Review paper
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SUGAR BEET MOLASSES AS OSMOTIC SOLUTION FOR IMPROVING ANTIOXIDATIVE POTENTIAL OF HERBS

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Abstract

Nutritional and therapeutic relevance of herbs is generally known, which is most related to their high phenolic content and other bioactive compounds present. However, the bioactive components are unstable, and extremely prone to degradation and/or reaction with some factors during processing and preservation. Osmotic treatment is the one of the preservation method with potential to prevent drying damages and maintain the functional properties of food. Most studies conducted with osmotic dehydration are more focused on the process, and less on the nutritive and antioxidative profile of obtained product. This review summarizes the impact of osmotic treatment on the antioxidative potential of osmodehydrated product, with an emphasis on the molasses as osmotic medium.

Immersion of the plant material in concentrated solutions on the mild temperatures, by means of osmotic treatment, has the advantage of preserving the plants' total antioxidant activity, due to the protective effect of the surrounding osmotic solution, the limitations of oxidative exposure, and avoiding adversely consequences of temperature. The type of osmotic solution directly affects the retention of bioactive compounds and the overall antioxidant profile of the material immersed in it, mainly due to the transport of bioactive substances from the solution to the plant. According to the literature molasses is a reach source of antioxidants, which potentially can diffuse into plant tissue during osmotic treatment. Some papers have reported that carriers of antioxidant activity in molasses are primarily phenolic compounds derived from sugar beet (Ferulic acid; Synergic acid; Vanilic acid; Galic acid; p-Coumaric acid; Kaempferol; Catechin; Luteolin), anthocyanides, betaine, choline, and colored products of the Millard reactions (melanoidins), which formed during the production of sugar.

In conclusion the published data show that molasses as osmotic medium enhancing the overall antioxidant activity of herbs, making osmodehydrated material excellent ingredients for functional food formulation.

***Key words**: Osmotic treatment, Herbs, Antioxidant activity, Sugar beet molasses.*

1. Introduction

Medicinal herbs have always occupied an important place in human nutrition, but they are of great interest for scientific research due to their pronounced antioxidant properties. The bioactive substances that are most responsible for the total antioxidant activity of herbs are phenolic compounds. Many studies have confirmed that foods rich in phenolic substances play an essential role in the prevention of cardiovascular diseases, cancer, neurodegenerative diseases, as well as many other problems that can be caused by oxidative stress [1, 2]. Futhermore, the natural polyphenols from herbs have been shown to have significant beneficial effects on human health including antibacterial, antiviral and atifugal activities [3]. However, phenols and other bioactive components are unstable and extremely prone to degradation and/or reaction with some factors during processing and preservation. Osmotic dehydratation (OD) is emerging as one of the

best preservation method with potential to prevent drying damages and maintain the antioxidative properties of food [4, 5].

In addition to the aim of maintaning initial quality, current trends in food technology are focused on the possibility of improving the nutritional profile of food products, primarily attributed to the increase in the content of specific nutrients and bioactive ingredients during production. There is a tendency to respond to the growing market needs for new products enriched with antioxidants that can have a positive impact on human health [6, 7]. On the other hand, it is desirable to achieve maximum environmental acceptability of the production process, with the greatest possible reduction of process waste, maximum economic feasibility and minimum energy consumption. OD of food raw materials, primarily in sugar beet molasses, gives a positive response to all these requirements [4,8].

The superiority of OD process in relation to the other drying methods is reflected in the fact that the water that is removed during the process does not change the physical state, consequently no additional energy is required for the phase transition. Also, the process does not require high operating temperatures, which is suitable both in terms of energy savings and in terms of reducing the negative impact on the sensory and nutritional quality of the product [9, 10]. OD of materials (fruits, vegetables, meat, herbs) resulted in a dehydrated product of increased microbiological stability and improved nutritional properties. During the OD, the food is placed in direct contact with the appropriate hypertonic solution, where the difference in their osmotic pressures is the driving force for the transport of matter. The dominant mass flow is the diffusion of water from the food tissue into the surrounding solution, and it is accompanied by the opposite mass flow, the diffusion of dissolved substances from the osmotic solution into the tissue. Since the cell membrane responsible for osmotic transport is not perfectly selective, dissolved substances present in the food cells (organic acids, reducing sugars, minerals, flavor and pigment compounds) can also be leached into the osmotic solution, which affect the sensorial and nutritional characteristic of the product [11, 12].

