

## THE IMPACT OF DIFFERENT DRYING METHODS ON SELECTED QUALITY PARAMETERS OF CELERY ROOT

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### Abstract

In present study, the impact of different drying methods (convective drying, lyophilization and combined drying) on the color, sensory and antioxidative attributes of celery root, was investigated. Samples of celery root were dried convectively in a dryer at 50°C to a constant mass, in a lyophilizer for 48 hours, and by combined dehydration that included low-energy osmotic pretreatment in sugar beet molasses and shortened consecutive lyophilization for 24 hours. Subsequently, dehydrated samples were powdered and subjected to the color instrumental analysis (L, a, b coordinates), sensory analysis (color intensity, taste and odor) and analysis of total phenols content and antioxidant capacity (determined by ABTS and DPPH methods). The results showed that convectively dried celery root sample was darker than combinedly dried, with a greater share of red and yellow tones. The greatest departure from usual taste and odor (grade 4) was characterized for convectively dried powder (grade 5.5 and 5.9), followed by combinedly dehydrated celery (grade 3.2 and 3.0). Regarding the impact of the drying type on the antioxidant capacity, the combined drying confirmed to be the most efficient, DPPH 163.28 µmol TE/100 g d.m. and ABTS 577.28 µmol TE/100 g d.m., due to the molasses input (an excellent source of antioxidants) in the dehydrated celery root. The powder of celery root previously osmotically dried in molasses had an 8.5% higher content of total phenols in comparison to lyophilized powder, even though lyophilization is one of the most effective methods in preserving phenols.

**Keywords:** *Combined dehydration, Lyophilization, Osmodehydration, Celery root, Antioxidant capacity*

### INTRODUCTION

Celery (*Apium graveolens* L. var. *rapaceum*), an aromatic vegetable, abounds in health-promoting compounds such as dietary fibers, minerals, vitamins and essential oils (Golubkina *et al.*, 2020; Singh *et al.*, 2023). Numerous studies have highlighted

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pronounced antioxidant properties due to the presence of phenols compounds (apigenin, luteolin, quercetin, ferulic acid, kaempferol, p-coumaric acid etc.) in celery root (Beltrán Sanahuja *et al.*, 2021; Pajević *et al.*, 2021). Celery root is used raw or cooked in everyday food, but its applicability in the food processing is limited due to its specific aromatic properties (Szarek *et al.*, 2024).

The high temperatures used in convective drying, a procedure common in the vegetable industry, lead to a reduction in the quality of the dried product, among which the most noticeable are loss of colour, change in texture, impair the flavour and loss of nutrients (Kręcisz *et al.*, 2023). Application of lower temperatures, such as lyophilization, creates a good basis for maintaining the nutritional and sensory dried products' properties, but it requires a lot of energy, and simultaneously the costs of the process and the process' duration are increased (Marić *et al.*, 2020; Ignaczak *et al.*, 2023). Therefore, a good solution in terms of economic and energy savings is energy-undemanding osmotic dehydration as a pre-treatment in combination with shortened lyophilization of high energy consumption proposed in the research of Filipović *et al.* (2022).

The increasing focus on utilizing side products from the food industry, like sugar beet molasses, highlights their potential as sources of natural bioactive compounds. These components might enrich foods, offering both nutritional benefits and ecological advantages (Molina-Cortés *et al.*, 2020; Shafia-Atikah *et al.*, 2020). One practical application of molasses is in osmotic dehydration, a process that is both energy-efficient and simple. Soaking fresh vegetables in concentrated molasses, allows the water to be drawn out of the vegetables while simultaneously allowing beneficial components from the molasses to be absorbed (Cvetković *et al.*, 2019; Filipović *et al.*, 2022).

The main objective of this research was to examine the effect of three different dehydration methods, the usual convective drying and lyophilization and the innovative combined drying procedure of osmodehydration in molasses and successive lyophilization, on color, sensory and antioxidant properties of celery root.

