POTENTIAL OF MILLED AMARANTH GRAIN PRODUCTS IN PROVIDING FOOD WITH ESSENTIAL MINERAL ELEMENTS
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ПОТЕНЦІАЛ ПРОДУКТІВ ПОМЕЛУ ЗЕРНА АМАРАНТУ У ЗАБЕЗПЕЧЕННІ ХАРЧОВИХ ПРОДУКТІВ ЕСЕНЦІАЛЬНИМИ МІНЕРАЛЬНИМИ ЕЛЕМЕНТАМИ

Svitlana MYKOLENKO[1)], Svitlana SYTNYK[1*)], Tatiana BOJŇANSKÁ[2)], Eva IVANIŠOVÁ [2)], Ivona JANKO[2)], Andrea HRICOVÁ[3)]

[1)] Dnipro State Agrarian and Economic University, Sergiia Yefremova Str. 25, 49600 Dnipro, Ukraine
[2)] Institute of Food Sciences, Slovak University of Agriculture in Nitra, Slovak Republic
[3)] Institute of Plant Genetics and Biotechnology, Nitra, Slovak Republic
Tel: 0989642684; E-mail: svitlana.mykolenko@hest.ethz.ch
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ABSTRACT
Amaranth grain is a promising pseudocereal, and milled amaranth grain products as ingredients may improve the nutritional value of food products. Twenty amaranth products from different Ukrainian varieties such as Kharkivs'kyi-1, Liera, Sem (Amaranthus hypochondriacus L.), Ultra (Amaranthus hybridus L.), and different milled fractions (flour, middling, coarse seed coat, and fine seed coat) were analysed in this study. Amaranth whole grain has 2-3- and 20-fold content of manganese, iron, copper, zinc, and calcium respectively in comparison to wheat. Flour fractions of the amaranth grain presented a reduced content of magnesium, potassium, calcium, manganese, and iron compared to their content in the whole grain. Studied amaranth grain and the milled products of different varieties revealed a significant (p>0.05) positive (0.47…0.90) correlation between all analysed essential minerals, except molybdenum, which demonstrated 0.46…0.56 correlations with calcium, zinc, potassium, iron, and copper. Milled amaranth grain products such as ingredients in bread, pasta, or cookies formulations at 10…50% substitution of wheat flour, might fulfil the daily requirements in magnesium, manganese, iron, copper, and molybdenum enhancing the nutrition value of the products.

ТЕЗИ
Зерно амаранту є перспективним псевдозлаком, продукти помелу якого можуть використовуватися як інгредієнти, здатні суттєво покращувати мінеральний склад харчових продуктів. Двадцять продуктів переробки зерна амаранту з різних українських сортів, як-от Харківський-1, Лєра, Сем (Amaranthus hypochondriacus L.), Ультра (Amaranthus hybridus L.) та різних фракцій помелу (борошно, крупка, крупні висівки, дрібні висівки) були досліджені на вміст макро- і мікроелементів. Вміст марганцю, заліза, міді, цинку і кальцію в зерні амаранту був вищим в 2-3 і 20 разів порівняно із зерном пшениці. Борошняна фракція зерна амаранту (борошно і крупка) мала знижений вміст магнію, калію, кальцію, марганцю та заліза. Встановлено, що досліджене зерно амаранту різних сортів і продукти помелу мали достовірний (p>0.05) позитивний (0.47…0.90) кореляційний зв'язок між вмістом усіх проаналізованих есенціальних металів, крім молібдену, який корелював на рівні 0.46…0.56 з кальцієм, цинком, калієм, залізом та міддю. Використання здрібнених продуктів зерна амаранту для виробництва хліба, макаронних виробів або печива при 10-50% заміні пшеничного борошна вищого сорту може задовольнити добову потребу людини в магнії, марганці, залізі, міді та молібдені суттєво поліпшуючи біологічну цінність харчових продуктів.

INTRODUCTION
Amaranth is a promising pseudocereal crop still underestimated in XXI century. Amaranth grain presents high nutrition value containing a wide variety of bioactive compounds (*Peter and Gandhi, 2017; De la Rosa et al., 2019*). Micronutrients scarcity is known to provoke the development of alimentary diseases (*White and Broadley, 2009*). Therefore, amaranth grain processed products might also be considered as food ingredients regarding the mineral composition. There are 17 grain amaranth varieties in Ukraine (*Hoptsiy et*

al., 2018). Amaranth grain is known as a source of magnesium, calcium, and iron (*Nascimento et al., 2014; Schmidt et al., 2021*).

