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ORIGINAL PAPER

DISTRIBUTION OF MACRONUTRIENTS IN ORGANICALLY GROWN JERUSALEM ARTICHOKE (*HELIANTHUS TUBEROSUS* L.) TUBERS THROUGHOUT THE GROWING PERIOD*

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Abstract

The aim of this research was to evaluate the distribution of macronutrients in organically grown Jerusalem artichoke (*Helianthus tuberosus* L.) tubers throughout the plant growing season. During the years of 2012 - 2014, the following Jerusalem artichoke cultivars were grown for our investigations on an organic farm in the south of Lithuania: Sauliai, Albik and Rubik. The soil had the following agrochemical characteristics: soil pH_{KCl} 6.7-7.5, available phosphorus 101-232 mg kg^{-1}, and available potassium 65-98 mg kg^{-1}. Additional fertilizing was applied to maintain such agrochemical characteristics during all research years. Samples were taken eight times during the growing season of tubers: in March-June (spring period) and August-November (autumn period). Dry matter (DM) content was determined by drying samples to the constant weight at the temperature of 105°C; N – by Kjeldahl method; P – photometrically after wet digestion in sulphuric acid; K, Mg – by atomic absorption spectrmetry (using an Analyst 200). The data were statistically treated using ANOVA data analysis and the management module of the integrated system Statistica. For the evaluation of the analytical results, one-factor analysis of variance was carried out. Averages of separate treatments were calculated, the standard deviation and the least significant difference at a 95% probability level were estimated using the Fisher's LSD test ($P < 0.05$). The distribution of macronutrients in organic Jerusalem artichoke tubers throughout the plant growing period is largely associated with their organo-

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genesis stage. The highest dry matter and nitrogen content were established in tubers of the cultivars Sauliai and Albik in March, while the highest content of potassium and magnesium was determined in tubers of the cultivars Rubik and Sauliai in May. The highest phosphorus content was in the tubers of cv. Rubik in November.

Keywords: Jerusalem artichoke, tubers, nitrogen, potassium, phosphorus, magnesium.

INTRODUCTION

Tubers of Jerusalem artichoke contain biologically active materials, which makes the plant a promising choice for use in production of fodder, dietary and increased nutritional value foods or high quality pharmaceutical raw material. Plant ontogenesis is characterized by the consistently inherited qualitative, morphological, anatomical, physiological and biochemical changes, and in terms of molecular biology it is consistent performance of evolutionary programme inherited by the organism of a vegetable under specific environmental conditions. The influence of weather conditions on the Jerusalem artichoke is apparent from the early development phases, for example high temperature fluctuations adversely affect the nutrient uptake, dry matter accumulation and photosynthetic productivity (Danilčenko et al. 2008, Ma et al. 2011, Danilčenko et al. 2013).

Concentrations of individual elements are highly dependent on the development stage, climatic conditions, agronomic practice and other factors. The Jerusalem artichoke is considered a species with a relatively high tolerance to water stress, even though its native habitat is not arid. It has been reported to be more responsive to high moisture than water deficit conditions (McLaurin et al. 1999).

Concentrations of macronutrients like nitrogen, potassium, phosphorus or magnesium in the tubers of various Jerusalem artichoke (JA) cultivars vary during the plant growing period (Meijer, Mathijssen 1991). Dormancy of buds of the Jerusalem artichoke tubers appears in organogenesis stage I. The moment when true leaves are formed is when organogenesis stage II begins – primer vegetative phytomers are formed in the growing tip (in March). Until the stem elongation stage (organogenesis stages III-IV), before a sprout forms 200-400 cm^2 leaf assimilation area, nutrition of the Jerusalem artichoke sprout is mesotrophic, i.e. nutrients come from the tuber and are products of photosynthesis (in April, May). During the bud stage (organogenesis stages V-VIII), plants are completely autotrophic, i.e. utilize own products of photosynthesis. At that time, a Jerusalem artichoke plant starts to form new tubers at the ends of the stolon, while over the ground sprouts are ready for a new physiological function, which is flowering (in June, July). Leaf area increases somewhat but in August, at the time of flowering, the plant ceases to grow completely and reaches the peak size during the entire growing season. The tubers grow intensively during organogenesis stage X (in September) but stop growing at organogenesis stage XI (in October), when they accumulate reserve materials extensively. During organogenesis stage XII (in November), material polymerization takes place in tubers, so that inulin is accumulated intensively. Tubers become fully mature. The aerial parts decay (Pugliesi et al. 1993, Barta, Patkai 2007).

