Amaranth Nutritional Properties Assessment Based on Potassium and Nitrate Concentration in Tissues

Alexander Vasilevich Kurovsky[1,2]*, Anastasiya Anatolievna Burenina[1], Svetlana Ivanovna Mikhailova, Ksenia Alexandrovna Petrochenko[1] and Tatyana Petrovna Astafurova[1]

Tomsk State University, Russian Federation, 634050, Tomsk, Lenin Prospekt, 36.
Tomsk Polytechnic University, Russian Federation, 634050, Tomsk, Lenin Prospekt, 30.

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The chemical composition of plants of amaranth belonging to various species is determined genetically to a great extent. The concentration of mineral nutrients in amaranth tissues may influence the quality of food and fodder raw stuff. We studied the potassium and nitrate concentration in the tissues of the plants of four amaranth species grown in Western Siberia in similar rainfed conditions. We suggest using the ratio "potassium concentration/nitrate concentration" in the biomass of the plants under study as an additional indicator of their nutritional properties. The content of potassium in *A. hypochondriacus* and *A. tricolor* dry weight was about 900 mEq/kg, in the tissues of *A. retroflexus* – 600 mEq/kg, in the tissues of *A. cruentus* – 455 mEq/kg. The maximal value of the mean nitrate content in dry matter for *A. cruentus* was 105.9 mEq/kg. The content of nitrates in *A. tricolor* tissues was 80 mEq/kg, and in *A. retroflexus* tissues – 40 mEq/kg. The minimal content of nitrates was registered in the sample of the dry matter of the plants of *A. hypochondriacus* – about 24 mEq/kg. The ratio "potassium concentration/nitrate concentration" in the plants of *A. hypochondriacus* ran up to a multiple of 45, in *A. retroflexsus* – 16.4, in *A. tricolor* – 10.8, and in *A. cruentus* – 4.5. *A. hypochondriacus* has the highest feeding value compared to other amaranth species, with soil conditions being similar, without watering and fertilizers. The indicator "potassium/nitrate" can be used for express assessment of amaranth nutritional properties.

Key words: *Amaranthus hypochondriacus* L.; *Amaranthus tricolor* L.; *Amaranthus cruentus* L.; *Amaranthus retroflexsus* L.; potassium and nitrates in dry matter; potassium/nitrate ratio.

The cultivated species of the amaranth (*Amaranthus* L.) attract researchers and farmers' attention due to their high productivity, high concentration of proteins, essential amino acid, vitamins and mineral saline. Species of various kinds – food (salad and grain), fodder, medicine and fancy – are being bred. A lot of attention is given to studying the chemical composition and nutrition value of the amaranth (Kononkov *et al.*, 2001; Zheleznov *et al.*, 2009; Gins, 2002; Venskutonis and Kraujalis, 2013). We consider it topical to investigate species specificity of the amaranth in terms of its ability to accumulate mineral nutrition elements that can determine the quality of food and fodder raw stuff (Vysochina, 2013; Faustova and Kosman, 2009).

Potassium is of high nutrient value for people and domestic animals compared to other macro elements accumulated by plants, but nitrates are harmful for a human or animal organism, especially in large quantities. In the last few decades nitrates have been viewed not only as the elements of mineral nutrition of plants but also as the elements producing a toxic effect on a human or animal organism. The basic mechanism of such toxicity is in large quantities of nitrates' penetrating (through food, water or milk) into animal organisms

* To whom all correspondence should be addressed.
E-mail: a.kurovskii@yandex.ru

where they turn to nitrites that combining with haemoglobin form methaemoglobin incapable of transporting oxygen (Kirovska-Cigulevska, 2002). The work is aimed at revealing species specificity of accumulating potassium and nitrates in amaranth plants and assessing their nutrition properties based on the data obtained.

MATERIAL AND METHODS

The objects under study were 4 species of the amaranth: *Amaranthus cruentus* L. cv. Cherginsky (the originator is the Institute of Cytology and Genetics, the Siberian Branch of the Russian Academy of Sciences, Novosibirsk, and Siberian Research Institute of Agriculture, Omsk), *A. tricolor* L. cv. Valentine and *A. hypochondriacus* L. cv. Kizlyarets (the originator is All-Russian Research Institute of Breeding and Vegetable-Seed Industry, Odintsovo), and wild-growing *A. retroflexus* L.