Wheat grain, especially wheat patent flour, is scarce in minerals (*Gómez-Galera et al., 2010; Baloch et al., 2014*). To explore functional properties of amaranth grain processed products might be useful to sustain food supply chains for better nutrition (*Kumar et al., 2016; Cotovanu and Mironeasa, 2022*).

High-fibre, high-protein, and high-starch amaranth semolina fractions were classified following the granulometric method by specific differential milling (*Tosi et al., 2001*). Particle size offers valuable information about the quality of amaranth flour depending on milled fractions. The roller milling of amaranth grain allowed producing fractions enriched with nutrients of functional properties to incorporate them as food improvers (*Sakhare et al., 2017; Ramesh and Prakash, 2020*).

Substitution of wheat flour with different types of amaranth grain processed products produced from Ukrainian amaranth grain varieties improved consumer quality of bread and increased the specific volume and crumb porosity, especially when using whole amaranth grain flour of the Kharkivs'kyi-1 variety, defatted flour from amaranth flakes and groats (*Mykolenko et al., 2020*). However, a comprehensive study of the macro- and microelements composition in amaranth grain, particularly made of the Ukrainian varieties, is limited to the best of our knowledge (*Levashova et al., 2018*). The research was aimed to assess essential metal elements as micronutrients in whole grain and milled products of *Amaranthus* L. of different Ukrainian varieties to enhance the nutritional values of food.

MATERIALS AND METHODS

Amaranth grain used in the study was presented by the following Ukrainian varieties: Kharkivs'kyi-1, Liera, Sem (*Amaranthus hypochondriacus* L.), and Ultra (*Amaranthus hybridus* L.) and harvested in 2018–2019 in Ukraine. Dockage-free amaranth grain was used and calibrated by size. Amaranth grain of 9–11% moisture content was grinded in Chopin CD1 Mill (Chopin Technologies, France) to obtain four different amaranth milled products: flour fractions FL (flour) and ML (middling) with a size of less than 160 µm, as products after the break and grinding rollers, respectively; bran fraction CSC (coarse seed coat) with a size of more than 800 µm after break rollers; bran fraction FSC (fine seed coat) with a size of 160–800 µm after grinding rollers (Fig. 1).

