Original scientific paper
UDC 635.128:581.192

THE VARIATION OF MINERAL CONTENT IN CELERY ROOT DURING THE TREATMENT IN TWO OSMOTIC SOLUTION

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Abstract

In this study, the changes in the content of potassium, magnesium, calcium and iron of celery root during osmotic treatment were evaluated and compared for different process conditions. The main objective was to investigate the possibility of enhancing the mineral content of treated material using sugar beet molasses as osmotic medium. Celery (*Apium graveolens*) has been known as a traditional medicinal plant or spice, and as an excellent source of minerals is vital for the maintenance of human health. During conventional drying of celery, high temperature and the presence of oxygen, can negatively affect the composition of the minerals. In order to preserve health benefits substances, osmotic treatment which involves immersion of the raw material in concentrated solutions on the mild temperatures, has been suggested. Osmotic treatment implies three simultaneous flows: migration of water from the submerged material into the surrounding solution, penetration of dissolved substances from the solution into the plant tissue and leaching out of the tissue`s own solutes. Due to the rich nutrient and mineral composition, molasses as osmotic solution might contribute an improvement to the nutritive quality of the treated products.

Osmotic treatment of celery root in two osmotic solutions (mixture of sucrose and sodium chloride aqueous solution and sugar beet molasses), at three temperatures (20, 35 and 50 ^{0}C), and immersion periods (1, 3 and 5 h) was performed. The influence of used osmotic agent, temperature and immersion time of the change of mineral content of the samples was investigated. The content of analyzed mineral matters in fresh and treated samples was determined by atomic absorption spectrophotometer according to the standard methods.

The results revealed observable improvement of the mineral content of celery root treated in molasses, while the samples treated with sucrose and sodium chloride solution showed reduction of the examined mineral matters. After 5 h of osmotic treatment in molasses, on the 50 ^{0}C, the content of minerals in samples (mg/100 g) was increased: for K from initial 365.85 to final 766.52; for Mg from 22.42 to 36.98, for Ca from 44.12 to 57.36 and for Fe from 0.76 to 0.91.

It can be concluded that molasses due to the rich mineral composition contributes to improving the nutritive quality of the treated products.

***Key words**: Osmotic treatment, Celery root, Mineral content, Sugar beet molasses.*

1. Introduction

Celery (*Apium graveolens)* has long been important in human nutrition as a healthy vegetable and spice, and also as a medicinal plant with numerous therapeutic properties in traditional medicine and pharmacology [1]. The presence of flavonoids and other phenolic compounds, vitamins, pigments and minerals is the most responsible for the healing effects of celery. Celery is rich in minerals essential for the normal functioning of almost all biochemical and enzymatic processes in the body, such as: magnesium, potassium, calcium, zinc, phosphorous, and iron [2,3]. The root of the celery contains 11.4% of dry matter, 0.94% of minerals, of which the potassium has the highest amount (one third of all minerals present) [4]. Potassium from celery contributes to its diuretic effect and can reduce blood pressure. Calcium, potassium and magnesium strengthen the immunologic system, while along with magnesium, iron is effective in alleviating the effects of anemia. Celery possesses the ideal quantities of iron and magnesium to prevent oncological diseases from progressing [5, 6].

The high percentage of water is the main reason for the perishable or damaging effect of the sensory and nutritive characteristics of fresh celery root after a short period. To remove water, conventional drying methods involve high temperatures and the presence of oxygen, which can negatively affect the nutritive composition of dried product [7, 8]. In order to preserve health benefits substances, osmotic treatment which involves immersion of the raw material in concentrated solutions on the mild temperatures, has been suggested [9]. Osmotic treatment is the phenomenon of mass transfer from plant material with a lower concentration of solute in hypertonic solution with higher solute concentration, through the cell walls and the surface plant tissue which acts as a semi-permeable membrane, in order to achieve the concentration equilibrium on both sides of the membrane. In this multicomponent diffusion process two main counter-current flows occur: migration of water from the submerged material into the surrounding solution and penetration of dissolved substances from the solution into the plant tissue [10, 11]. Simultaneously, along with water flow some components of plant such as minerals, vitamins, organic acids, etc. also migrate towards the osmotic solution. Leaching out of the tissue`s own solutes, although quantitatively minor affects the nutritive value of osmotic dehydrated products [12].