We did field tests in the research farm of Siberian Botanical Garden (SibBG) at Tomsk State University in 2009–2011. The soil in the site is dark grey, medium podzolized, its texture is medium clay-loam: pH_{KCl} – 6.0, active compounds (according to Kirsanov) $Ê_2Î$ – 80, $Ð_2Î_5$ – 280 mg/kg, humus content – 3.2 %. To grow the amaranth we used the technique recommended for Western Siberia (Gins, 2002). The preceding crop was annual grass. The depth of soil cultivation was 20–22 cm. The secondary tillage included prevernal dragging. Before sowing the soil was moulded at a depth of 8–10 cm. We sowed the seeds produced by SibBG at a depth of 1–1.5 cm in the first decade of June. The way of sowing was wide-row, with 45-centimetre inter-row spacing; the seed application rate was 320 it./m^2 (0.30 g/m^2). Crop tending during the vegetation period included bursting and weeding. The plants were grown in the rainfed conditions, without fertilizers and herbicides. Herbage sampling was done during blooming period – at the beginning of fruit-bearing period, in III decade of August – I decade of September. All the plants' parts collected were dried in a drying oven until they had air-dry weight.

To prepare the aqueous extracts for ionometric measurements we used a cold extraction method. The dry matter of the amaranth plants under study was ground carefully and ponded by the solvent in ratio 99:1. To study the concentration of potassium ions we used distilled water as an extracting solution; to measure the concentration of nitrate anions we used 1-percent solution of aluminum potassium sulfates. The extraction took place in dark glass vessels for 24 hours after 5-minute shaking.

The concentration of potassium and nitrogen in samples under study was measured with the help of potentiometry using ion-selective electrodes (Kurovskiy *et al.*, 2013).

The data analysis included calculation of Means and 95-% Confidence Intervals for Means.) (Rokitsky, 1973; Lakin, 1990). Such choice was caused by the test for Normality to the samples the results of which displayed the correspondence of empiric Distribution of experimental data values to normal distribution.

RESULTS AND DISCUSSION

The analysis of the soil from experimental sites showed that the value of the concentration of potassium ions and nitrates was low (Table 1). The nitrate concentration in agrocoenosis with different types of soils may vary considerably. Many types of soils have much higher concentration of nitrate nitrogen than the one we registered, but in the soils with active denitrification process and nitrate-reduction the concentration value of NNO_3 is similar to our data. These values vary in a range of 0.32–0.98 milliequivalents/kg of dry soil (W³odarczyk *et al*., 2007).

As for potassium, it is important to clearly define the form of the macroelement while analysing and interpreting the quantity of its concentration in the soil, because there is a substantial difference in the concentration of water-soluble and acid-soluble fraction of potassium (Królak *et al*., 2007). The concentration of common potassium in various soils may be 150–250 mg/kg of dry weight (Wakeel *et al*., 2005), which equals approximately 4–6.5 mEq/kg. In this work we used the potentiometric method to measure the concentration of potassium ions in water extracts from the soil. The results obtained (Table 1) are in accord with the data from the paper (Mengel, 1993), in which the concentration of K^+ in the samples of fertilized soil was shown to vary from 0.15 to 1.2 mEq/kg depending on the amount of added K_2O – from 0 to 1000 kg/ha. Consequently, we can assume that the values we registered – about 0.4 mEq/kg (Table 1) are the evidence of rather little amount of common potassium in the soils.

Thus, the conditions (without watering and fertilizers) in which the plants of the amaranth species under study were grown could not provide optimum content of water-soluble potassium and nitrates in the soil. The values of pH were in the lower limit of the range optimum for the amaranth (Olufolaji *et al*., 2010).

Figure 1 shows the analysis of the mean content of water-soluble potassium in the tissues of the amaranth plants under study. The graph indicates that maximum values of the mean content of potassium in dry matter were registered for the species *A. hypochondriacus* and *A. tricolor* (about 900 mEq/kg). The values of this indicator for these two species are practically the same. The content of K^+ in the tissues of *A. retroflexus* was 600 mEq/kg. The minimum content of potassium was found in the samples of dry matter of the plants of *A. cruentus* – about 455 mEq/kg, which is half the value of potassium content in the tissues of *A. hypochondriacus* and *A. tricolor*.