## MATERIALS AND METHODS

### Material used

Fresh celery root (*Apium graveolens* L. var. *rapaceum*, Alabaster variety) was bought in a grocery store in Novi Sad, Serbia. The celery root contained an average dry matter content of 9.25%, total phenols content was 860.56 mg GAE/100 g d.m. and the determined antioxidant activities were 147.75  $\mu\text{mol TE}/100\text{ g d.m.}$  for DDPH method and 576.57  $\mu\text{mol TE}/100\text{ g d.m.}$  for ABTS method. The sugar beet molasses, utilized as a solution in the osmotic pre-treatment process, was sourced from a sugar factory (Crvenka, Serbia) and with the total dry matter content of 86.24%. Fresh celery root samples were prepared in the same way for all three dehydration methods: washed under tap water, dried with a towel, peeled and cut with a knife into cubes measuring 1 cm on each side.

### **Convective drying**

Drying of diced celery root samples to constant weight at 50°C was performed using a convective dryer (Instrumentaria, Zagreb, Croatia), after which they were pulverized using a universal laboratory mill (Solem, ZBPP, Bydgoszcz, Poland) to create celery powder.

### **Lyophilization**

In this drying procedure, fresh diced celery root samples were frozen at -30°C before being subjected to lyophilization with an apparatus (Christ ALPHA1-2 LDPLUS, Osterode am Harz, Germany). The settings for freeze-drying process included a pressure of 1.6 Pa, a condenser temperature of -57°C, over a processing time of 48 hours. Following this step, the dried samples were ground into a powder using a laboratory mill.

### **Combined drying**

This method was conducted in two phases: osmodehydration in molasses, followed by the lyophilization process. The celery root cubes were immersed in vessels containing molasses (1:5 ratio). Osmotic dehydration occurred for 5 hours at atmospheric pressure and room temperature. After this period, the osmotreated celery root samples were removed from the osmotic solution, rinsed with tap water to eliminate excessive molasses from the surface, and patted with absorbent paper to absorb additional moisture. The osmodehydrated samples were then frozen and stored overnight, before undergoing lyophilization using same device. The lyophilization parameters were the same as in previous procedure, but the drying time was shortened to 24 hours. After this time, dried celery root samples were ground.

### **Total phenols content and antioxidant capacity determination**

To determine the total phenols content and antioxidant capacity of dried celery powder, a mixture of 2.5 mL of ethanol, acetic acid, and water (in a ratio of 50:8:42) was combined with 500 mg of pulverized sample and mixed for 2 minutes on a vortex. The mixture was then centrifuged in duration of 3 minutes at 12,000 rpm. The liquid phase was separated and subsequently filtered using a 0.45 µm filter.

Total phenols content in these extracts was measured by the Folin-Ciocalteu method, as described in the paper Nićetin *et al.* (2024). The results were calculated using a calibration curve and expressed as milligrams of gallic acid equivalents in 100 grams of dry matter. Antioxidant capacity was assessed using two methods for free radical scavenging: the DPPH assay according to Šaponjac *et al.* (2016) and the ABTS assay according to Aborus *et al.* (2018). The results were calculated by using appropriate calibration curves and expressed as micromole Trolox equivalents per 100 grams of dry matter.

### **Color determination**

The color attributes of the samples were evaluated in six replications, using the device Chroma Meter (CR-400, Konica Minolta, Tokyo, Japan) with a contact surface diameter of 8 mm. Calibration was done in advance, using a white reference standard. The color analysis' results were displayed in accordance with the CIElab color system, which implies the following coordinate definitions: L denotes brightness with values from 0 (black) to 100 (white), a measures greenness/redness (-a for green to +a for red), and b blueness/yellowness (-b for blue to +b for yellow) (Šobot *et al.*, 2019).

### **Sensory evaluation**

A panel of ten evaluators was established in accordance with the ISO 6658:2017 standard. Determining descriptors for sensory evaluation of dried celery root was initially conducted by the lead evaluator and later refined by the other panelists. The final list included three descriptors: one for color intensity and two for deviations from the standard taste and odor. A seven-point scale was utilized, with 1 representing the lowest score and 7 the highest for color intensity. The optimal score for taste and odor were established to be 4.

Sensory testing of the samples was conducted in the laboratory of the Institute of Food Technology in Novi Sad, Serbia, following the ISO 8589:2007 standard. Dried samples were offered to the panelists on white plastic trays, each labeled with a randomly assigned three-digit code. The panelists were received water to cleanse their mouths between each tasting.