After osmotic treatment, a partially dried product is obtained, enriched with nutritive components of the solution used. Therefore, the choice of osmotic solution is very important and should depend on the expected degree of dehydration and the desired sensory and nutritional properties of dehydrated products [13]. The two most widely used solutes for hypertonic aqueous solution in osmotic treatment are sucrose and sodium chloride. Some authors have reported the advantages of using the ternary solution (mixtures of sugars and salts), in terms of achievement higher water losses and providing an increase in the total solution concentration, without reaching the saturation limits [14]. In recent research, sugar beet molasses, by-product in sugar industry and highly concentrated dark, viscous syrup is used as osmotic solution. Due to the rich nutrient and mineral composition, molasses has the potential to contribute an improvement to the nutritive quality of the treated products in osmotic treatment. It is known that sugar beet molasses contains significant amounts of minerals, especially potassium, calcium, iron and magnesium. Particularly significant is the fact that all mineral components in the molasses are in dissolved state and the potassium is in much greater quantities than all other cations (about 4g K/100 g molasses) [15, 16, and 17].

In this study, the changes in the content of potassium, magnesium, calcium and iron of celery root during osmotic treatment were evaluated and compared for different process conditions. The main objective was to investigate the possibility of enhancing the mineral content of treated material using sugar beet molasses as osmotic medium.

2. Materials and Methods

For the experiment, fresh celery root was purchased at local grocery, immediately before use. Celery root was cut into cubes, dimension of approximately 1 x 1 x 1 cm. In this work, two different solutions were used as osmotic mediums. The first one, aqueous ternary osmotic solution (S_1) was prepared on the basis of the maximum solubility of sodium chloride (350 g) and sucrose (1,200 g) in 1 kg water at 20 ^{0}C. Three components were mixed in the ratio: sucrose 47.04%, NaCl 13.72% and distilled water 39.2%, using an electric propeller mixer. The second osmotic solution, concentrated sugar beet molasses, was obtained from the sugar factory Crvenka, Serbia, and was used in experiments without additional preparation (in the further text indicated as S_2).

Table 1. Basic chemical composition of sugar beet molasses applied in the research

Parameter	%/mg/100 g
Dry matter content, (%)	81.54
Sucrose, (%)	50.07
Total reducing sugars, (%)	52.23
Invert sugar, (%)	0.56
Potassium, mg/100 g	4060.07
Sodium, mg/100 g	590.21
Calcium, mg/10 0g	185.31
Magnesium, mg/100 g	85.39
Iron, mg/100 g	4.41
Zinc, mg/100 g	0.98
Manganese, mg/100 g	0.25

The samples of fresh celery root were immersed in 18 laboratory jars filled with these two solutions, where the material to solution ratio was 1 : 5 (w/w) in all cases. Osmotic treatment was carried out at three different temperatures of 20 ^{0}C, 35 ^{0}C, and 50 ^{0}C, which were maintained constant in incubator (In 160, Memmert, Schwabach, Germany). After determining the intervals of immersion time (1, 3, and 5 hours), samples were taken out from the osmotic solutions, washed with water and blotted with paper towels to remove adhering solution and excessive water from the surface. The content of analysed minerals K, Mg and Ca in fresh and osmotically treated samples was determined by atomic absorption spectrophotometer according to the standard method SRPS EN ISO 6869:2008 [18]. Determination of the content of Fe in fresh and treated celery root samples was done in accordance to the FINSLab-5.4-3M-004/13 method [19]. Each measurement was performed in triplicate.