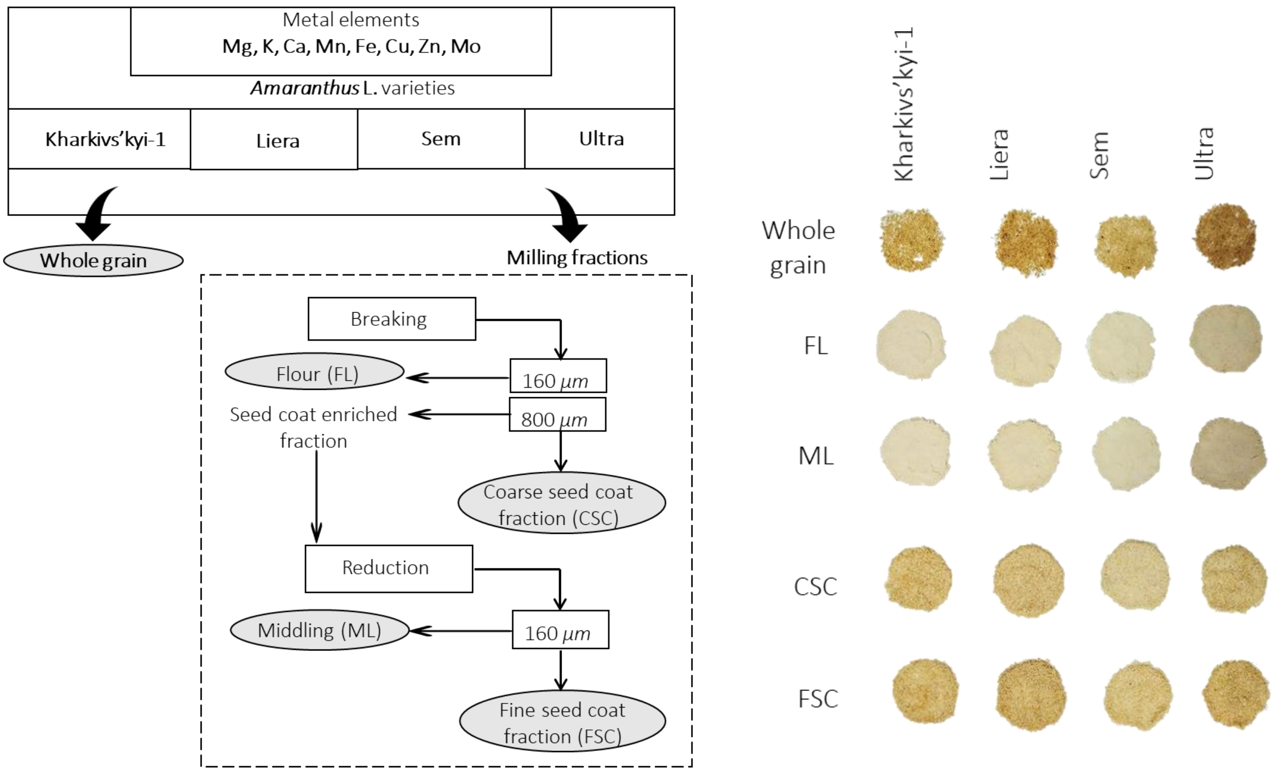

Fig. 1 - Experimental sampling chart (a), amaranth grain and milled products of different varieties (b)

Milled fractions of amaranth grain and whole grain were analysed by the content of metal elements. The samples were mineralized using a microwave pressure splitting system (Ethos one, Milestone, Italy) in a medium with 5 ml of concentrated nitrate acid (69%, chemically pure) and 1 ml of hydrogen peroxide (30%, chemically pure) with the addition of 1 ml of deionized water. The material samples obtained in this way were qualitatively and quantitatively analysed using inductively coupled plasma-optical emission spectrometry (ICP-OES) on the Agilent ICP-OES 720 instrument (Agilent Technologies, Germany) for the content of magnesium, potassium, calcium, manganese, iron, copper, zinc, and molybdenum. The sample evaporates and the element of interest is sprayed at an extremely high argon plasma temperature (~7000°C). ICP-OES is used to detect metals only in liquid samples, and the wavelength is specific to each element, taking into account its atomic mass and concentration intensity. The mineral concentration was expressed in mg per 100 g of dry matter. The moisture content of the samples was determined by AOAC 952.08, 2000 method. A 5 g of the weighed sample was placed in a dryer at 102°C ± 2°C until the sample acquired a constant mass. Statistical processing of experimental data was performed in MS Excel and STATISTICA software. Pearson correlation analysis was performed at $p<0.05$, and cluster analysis was done by the agglomerative hierarchical clustering method (Ward's method).

RESULTS

Table 1 shows the content of macro- and microelements in whole amaranth grain of different varieties. Metal elements could be divided into three groups by their content (mg·100 g^{-1}): <1.0 – molybdenum; 1.0-10.0 – manganese, iron, zinc, copper; 100.0 - 400.0 potassium, calcium, magnesium. In terms of molybdenum, copper, zinc, and magnesium content, whole amaranth grain of Liera and Sem varieties did not differ significantly. The range of molybdenum content was in range of 0.022 - 0.052 mg·100 g^{-1}. Moreover, the whole amaranth grain presented a low concentration of molybdenum, a minor dispersion of its absolute content was depending on the variety, and its maximum accumulation in the seeds reached for the Kharkivs'kyi variety: 0.052 mg·100 g^{-1}.

Table 1

Macro- and microelements in whole amaranth grain

Variety	Mo [mg·100 g^{-1}]	Cu [mg·100 g^{-1}]	Zn [mg·100 g^{-1}]	Mn [mg·100 g^{-1}]	Fe [mg·100 g^{-1}]	K [mg·100 g^{-1}]	Ca [mg·100 g^{-1}]	Mg [mg·100 g^{-1}]
Kharkivs`kyi-1	0.052a	1.2a	2.75a	3.3a	9.6ac	261a	173a	181a
Liera	0.024b	1.2a	3.26b	2.5b	9.4a	382b	185a	270b
Sem	0.022b	1.3a	3.32b	3.1a	8.3b	411c	195b	287b
Ultra	0.040c	1.3a	4.06c	3.5a	10.1c	374b	151c	268b

Note. The mean values of the obtained results are shown, and different letters for each value in the table show statistically significant differences ($p<0.05$).

Copper showed 1.2 - 1.3 mg·100 g^{-1} content in the grain of all the studied varieties. The results of zinc concentrations in the studied grain were corresponding to the optimal range. The manganese content in the whole grain of the amaranth varieties was 2.5 - 3.5 mg·100 g^{-1}; these values were insignificant and met the lowest limit of the threshold for plants: 2.0 - 30.0 mg·100 g^{-1} (*Kabata-Pendias, 2000*). Iron of the studied amaranth grain reached a higher concentration compared to other metal elements of the group including copper and manganese. Its content in the seeds of the studied varieties varied between 8.3 and 10.0 mg·100 g^{-1}, while the optimal content in plant tissues is known to be around 5.0 - 30.0 mg·100 g^{-1}. But there was no significant difference among the varieties. Potassium was concentrated in the whole grain within the range of 261 - 411 mg·100 g^{-1}. Meanwhile, the calcium content in the tested seeds met the range of 151 - 195 mg·100 $g^{-1,}$ when magnesium concentration occurred at 181 - 287 mg·100 g^{-1}.