The aim of this study was to evaluate the distribution of macronutrients in organically grown Jerusalem artichoke (*Helianthus tuberosus* L.) tubers throughout the plant growing season.

MATERIALS AND METHODS

Field experiments on three Jerusalem artichoke (*Helianthus tuberosus* L.) cultivars: Albik, Rubik (late variety), Sauliai (medium-early variety) were carried out on an organic farm in the south of Lithuania, in 2012-2014. The soil at the experimental site is *Haplic Dystri Arenosols* according to the FAO-UNESCO soil classification. Composite soil samples were taken with the sampling auger from randomly selected points of each treatment replicate, from the surface soil layer of 0-20 cm in depth, before Jerusalem artichoke was planted (in November of 2011). The soil's agrochemical characteristics were as follows: soil pH_{KCl} 6.7-7.5, available phosphorus 101-232 mg kg^{-1}, and available potassium 65-98 mg kg^{-1}.

Additional fertilizing maintained such soil properties during all research years. In the experimental area, the soil was drained by a drainage system and the relief was artificially levelled. The experimental plants were grown in the following manner: Jerusalem artichokes – interlinear – 0.7 m, with the inter-plant distance of 0.3 m, in 4 replications. The replicates were distributed at random. For this reason, the plants were not fertilized additionally nor were they treated with pesticides. The tubers of Jerusalem artichoke were uprooted at the end of every month, i.e. eight times during their growing season: in March-June (spring period) and August-November (autumn period). For analysis, 5 kg of tubers were collected from every replicate. Jerusalem artichoke tubers were washed with water. Samples were weighed and air-dried for a day to reduce the water content. All samples were oven -dried at 70-80°C for 24 h. The dry samples were ground to fine powder using a stainless steel mill. Dry matter (DM) content was determined by drying samples to the constant weight at temperature of 105°C; N – by the Kjeldahl method; P – photometrically after wet digestion in sulphuric acid; K, Mg – by atom absorption spectrometry (using Analyst 200).

Weather conditions during the growing seasons of tubers in 2012-2014 were compared with the perennial 1924-2014 data (data were derived from the Varena Meteorological Station observations). Air temperature and rainfall distribution during the analysed years varied. In 2012 the first half of the plant growing period was wet and warm, while the second one was dry.

In 2013 the beginning of the season (April-May) was cool. June and July were extremely dry, whereas August to October was average regarding rainfall and air temperature. In 2014, May to June appeared to be wet and cool, while the other months were dry or extremely dry and warm.

The data were statistically treated using ANOVA data analysis and the management module of the integrated system Statistica. For the evaluation of the analyses, one-factor analysis of variance was carried out. Averages of separate treatments were calculated, the standard deviation and the least significant difference at a 95% probability level were estimated using the Fisher's LSD test ($P < 0.05$).

RESULTS AND DISCUSSION

The pattern of dry matter accumulation varies due to differences in growth characteristics, photoperiodic requirements, time of planting, location and other factors (Barta, Patkai 2007). In late March, when the growth and development of tubers started, the highest dry matter content (Figure 1) was

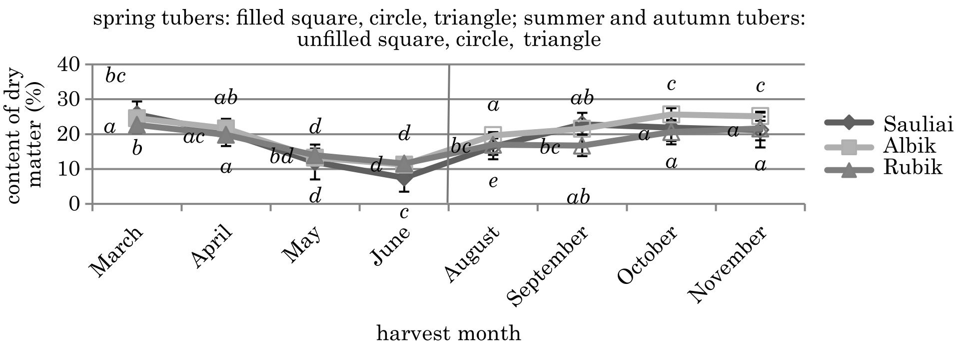

Fig. 1. Distribution of DM contents in organically grown Jerusalem artichoke tubers (%). The same letters in a row show no significant differences between means ($p < 0,05$)

