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Minerals bioaccumulation in wheat plants study using X-ray fluorescence

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Abstract :

The study aims to determine the wheat plants' accumulation of minerals from the soil and the translocation of minerals in different parts of the wheat plant: root, stem, leaves, and grains. The sampling campaigns took place at different growing seasons and the plant samples were collected together with the growing soil samples. The concentrations of P, Na, K, Mg, Ca, Mn, Zn, Fe, and Cu were determined by wavelength dispersive X-ray fluorescence spectrometry. The accumulation coefficients of the minerals were calculated.

Keywords: wheat, minerals, WDXRF, bioaccumulation

1. Introduction

For good health, adequate consumption of macronutrients, mineral elements and bioactive compounds is essential which is found in plants [1]. Cereals constitute the major component of the human diet (44 % of the daily intake of Fe, 27 % of Mg, 25 % of Zn and 31 % of Cu [2]. Therefore, the understanding of the determinants of grain mineral concentrations is of major importance to identify remediation techniques for soil and plant nutrition.

Wheat is one of the most important cereal crops in the world. The consumption of wheat is increasing globally, including in countries with climates that are not suitable for wheat production [3].The economic importance of wheat and its contribution to the diets of humans and livestock cannot be disputed. It is source of starch and energy, contains significant amounts also provides substantial amounts of components which are essential and beneficial for health, notably protein, vitamins (notably B vitamins), lipids, minerals, dietary fiber, and phytochemicals [3].

Wheat is one of the most important cereal crops in the world as it is used in the production of a diverse range of traditional and modern processed foods [4].

Mineral elements are inorganic substances, present in all body tissues and fluids and are involved in wide variety of metabolic and physiological processes, whose proper functioning requires the supply of well-defined amounts [1].

Minerals are important components required by humans in their daily food. Minerals are divided into two groups: (i) macro minerals, which are needed in large amounts, e.g., calcium (Ca), magnesium (Mg) and potassium (K), etc., and (ii) micro minerals or trace elements, which are required in smaller quantities, e.g., copper (Cu), zinc (Zn), iron (Fe), boron (B), selenium (Se) [5]. All body processes depend upon the action of minerals to activate enzymes performing metabolic functions. Deficiency of specific minerals may lead to various chronic diseases [6,7] .Due to the high consumption of wheat in a variety of food products all over the world, wheat is considered an important source of minerals [8] .The concentration of minerals in wheat flour is genetically determined by the choice of cultivar and environmentally determined by soil, climate and management practices [9]. Concentration of minerals in wheat products can be increased by using whole grain flour instead of white flour. Also, suitable conditions together with selection of wheat cultivars that have a high mineral concentration, can be used to promote high mineral bioavailability [10] (Lopez et al. 2003). Mineral concentration variability in cultivars has been studied by several authors using wheat grown in inorganic systems [11, 12]. New techniques present today, allow investigations of a much higher number of minerals, as well as better accuracy as compared to the majority of the above mentioned studies. The amount of different minerals in the grain depends on the levels transported by roots during grain development and amount redistributed to the grain by vegetative tissue through the phloem [13]. Photosynthetic activity of vegetative tissue is an important factor in determining grain mineral concentration as well as the yield. Different wheat genotypes vary in photosynthesis and chlorophyll concentration [14] Correlation between the chlorophyll and Fe concentration was reported by [15]. They found that higher chlorophyll content at final grain filling increased the amount of Fe in the grain . Carbon dioxide enrichment was found to inhibit the assimilation of nitrate to organic nitrogen compounds. Low availability of nitrogen lead to reduced photosynthesis in wheat plant, also negatively affecting the grain quality for example, mineral concentration [16].

The objectives of the present research were to study: 1. the mineral composition of the soil; 2. the mineral composition of the wheat plant at different growth stages; 3. the mineral composition of the wheat flour obtained from the studied lot.

