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THE MINERAL COMPOSITION OF POTATOES AND ITS INFLUENCE ON THE DARKENING OF TUBERS PULP

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Abstract. Potato tubers are one of the most widespread and valuable food products in the world. An important component of their nutrients are minerals. Significant part of them is presented in potatoes in the form of mineral salts that are easily soluble in water. The total quantity of minerals in potato tubers is about 0.4–1.9% of the total weight and includes more than 30 elements. The objects of the study were five varieties of potato tubers that according of the length of the growing season belong to two ripeness groups: medium-early (Satina – control, Red Lady, Mozart) and medium-ripe (Aroza – control, Sifra). The quantitative composition of macro- and microelements (K, Ca, Mg, Na, Al, Fe, Mn, Ni and Cr), content of heavy metals (Cu, Zn, Pb and Cd) was determined and influence of some mineral substances (K, Fe and Cu) on the resistance of raw and cooked potato tubers to different types of darkening was assessed. Mineral substances were determining by corpuscule-emission spectrometry with inductively-linked plasma. Potassium had the highest quantity among macronutrients. Its amount changed from 5860 mg in the Sifra variety to 3740 mg in the Satina. Magnesium content was averaged 200 mg, and calcium ranged from 68 mg in Red Lady to 159 mg in Cifra. The main quantity of microelements was represented by aluminum and iron. The content of heavy metals in potato tubers did not exceed the permissible concentrations, and in some cases it was lower: lead was found in the traces quantities, zinc was almost twice less and copper was in five times lower than the maximum permissible concentration. Direct relationship between the amount of potassium and the degree of darkening of cooked tubers was revealed: if its amount in the tubers increased therefore resistance to darkening of potatoe increased too. It was established that iron and copper can also affecting on the processes of darkening in potato tubers, although a clear relationship between their quantity and the depth of these processes was not found. The reason may be the imperfection of the visual method of detecting of degree of darkening and the possible formation of complex compounds with these minerals, as a result of which they become unavailable for the reaction.

Key words: potato tubers, mineral composition, ripeness group, heavy metals, resistance to darkening.

Introduction. Formulation of the problem

The potato plant (*Solanum tuberosum* L.) became widespread throughout the world due to its wide

cultivation area, resistance to environmental conditions, economy, large number of varieties and versatile application [1-4]. It is the fourth crop in the world in total annual production about 300 million

t/year after the cereals rice, wheat and maize and the only major food crop that is a tuber [5]. Potato is an important global crop as it may be to transfer into many products and thus guarantee the food security of the country [6].

Despite the fact that potatoes account only about 2% of the energy resources of food in the world, but they are still a main food for many countries. Potatoes in the human diet in developed countries are about 540 kJ (130 kcal) per day, and in developing countries are 170 kJ (42 kcal) [7].

Potato tubers are an important source of valuable substances for human nutrition, such as carbohydrates, dietary fibers, vitamins and etc. [8-11]. They due to the nutritional have one of the first places, and among the substances present there, macro- and microelements have an important place. A person as a result consumption of the daily rate of potatoes (about 300 g of tubers) may be to cover the body's significant need for minerals that presented in easily dissolved forms.

The high content of potassium in potato tubers help to hold the necessary level of acidity in the body, phosphorus takes part in the formation of bone tissue, calcium salts give it stability, and iron takes part in the formation of hemoglobin.

The certain mineral substances can be changed of the quality of potato tubers at the storage and processing that lead to darkening of the their pulp.

Complex studies about effect of period vegetation of potatoes (ripening group) on the content of macro elements, microelements and heavy metals in tubers and established the impact of mineral composition on the tendency of tubers to the different kinds of darkening have not been conducted.

Analysis of recent research and publications

Mineral substances set up about 0.4-1.9% of the weight of raw potato tubers and include more than 30 different elements [12-14].

The quantity of minerals and their elemental composition in potato tubers is not constant and change depending on the variety [15,16], climatic conditions [17,18], soil type [19], agricultural techniques, growing and harvesting technologies [20-23], duration and storage conditions [24] and etc.

Mineral substances distributed unevenly. Most of them are in the peel: about 17% zinc, 34% calcium and 55% iron [25-26].

The first place among the mineral substances in the potato tubers is potassium; the content of it is 50-60% of ash [2,11].

Phosphorus and chlorine set up the second and third place among the mineral substances of tubers and make up about 15% in the sum. The amount of calcium and magnesium practically remains constant (up to 6%).