The osmotic solution has the greatest influence, both in quantitative and qualitative sense, on the matter transport during the OD, and thus determines the final quality of the dehydrated product. After OD, a partially dried product enriched with nutritional components from the used solution was obtained. Unlike common osmotic solutions used in OD of food (such as saturated aqueous solution of sucrose or/and sodium chloride), sugar beet molasses is a quality multicomponent system, with a high content of sugar components, proteins and other active nitrogen compounds (purine bases, pyrimidine, nucleosides), organic acids, betaine, mineral components and vitamins. The high content of dry matter in molasses (over 80%) enables high potential of matter transfer during the osmotic process, and thus efficient drying and absorption of nutritionally valuable substances from molasses, in the function of obtaining a nutritive improved food product [13, 14].

As a good source of natural antioxidants (phenolic compounds, melanoidin, betaine and choline), sugar beet molasses has significant antioxidant potential, so it can positively affect the overall antioxidant content of the osmotically dehydrated product. Also, molasses is a side-product of sugar production, so involving in the process of OD, represent a new alternative for the use of this material previously consdered as industrial waste [8, 13].

Although there are numerous studies on the process of the OD, effect on the quality of osmodehydrated product, especially in terms of antioxidant activity, has been insufficiently investigated. The vast majority of research relates to the kinetic of the process, and only a few evaluate the effects of the process on the antioxidative properties of osmotically dehydrated food [15]. Quality assessment from the nutritional and functional aspect is important, because these factors directly affect the acceptability of the dehydrated product, which can be impaired due to physical and chemical changes that the product may undergo during OD. Therefore, this review summarizes the influence of OD on the antioxidative properties of osmotically dehydrated plants, with an emphasis on the investigation of the improving the antioxidant potential of herbs using sugar beet molasses as osmotic medium.

2. Sugar beet molasses as osmotic solution for improving antioxidative potential of herbs

2.1 Influence of OD on antioxidant activity of plants

Nowadays, there is a growing interest in finding processes that can preserve or improve the sensory and functional properties of food. Most studies dealing with OD are more focused on process modeling and optimization of process conditions, and less on the impact of these conditions on the quality of the final product. Current research efforts are aimed at understanding the effect of OD on sensory, functional and nutritional product quality, and in particular on its antioxidant properties [15, 16].

In comparison with the conventional drying techniques, OD has advantage in maintaning the overall antioxidant capacity of the plant material, due to the use of lower temperatures, the protective effect of the surrounding osmotic solution and the limitation of oxidative exposure during proces [7, 13]. Devic *et al.,*

[17], suggested that the main mechanism responsible for the reduction of phenolic compounds during the osmotic treatment is water diffusions. Water soluble phenols can leaching out with water flow from the plant material into the surrounding solution. However, it was observed that by applying more concentrated solutions, at lower temperatures, a remarkable preservation of the antioxidant activity of OD samples was achieved. Antioxidant compounds of higher molecular weights, such as tannins and procyanidins, are more retained in the dehydrated product, because they provide resistance to the transport into the osmotic solution during the process [16, 18]. Likewise, the incorporation of osmoactive substances from the solution into the immersed material prevents damage to the cells of the surface layers of the treated tissue and creates a protective barrier that limits the migration of compounds which are responsible for antioxidant capacity of plant. In addition, the penetration of the osmotic solution into plant tissue promotes an environment of reduced oxygen and moisture concentration, thus preventing the oxidation of bioactive compounds through the activity of enzymes present in the tissue [16, 17]. Quiles *et al.,* [19], have shown that OD of apples in sucrose solution inhibits the action of the enzyme polyphenol oxidase, which contributes to the preservation of the polyphenols present. The type of osmotic solution directly affects the retention of bioactive compounds and the overall antioxidant potential of dehydrated plant material. The use of different solutions causes different retention of antioxidant compounds, e.g. sucrose solution allows greater retention of anthocyanins, and glucose/ fructose solutions have a greater effect on the preservation of phenol content and overall antioxidant capacity [20]. Almeida et *al*., [16], achieved retention of total antioxidant activity up to 97% in banana samples dehydrated in concentrated sucrose solutions. Singla *et al*., [21], proved in their research that the process of OD does not significantly change the antioxidant capacity and content of total phenols in mushrooms. Hereida *et al.,* [7], reported that the OD in addition to the preservation of bioactive compounds may even lead to a slight increase in the total antioxidant value of the dehydrated product. In their reasarch, the content of carotenoids, such as lycopene and β-carotene in osmotically dehydrated tomatoes under certain process conditions was increased. They assumed that this increase might be related to the biosynthesis of these carotenoids, which occurs as response to the osmotic stress.

