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MINERAL COMPOSITION OF VEGETABLE BIOMASS OF *AMARANTHUS* L. SPECIES

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The mineral composition is explored of the four species of *Amaranthus* L.: *A. lividus* L., *A. tricolor* L., *A. acutilobus* Uline et W. L. Bray, and *A. blitoides* S. Wats. The leaves were analyzed when the plants were in the vegetative phase of development. The element concentrations determined by techniques of atomic absorption spectrometry with inductively coupled plasma spectrometry. The order of the elements is as follows: *A. acutilobus*, *A. lividus*: К > Ca > Mg > S > P > Fe > Al > Na > Zn > Mn > B > Ba > Ni > Pb > V > Cd > Cr; *A. blitoides*: К > Ca > Mg > S > P > Fe > Al > Na > Zn > Mn > Ba > B > Ni > Pb > V > Cd > Cr; *A. tricolor*: К > Ca > S > Mg > P > Fe > Al > Na > Zn > Mn > B > Ba > Ni > Pb > V > Cd > Cr. Potassium is the main ash element in the leaves of all studied species of *Amaranthus*. Its content varied from 39,010.00 to 44,926.67 mg/kg. *A. tricolor* is significantly different among other species for the ratio of sulfur and magnesium. In its leaves, a large amount of sulfur is found. The species with ascending stems (*A. acutilobus* and *A. blitoides*) contained sulfur up to 4020.00 and species with erect stems (*A. lividus* and *A. tricolor*) within 5,724.00–6,314.40 mg/kg. Maximum content of Mg was 6,734.33, P 1,706.33, Fe 1,133.28 mg/kg. The content of heavy metals was in a safe quantity, except nickel. The highest coefficients of variation (%) are characteristic of the content of barium (45.07), sodium (31.18), vanadium (28.22) and potassium (26.62). The most stable is the content of phosphorus (3.25%). The mineral composition of leaves of amaranth showed its high value as a vegetable product.

Keywords: *Amaranthus acutilobus*, *Amaranthus blitoides*, *Amaranthus lividus*, *Amaranthus tricolor*, mineral composition

Introduction

The use of plants of the genus *Amaranthus* L. today is a promising trend in vegetable growing. In the world, they are widely used in countries of Asia and Africa (Olasantan, 1992; Timothy et al., 1996; Kachigumaetal., 2015). For example, in South Korea, amaranth leaves are used in dried form and exported to the United States (Pemberton end Lee, 1996). Amaranth is one of the four most used plants of natural flora in South Africa. Shackleton et al. (1998) have shown that more than half of the respondents (59%) have consumed it as a nutritional supplement to oatmeal and corn.

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Among the Ukrainian developments, there are recipes of jelly marmalade with the addition of amaranth leaves powder (Karnaushenko and Ustimenko, 1995; Molodozhen, 1996). It is proved that the introduction of such an additive increases the kinematic viscosity and density of jelly masses, enriches with vitamins, protein, micro and macro elements. The addition of leafy flour reduces the use of citric acid to 50% and eliminates the use of colorants due to the reaction of melayidine formation, and also extends the shelf life of finished products. Plants of the genus *Amaranthus* are common in the culture of Ukraine, mainly as fodder and grits. The least attention was paid to the use of amaranth in vegetable growing. The most commonly cultivated are *Amaranthus cruentus* L. (syn. *A. paniculatus* L.) and *A. caudatus* L., rarely *A. lividus* L., *A. tricolor* L., *A. hypochondriacus* L. and *A. mantegazzianus* Passer. The *A. acutilobus* Uline et W. L. Bray and *A. blitoides* S. Wats. known as plants of natural flora, but have a great potential for use.

The rich chemical composition of the amaranth causes the effectiveness of its use as a medicinal plant. It detects radio and cytoprotective, anti-inflammatory, detoxifying, antitumor action, enhances protective functions, and also positively affects the potential of the human organism (Fisun et al., 2002; Yerashova et al., 2002).

The above-ground biomass of amaranth, simultaneously with the widespread use as a source of amino acids, pectin, and trace elements, has an antibacterial effect and is used in the form of decoctions for the treatment of colds. Extractive drugs can be used in the treatment of tonsillitis, cystitis, and pyelonephritis. The therapeutic ability of the leaves of amaranth is found both when they are used for animal feed and food for humans. Amaranth has show antioxidant, tread, and immunomodulatory properties due to the high content of biologically active substances (rutin, amaranthine, vitamins A, C, E, unsaturated fatty acids, squalene) and can be used for the treatment of radiation sickness and other diseases (Zayachkivska and Kozak, 1997; Makeev et al., 2002).

Material and methodology

Taking into account world experience, as well as our own observations, we have been chosen following species for the research: *A. acutilobus*, *A. blitoides*, *A. lividus*, *A. tricolor*. *A. tricolor* was presented by two samples, obtained from Germany and China (cultivar H Yue Ye Te Tsai) (Figure 1).