2. Materials and Methods

2.1. Study area

The samples analysed in the study come from Geangoești, Dragomirești jud. Dâmbovița, Coordinates: 44° 55' North, 25° 20' East .

Dragomirești area is located in the south-west of Targoviste Municipality at a distance of 10 km from two old capitals of the Romanian Country, namely Targoviste and Câmpulung, and they are situated at an altitude of 300 meters above sea level.

The village is crossed from west to east by the Dâmbovița River, and the component villages are on either side of the river. On the right side as the river flows we have the villages of Decideni, Râncaciov and Ungureni, and on the left Dragomirești, Geangoești and Mogoșești. This locality is located on the border between hills and plains in this area, the relief is mixed, here we find both plain and hilly landforms, but in a smaller proportion.

In terms of its position to the major landforms, Dragomirești village can be placed on the line separating the hills from the plains, namely Ploiești-Târgoviște-Pitești. The settlement is crossed from east to west by two hills running parallel to the Dâmbovița River flowing between them. At certain points the hills also form the boundary of the locality, and their heights descend visibly in this geographical setting. Figure 1 shows the location of samples on the map and the sites from which samples were collected.



Figure 1- Location of the lot in Dragomireşte (Source: ancpi.geoportal.ro)

2.2. Sample collection and processing

The samples of soil and plants were collected at the same time and from the same place. Sampling was carried out in several stages: the first sampling was carried out 3 months after sowing, the second stage 6 months after sowing and the third sampling 9 months after sowing. The minerals content of the samples was determined by Supermini200 X-ray fluorescence X-ray fluorescence spectrometer (WDXRF) - Rigaku (Japan).

Each sample was added in powder form (by grinding in ceramic mill), and 0.5-1 g sample was weighed. These were mixed with 2-2.5 g binder (BOREOX - FLUXANA, C6H10O5). The homogenous mixture was pressed with the TestChem LPR-250 laboratory press with a force of 110kN, producing a 3 g sample pellet, 30 mm in diameter and 3 mm high. Total sample scanning time: 30 min. Detection limit is 1ppm - 10ppb; accuracy <0.1-0.5%.

3. Results

The results of the soil metal content in the Geangoesti area are presented in Table 1.

Table 1- Soil minerals concentration

Mineral (ppm)		Min	Max	Mean	Median	St. dev	Q1	Q2	Q3
P	first sample	0.920	1.181	1.056	1.062	0.143	0.115	0.131	0.143
P	second sample	1.072	1.406	1.228	1.205	0.168	0.135	0.146	0.157
Na	first sample	0.920	1.181	1.056	1.062	0.143	0.939	1.062	1.179
Na	second sample	1.072	1.406	1.228	1.205	0.168	1.139	1.205	1.305
K	first sample	3.478	4.262	3.890	3.904	0.261	3.802	3.904	3.994

K	second sample	3.488	3.768	3.615	3.582	0.113	3.519	3.582	3.726
Mg	first sample	0.909	1.278	1.076	1.048	0.135	0.984	1.048	1.171
Mg	second sample	0.947	1.505	1.229	1.267	0.203	1.081	1.267	1.376
Ca	first sample	1.074	2.038	1.382	1.286	0.326	1.164	1.286	1.438
Ca	second sample	1.101	2.107	1.397	1.298	0.332	1.164	1.298	1.434
Mn	first sample	0.201	0.281	0.232	0.217	0.031	0.211	0.217	0.257
Mn	second sample	0.166	0.241	0.210	0.214	0.028	0.201	0.214	0.225
Zn	first sample	0.039	0.052	0.044	0.042	0.006	0.040	0.042	0.046
Zn	second sample	0.030	0.051	0.041	0.043	0.009	0.034	0.043	0.048
Fe	first sample	7.541	10.503	8.576	8.247	1.001	7.987	8.247	9.163
Fe	second sample	7.127	8.836	7.655	7.755	0.543	7.400	7.755	8.058
Cu	first sample	35.000	48.000	41.375	42.000	5.069	36.750	42.000	44.750
Cu	second sample	25.000	50.000	39.000	41.500	8.281	32.750	41.500	44.250

where P- phosphorus, Na- sodium, K- potassium, Mg- magnesium, Ca- calcium, Mn- manganese, Zn- zinc, Fe- iron, Cu- copper

For the minerals analyzed, there was an increase in concentrations at the second sampling for P, Na, Mg, Ca, Cu and a decrease in concentrations for K, Mn, Zn, Fe. The increase in concentrations is due to fertilizer use. The second sampling was carried out after fertilization.