The results were interpreted based on Tukey's HSD (honestly significant distance) test, at a significance level of $p < 0.05$, at a confidence level of 95%. Post-hoc Tukey HSD test is performed after a two-factor variance analysis (ANOVA). First, the ANOVA test determines the influence of the process parameters (independent variable) on system responses, and the Tukey HSD test determines the statistical significance of the difference between the mean values of the individual samples, due to the change in the value of the process parameters. Tukey's HSD test shows how much any two mean values should be distant to be statistically different. For the difference of the two mean values greater than the standard deviation (SD), are proven to be statistically significant with this test [20]. Descriptive statistical analysis, using Microsoft Excel 2007 and Statistica 10 (StatSoft, Tulsa, Oklahoma) software [21], was used to calculate mean, standard deviation, and variance of variables.

3. Results and Discussion

In the diagrams (Figures 1 - 4) experimental values (mean values of three measurements ± standard deviation) of mineral content (K, Mg, Ca and Fe) in fresh celery root (control sample) and samples, osmotically treated with solutions S_1 and S_2 were presented. Experimental data represent changes in the content of the observed minerals in the treated samples compared to the control, depending on the value of the process parameters (t and T) varied according to the adopted experimental plan (Table 2.).

The values of the mineral matter content in the control and osmotically treated samples were expressed in mg/100 g of the initial sample. The data in the diagrams also show the results of a post-hoc Tukey HSD test, based on which the significance of the differences in the contents of the investigated minerals, between the individual celery root samples was assessed. It was found that most of the samples were statistically significantly different at $p < 0.05$, which proved that the tested samples were sufficiently diverse to approach statistical analysis.

On the diagram in Figure 1., a change in the content of K during osmotic treatment of the celery root samples in osmotic solution S_1 and S_2 was shown. By comparison of the samples, dehydrated in different time periods (1, 3 and 5h) and at different temperatures (20, 35, and 50 ^{0}C) in the S_1 solution, it was noted that increasing the duration of the process and increasing the temperature leads to a gradual loss of K in the samples. In accordance with the trend of reducing the content of K with increasing process temperature and immersion time, the lowest content of K was measured in the samples treated in S_1 at 50 ^{0}C after 5 h.

On the other hand, during osmotic treatment in the S_2 solution, the content of K increases relative to the initial value in the root samples. The increase in this mineral in the treated samples is supported by the fact that the sugar beet molasses contains about 4,000 mg/100 g of potassium, and it is certain that by mass transfer during the process, potassium from molasses diffuses into treated plant tissues. By increasing the process temperature and the immersion time in the molasses, the values of the K content in all osmotically treated samples evenly grow. After 5 h of osmotic treatment in molasses, at the 50 ^{0}C, the content of K in the sample was doubled: from initial 365.85 mg/100 g to final 766.52 mg/100 g.

Based on Figure 2 it was observed that the osmotic treatment of the celery root in the solution S_1 affects the reduction of the content of Mg in regard to the content in fresh samples. It is noticed that, in relation to the control sample, already after the first hour of the process, there was a significant reduction ($p < 0.05$) of Mg content in the samples immersed in S_1. By further prolonging the process duration and increasing the temperature, the decreasing trend of Mg content in samples continues.

In contrast, in samples of celery root submerged in S_2 solution, it is evident that enrichment of samples with Mg occurs, in proportion to the increase in the value of process parameters. The most pronounced increase in Mg content (about 1.5 times) is observed on the highest process parameters: from 22.42 mg/100 g to 36.98 mg/100 g.

Table 2. Experimental design

Sample number	1	2	3	4	5	6	7	8	9
t (h)	1	1	1	3	3	3	5	5	5
T (^{0}C)	20	35	50	20	35	50	20	35	50

