarly, if they require a high content of manganese, they can select a different seed mixture with proportions adjusted to provide the desired mineral content.

Example Mixtures: for a high potassium content: a mixture consisting of 35% flax seeds, 37% hemp seeds, and 28% chia seeds. For a high manganese content: a mixture consisting of 15% flax seeds, 42% hemp seeds, and 43% chia seeds.

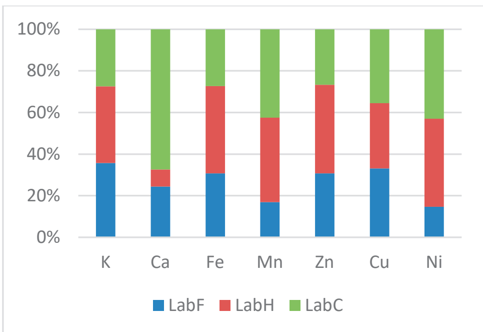

Figure 7. Contribution of minerals while using a seed mixture (Compositional mineral fingerprint)

(Legend: LabF = Flax mineral content analyzed in the lab; LabH = Hemp mineral content analyzed in the lab; LabC = Chia mineral content analyzed in the lab)

CONCLUSIONS

Our determinations using using the XRF spectroscopy revealed that chia seeds registered the highest content of calcium while hemp seeds have the greatest content of iron, observation being in accordance with the studies from literature data. But, using this method for minerals analysis we found higher quantities of K, Ca and Cu than those reported in other studies.

The observed relationships between minerals (such as K and Ca, Sr and Mn, Cu and Rb) differ across different seed types (flax, hemp, and chia). This suggests that the interactions between minerals may be influenced by the specific characteristics or properties of each seed type, including genetic factors, growth conditions, and metabolic processes.

The observed mineral interactions may have implications for agricultural practices and plant nutrition management. Farmers and agricultural researchers could explore ways to optimize mineral uptake and balance in seed crops through soil management practices, fertilization strategies, and crop breeding programs.

The observed mineral relationships could inform food formulation and nutritional strategies. Food manufacturers and nutritionists may leverage this information to develop seed-based products with optimized mineral profiles to meet specific dietary requirements or address nutritional deficiencies.

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