Discoloration (different types of darkening) of potato tubers is one of the most common defects observed in the raw, cooked and processed

tubers [19,27-29]. This phenomenon negatively effects on the appearance and marketability of the product [30-32] and, in addition, can be to reduce its nutritional and biological value [17,33].

Discoloration can be of different nature: fermentative (raw tubers) and non-fermentative (cooked and processed tubers) [34-35].

Mineral substances that are present in potato tubers in sufficiently large quantities may be to influence as a positive as a negative on the depth and intensity of the processes of tuber darkening [33].

Some investigations indicate on a possible negative effect of magnesium on the processes of darkening of potato tubers [36].

There are different opinions about the influence of calcium on these processes. Some authors, taking into account the genetic variability of varieties, consider that calcium plays an important role in the quality of potato tubers, especially in the case of necrosis and discoloration. It, in combination with other minerals, such as magnesium, can be a positive effect on the organoleptic properties of raw and processing potatoes. Considering the significant effect of calcium on plant cells, it may be to concluded that this mineral can directly or indirectly may be to effect on the quality of potato tubers and, in particular, on the tendency to darkening [36].

Karlsson et al. [37] studied the effect of calcium fertilization (0 and 28 kg·ha⁻¹) with different levels of nitrogen (0.23 and 46 kg·ha⁻¹) on enzymatic browning in bruised tubers (without skin abrasion) in the cultivars of Russet Burbank, Atlantic, Snowden, Superior and Dark Red Norland during 1999–2001. As a result, they established that browning susceptibility was more depend on from the cultivar and season than calcium concentration.

A positive effect of calcium chloride during blanching of potato tubers was determined. The CaCl₂ replaces iron in the iron-chlorogenic acid complex and copper in the copper-polyphenol oxidase complex and thus eliminate color changes in both raw and cooked tubers [34].

Most researchers noted that the main minerals that may be to influence on the processes of darkening in potato tubers are potassium, iron and copper [33].

The **purpose** of the research is establishing the mineral composition of potatoes of different varieties, which belong to different groups of ripeness and investigation of the effects of some elements on the tendency to enzymatic and non-enzymatic darkening of the tubers.

To achieve the purpose, the following **objectives** were formulating:

- to investigate the macro elements and microelements of potato tubers of different varieties that belong to different ripeness groups;
- to determine the effect of the ripeness group on the level accumulation of heavy metals in potato tubers;

– to establish the effect of certain minerals of potatoes on the tendency to enzymatic and non-enzymatic darkening of the tubers.

Research materials and methods

The five varieties of potatoes of companies of HZPC (Netherlands) and Solana (Germany) that belonging to two ripeness groups: medium-early (Satina – control, Red Lady, Mozart) and medium-ripe (Aroza – control, Sifra) were researched.

The mineral composition of potato tubers was investigating in the Ukrainian Laboratory of Quality and Safety of Products of Agriculture of NULES of Ukraine. The mineral elements of K, Ca, Mg, Na, Fe, Mn, Cu, Zn, Al, Ni, Pb, Cr and Cd in the potato tubers were determine by corpuscule-emission spectrometry with inductively-linked plasma. The quantity of each of the element was expressed by mg per 100 g of dry matter (DM).

Resistance to darkening the pulp of raw tubers of potatoes. Resistance to darkening was set after determining the color of cutted tuber and it estimating through some time. After 10 min, 1, 2 and 3 h, the tubers were inspected and characterized the degree of darkening [38-39].

Scales for evaluation have nine etalons. Every etalon corresponds to a certain assessment (in points): 9 – color of the pulp is pure without any shade; 8 – the pulp has a slightly grayish tinge; 7 – the pulp has a grayish tinge; 6 – light-gray pulp; 5 – pulp saturated gray; 4 – dark-gray pulp; 3-1 – pulp from dark-gray to black.

Resistance to darkening of the pulp of boiled tubers. The studies were performed by visually evaluating of boiled potato tubers after cleaning of peel: 5 points – the pulp does not darken within 2 h after cooking; 4 points – weak darkening; 3 points – average darkening; 2 points – significant darkening; 1 point – darkens very too [40].

Statistical data processing. All the numerical data obtained were processed with the Excel program from the service software package Microsoft Office 2007. The experiment was performed in three repetitions. The data are reported as mean values $\pm$ standard deviation (SD).