Experiment organization

Plants grown on the experimental site of the Department of Cultural Flora of M.M. Gryshko National Botanical Garden (NBG) of NAS of Ukraine were studied. The data of the quantitative elemental composition were obtained in the Center of collective use by devices Spectrometric Center of Elemental Analysis «SCEA» of NBG. Plants were in the vegetative phase of development. The leaves were taken for analysis since in this period of development they form the largest part of the plant.

Figure 1 Plants in the vegetative phase of development
a – *Amaranthus acutilobus* Uline et W. L. Bray; b – *A. Lividus* L.; c – *A. blitoides* S. Wats.; d – *A. tricolor* L.; e – *A. tricolor* 'H YueYeTeTsai'

Methodology of element concentration

For the determination of element concentrations, crushed material was dried at 35 °C and dissolved in concentrated nitric acid. Samples were placed in a chemical microwave oven. In it, under the action of the given parameters of pressure and temperature occurred decomposition of biomaterial. The extract was obtained were injected directly to the mass spectrometer and for using a concentric sprayer was translated into an aerosol with subsequent submission to argon plasma, where ionization took place. Then the separation of ions by mass-charging ratio took place and measuring the intensity of the signals the segmented ion analytes. The element concentrations determined by techniques of atomic absorption spectrometry with inductively coupled plasma spectrometry (ICP mass spectrometry). The concentration of chemical elements in the extract was determined on the device ICAP 6000 Series ICP Spectrometer (Thermo Scientific). Element concentrations expressed as mg/kg dry weight. The repetition of experiment – triple (Kovtun-Vodyanytska, 2016).

Statistical analysis

For statistical evaluation were used standard methods using statistical software Microsoft Excel 2010.

Results and discussion

Determination of the elemental composition of amaranths leaves revealed the high content of valuable macro and microelements. The most accumulated potassium and calcium – extremely important elements in the human diet (Vitamin and mineral requirements in human nutrition, 2004). In general, the elements contained in the leaves of different species of amaranth can be ranked by number (from greater to smaller) into the following rows:

A. acutilobus, *A. lividus*: K > Ca > Mg > S > P > Fe > Al > Na > Zn > Mn > B > Ba > Ni > Pb > V > Cd > Cr;
A. blitoides: K > Ca > Mg > S > P > Fe > Al > Na > Zn > Mn > Ba > B > Ni > Pb > V > Cd > Cr;
A. tricolor: K > Ca > S > Mg > P > Fe > Al > Na > Zn > Mn > B > Ba > Ni > Pb > V > Cd > Cr.

As the analysis showed, potassium is the main ash element in the leaves of all studied species of *Amaranthus*. Its content varied from 39,010.00 to 44,926.67 mg/kg (Table 1). Amaranth plants accumulated calcium from 28,523.33 to 36,126.67 mg/kg, which makes the raw material a valuable nutritional supplement. The magnesium content in all samples was observed at a rather high level (4,586.00–6,734.33 mg/kg), the lowest was in *A. acutilobus*. *A. tricolor* is significantly different among other species for the ratio of sulfur and magnesium, since both samples of this species revealed more sulfur than magnesium. A large amount of sulfur was found in the leaves of the species under study, with a significant difference between species with ascending stems (*A. acutilobus* and *A. blitoides*) containing sulfur up to 4,020.00 and species with erect stems (*A. lividus* and *A. tricolor*) – within 5,724.00–6,314.40 mg/kg. The same tendency is typical for phosphorus, sodium manganese and boron – they were detected the least in *A. acutilobus* and *A. blitoides*. Instead, iron and aluminum in the leaves of these species are larger than in samples with erect stems.

Table 1 Elemental composition of leaves of *Amaranthus* species (mg/kg)