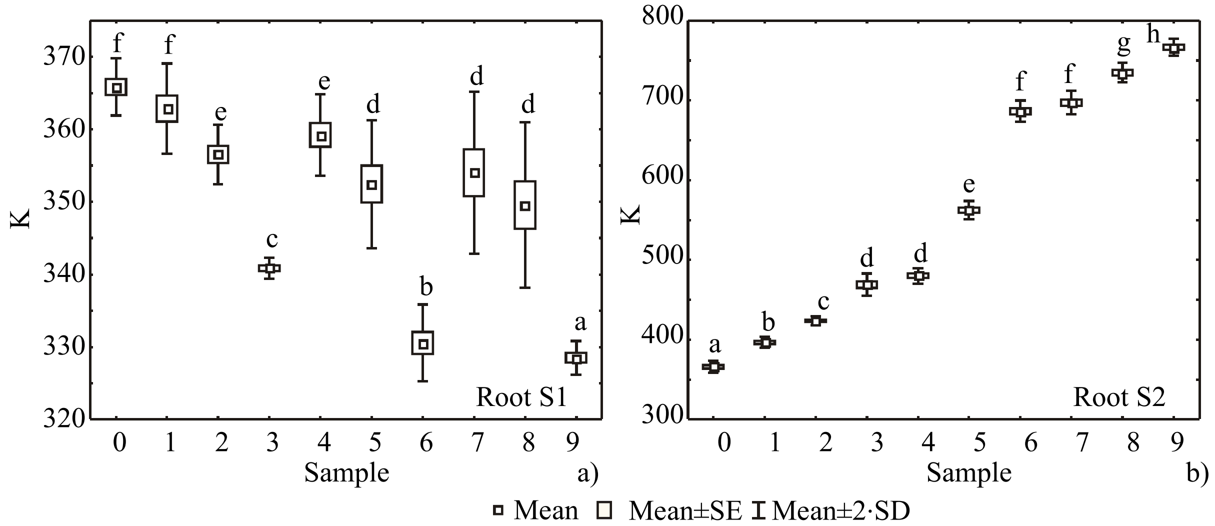

Figure 1. The content of K, in celery root samples, according to the time and temperature of the process, during osmotic treatment: a) celery root in solution S1, b) celery root in solution S2,

$^{a-h}$ Different letters written in the superscript indicate the statistically significant differences in means, on p < 0.05 level; 0 - control sample; the samples are numbered as in Table 2., n = 3. SD - standard deviation, SE - standard error

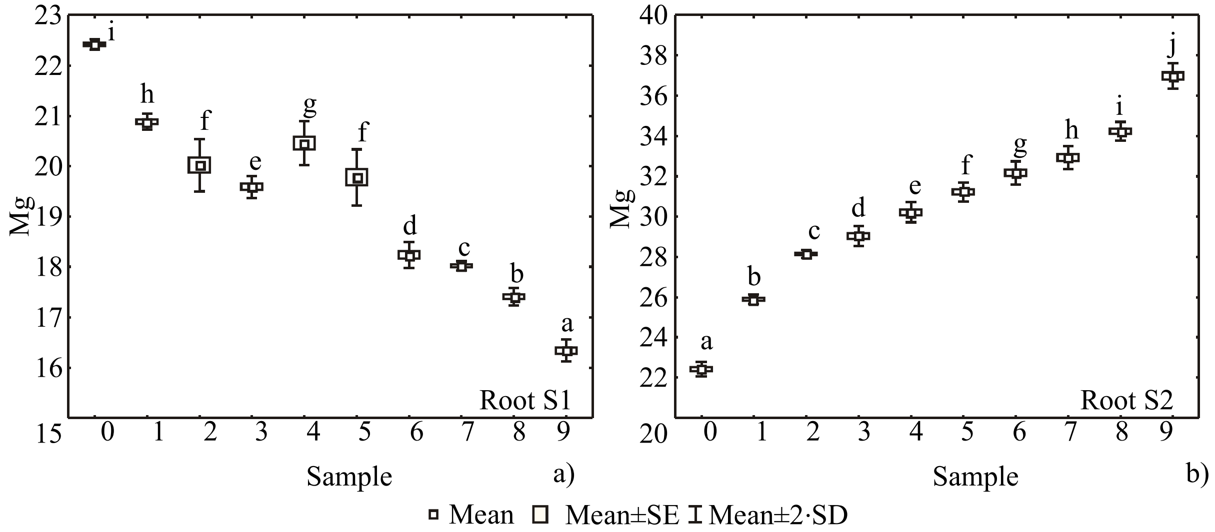

Figure 2. The content of Mg, in celery root samples, according to the time and temperature of the process, during osmotic treatment: a) celery root in solution S_1, b) celery root in solution S_2