Results of the research and their discussion

The mineral composition of potato tubers of the different varieties and ripeness groups. The investigation of mineral composition in potato tubers of 5 varieties of the HZPC (Netherlands) and Solana (Germany) companies, that according of the length of growing season belong to two ripeness groups: medium-early (Satina – control, Red Lady, Mozart) and medium-ripe (Aroza – control, Sifra) were conducted by authors. The researches were conducted after passed of potatoes tubers the treatment period before the storage. In potato tubers were determined the content of macro elements

(potassium, calcium, magnesium and sodium) (Table 1) and microelements (aluminum, iron, manganese, nickel and chromium) (Table 2).

Table 1 – The macro elements of potato tubers of the different varieties and ripeness groups, mg per 100 g DM (n=3, p<0.05)

Varieties	K	Ca	Mg	Na
medium-early				
Satina – control	3740 $\pm$ 100	145.36 $\pm$ 3.87	250 $\pm$ 30	20.17 $\pm$ 3.38
Red Lady	5020 $\pm$ 70	67.53 $\pm$ 0.96	210 $\pm$ 20	30.15 $\pm$ 0.40
Mozart	4880 $\pm$ 130	123.75 $\pm$ 6.97	180 $\pm$ 20	31.15 $\pm$ 1.37
medium-ripe				
Aroza – control	4970 $\pm$ 30	152.23 $\pm$ 8.56	190 $\pm$ 20	28.47 $\pm$ 0.77
Sifra	5860 $\pm$ 120	159.54 $\pm$ 5.81	220 $\pm$ 30	19.14 $\pm$ 0.76

Table 2 – The microelements of potato tubers of the different varieties and ripeness groups, mg per 100 g DM (n=3, p<0.05)

Varieties	Al	Fe	Mn	Ni	Cr
medium-early					
Satina – control	18.76 $\pm$ 0.12	20.89 $\pm$ 4.51	1.93 $\pm$ 0.21	1.93 $\pm$ 0.21	0.78 $\pm$ 0.07
Red Lady	51.89 $\pm$ 0.41	38.05 $\pm$ 1.50	4.55 $\pm$ 0.05	4.55 $\pm$ 0.05	0.28 $\pm$ 0.06
Mozart	48.83 $\pm$ 5.44	35.19 $\pm$ 4.07	1.68 $\pm$ 0.10	1.68 $\pm$ 0.10	0.62 $\pm$ 0.06
medium-ripe					
Aroza – control	34.23 $\pm$ 2.48	26.06 $\pm$ 1.77	2.35 $\pm$ 0.03	2.35 $\pm$ 0.03	0.62 $\pm$ 0.06
Sifra	36.73 $\pm$ 1.02	24.25 $\pm$ 5.61	1.81 $\pm$ 0.27	1.81 $\pm$ 0.27	0.78 $\pm$ 0.07

The results of our research on the quantitative composition of macro elements in potato tubers agree with the results of other researchers, who note that potassium has the largest amount in this group of elements [6,11,12]. Its amount varied in the wide range from 3,740 mg in tubers of the Satina variety to 5,860 mg in the Sifra. Potato tubers of other varieties contained an average about 5,000 mg of potassium. It should be noted that the increase in the growing season contributed to the accumulation of a larger amount of potassium and changed by 840–1,230 mg depending on the variety. However, in our opinion, the obtained results indicate that the main factor that determines the quantity of potassium is varietal characteristics, since the potato tubers were grown in the same conditions and on the same organo-mineral background. The same opinion is held by other researchers. They indicate that the quantity of potassium that accumulation in potato tubers determined by the genetic characteristics of the variety [15]. Other factors (growing technology and etc.) do not have a significant effect on the accumulation this element [16].

The second place, among the macro elements in the potato tubers was magnesium. The other authors confirmed our results [6,16,31]. Magnesium content changed depending on the variety and ranging from 180 mg in the Mozart variety to 250 mg in the Satina (Table 1). The influence of the ripeness group on the amount of accumulation of this element was not established.

Potato tubers depend on the calcium content were divided into two groups: 68 mg (Red Lady) and 123-159 mg (Sifra, Satina, Mozart and Aroza) (Table 1). In the case of this element, a clear dependence was observed between the length of the growing season (ripeness group) and the amount of accumulated calcium: in the group of medium-ripe varieties, its content exceeded that of medium-early varieties by 14.18–84.7 mg, depending on the variety.