2.2 Antioxidant potential of sugar beet molasses

In order to avoid the use of synthetic antioxidants which can exhibit a detrimental impact upon health, scientific research is increasingly focused on finding alternative sources of antioxidants preferably natural origin. Special attention has been paid to the possibility of isolating antioxidants from waste materials and side-produst in food industries, such as sugar cane or sugar beet molasses [22, 23]. Experimental verification of molasses as a promising antioxidant agent in the work by Molina-Cortés *et al.*, [8], opens a new perspective in which an agroindustrial waste is transformed into a specific product with potenital therapeutic use. In addition to the fact that sugar beet molasses is a rich source of many important nutrients, there are studies that indicate that molasses also has significant antioxidant capacity. Several researches have confirmed the presence of phenolic compounds in molasses, which give it a possible role in the prevention of diseases caused by oxidative stress [3, 23].

The antioxidant components in molasses may originate from the sugar beet or cane (for example, phenolic compounds), or be generated during the processing in sugar production (for example colored products of Mylard reactions-melanoidins) [23]. The products of non-enzymatic tanning (melanoidins) formed during sugar processing, trough numerous reactions of reducing sugars and amino acids, so high concentrations of these compounds remain in molasses in a wide range, from small organic compounds to complex aromatic polymers [24]. It has been evidenced that melanoidins have significant antioxidant and antimicrobial abilities, and might prevent lipid oxidation. Also, there are findings that melanoidins have a beneficial effect on the defense system of living organisms [24, 25].

According to Maestro-Durán *et al.*, [26], 12 phenolic compounds were identified in sugar beet molasses: six benzoic acids (gallic, protocatechin, p-hydroxybenzoic, salicylic, vanillin and syringic), two cinnamic acids (p-coumarin and ferulin), three phenolic aldehydes (protocatechin) -hydroxy-benzoic and vanillin aldehyde) and one phenolic alcohol (guaiacol). Valli *et al.*, [24], compared the phenolic profiles of sugar cane and sugar beet molasses and found that syringic acid is the phenolic component that is mostly present in sugar cane molasses, while in sugar beet molasses it is present in low quantities. On the other hand, the main phenols in sugar beet molasses are ferulic acid, luteolin and campherol, and these compounds are found in small amounts in sugar cane molasses or have not been identified.

A group of authors from China examined the total phenol content, antioxidant activity using 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) - ABTS methods and the total anthocyanin content in sugar beet molasses. As the results of the research, the following values were obtained: total phenol content 17.36 mg GAE/100 mL, antioxidant activity 16.66

mgTE/g, and total anthocyanin content 31.81 mg/100 g. The chemical compositions of sugar beet molasses extract were identified by the appropriate HPLC method, and included ten antioxidant components (phenolic acids and glucosides): gallic, p-hydroxybenzoic, vanillic, syringic and ferulic acid, catechin, cyanidin-3-O-rutinoside -3-O-glucoside, delfinidin-3-O-rutinoside, and delfinidin-3-O-glucoside [27].