$^{a-h}$ Different letters written in the superscript indicate the statistically significant differences in means, on p <0.05 level; 0 - control sample; the samples are numbered as in Table 2, n = 3. SD - standard deviation, SE - standard error

As in the previous cases, osmotic treatment in S_1 solution resulted in Ca and Fe losses in all treated celery root samples (Figures 3 and 4). Compared to the content of these minerals in the control sample, there is a constant decreasing trend with increasing processing time and temperature, so the lowest values of Ca and Fe content are obtained in samples treated for 5 hours at the temperature of 50 °C. During osmotic treatment of celery root samples under the same process conditions, but in the S_2 solution, the progressive increase in Ca and Fe content was noticed. Dynamics of increase of Ca and Fe in samples treated with molasses is similar to the previous minerals tested. For Ca final increase was from 44.12 mg/100 g to 57.36 mg/100 g and for Fe from the initial 0.76 mg/100 g to 0.91 mg/100 g.

Reduction of the amount of minerals during osmotic treatment in aqueous solution of sucrose and sodium chloride occurs as a result of the diffusion of a part of the cellular juices from the celery root tissue into the surrounding solution. It is the third mass flow in osmotic treatment, which is in comparison with other two mass transfers quantitatively inferior, but influences on the change in the nutritive quality of the treated material. Due to the partial loss of minerals present in the cellular juices of samples, there is a certain decrease in the nutritive value of the treated material [15]. The loss of mineral matters in samples is higher after prolonged exposure to treatment at higher temperatures, since then the diffusion of water and at the same time in water soluble minerals (K, Mg, Ca and Fe) from the treated samples is higher.

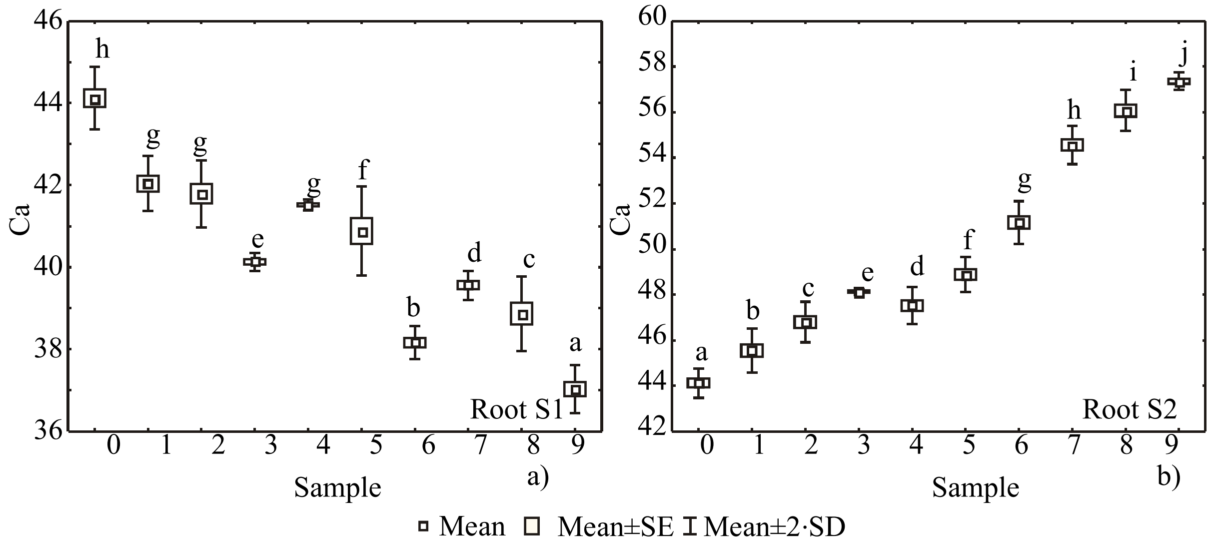

Figure 3. The content of Ca, in celery root samples, according to the time and temperature of the process, during osmotic treatment: a) celery root in solution S_1, b) celery root in solution S_2

$^{a\text{-}h}$ Different letters written in the superscript indicate the statistically significant differences in means, on $p < 0.05$ level; 0 - control sample; the samples are numbered as in Table 2, n = 3. SD - standard deviation, SE - standard error