The amount of sodium did not depend on the ripeness group of potatoes and changed only by varieties within small limits from 19.14 mg in Sifra to 31.15 mg in Mozart.

Among microelements, aluminum was the most quantity in potato tubers. In the varietal section, its amount in some cases changed almost twice: from 18.76 mg in the Satina variety to 51.89 mg in the Red Lady. Potato tubers of other varieties had aluminum content at the level of 34–48 mg. Correlation between the quantity of aluminum and ripeness group was not observed.

The microelement iron was also accumulated in significant quantities in potato tubers. The content of this element ranged from 20.89 mg in the Satina variety to 38.05 mg in the Red Lady. We did not observe any dependence between the ripeness group and the quantities of this element as in the case of aluminum.

Other microelements (manganese, nickel and chromium) were presented in small amounts from 0.08 to 4.55 mg and therefore, on our opinion, have not a significant effect on both the nutritional value of potato tubers and the processes that take place in them during of storage or processing.

The heavy metals of potato tubers of the different varieties and ripeness groups. The main mineral contaminants of food raw materials are heavy metals. The content of heavy metals in food products and food raw materials should not exceed the permissible levels established by sanitary rules and norms (SanPiN), medical and biological requirements and sanitary standards for the quality of food raw materials and food products No. 5061 (Ukraine). There are about 20 toxic heavy metals, but they are not equally toxic. Only the content of cadmium, copper, mercury, lead, zinc, tin, arsenic and iron is controlled in food products and food raw materials, that also include potato tubers. We determined only four elements in our researches: cadmium, copper, lead and iron. According to established standard norms, the amount of these elements in potato tubers should not exceed the maximum permissible concentration (MPC):

zinc – 10 mg/kg, copper – 5 mg/kg, lead – 0.5 mg/kg, cadmium – 0.03 mg/kg) (GOST 30178-96, 1996).

The results of investigation of the content of heavy metals in potato tubers are presented in the Table 3.

Table 3 – The content heavy metals in the potato tubers of the different varieties and ripeness groups, mg per 100 g DM (n=3, p≤0.05)

Varieties	Cu	Zn	Cd	Pb
medium-early				
Satina – control	0.89±0.01	3.44±0.05	0.037±0.002	<0.004
Red Lady	1.26±0.07	3.66±0.10	0.020±0.002	0.008±0.01
Mozart	0.97±0.06	3.60±0.36	0.026±0.002	<0.004
medium-ripe				
Aroza – control	1.35±0.04	5.40±0.12	0.034±0.002	<0.004
Sifra	1.11±0.04	5.30±0.11	0.017±0.001	0.04±0.01

Analyzing the obtained results, it can be seen that the content of heavy metals in potato tubers does not exceed the established norms, and in some cases the obtained result is even several times lower. Thus, the amount of zinc in the potato tubers of experimental varieties was from 3.44 to 5.4 mg, which is almost two times less than the MPC, and copper - from 0.89 to 1.35 mg, which is less than the MPC by almost seven times. The amount of cadmium in the tubers ranged from 0.017 to 0.037 mg, which almost does not exceed the norm, and lead in general was less than 0.04 mg (MPC up to 0.5 mg). The influence of maturity group on the amount of accumulation of heavy metals was not established in our studies.

The effect of mineral substances on the degree of darkening of potato tubers. Some mineral substances can affect the marketable and culinary qualities of potato tubers, in particular, the resistance to darkening of the pulp. One of the reasons for the internal blackening of potato tubers can be an excess of tyrosine, which is caused by a potassium deficiency. An excess of tyrosine causes darkening of the pulp when cooking potatoes [42].

The positive effect of potassium on the quality of potatoes is explained by the fact that it increases resistance of tubers to diseases during long-term storage, improves organoleptic properties (taste, consistency) and reduces susceptibility to various types of darkening, that contributes to increasing the yield of marketable products [33].

We conducted a comparative analysis between the resistance of cooked tubers to darkening and the amount of potassium in potato. The results of these investigations are presented on the Fig. 1.

As can be seen from Fig. 1 there is a clear regularity between the amount of potassium and the resistance of tubers to darkening. The difference in quality is especially visible between the tubers of Sifra and Satina varieties that have the highest and lowest potassium content.