found in tubers of cv. Sauliai (25.7%), followed by cv. Rubik (23.7%), cv. Albik (24.5%). From the beginning of the intense growth and development of tubers, the dry matter content was redistributed to other parts of plants. In April, May and late June, a downward trend in the dry matter content was found in tubers of the cultivars Albik and Rubik (respectively 2.08 and 1.42%). In late August, when new tubers were developed, the highest dry matter content was determined in cv. Albik (Figure 1). Such a tendency to increase the dry matter content continued during the rest of the tuber development stages: their intense growth, when maturing and to the end of the plant growing season.

The high cultivar-specific differences in the dry matter content in tubers are in correlation with the harvest date. The reduction is due to two factors:

the different soil water content and different high transpiration during the physiological development of tubers; number and diameter of tubers are very imported of the dry mattercontent (Somda et al. 1999, Rodrigues et al. 2007, Kocsis et al. 2008). Tuber maturation, growth pattern, minerals and the moisture content assimilated by the plant affect the dry matter content. The lack of moisture reduces tuber and dry matter yield (Barta, Patkai 2007).

Nitrogen, especially its nitric form, is a very mobile and easily leached element, therefore, under unfavourable meteorological conditions, it might be subject to rather big losses (Rodrigues et al. 2007, Kocsis et al. 2008). The efficiency of nitrogen quantitative accumulation depends on many factors: meteorological conditions, soil regeneration, soil cultivation and tillage systems. They all influence the processes of mineralization, nitrification and also denitrification, which change the structure of various nitrogen compounds as well as their accessibility to plants. The human body needs nitrogen to make proteins in muscles, skin, blood, hair, nails and the DNA (Cieslik et al. 2011).

It is stated that nitrogen quantity is not stable during the whole growing period of Jerusalem Artichokes. Our research showed such a tendency as well. Presumably, the cultivar-specific characteristics had some essential influence on the nitrogen quantity. The allocation of phloem-mobile macronutrients (especially N, P, K) is similarly controlled in most plant species. When the pH interval ranges from 5 to 8, plants demonstrate good absorption of nitrogen, sulphur and zinc (Cieslik et al. 2011). The soil where Jerusalem artichokes were growing had the pH between 6.7 and 7.5, which may have had a positive impact on nitrogen accumulation during the growth and development of tubers.

In March, the significantly biggest nitrogen quantity was found in cv. Albik tubers (2.9 g kg^{-1}), followed by the tubers of Sauliai and Rubik tubers (2.09 g kg^{-1}). In the middle of the season, in June, the nitrogen quantity decreased considerably in tubers of the cultivars Sauliai, Albik, and Rubik, by 1.10, 0.85, 0.25 g kg^{-1}, respectively. In the period of May to June in 2014, the weather was wet and cool, which could have caused a decrease in the nitrogen quantity. When new, autumn tubers began to grow, the nitrogen content of tubers increased in June, but not in cv. Sauliai tubers. Before the cold season began, to the end of the plant development in November, the nitrogen quantity in tubers of all the cultivars slightly fluctuated towards an increase. The biggest quantity of nitrogen in November, just the same as at the beginning of the plant growing season, was in cv. Albik tubers – 1.92 g kg^{-1}, while the tubers of cv. Sauliai and cv. Rubik had 1.55 and 0.59 g kg^{-1} of this element, respectively (Figure 2). Phloem-mobile nutrients, such as N, P and K, are the highest in the vegetative parts early in the season and decrease with maturity (Cieslik et al. 2011).