Iron (Fe) is the element directly responsible for the production of chlorophyll in the leaves.Increased chlorophyll concentration leads to increased uptake of the soil metals K, Ca, Mg. The concentration of Fe decreased because the plant absorbed these metals from the soil.

Calcium, potassium and sodium concentrations vary from sample to sample. This is due to the branching process of the wheat plant stem.

The correlation matrix was performed and the values obtained are presented in Table 2.

Table 2 - Correlation coefficient matrix for minerals in the Geangoești soil-area

	P	Na	Mg	K	Ca	Mn	Fe	Zn	Cu
P	1								
Na	-0.63909	1							
Mg	0.086576	-0.06114	1						
K	-0.07305	0.788535	0.121421	1					
Ca	0.092895	0.188751	0.681571	0.754513	1				
Mn	-0.29242	0.474767	0.272655	0.608548	0.609996	1			
Fe	-0.15768	0.65956	0.406609	**0.894126**	**0.887692**	0.754352	1		
Zn	0.136291	0.152184	**0.960935**	**0.894298**	**0.995752**	**0.954625**	**0.971053**	1	
Cu	0.602255	-0.04347	0.274345	0.719562	0.774113	0.349892	0.641415	0.755108	1

There is a very strong correlation between Zn-Mg, Zn-Ca and Zn-Mg strong correlation between Fe-K, Fe-Ca, Zn-K and a moderate correlation between K-Na, Ca-K, Cu-K, Cu-Ca, Cu-Zn. The lowest values of correlation coefficients are obtained for P, Na and Mg relative to the other metals.

To assess the ability of wheat to accumulate minerals from the soil and to translocate them from the root to the aerial part of the plant, the following coefficients were calculated: transfer coefficient (TC) and translocation factor (TF).

The transfer coefficient (TC) (or bioaccumulation factor) is defined as the ratio between the concentration of minerals in the root and their content in the soil (mg/kg) . It provides information about the plant's ability to accumulate minerals from the soil.

If TC >1: the plant accumulates metals

If TC<1: the plant does not absorb metals from the soil.

$$TC = \frac{CR}{Gs} \quad (1)$$

where TC-the transfer coefficient

CR- root metal concentration

Gs - soil metal concentration

In the third month after sowing, when the first harvest was made, the plant was 20-25 cm tall and had 3-4 leaves. As the plant was small, only the soil-plant transfer factor was calculated.

Table 2 - Soil-plant transfer factor. First sampling (ppm)

Sample name	Mineral					
	P	Mg	K	Ca	Mn	Fe
G 4/ S	12.6717	0.7935	6.3999	4.1045	d.s.	0.7570
G 7/ S	9.6021	d.s.	3.8400	1.9194	d.s.	0.8402
G 11/ S	28.8418	1.4224	6.7699	2.8527	d.s.	0.3586
G 7/ S	13.4353	d.s.	5.8889	4.3375	d.s.	0.8443

where d.s. - detected only in soil

Analysing the values of heavy metal concentrations in Table 2 it can be seen that:

- Magnesium is absorbed only by sample G 11/ S
- Aluminium and iron are the metals that the plant does not accumulate
- Phosphorus, potassium and calcium are the elements absorbed by the plant from the soil
- Magnesium was not detected in wheat plant for samples G 7/ S, G 7/ S
- Manganese were not detected in the wheat plant.