### **Statistical analysis**

The significance of differences across all quality responses of the three different dried celery root samples was evaluated using analysis of variance (ANOVA). STATISTICA 12.0 software (2013) (StatSoft Europe, Hamburg, Germany) was used for ANOVA analysis.

Principal component analysis (PCA) was applied in order to characterize and differentiate tested samples and their responses. PCA calculation was performed using Microsoft Excel ver. 2016. (Microsoft Corporation, Redmond, WA, USA), with the XLSTAT Version 2014 5.03 Add-in (Lumivero, Denver, CO, USA).

## **RESULTS AND DISCUSSION**

The obtained results for chemical (total phenols content and antioxidant capacity), physical (color) and sensory changes (color intensity, taste, odor) in celery root depending on the applied drying method, are shown in Table 1. The results indicate that the drying method had a statistically significant effect on all analyzed parameters of dried celery root.

Table 1. The effect of different drying methods on celery root' phenols content, antioxidant capacity, colour and sensory parameters

	Convective drying	Lyophilization	Combined drying
<b>Total phenols content (mg GAE/100 g d.m.)</b>	246.47±1.81 <sup>a</sup>	820.41±6.78 <sup>b</sup>	890.14±7.63 <sup>c</sup>
<b>Antioxidant capacity by DPPH method (µmol TE/100 g d.m.)</b>	42.37±0.34 <sup>a</sup>	141.21±1.41 <sup>b</sup>	163.26±1.58 <sup>c</sup>
<b>Antioxidant capacity by ABTS method (µmol TE/100 g d.m.)</b>	168.91±0.84 <sup>a</sup>	563.27±2.09 <sup>b</sup>	577.28±6.63 <sup>c</sup>
<b>Brightness (L)</b>	41.69±0.27 <sup>a</sup>	79.57±0.63 <sup>c</sup>	54.10±0.28 <sup>b</sup>
<b>redness (+a)</b>	8.56±0.04 <sup>c</sup>	3.54±0.03 <sup>a</sup>	6.07±0.06 <sup>b</sup>
<b>yellowness (+b)</b>	19.76±0.15 <sup>b</sup>	27.64±0.53 <sup>c</sup>	16.86±0.14 <sup>a</sup>
<b>Color intensity</b>	4.72±0.04 <sup>b</sup>	3.10±0.06 <sup>a</sup>	5.30±0.08 <sup>c</sup>
<b>Taste</b>	5.5±0.05 <sup>c</sup>	4±0.03 <sup>b</sup>	3.20±0.06 <sup>a</sup>
<b>Odor</b>	5.9±0.02 <sup>c</sup>	4±0.07 <sup>b</sup>	3.00±0.02 <sup>a</sup>

\*Results are presented as average value ± standard deviation, <sup>a-c</sup> Different letters in superscript of the same table row denote the statistically significant difference between values at a level of significance of  $p < 0.05$  (based on post-hoc Tukey HSD test)

Comparison of total phenols and antioxidant capacity of celery root powder dried by three different methods clearly indicates that convective drying has the most negative effect on these values. This finding is in line with existing researches of Sorouret *et al.* (2015) and Ramachandraiah & Chin (2017), which confirmed a marked loss of total phenols in celery samples after the application of convective drying, especially at higher temperatures. Marić *et al.* (2020) reported reduced total phenols content by about 50% after convective drying at 50°C and about 75% after drying at 70°C in comparison to the fresh carrot. In contrast, many authors have shown that the lyophilization process is successful in preserving total phenols compared to the convective drying (Marić *et al.*, 2020; Kręcisiz *et al.*, 2023). The results in this research revealed that celery root powder that underwent osmotic dehydration in molasses followed by lyophilization, exhibited an 8.5% greater total phenols, compared to the lyophilized celery powder alone. Considering that molasses is widely known for its high phenolic content (Cvetković *et al.*, 2019; Filipović *et al.*, 2024), the highest value of total phenols in the combined dried sample is obviously the contribution of molasses that diffused during the osmotic treatment into the celery root tissue. Also, in terms of antioxidant capacity determined by two different methods, celery root subjected to osmotic treatment prior to lyophilization showed the superior values (DPPH 163.28 µmol TE/100 g d.m. and ABTS 577.28 µmol TE/100 g d.m) in comparison with celery root dried using more conventional convective and lyophilization methods. In relation to lyophilization, which was assessed as a highly efficient approach for retaining the antioxidative potential of dried material (Marić *et al.*, 2020), convectively dried celery root had about 70% lower values of antioxidant capacity assessed by both employed methods (Table 1). In