Phosphorus has a particularly important role in plant development. It participates in energy exchange and protein metabolism, it stimulates root

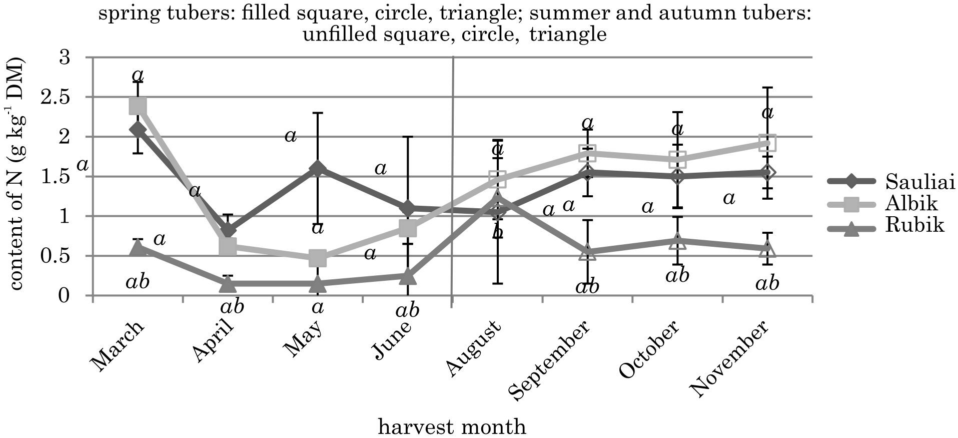

Fig. 2. Distribution of N content in organically grown Jerusalem artichoke tubers (g kg^{-1} DM). The same letters in a row show no significant differences between means (p < 0,05)

growth as well as blossoming/flowering, and it strengthens plant cells. This element participates in the synthesis of carbohydrates and proteins during the process of Jerusalem artichoke tuber formation. Various phosphorus compounds are in the composition of cellular nuclear enzymes and coenzymes. The health benefits of phosphorous for humans include healthy bone formation, improved digestion, regulated excretion, protein formation, hormonal balance, improved energy extraction, cellular repair, optimized chemical reactions, and proper nutrient utilization. The health benefits of phosphorous make it an important constituent of any diet (Somda et al. 1999). The results showed that after dormancy, since March when the intensive growth and development of tubers begins, the highest phosphorus content was in cv. Rubik tubers. Tubers of cv. Sauliai were distinctly different as their phosphoprus content at that time was one-third less than in tubers of the cultivars Rubik and Albik. This amount decreased in April, following the same trend. When new tubers grew from August until the end of November, the highest phosphorus content remained in cv. Rubik (Figure 3). From August until the end of September, when new tubers were developing, the highest phosphorus content is found in cv. Albik tubers (respectively 5.22, 6.71 g kg^{-1}). During the intensive growth and the maturing of tubers at the end of October, the highest phosphorus content was determined in tubers of cv. Rubik (6.71 g kg^{-1}). At the end of the growing season, the amounts of phosphorus in tubers of all the varieties did not differ significantly compared with the content found from in September to October.

The concentration of P in the tubers remained four to eight times as high as in other plant tissues regardless of the harvest date (Cieslik, Baranowski 1997, Cieslik et al. 2005). Similar quantities of phosphorus in Jerusalem artichoke tubers are presented by Somda et al. (1999) – 0.75% DM. This evidence suggests that during the reproductive phase, leaves, stems and

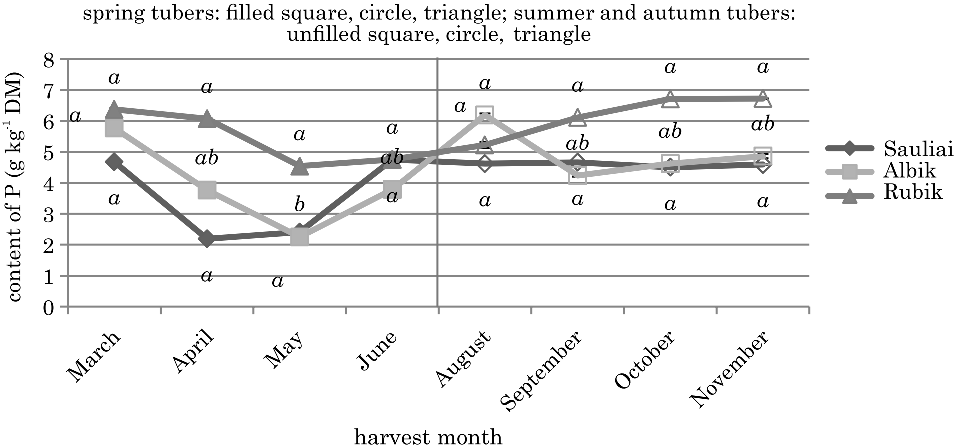

Fig. 3. Distribution of P content in organically grown Jerusalem artichoke tubers (g kg^{-1} DM). The same letters in a row show no significant differences between means (p < 0,05)

other vegetative parts compete for assimilates with the developing tubers, and sometimes previously accumulated carbon and minerals are mobilized and redistributed (Barta, Patkai 2007).