Table 2 shows the metal elements composition in the milled amaranth grain products. All metal elements content in the bran fractions differed significantly from flour counterparts. At the same time, the fractions represented mainly by perisperm particles (FL and ML) of Liera and Sem varieties showed no difference in manganese, potassium, magnesium, calcium, copper and zinc, calcium, copper, molybdenum, respectively. Flour (FL) of all the varieties of *Amaranthus* L. had a decrease in macroelements (potassium, calcium, magnesium) as well as manganese and iron. On top of that, zinc concentration decreased for Kharkivs'kyi-1, Liera, and Ultra varieties.

The middling fraction ML in all studied varieties presented a relative concentration of magnesium to whole grain. Middling fractions of three varieties showed an increase in potassium, calcium, manganese, iron, zinc, copper, and molybdenum. The concentration of the essential elements of this fraction for the Liera variety had a decrease in manganese, iron, potassium, zinc, calcium, copper, and molybdenum.

Table 2

Essential macro- and microelements in amaranth milled grain products

Variety	Mn [mg·100 g⁻¹]	Fe [mg·100 g⁻¹]	K [mg·100 g⁻¹]	Mg [mg·100 g⁻¹]	Zn [mg·100 g⁻¹]	Ca [mg·100 g⁻¹]	Cu [mg·100 g⁻¹]	Mo [mg·100 g⁻¹]
Flour (FL)								
Kharkivs`kyi-1	1.5a	4.8a	138a	97a	1.58a	83a	0.7a	0.016a
Liera	2.3b	9.1b	338b	245b	3.12b	165b	1.4b	0.052b
Sem	2.3b	7.1c	338b	239b	3.45c	169b	1.5b	0.027c
Ultra	2.8c	9.2b	261c	200c	2.74d	141c	1.2c	0.016a
Middling (ML)								
Kharkivs`kyi-1	5.1a	18.2a	444a	322a	4.75a	287a	2.1a	0.069a
Liera	3.6b	15.7b	551b	397b	4.54b	270b	1.7b	0.055b
Sem	3.9c	13.6c	583c	411c	4.53b	265b	1.6b	0.050b
Ultra	3.3d	8.7d	253d	187d	2.87c	144c	1.2c	0.019c
Fine seed coat (FSC)								
Kharkivs`kyi-1	4.0a	11.9a	329a	228a	3.56a	187a	1.3a	0.081a
Liera	1.7b	6.3b	246b	182b	2.10b	109b	0.9b	0.021b
Sem	3.7c	10.3c	542c	391c	4.24c	210c	1.7c	0.021b
Ultra	3.6c	7.7d	282d	212d	3.05d	154d	1.2a	0.012c
Coarse seed coat (CSC)								
Kharkivs`kyi-1	4.4a	1.3a	366a	236a	3.71a	233a	1.5a	0.075a
Liera	2.9b	10.0b	464b	303b	3.81ac	218b	1.2b	0.027b
Sem	1.7c	4.2c	232c	159c	1.99b	119c	0.9c	0.015c
Ultra	6.6d	16.9d	255d	437d	3.91c	361d	1.4a	0.006d
Daily intake, mg·100 g⁻¹								
Ukraine	2	17	-	500	15	1200	1	0.07
EPSA	3	19.6	3500	350	14	1000	1.6	0.065
Upper level	-	-	-	250	25	2500	5	0.6

Notes. The mean values of the obtained results are shown, and different letters for each value in the table show statistically significant differences ($p<0.05$). The norm value is calculated for an individual weighing 70 kg

The fine seed coat fraction (FSC) of the Liera variety contained fewer metal elements than the whole grain. Additionally, almost all elements of this fraction for the Ultra variety, except manganese and calcium, decreased drastically too. The FSC of amaranth grain of the Kharkivs'kyi-1 variety showed a higher content of the macro- and microelements compared to the unprocessed grain. A similar trend was for the coarse seed coat (CSC) of the Sem variety, which also had a high content of the studied elements with exception of molybdenum. Moreover, manganese content in middling and coarse bran surpassed the recommended daily intake of 2-3 mg·100 g^{-1}. The middling fraction showed iron in a concentration close to the recommended one, while other milled amaranth grain products concentrated this element at less quantity. The range of the recommended calcium daily intake is 1000 - 2500 mg·100 g^{-1}. This metal content varied from 83 to 361 mg·100 g^{-1} in all the milled fractions. Copper intake in the human body is known to be 1-1.6 mg·100 g^{-1}. The milled products of amaranth varieties mainly included this element up to 1 mg·100 g^{-1}, and its concentration reached 2.0 mg·100 g^{-1} in middling of the Kharkivs'kyi-1 variety. The molybdenum in 100 g of all fractions of amaranth grain of the Kharkivs'kyi-1 variety, except flour, was close to the recommended daily intake.