The second sampling took place in the sixth month after sowing, when the plant was developed and the spike was formed. For these samples the root-soil transfer factor and the translocation factor in the soil-plant system were calculated.

Transfer factor

Translocation factor (tf) of metals in the soil-plant system
Metal concentrations detected in the root and in different parts of the wheat were used to calculate the translocation factor,
Metal concentrations detected in different parts of the wheat were used to calculate the translocation factor,
The translocation factor was calculated as the ratio of the total metal concentration in the stem, leaves, ear and the metal content in the roots.

$$Tf\ r-t = \frac{Ct}{Cr} \quad (2)$$

where Tf is the root-stem translocation factor
Ct is the metal concentration in the stem
Cr is the metal concentration in the root

$$Tf\ t-f = \frac{Cf}{Ct} \quad (3)$$

where Tf t-f is the stem-to-leaf translocation factor
Cf is the metal concentration in leaves
Cr is the metal concentration in the stem

$$T_{f\ t-s} = \frac{Cs}{C_t} \quad (4)$$

where Tf t-s is the stem-spike translocation factor
Cf is the metal concentration in the spike
Cr is the metal concentration in the stem

Table 4 - Root-stem translocation factor. Second sampling

Sample name	Mineral							
	P	Na	Mg	Al	K	Ca	Mn	Fe
4 T/ R	6.858	d.r.	0.836	0.109	8.339	4.329	d.r.	0.260
6 T/R	9.877	d.r.	0.434	0.035	8.809	3.879	d.r.	0.144
7 T/ R	8.194	d.r.	0.318	0.034	7.749	2.778	d.r.	0.088
10 T/ R	10.799	d.r.	0.279	0.026	7.316	2.579	d.r.	0.066
11 T/ R	7.022	d.r.	0.226	0.063	7.996	4.161	d.r.	0.107
13 T/ R	8.163	d.r.	0.355	0.061	7.487	4.259	d.r.	0.133
16 T/R	7.356	d.r.	0.492	0.113	8.188	2.524	d.r.	0.2291

where d.r. - detected only in the root

Analysing the values in Table 4 it can be seen that:

- The metals Na (sodium) and Mn (manganese) are not detected in the plant stem
- The metals Mg(magnesium), Al(aluminum) and Fe(iron) are not translocated into the stem
- The elements P(phosphorus), Ca(calcium) and K(potassium) are translocated to the stem

Table 5- Stem-to-leaf translocation factor

Sample name	Mineral					
	P	Mg	Al	K	Ca	Fe
6 F/ T	0.881	1.776	4.803	0.520	1.644	3.105
7 F/T	0.618	4.054	12.822	0.338	1.846	9.830
10 F/T	0.720	2.768	3.991	0.735	2.286	3.858
11 F/ T	0.451	3.464	9.216	0.265	1.005	8.329
13 F/ T	0.818	2.384	6.113	0.463	1.435	7.543
16 F/T	0.803	1.447	1.821	0.524	2.169	3.048

The calculated transfer factor values (Table 5) indicate easier translocation for iron, magnesium and aluminium and harder for calcium. Potassium and phosphorus is not translocated to the leaf.

Table 6- Stem-to-spike translocation factor

Sample name	Mineral					
	P	Mg	Al	K	Ca	Fe
1 Sp/ T	1.479	0.430	2.123	0.546	0.412	2.199
4 Sp/T	1.779	0.770	1.082	0.561	0.831	0.793
7 Sp/T	1.697	0.999	3.857	0.627	0.721	3.316
11 Sp/ T	2.502	1.835	1.192	0.727	0.599	2.281

Analyzing the values in Table 6 it can be seen that wheat spike accumulates phosphorus, aluminum and iron in the stem.