Potassium is known as an activator of enzymes as well as a prominent factor in osmoregulation, which is important for the functions of enzymes and protein metabolism. It helps plants to adapt to unfavourable environmental conditions. The high concentration of K in tubers indicates a relationship between growth and storage capability. In that case, the plant tolerates better any shortage of moisture and becomes more resistant to frost (Barta, Patkai 2007, Wen et al. 2009). Potassium is part of every cell in the body. However, it is often taken for granted, despite its role in maintaining fluid balance, and keeping brain, nerves, heart and muscles functioning normally (Cieslik et al. 2011).

The results showed that in March and at the end of June, when the intensive growth and development of spring and autumn tubers begins, the highest potassium content was in March in tubers of cv. Rubik (39.7 g kg^{-1}) – Figure 4.

The more noticeable quantity increase of this element and later its decrease in tubers was noticed on different dates among all the varieties: cv. Rubik in June, cv. Albik in August, and cv. Sauliai in September. According to other researches, 47.6% of K and 36.5% of P found in the tubers at the end of the season are derived from the stem (Seiler 1990, Wen et al. 2009). This amount decreased following the same trend in April and May. When the new tubers grew from August until the end of November, the highest potassium content remained in tubers of cv. Rubik, while tubers of cv. Sauliai had the lowest cntent of this element most of that time (Figure 4). At the end of the growing season, the K content of tubers did not differ significantly

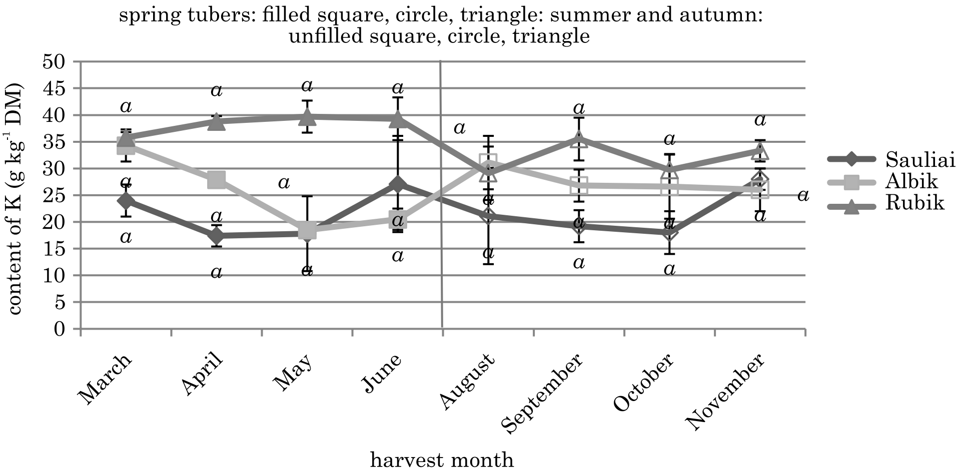

Fig. 4. Distribution of K in organically grown Jerusalem artichoke tubers (g kg^{-1} DM). The same letters in a row show no significant differences between means (p < 0.05)

among the investigated Jerusalem artichoke varieties. The complexity of the general patterns of nutrient element concentration and content in various plant parts during the season is in part related to the general phloem mobility of individual elements and their redistribution to reproductive organs during the latter part of the growth cycle (Somda et al. 1999, Bornet 2001, Wen et al. 2009, Cieslik et al. 2011). According to some research, the potassium content in Jerusalem artichoke tubers can fluctuate from 150 to 650 mg 100 g^{-1} (Seiler 1990, Ma et al. 2011).