Table 3 and Figure 2 show a correlation between the content of essential minerals in the amaranth grain and the milled products. All elements, except molybdenum, showed a positive and reliable correlation. For molybdenum, a significant average-strength correlation (0.46...0.56) was characteristic of calcium, zinc, potassium, iron, and copper. Zinc demonstrated the highest level of correlation with essential metals, the presence of which in the amaranth grain and the milled products was associated with magnesium, potassium, calcium, iron, and copper (0.83...0.90), and with manganese at the level of 0.75 at $p<0.05$. Magnesium showed a strong positive correlation with potassium, calcium, and zinc (0.81...0.90), when calcium and iron content correlated with iron

(0.86) and manganese (0.88) respectively. Furthermore, copper showed a weaker correlation (0.69...0.77). Thus, according to the interconnectedness of concentration, essential metals in the amaranth grain and its milled products were arranged in the following order: Zn → Mg, Ca, Fe → K → Mn → Cu → Mo.

Table 3

Correlation matrix of essential minerals in amaranth grain and milled products

Mineral	Mg	K	Ca	Mn	Fe	Cu	Zn	Mo
Mg	1.00	0.81	0.88	0.64	0.77	0.75	0.90	-
K	0.81	1.00	0.73	0.47	0.62	0.71	0.83	0.56
Ca	0.88	0.73	1.00	0.79	0.86	0.77	0.86	0.46
Mn	0.64	0.47	0.79	1.00	0.88	0.69	0.75	-
Fe	0.77	0.62	0.86	0.88	1.00	0.70	0.85	0.53
Cu	0.75	0.71	0.77	0.69	0.70	1.00	0.86	0.55
Zn	0.90	0.83	0.86	0.75	0.85	0.86	1.00	0.51
Mo	-	0.56	0.46	-	0.54	0.55	0.51	1.00