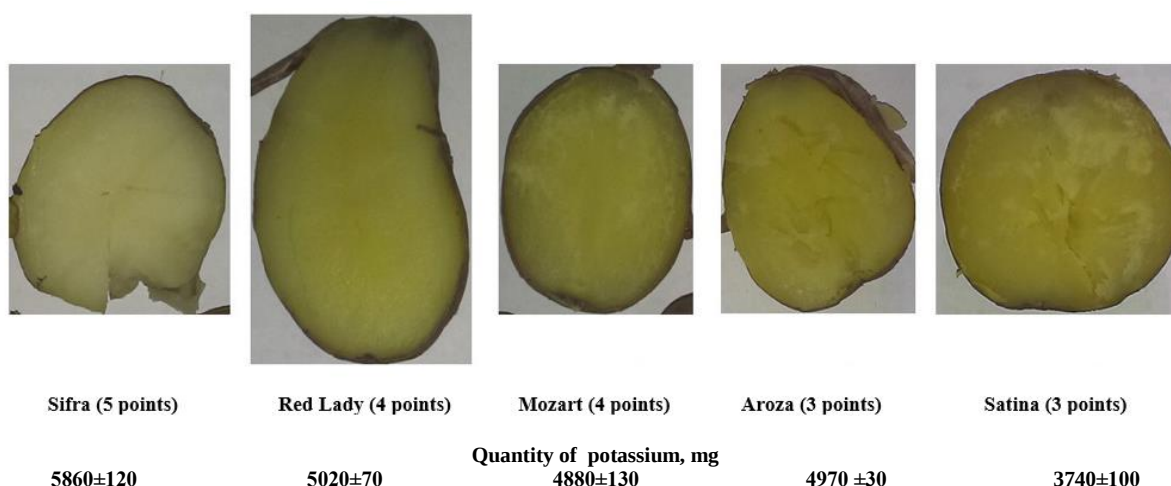


Figure 1 – Correlation between resistance to darkening of the pulp of boiled potato tubers and the amount of potassium

The reason for the non-enzymatic darkening of the pulp of raw tubers can be the reaction between iron or copper with chlorogenic acid and formation of dark-colored compounds [43,44].

A comparative analysis between the resistance of raw tubers to darkening and the amount of iron and copper in potato tubers presented in the Table 4.

Table 4 – Resistance of raw potato pulp to darkening depending on the amount of iron and copper (n=3, p≤0.05)

Varieties	Degree of darkening, average, points	Fe, mg	Cu, mg	Fe+Cu, mg
medium-early				
Satina – control	5.5	20.89	0.89	21.78
Red Lady	8	38.05	1.26	39.31
Mozart	8.5	35.19	0.97	36.16
medium-ripe				
Aroza – control	6.5	26.06	1.35	27.41
Sifra	8.75	24.25	1.11	25.36

The results of the our researches did not allow to establish a clear direct relationship between the amount of iron and copper and the degree of darkening of raw potato tubers. Thus, the Red Lady variety, that has the largest amount of iron and copper (a total of 39.31 mg), has a high resistance to darkening (8 points). Potatoes of the Mozart variety with an amount of Fe+Cu 36.16 mg had even greater resistance to darkening – 8.5 points. The potatoes tubers of Sifra variety that had the highest resistance to browning (8.75 points), contain 25.36 mg (Fe+Cu), but it was not the lowest result. Therefore, direct relationship between the amount of these metals and the degree of darkening we did not appearing.

In our opinion, such results are explained by the fact that in potato tubers, along with the processes of formation of dark-colored substances (the reaction between iron and copper with chlorogenic acid), other reactions take place in, where these substances participate. As a result, their negative effect were excluded.

Another reason may be the errors in the visual assessment of the degree of darkening. Other methods of assessment: spectrophotometry, high-performance liquid chromatography [45], gas chromatography [46], digital image evaluation technology [47] may be more correctly establish tendencies about influence of the concentration of copper and iron metals on the degree of darkening of potato tubers.

Conclusion

The researches of the content of mineral substances in potato tubers of different varieties that belong to different ripeness groups were conducted.

It was established that potassium, magnesium and calcium had the highest content among macro elements. The potassium content changed depending on the variety and ripeness group from 3,740 mg in the tubers of the Satina variety to 5,860 mg in the Sifra. Despite the fact that some cultivars in the medium-ripe group accumulated a slightly larger amount of K than most cultivars of the medium-early, we explain by genetic characteristics of the cultivar that play a main role in the accumulation of this element. The quantity of magnesium in potato tubers was high and changed from 180 mg in Mozart to 250 mg in Satina. There was no correlation between the ripeness group and the quantity of its accumulation. According to the quantity of calcium, potato tubers divided into two groups: 67.53 mg (Red Lady) and 123.75–159.54 mg (Sifra, Satina, Mozart and Arosa). In this case, there was a clear relationship between the ripeness group and the

quantity of accumulation, but we think, that the decisive value belongs to the variety.