consistency with the current results, Kręcisz *et al.* (2023) reported that the drying method significantly affected the total phenols content and antioxidant capacity of celery, with lyophilization resulting in higher values compared to convective drying. Compared to the lyophilized sample, celery root processed by combined drying showed improved antioxidant capacity - 15.6% higher by the DPPH assay and 2.5% higher by the ABTS test, due to the molasses input, which is recognized for its pronounced antioxidant potential (Chen *et al.*, 2017; Mordenti *et al.*, 2021).

Regarding the influence of the drying type on the brightness and the share of yellow tone of celery root, the lyophilization proved to be the most effective. Convective drying showed the most negative influence on the brightness of the celery sample. The results revealed that convectively dried celery is even darker than the combinedly dehydrated, with higher share of red and yellow tone. Unlike convectively dried celery root, where the dark color comes from enzymatic and non-enzymatic browning reactions in the presence of oxygen at an elevated temperature (50°C) (Kręcisz *et al.*, 2023), the darkness of the combined dried sample comes from molasses that penetrated into the celery tissue during osmotic treatment. Sugar beet molasses owes its deep coloration mainly to melanoidins and caramelization substances formed during the industrial sucrose production (Šobot *et al.*, 2019).

Based on sensory assessment, the intensity of the celery root sample coloration is most pronounced after combined drying, followed by the convectively dried sample. After the lyophilization procedure, sample retained the taste and odour characteristic for celery root. The most marked variation from the typical flavor and scent of celery root (grade 4) was characterized for the convectively dried powder (grade 5.5 and 5.9), while the combined drying caused less pronounced deviation (grade 3.2 and 3.0). A lower deviation from the standard taste and odor after combined drying can also be rated as desirable because molasses masks the pronounced herbaceous and punget aroma of celery root.

PCA was applied to discover the correlation structure between experimentally determined responses of antioxidant characteristic, instrumental colour and descriptive sensory analysis and applied different types of drying. The scatter plot of the PCA (Figure 1) conducted on the tested samples, it provides additional insights and a visual representation of data trends and their ability to distinguish groups (Filipović *et al.*, 2024). The first two principal components (represented at x-axis and y-axis) of the data matrix high accounted of the total variance in the experimental dataset (for 100%).

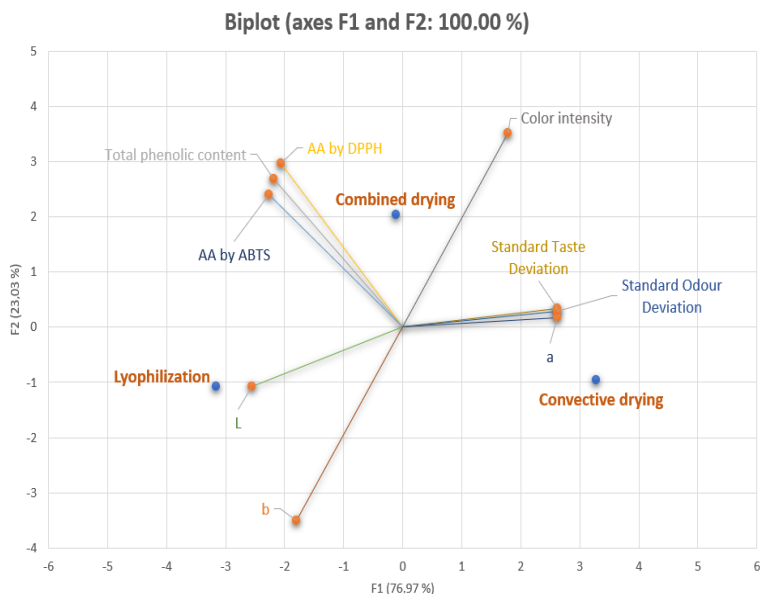


Figure 1. PCA scatter plot diagram depicting the relationships among selected parameters of celery root samples regarding dehydration type