Note. Correlation are statistically significant at p<0.05

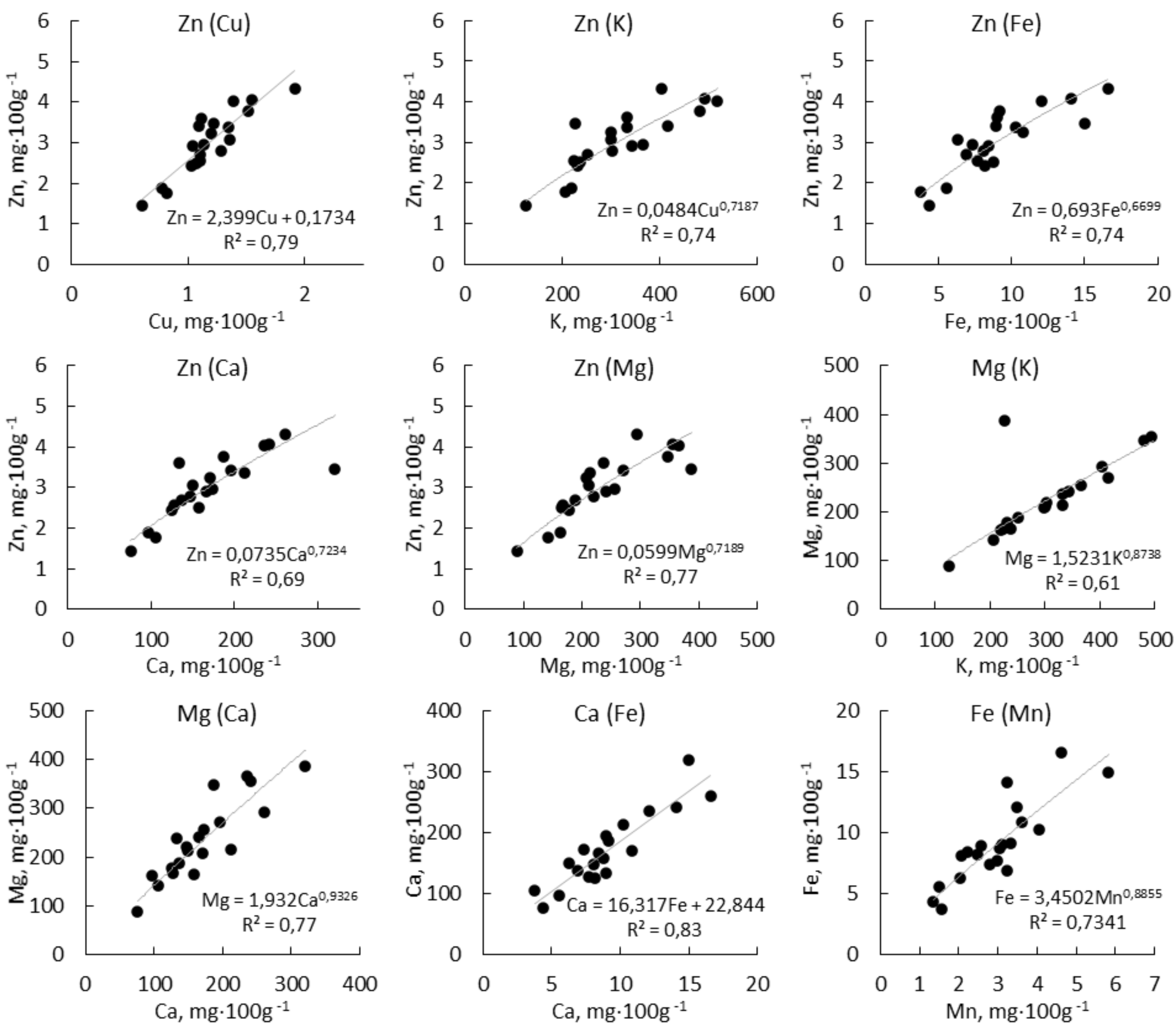

Fig. 2 – Correlation of essential minerals in amaranth grain and milled products

The concentration of zinc, magnesium, and calcium in the whole amaranth grain and the milled products increased with higher copper, potassium, iron, calcium, magnesium, and manganese content. Cluster analysis of the composition of amaranth grain and the milled products revealed essential metals assembling into three separate clusters (Fig.3).

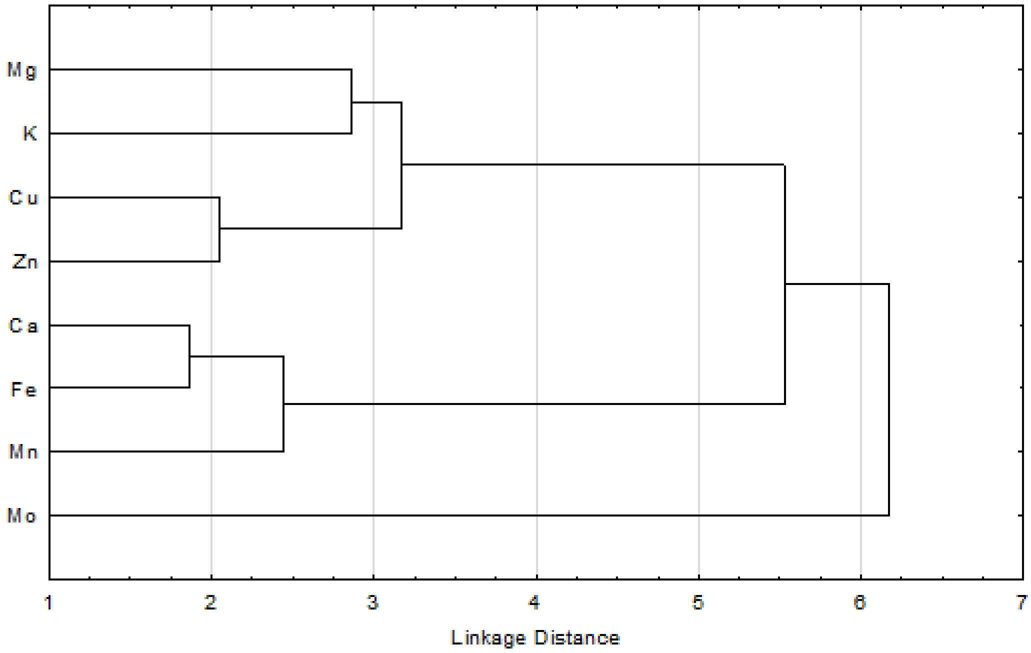

Fig. 3 - Cluster analysis of essential minerals in amaranth grain and milled products

The first cluster included magnesium, potassium, copper, and zinc. The second cluster comprised calcium, iron, and manganese, and its statistical relatedness was higher than in magnesium and potassium. The third cluster was presented by trace element molybdenum with lower concentration capacity, demonstrating a lack of correlation at a reliable level with metals such as magnesium and manganese. According to the level of statistical relatedness of the metal element concentration in amaranth grain and the milled products, the closest pairs were calcium, iron, zinc, and copper, which positively correlated at the level of 0.86 ($p<0.05$).