Magnesium is an essential plant nutrient. It has a wide range of key roles in many plant functions. One of the well-known roles of Mg is performed in photosynthesis, as this element is a building block of chlorophyll, which makes leaves green. Tubers are especially sensitive to drought in the late season, when water shortages can impact tuber bulking. Water stress early in the season (first third) did not have a significant effect on final tuber yield, whereas stress during the middle developmental period had a pronounced effect on the final yield. The middle third of the growing season is the period during which the most rapid accumulation of dry matter occurs (Barloy, Le Pierres 1988, Barta, Patkai 2007). For humans, magnesium is an essential mineral for being healthy, and is required for more than 300 biochemical reactions in the body. Multiple health benefits of magnesium include transmission of nerve impulses, body temperature regulation, detoxification, energy production, and the formation of healthy bones and teeth (Barloy, Le Pierres 1988).

At the start of the growth and development of tubers in March, a large change in the Mg content of tubers was noticed. The cultivar Sauliai had tubefrs with the highest magnesium quantity in May (19.6 g kg^{-1}). The average magnesium quantities could depend on the warm and wet weather in the spring of 2012. The cultivar Sauliai was growing extremely well and at the end of June the magnesium content in its tubers decreased, eventually being 20-fold lower than at the end of May. The weather was rather wet and cold in the first half of 2014, when sping tubers were developing. The second part of the year was extremely dry and warm. It could have effected small amounts of magnesium in Jerusalem artichokes when autumn tubers were forming. Magnesium activates more than 300 enzymes, and it influences the RNR transposition, i.e. it is responsible for genetic information transfer into protein. It is also actively involved in transformations of carbohydrates, protein and fat. The magnesium content of tubes of the cultivars Albik and Rubik remained stable throughout the growing season: 0.51 - 1.86% and 0.7-1.29 g kg^{-1}, respectively (Figure 5). In spring, Jerusalem artichokes accu-

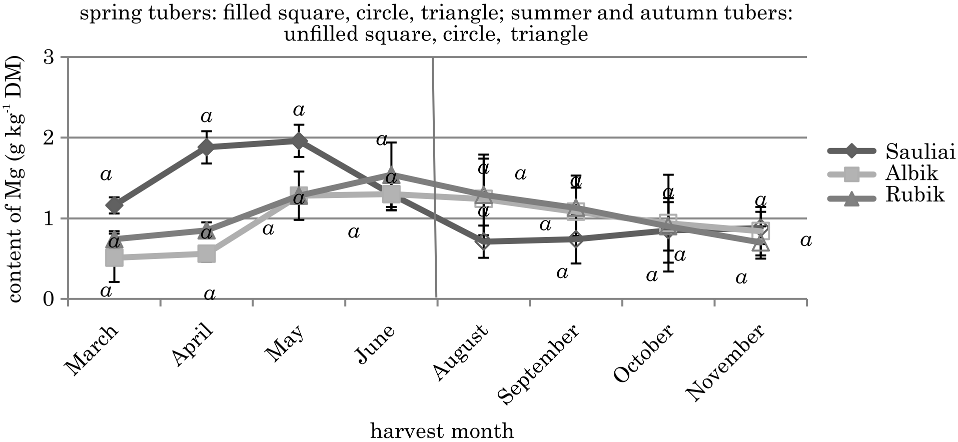

Fig. 5. Distribution of Mg content in organically grown Jerusalem artichoke tubers (g kg^{-1} DM). The same letters in a row show no significant differences between means ($p < 0.05$)

mulate up to 17 mg of magnesium (11%). Possibly conditions such as low soil pH, low temperatures, dry soil conditions and high levels of competing elements, such as potassium and calcium, reduce the availability of magnesium. Under such conditions, magnesium deficiency is more likely. Magnesium deficiency might be a significant limiting factor in crop production (Barloy, Le Pierres 1988).

A previous study on the effect of reproductive growth on vegetative growth and tuber yield showed that reproductive growth restricted vegetative growth and reduced tuber yield and quality. In general, chemical element accumulation in the tubers occurred at the expense of the vegetative organs (Rodrigues et al. 2007).

CONCLUSIONS

The distribution of macronutrients of the organically grown Jerusalem artichoke tubers throughout the growing period is largely associated with their organogenesis stage. The highest dry matter and nitrogen contents were found in tubers of the cultivars Sauliai and Albik: 25.73 g kg^{-1} and 2.39 g kg^{-1}, respectively, in March, while the highest content of potassium and magnesium was in tubers of cvs Rubik and Sauliai: 39.7, 1.96 g kg^{-1}, respectively, in May. The highest phosphorus content was in tubers of cv. Rubik in November 6.72 g kg^{-1}.

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