The concentration of potassium in the tissues of the plants under study (*A. cruentus* and *A. retroflexus)* is, on the whole, in accord with the literature data, according to which the amount of this mineral nutrient in plants of various species of the amaranth may be as big as 1–2 % of dry weight (Fazaeli *et al*., 2011). The calculation of the potassium concentration we measured in terms of percentage points for the species *A. cruentus* and *A. retroflexus* results in 1.7 % and 2.3 % correspondingly. However, the species *A. hypochondriacus* and *A. tricolor* display a much higher percentage of potassium in dry matter – about 3.5 %.

Many a time did we measure the dry matter content in the tissues of amaranth during sample processing and drying, it was 20±2 %; so, we can extrapolate the data presented in Figure 1 to the potassium content values in wet weight with a sufficient degree of accuracy. These values are usually related to intracellular concentration of K^+. For *A. cruentus* the calculated concentration of K^+ is on average 90 mg-eq/kg of wet weight, for *A. hypochondriacus* and *A. tricolor* – 180–190 mEq/kg, for *A. retroflexus* – 120 mEq/kg. For *A. cruentus* and *A. retroflexus* these values

Table 1. Physico-chemical characteristics of soils used in the experiment

Content of K^+, milliequivalents/kg dry weight	Content of NO_3^-, milliequivalents/kg dry weight	pH of water extract
0.36±0.04	0.51±0.01	5.9±0.17

Means and standard deviations are given in the table

correspond to the classicla concepts of K^+ concentration in the plant cell (Klarkson, 1974). The high concentration of potassium in the tissues of the breeds Valentina and Kizlyarets is in accord with the data showing that under particular soil-climate condiitons the potassium concentration in dry weight of *A. hypochondriacus* amounts to 4–4.5 % (Abbasi *et al*., 2012). The total concentration of minerals in wet weight of this amaranth species may be as high as 18.2–18.5 % (Vujacic and Susic, 2013). On the whole, a high concentration of potassium in the tissues of *A. hypochondriacus* and *A. tricolor* comfirms the data on their high food and fodder quality (Kononkov *et al*., 2001).

We consider it important to mention two points in relation to the results of measuring the potassium concentration in the wet weight of amaranth. First, as we have shown above, the concentration of soluble potassium in the soil where the plants under study were grown was lower than the optimal level. Second, the difference in magnitude of the potassium concentration in four amaranth species grown in similar conditions proved to be sufficient (Fig. 1). The main factor that caused the differnce, as we see it, may be genetic determination of mineral nutrition, including the mechanisms of uptake of ions from soil solution and further xylemic transport. Nowadays genetic variations in different aspects of mineral nutrition are discussed in a number of papers (Guodong and Yuncong, 2009; Clark, 1983). In our previous research (Kurovskiy, 2009) we indicated that wild herbs of 8 species growing in a small area under the same conditions display sufficient differences in accumulating cationic macronutrients. We showed, in particular, that the calcium/potassium ratio in the tissues of plants belonging to various species differed by an order of magnitude. We consider such effects to be related to evolutionary-formed differnces in plants' demand for cationic macronutrients. These differnces may be caused (together with other factors) by the role of cations in pH regulation and other parameters of homeostasis in tissues with various composition and quantity of acids (Osmolovskaya *et al*., 2007).

Figure 2 presents the data of the mean concentration of nitrates in the plants belonging to four amaranth species. The maxmal value of the mean concentration of nitrates in the dry weight was found in *A. cruentus* – about 105.9 mEq/kg. The nitrate concentration in the tissues of *A. tricolor* was 80 mEq/kg, and *A. retroflexus* – 40 mEq/kg. The minimal concentration of nitrates was found in the dry weight samples of *A. hypochondriacus* – about 24 mEq/kg, which is 4 times less than in *A. cruentus*. A relatively high concentration of NO_3^- in *A. cruentus* is in accord with the data on its strong ability to accumulate nitrates (Musa *et al*., 2011).

On the whole, the analysis of nitrate concentration in plant tissues revealed two important aspects. First, as is the case with potassium concentration, we found a high degree of species-specificity in nitrate accumulation in the plants under study. The second aspect of the obtained data is connected with a possible toxicity of large quantities of nitrates while using amaranth wet weight as food or fodder. The experts from the University of Lincoln (Nebraska, the USA), having summerised more than 700 measurements of nitrate concentration in various plant components showed that the highest values of nitrate accumulation were registered for one of amaranth species – *A. palmeri* S.Wats. The values were at the level of 10900 ppm, which is 5 times bigger than potential toxic concentration being 2100 ppm of nitrate nitrogen (Rasby *et al*., 2007). If we use the units of measurement employed in the work mentioned above, our results will be the following: the concentration of NNO_3 in the dry weight of *A. cruentus* will be 1482 ppm, in *A. tricolor* – 1169 ppm; in *A. retroflexus* and *A. hypochondriacus* – 550 and 340 ppm of nitrate nitrogen,