Table 4 shows a range of essential mineral elements in grain of *Triticum sp.* and *Amaranthus sp.* Amaranth grain of Krepysh, Kizlyarets, Kinelsky, and Yantar varieties were characterized by 2-5-fold content in molybdenum, manganese, potassium, calcium, and magnesium to wheat grain.

Table 4

Content of essential nutritional elements in wheat and amaranth grain

Species	**Mo [mg·100 g⁻¹]**	**Cu [mg·100 g⁻¹]**	**Zn [mg·100 g⁻¹]**	**Mn [mg·100 g⁻¹]**	**Fe [mg·100 g⁻¹]**	**K [mg·100 g⁻¹]**	**Ca [mg·100 g⁻¹]**	**Mg [mg·100 g⁻¹]**	**Reference**
Triticum sp.	0.023 – 0.033	0.14–0.18	0.85–1.36	2.43–3.69	2.11–3.77	278–410	2–3	60–95	*Miroshnichenko et al, 2017*
Amaranthus sp.	-	0.57	4.55	4.42	7.35	552	200	328	*Mota et al., 2016*
Amaranthus hypochondriacus L. var.:									*Fursa et al, 2013*
Voronezhskiy	0.022	1.6	3.1	7.3	51.0	830	474	270	
Krepysh	0.182	3.8	2.4	11.5	47.9	251	425	400	
Kizlyarets	0.223	0.8	2.9	7.1	36.4	738	427	420	
Kinelskiy	0.102	3.6	6.5	12.5	41.6	483	262	191	
Yantar	0.186	1.7	5.5	3.0	28.6	780	337	328	

The copper content in the grain of amaranth varieties (*Fursa et al, 2013*) had a high variability; the Kinelsky variety contained 0.8 mg.100 g^{-1} of this metal, which was less than in the studied raw materials, while another four varieties (Yantar, Kizlyarets, Krepysh, and Voronezhsky) included more copper. Iron content in the grain of all amaranth varieties found by *Fursa et al. (2013)* surpassed the studied varieties as well as results presented by *Mota et al. (2016)*. Nevertheless, amaranth grain of the Liera and the Sem varieties showed the same molybdenum, copper, zinc, and magnesium content. These varieties are known by their similar genotypic characteristics (*Hoptsiy et al., 2018*). *Mota et al (2016)* showed that amaranth grain had a high content of potassium, calcium, and magnesium compared to the varieties studied in the work. Only copper presented a lower content to the Ukrainian varieties. Copper can exhibit antagonistic interactions with iron and molybdenum (*Agarwala et al., 1989; Palmer and Guerinon, 2009*). However, according to the results of the study, a positive correlation between copper and iron (0.70) took place. But among all essential elements, the correlation between copper and molybdenum content was the lowest (0.55). Zinc promotes the assimilation of copper by plants, being at the same time an antagonist of manganese and iron (*Kabata - Pendias, 2000*). So far, positive correlations between zinc concentration and copper (0.86), iron (0.85), and manganese (0.75) in the amaranth grain and its milled products were revealed.

Biochemical role of magnesium, calcium and potassium in plants has many similarities (*Hauer-Jakli and Tranknen, 2019*). This is consistent with the results of our study, where the correlation between the concentration of magnesium and these minerals was 0.88 and 0.81, respectively. In contrast to wheat grain, the elemental composition of amaranth grain was characterized by higher content of copper, zinc, iron, and magnesium, the increase of which was up to 3-fold. Calcium of the amaranth grain was 20 times higher than its content in the wheat grain. *Kiewlicz and Rybicka (2020)* proved that amaranth grain flakes could better cover recommended intake of calcium, iron, potassium, magnesium, manganese, sodium, and zinc, in particular magnesium and iron, compared with flakes of rye, barley, winter wheat, spelt wheat, buckwheat, corn, quinoa, millet, oats, or rice. All analysed milled fractions (based on the median for the studied varieties of the amaranth grain) provided above 10% of the recommended daily intake for manganese, iron, magnesium, zinc, calcium, copper, and molybdenum when using 100 g of the product a day in accordance with the EPSA directives (Table 5).