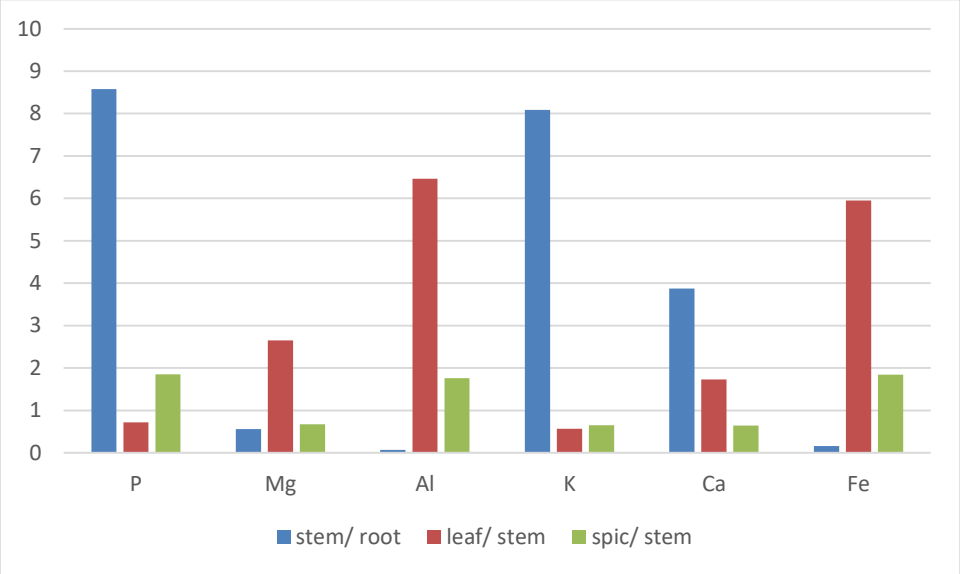


Figure 6-Mean values of translocation factors in the soil-plant system

The diagram in Figure 6 demonstrates that plant components accumulate minerals differently. The plant translocates phosphorus, potassium and calcium from the root to the stem. The calculated transfer factor values indicate an easier translocation of these metals from soil to stem; phosphorus (8.5793), potassium (8.087), calcium (3.873) .

The order of the average values of the root-stem translocation factor is as follows: P>K>Ca>Mg>Fe>Al. It can also be observed that the metals Na, Mn and Zn are blocked by the plant at the root level.

The plant translocates aluminum, iron, magnesium and calcium from stem to leaf.

Potassium, iron and aluminum are translocated from the stem to the spike.

On the assessment of metals in grain wheat

Wheat plays a special role in human nutrition, therefore, the analysis and monitoring of wheat grain quality indicators is a basic trend for the strategy to increase the productivity and quality of wheat crops. Currently, particular attention is being paid to both improving wheat quality.

The concentration of metals in wheat grains is shown in Figure 7. The order of values of metal concentrations in wheat grain is as follows :K>Ca>Mg>Fe>Zn.