A noticeable separation of the three tested celery root samples was achieved, because of the distinct differences in quality responses, as evident from the presented scatter plot diagram. The position of celery root samples on the scatter plot was predominantly determined by dehydration type, where the combinedly dried and lyophilized samples were positioned on the left side of the biplot (negative values of the first principle component (F1)), and convectively drying sample was arranged on the right side of diagram, characterized by positive values of F1. The responses' projection suggested that total phenols content and antioxidant capacities measured by DPPH and ABTS were located at higher positive values of the second principal component. The difference between antioxidant activities and phenols content for combinedly dried and lyophilized samples were less profound, since both samples shared similar responses patterns, signifying the positive effect of these two drying type on these nutritive quality properties. The most pronounced L and b values were identified for lyophilized sample and were positioned at the bottom left part of the biplot. Convectively dried sample was characterized by high standard taste and odour deviation and a value. The color intensity was distributed between combinedly and convectively dried sample, showing a slightly more positive correlation with combined drying. All tested responses except color intensity and b value exerted a significant contribution to the first principal component.

## CONCLUSIONS

Based on the results, osmotic-pretreatment in molasses in combination with lyophilization, influenced higher values of the total phenols content and antioxidant capacity of the examined celery root than lyophilization, which is considered a very successful method in preserving antioxidant capacity. Also, it was shown that combined drying had a less pronounced influence on the deviation from the color and sensory parameters of celery root, compared to convective drying.

It can be concluded that combined drying, in addition to providing an economic advantage, energy efficiency and an ecological advantage due to the inclusion of by-products in the process, also affects the improvement of the antioxidant potential of the dried material. Future research should be focused on the possible application of combined dried celery powder enriched with bioactive components from molasses as an ingredient of various food products.

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## UTICAJ RAZLIČITIH METODA DEHIDRACIJE NA ODABRANE PARAMETRE KVALITETA KORENA CELERA

### Sažetak

U ovom radu ispitan je uticaj različitih metoda dehidracije (konvektivno sušenje, liofilizacija i kombinovana osmodehidracija i liofilizacija) na parametre boje, senzorne atribute i antioksidativna svojstva korena celera. Uzorci korena celera su sušeni konvektivno u sušari na 50°C do konstantne mase, u liofilizatoru 48 sati, i kombinovanom dehidracijom koja je uključivala niskoenergetski osmotski predtretman u melasi šećerne repe i skraćenu uzastopnu liofilizaciju u trajanju od 24 sata. Potom su dehidrirani uzorci usitnjeni u prah i podvrgnuti instrumentalnoj analizi boje (L, a, b koordinate), senzornoj analizi (intenzitet boje, ukus i miris) i analizi ukupnog sadržaja fenola i antioksidativne aktivnosti (određeno ABTS i DPPH metodama). Rezultati su pokazali da je konvektivno osušeni celer tamniji od kombinovano dehidriranog, sa većim učešćem crvenog i žutog tona. Najizraženije odstupanje od standardnog ukusa i mirisa (ocena 4) je okarakterisano za konvektivno

sušeni prah (ocene 5,5 i 5,9), a potom kombinovano dehidrirani celer (ocena 3,2 i 3,0). Što se tiče uticaja tipa dehidracije na antioksidativni potencijal, najefikasnijim se pokazala kombinovana metoda, DPPH 163,28 mmol TE/100 g d.m. i ABTS 577,28 mmol TE/100 g d.m, zbog sadržaja melase (odličan izvor antioksidanata) u dehidriranom korenu celera. Prah korena celera koji je prethodno osmodehidriran u melasi imao je čak 8,5% veći sadržaj ukupnih fenola u odnosu na liofilizovani prah, iako se liofilizacija smatra jednom od najboljih metoda dehidracije u smislu očuvanja fenolnih jedinjenja.

**Ključne reči:** *kombinovana dehidracija, liofilizacija, osmodehidracija, koren celera, antioksidativna aktivnost*