Table 5

Covering essential minerals daily intake by amaranth flour and bread, %

Product	[%]	Type of product	Mn	Fe	K	Mg	Zn	Ca	Cu	Mo
Flour	100	Flour	68	37	8	56	19	14	72	29
		Middling	111	67	13	92	29	24	92	72
		Fine seed coat	108	41	8	56	21	15	70	29
		Coarse seed coat	108	48	8	69	24	20	72	29
Wheat bread	100	Flour	101	55	11	83	28	20	107	44
		Middling	165	99	19	136	43	35	136	107
		Fine seed coat	161	61	12	83	31	23	103	43
		Coarse seed coat	161	72	12	102	35	30	107	43
	50	Flour	51	27	6	41	14	10	54	22
		Middling	83	49	9	68	21	18	68	53
		Fine seed coat	80	30	6	42	16	11	52	21
		Coarse seed coat	80	36	6	51	18	15	54	21
	25	Flour	25	14	3	21	7	5	27	11
		Middling	41	25	5	34	11	9	34	27
		Fine seed coat	40	15	3	21	8	6	26	11
		Coarse seed coat	40	18	3	25	9	7	27	11
	15	Flour	15	8	2	12	4	3	16	7
		Middling	25	15	3	20	6	5	20	16

Product	[%]	Type of product	Mn	Fe	K	Mg	Zn	Ca	Cu	Mo
		Fine seed coat	24	9	2	12	5	3	15	6
		Coarse seed coat	24	11	2	15	5	4	16	6
	10	Flour	10	5	1	8	3	2	11	4
		Middling	17	10	2	14	4	4	14	11
		Fine seed coat	16	6	1	8	3	2	10	4
		Coarse seed coat	16	7	1	10	4	3	11	4

Note. The calculation considered the flour and the bread consumption level as 100 and 200 g a day

At the same time, 100 g of middling fractions, fine or coarse seed coat could provide 108-111% of the daily need in manganese. Moreover, the optimal intake of manganese, magnesium, copper, and molybdenum is overtopped when bread produced of 100% amaranth product is introduced into the daily diet at 200 g a day, especially when the middling is used as an ingredient of the formulation. Therefore, it is reasonable to use the milled amaranth grain-derived products in the composite flours, for example, together with wheat flour of the highest grade, which is known to be depleted of the essential minerals. Replacing wheat flour with amaranth one resulted in a significant increase in the intake of manganese and copper (10%); manganese, magnesium, and copper (15%): magnesium, iron, magnesium, copper, and molybdenum (25%). Bran fractions and middling should be introduced into the bread formulations at 10-15% to achieve a similar effect.

Pasta is a popular food based on flour and water all over the world. Wheat flour replacement by the amaranth products at 15% in pasta formulations might cover up to 10% of the manganese recommended intake. But the noticeable mineral improvement of the product occurs if wheat flour is replaced with the amaranth products up to 25%. This makes it possible to meet more than 10% of the daily need in manganese, copper for all the milled products studied, and in iron, magnesium, and molybdenum when using the middling. Considering the absence of gluten and functional properties of amaranth starch, increasing the amaranth flour in pasta up to 50% could deteriorate the quality of the product.

Milled amaranth grain products could significantly improve cookies quality (*Mykolenko and Zakharenko, 2020*). Meanwhile, compared to bread and pasta, the daily intake of cookies is more limited and does not exceed 35 g a day in the common diet. From this point of view, only complete replacement of wheat flour with milled amaranth counterparts may result in the mineral-enriched product. The cookies with amaranth flour can provide 11-15% of magnesium, manganese and copper recommended daily intake, whereas 50% substituted wheat flour by the amaranth middling or the bran fractions would assist 9-11% covering in magnesium, manganese, and copper.

CONCLUSIONS

Amaranth grain presented high content of zinc, magnesium, and calcium which makes this crop a promising improver of the nutritional value of food products. The highest concentration of manganese, iron and zinc occurred in the amaranth grain of the Liera variety, and potassium, calcium, and magnesium accumulated mostly in the grain of the Sem variety. The Kharkivs'kyi-1 variety grain showed the highest molybdenum content among minerals. The amaranth flour was characterized by reduced potassium, calcium, magnesium, manganese, and iron content in comparison to the whole grain. According to interconnectedness, the essential minerals in the amaranth grain and the milled products were arranged in the following order: Zn → Mg, Ca, Fe → K → Mn → Cu → Mo. Wheat-amaranth composite flour in the bread formulations might cover daily intake level of manganese and copper (90-10), manganese, magnesium, and copper (85-15), magnesium, iron, magnesium, copper, and molybdenum (75-25). Bran fractions and middling should be introduced into the bread formulations at 10–25% to achieve a similar effect, while 50% replacement of wheat flour with these amaranth products is needed in the cookie formulations.

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