Elements	*A. acutilobus*	*A. blitoides*	*A. lividus*	*A. tricolor*	*A. tricolor* 'H YueYeTeTsai'	V (%
K	42,111.67* ±2,245.98**	42,083.33 ±1,738.18	44,926.67 ±1,837.36	39,010.00 ±2,404.69	39,276.67 ±605.77	26.62
Ca	28,523.33 ±1,254.80	35,516.67 ±3,72.11	31,396.67 ±6,40.72	34,590.00 ±716.49	36,126.67 ±1,931.07	9.63
Mg	4,586.00 ±187.21	6,241.00 ±91.54	6,734.33 ±215.34	4,835.33 ±174.26	5,996.00 ±185.62	16.32
S	4,003.60 ±118.14	4,020.00 ±89.03	6,314.40 ±200.12	5,724.00 ±81.94	6,170.40 ±61.77	21.88
P	1,590.33 ±2.27	1,578.33 ±2.94	1,616.67 ±7.12	1,661.00 ±16.72	1,706.33 ±9.91	3.25
Fe	1,056.52 ±136.40	1,133.28 ±69.04	726.05 ±18.12	746.37 ±14.87	863.53 ±21.15	20.22
Al	840.00 ±127.99	881.67 ±160.72	635.67 ±80.11	667.00 ±78.64	587.67 ±85.06	18.04
Na	201.67 ±13.23	199.83 ±10.34	401.70 ±46.50	362.17 ±9.11	327.77 ±16.71	31.18
Zn	65.25 ±11.64	48.05 ±0.91	67.19 ±4.37	52.98 ±5.04	60.42 ±12.89	13.82
Mn	44.53 ±1.02	43.71 ±2.88	49.16 ±5.28	46.12 ±3.02	52.79 ±0.81	7.89
B	30.86 ±2.11	33.65 ±2.97	34.35 ±0.59	36.61 ±2.24	37.49 ±1.76	7.56
Ba	29.25 ±4.75	40.40 ±2.49	14.99 ±0.80	17.21 ±0.60	17.65 ±1.31	45.07
Ni	1.80 ±0.12	2.10 ±0.03	1.64 ±0.08	1.81 ±0.12	1.77 ±0.13	9.26
Pb	1.48 ±0.08	1.79 ±0.29	1.24 ±0.37	1.60 ±0.38	1.39 ±0.04	13.91
V	1.23 ±0.21	1.30 ±0.06	0.71 ±0.08	0.83 ±0.07	0.78 ±0.09	28.22
Cd	0.23 ±0.03	0.18 ±0.02	0.17 ±0.01	0.16 ±0.01	0.26 ±0.01	21.51
Cr	–***	–	–	–	–	–

Notes: V, % – variation coefficient; * – arithmetic mean; ** – Standard error of the mean; *** – <0.0000.

The zinc content ranges from 48.05 to 67.19 mg/kg. The highest variation is observed between samples for the content of barium (45.07%), the quantity of which is significantly (approximately twice) predominant in *A. acutilobus* and *A. blitoides*.

A. lividus is most distinguished among the studied samples because of predominance of potassium (44,926.67 mg/kg) and magnesium (6,734.33 mg/kg) content. The main source of valuable macronutrients was *A. lividus* and *A. tricolor* 'H YueYeTeTsai',the last one had the highest calcium and phosphorus content (36,126.67 and 1,706.33 mg/kg, respectively).

Ni, Pb, V, Cd, and Cr form a group of trace elements, the content of which does not exceed 10 mg/kg. Their significance is extremely important for metabolic processes in the organism, but the amount of consumption is regulated by maximum permissible standards (Vitamin and mineral requirements in human nutrition, 2004). According to the WHO requirements for medicinal plant material (Kovtun-Vodyanytska, 2016), their maximum content is as follows: Ni – 1.5, Pb – 10, Cd – 0.3, Cr – 1.5 mg/kg. The vanadium toxicity threshold is 10–20 mg/kg daily ration (Smolyar and Petrashenko, 2010). Our data indicates that the content of these elements is in a safe quantity, except nickel. Its accumulation in amaranth leaves is probably caused by high background content in the soil. It is significant that no sample contained chromium (Table 1).

The largest variation between samples is observed in the content of barium (45.07%). The great variability is the content of sodium (31.18%), vanadium (28.22%) and potassium (26.62%). The most stable is the content of phosphorus (3.25%), boron (7.56%), manganese (7.89%), nickel (9.26%) and calcium (9.63%), because their variation coefficients do not exceed 10%.

Our research analyzed the mineral composition of the four species of *Amaranthus*. For plants grown in Ukraine, this is the first study to compare plants of these species: *A. acutilobus*, *A. blitoides*, *A. lividus*, *A. tricolor*. The tradition of using of amaranths as a vegetable is especially widespread in Africa. Kachiguma et al. (2015) provide data on the content of some mineral elements for *A. lividus* compared to *A. hybridus* L., *A. cruentus* and *A. hypochondriacus*. The most important thing is that our samples were dominated by potassium (up to 44,926.67 mg/kg), while in samples grown in the Central Malawi calcium more than potassium. The content of potassium in *A. lividus* (44,926.67 mg/kg) in our experiment is three times greater than the African samples (1,473–1,563 mg/100 g) (Kachiguma et al., 2015). Amaranths from Central Malawi accumulated much less calcium than in Ukraine, their maximum values were 2,381 mg/100 g and 36,126.67 mg/kg, respectively. Amaranths collected by researchers in Africa accumulation magnesium 383.4–513.9, iron – from 14.21 to 27.06 and zinc from 1.03 to 3.46 mg/100 g. The content of iron and zinc was much lower than in our samples, but the quantity of magnesium is comparable to our data.

Conclusions

The results of the analysis of the mineral composition of leaves of different species of *Amaranthus* showed their high value as a vegetable product. *A. acutilobus*, *A. blitoides*, *A. lividus*, *A. tricolor* have high levels of potassium, calcium, and magnesium, which makes it possible to use them in dietary nutrition and fodder production. The growth of amaranths in Ukraine provides a high concentration of a wide range of macro and microelements in the raw material.

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