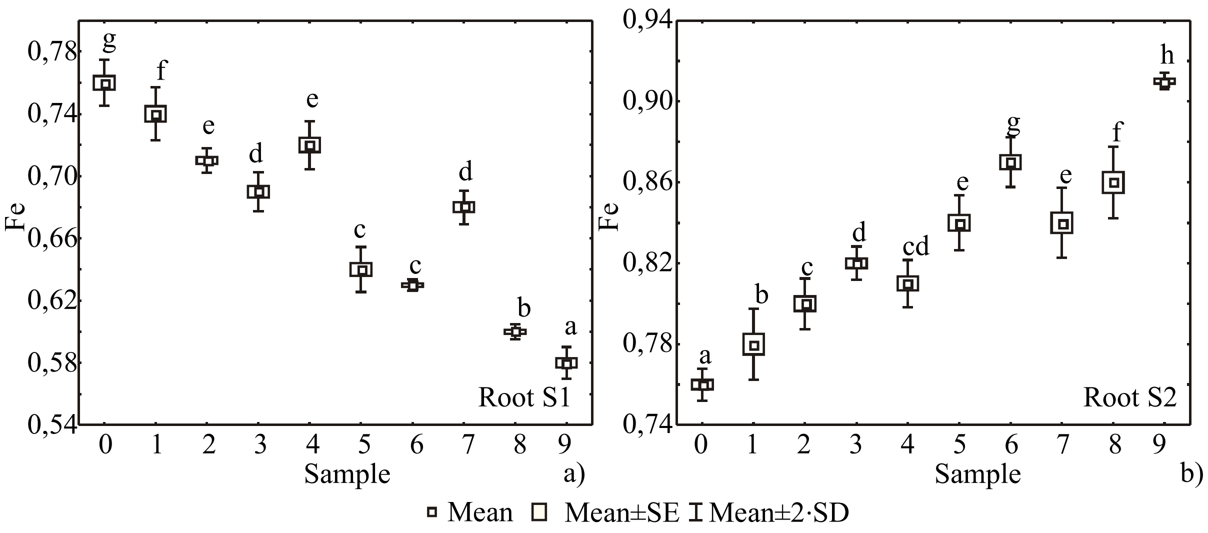

Figure 4. The content of Fe, in celery root samples, according to the time and temperature of the process, during osmotic treatment: a) celery root in solution S_1, b) celery root in solution S_2

$^{a\text{-}h}$ Different letters written in the superscript indicate the statistically significant differences in means, on $p < 0.05$ level; 0 - control sample; the samples are numbered as in Table 2., n = 3. SD - standard deviation, SE - standard error

The application of sugar beet molasses as an osmotic agent during treatment leads to an increase in the content of the tested minerals in the treated samples, and thus increases their nutritional value. Sugar beet molasses is a rich source of mineral substances, which is contained in it in a dissolved state [22], so the transfer of mineral matters from the molasses into the submerged root samples is expected. As a result, osmotically treated products with increased mineral content are produced. Increasing temperature during osmotic treatment cause reduction in molasses viscosity, reducing external resistance to mass transfer and making mineral transport easier [23]. Therefore, the samples obtained at temperatures of 50 °C, have the highest quantities of analysed minerals.

Acknowledgement

These results are part of a project supported by the Ministry of Science and Technological Development of the Republic of Serbia, TR-31055, 2011-2018.

4. Conclusions

- According to the obtained results, it can be concluded that the rich mineral composition of sugar beet molasses contributed to a significant increase in the content of mineral matter (K, Mg, Ca and Fe) in the osmotically treated celery root, which from the aspect of nutritive quality, preferred molasses as an osmotic solution.

- Osmotic treatment of celery root in sugar beet molasses provides semi-products of prolonged sustainability, as well as improved nutritive properties in a cost-effective, energy-efficient and environmentally acceptable manner. In addition, in this manner, the sugar beet molasses, which represents an excellent natural source of minerals and antioxidants, but is neglected in human nutrition due to its specific sensory properties, would have usable value in the food industry.

5. References

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