Among microelements, the highest content in potato tubers was aluminum (up to 51.89 mg in the Red Lady variety). Other varieties accumulated 34.23 till 48.83 mg. The iron content ranged from 20.89 mg in the Satina variety to 38.05 mg in the Red Lady. Other microelements were contained in small amounts and therefore did not have a significant impact on both the nutritional value of potato tubers, physiological and biochemical processes. The influence of ripeness group on the amount of accumulation of these substances was not found.

The quantity of heavy metals in potato tubers did not exceed of MPC, and in some cases was lower: lead was detected in traces quantities; zinc was almost two times less, and copper was five times less than MPC. The influence of the ripening group on the accumulation of heavy metals was not detected.

A direct relationship between the quantity of potassium and the degree of darkening of the cooked potatoes tubers was established: if it more accumulates in the tubers, therefore they had more resistant to darkening. Thus, Satina, that contained 3,740 mg of potassium, had the least resistance to darkening (3 points), and Sifra, with an amount of 5,860 mg, had the highest resistance (5 points).

Iron and copper may be affected on the darkening processes in potato tubers, but a clear relationship between their amount and degree of darkening was not established. In our opinion, the cause may be other substances that blocking the action of these metals. Another reason is imperfect visual method of determination of darkening. Therefore, further researches can be directing to the study of various factors that may influence on the reactions with these metals, and to utilize another methods of darkening determination.

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МІНЕРАЛЬНИЙ СКЛАД БУЛЬБ КАРТОПЛІ ТА ЙОГО ВПЛИВ НА ПОТЕМНІННЯ М'ЯКУША

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Анотація. Бульби картоплі є одними із найбільш розповсюджених та цінних продуктів харчування в усьому світі. Важливою складовою їх поживних речовин є мінеральні речовини. Значна їх частина знаходиться у картоплі у вигляді мінеральних солей, які легко розчинні у воді. Загальний вміст мінеральних речовин у бульбах картоплі становить близько 0,4–1,9% від загальної маси і включає більш, ніж 30 елементів. Об'єктами дослідження були п'ять сортів бульб картоплі, які за тривалістю вегетаційного періоду належать до двох груп стиглості: середньоранні (Сатіна – контроль, Ред Леді, Моцарт) та середньостиглі (Ароза – контроль, Сіфра). В результаті проведених досліджень було визначено кількісний склад макро- та мікроелементів (K, Ca, Mg, Na, Al, Fe, Mn, Ni та Cr), вміст важких металів (Cu, Zn, Pb та Cd) та оцінено вплив деяких мінеральних речовин (K, Fe та Cu) на стійкість сирих і варених бульб картоплі до різного роду потемнінь. Мінеральні речовини визначали методом атомно-емісійної спектроскопії з індуктивно зв'язаною плазмою. Серед макроелементів найбільше було калію. Його кількість змінювалася від 5860 мг у сорту Сіфра до 3740 мг у сорту Сатіна. Вміст магнію в середньому становив 200 мг, а кількість кальцію змінювалася від 68 мг у Ред Леді до 159 мг у Сіфрі. Основна кількість мікроелементів була представлена алюмінієм і залізом. Вміст важких металів у бульбах картоплі не перевищував допустимих концентрацій, а в окремих випадках був значно нижчим: свинцю виявлено сліди, цинку – майже вдвічі менше, а міді – у п'ять разів менше від гранично-допустимої концентрації. Виявлено прямий зв'язок між кількістю калію та ступенем потемніння варених бульб: із зростанням його кількості у бульбах, збільшувалася їхня стійкість до потемніння. Встановлено, що залізо та мідь також можуть впливати на процеси потемніння в бульбах картоплі, хоча чіткої залежності між їхньою кількістю та глибиною протікання цих процесів не виявлено. Причиною може бути недосконалість візуального метода визначення ступеня потемніння та можливим утворенням комплексних сполук із цими речовинами, в результаті чого вони стають недоступними для реакції.

Ключові слова: бульби картоплі, мінеральні речовини, група стиглості, важкі метали, стійкість до потемніння.