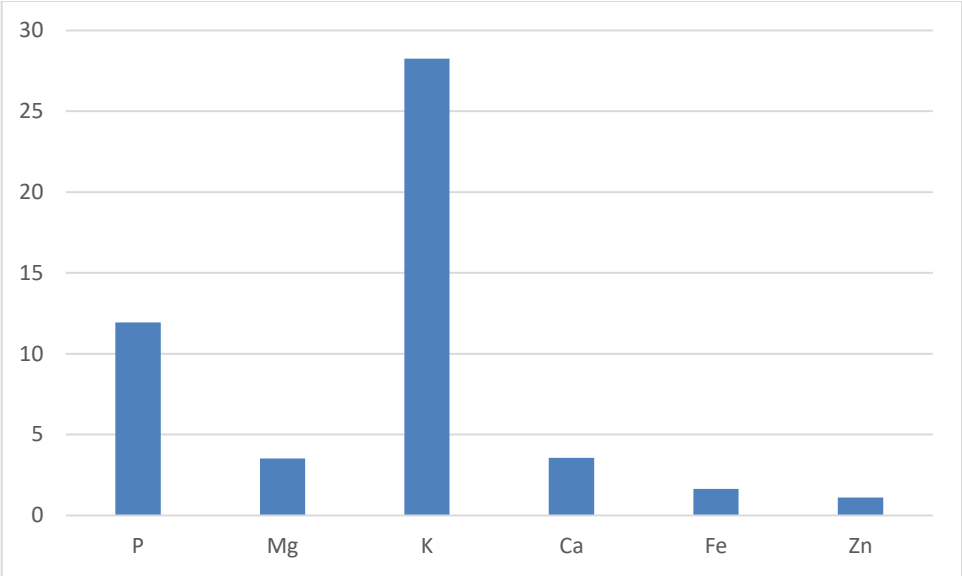


Figure 7- Concentration of minerals in wheat grains (ppm)

4. Discussion

More than three billion population of the world is facing deficiency of minerals. Minerals deficiency results in low working efficiency, high healthcare costs and increased rates of premature death [17]. Population of developing countries is especially at risk, because the people do not have enough money to buy mineral rich food such as meat, poultry, fish, fruits and vegetables. [18]

Many studies have reported that the use of N fertilizers favors the accumulation of nutrients in grains, these nutrients are Ca, Cu, Fe, Fe, K, Mn, N, Ni, P and Zn[19, 20]. Nitrogen can have the positive impact of N on root growth and storage protein synthesis, enhancing the plant's ability to accumulate nutrients in the grain[21,22]. Remarkably, it was observed that significant reductions in Ca, Cu, Fe, Fe, K, Mg, Mn, P and Zn were observed in response to N application[23, 24, 25]. These decreases are due to the fertilization with N increasing grain yield and causing a dilution effect, in which the proportion of starch increases compared to the accumulated nutrients [25]. Jaskulska et al[26] found only slight changes in mineral composition after N application, with a small increase in Ca concentration. In the literature, no single factor, such as pH or organic matter content, could be identified to explain the effects of N fertilization on mineral concentration in wheat grains. It was concluded that the response of wheat grain mineral concentration to N fertilization is highly site-specific and probably influenced by complex interactions between various factors, including environmental conditions, management practices and the specific cultivars used.

Another important factor for nutrient accumulation in wheat grain is water. The majority of studies that have examined the nutrient content of wheat berries have focused on temperate climates and acid to neutral soils, using crops suitable for such conditions [27, 28]. Because of the influence of environment on mineral accumulation in grains, it is essential to increase the number of studies conducted in arid and semi-arid environments . By extending research efforts to fertilizers with different N contents and diversifying the ecological environments, a better understanding of the interactions between environment, fertilization and mineral content can be obtained.

5. Conclusions

From the soil and wheat plant study, it was observed that the mineral concentrations in the plant, wheat spike and wheat flour are influenced by the growing area. The distribution of mineral elements varies widely in different parts of the plant, with most minerals localized in the root of the plant. For determining the accumulation of minerals by the wheat plant, the translocation factor was calculated and it was found that the roots, stem, leaves and spikelets of the wheat plant need different concentrations of minerals to grow.

It was found that the use of fertilizers leads to increase the concentration values of P, Na, Mg and Ca in both soil and wheat plant.

In the first sampling, 6 minerals (P, Mg, Ca, K, Mn, Fe) were detected in the wheat plant, and in the second sampling, 8 minerals (P, Na, Mg, Al, K, Ca, Mn, Fe) were detected in the root of the plant. The fertilizer was also responsible for this. The second harvest was realized after the analyzed lot was fertilized. Increased levels of heavy metals in the soil pose a direct risk of soil pollution and thus affect the plants that absorb them, the animals that consume the plants and humans. Three heavy metals (manganese, zinc and copper) were detected in the soil in the Geangosesti area. The concentration of these heavy metals is below the maximum limit allowed by the legislation in vigor. Only one heavy metal Zn (zinc) was detected in the wheat flour obtained from the lot, with a concentration of 1.09 ppm.

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