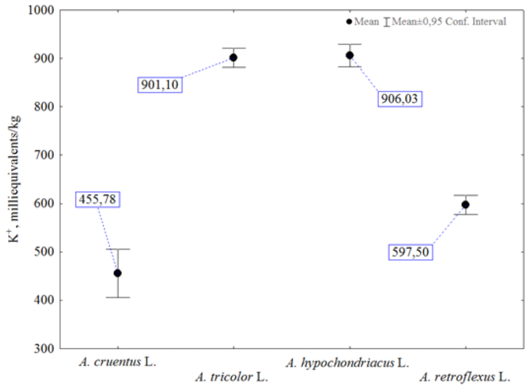

Fig. 1. Mean concentration of potassium ions in the tissues of four amaranth species

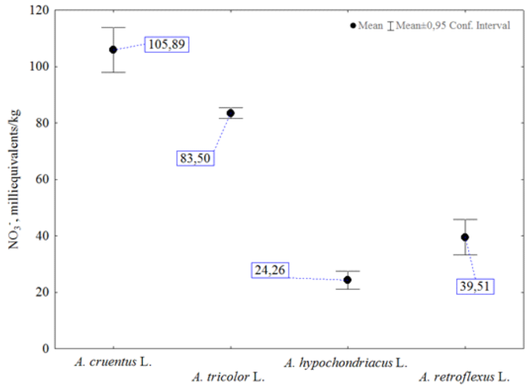

Fig. 2. Mean concentration of nitrates in the tissues of four amaranth species

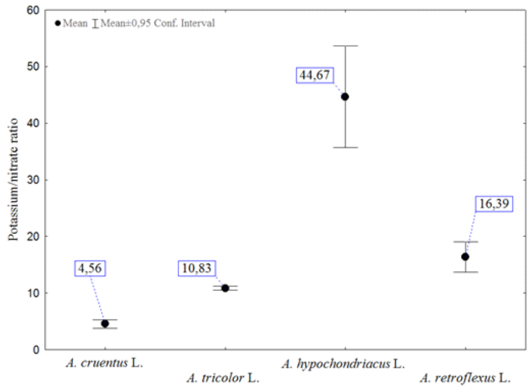

Fig. 3. Ratio «potassium concentration/nitrate concentration» in the tissues of four amaranth species

correspondingly. Thus, grown in the same soil conditions, without mineral fertilizers, *A. cruentus* accumulated nitrates in the quantities correlating with potentially toxic limit, in the tissues of *A. tricolor* nitrate concentration was approximately 2 times lower, and in *A. hypochondriacus* and *A. retroflexus* – 4–6 lower the toxic level.

Summerizing the obtained data we suggest considering an indicator for food quality of the amaranth to be quantitative potassium/ nitrate concentration ratio in plants' tissues. The reason why we introduce this indicator is potassium usefulness (as a macronutrient) and the harmfulness of large quantities of nitrates for people and animals. The results potassium/nitrate ratio calculations are presented in Figure 3.

The graph indicates that *A. hypochondriacus* cv. Kizlyarets is leading based on this indicator, in the tissues of which potassium concentration is 45 times higher than nitrate concentration. The wild species *A. retroflexsus* takes the second position. The potassium/nitrate ratio coefficient for this species is 16.4, and for *A. tricolor* cv. Valentine – 10.8. The smallest value of the potassium/nitrate ratio was found in the tissues of *A. cruentus* cv. Cherginsky. They were 9 times less than the ones for the breed of Kizlyarets (4.5).

CONCLUSION

Based on the total of the data analyses we can conclude that *A. hypochondriacus* displays the highest food and fodder quality compared to other species, all of them grown in the same soil conditions, without watering and using mineral fertilizers. *A. tricolor* together with high concentration of potassium accumulates a lot of nitrates. A high concentration of nitrates is characteristic of *A. cruentus*, which, in our view, may deteriorate the nutrient properties of the species. *A. retroflexus* is characterized by an intermediate nutrient value. The potassium/nitrate ratio can be used for express assessment of amaranth nutritional properties.

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