Studies regarding the antioxidant and anti-inflammatory properties of sugar beet molasses, as well as its protective effect against oxidative DNA damage, have shown positive results. There are scientific claims that sugar beet molasses extracts can prevent the growth of cancer cells in cases of breast, liver and colon cancer. Three polyphenolic compounds (gallic acid, cyanidin-3-O-glycoside chloride and epicatechin), isolated from sugar beet molasses, confirmed cytotoxic activity against these cancers. The ethyl acetate extract showed the highest antioxidant activity among the tested extracts, and among the isolated compounds, gallic acid accentuates as the most powerful antioxidant. However, antitumor activity is more pronounced with anthocyanins than with flavonoids. Thus, cyanidin-3-O-glycoside exhibited the strongest cytotoxic effect, especially on colon cancer cells (94.86%). It also contributes to the inhibition of the multiplication of tumor cells in the liver (87.27%) and breast (67.13%). The results of the research suggest that there is a potential for the use of polyphenols isolated from molasses in the treatment of tumor disease [28, 29].

Betaine and choline, present in molasses in an amount of up to 6% and less than 1%, respectively, possess antioxidant activity [12]. Betaine enables the conversion of homocysteine to methionine, and it is known that a high concentration of homocysteine is one of the most important risk factors for cardiovascular disease. Betaine is well absorbed in the digestive tract and along with folate reduces oxidative stress *in vivo* by reducing the concentration of homocysteine in laboratory mice in the study of Baraka *et al.*, [30]. Choline is a precursor of betaine and also has a function in the body's defense mechanism against oxidative stress.

2.3 Influence of sugar beet molasses on antioxidant activity of osmodehydrated plants

The importance of phenolic and other antioxidants in the diet is well known, so the study of the effects of OD on these substances is very valuable [13]. Bioactive compounds in plants submitted to OD can suffer damage, by varying the parameters during the process. Also, their final content depends on possible chemical and biochemical transformations, or loss due to diffusion with water flow. In contrast, water loss can cause an increase in the concentration of chemical compounds relative to the fresh material. Also, solid gain from osmotic solution can cause the obvious variations in the concentration of present compounds in the osmotically dehydrated products [31]. As well as mass transfer indicators, antioxidant activity of plant material subjected to OD are affected by osmotic solution (type and concentration), osmotic solution temperature, sample/solution ratio, sample shape and size, sample immersion time [13].

In Table 1 are presented the experimental values of antioxidant indicators for celery leaves dehydrated in two different osmotic solutions: aqueous solution of sodium chloride and sucrose (ternary solution) and sugar beet molasses, during 1, 3 and 5 hours of the process (parameter t) and on three different temperatures 20, 35 and 50 ^{0}C (parameter T). Experimental data show the values of total antioxidant activity (by fluorescence recovery after photobleaching - FRAP, ABTS, 2,2-diphenyl-1-picrylhydrazyl - DPPH, hydroxypropyl methylcellulose - HPMC, mercury reduction antioxidant power - MRAP methods) and total content of phenolic compounds (FC) in fresh

Table 1. Antioxidant indicators for OD of celery leaves in ternary solution and sugar beet molasses, [33]

Solution			Ternary solution						Sugar beet molasses					
No	t	T	FRAP	ABTS	DPPH	HPMC	MRAP	FC	FRAP	ABTS	DPPH	HPMC	MRAP	FC
	H	°C	mM Fe(II)	mM Trolox	mM Trolox	% mL	% mL	mg GAE/L	mM Fe(II)	mM Trolox	mM Trolox	% mL	% mL	Mg GAE/L
0	0	20	1.424^{a}	0.980^{d}	0.414^{b}	0.046^{d}	0.019^{a}	0.158^{f}	1.424^{a}	0.980^{c}	0.414^{d}	0.046^{a}	0.019^{e}	0.158^{e}
1	1	20	1.401^{ac}	0.979^{d}	0.407^{b}	0.042^{b}	0.018^{d}	0.156^{ef}	1.423^{b}	1.004^{a}	0.416^{d}	0.046^{b}	0.020^{a}	0.162^{ab}
2	1	35	1.423^{a}	0.971^{df}	0.405^{b}	0.042^{b}	0.017^{a}	0.154^{a}	1.444^{ab}	1.013^{a}	0.415^{ab}	0.048^{c}	0.020^{f}	0.161^{ae}
3	1	50	1.420^{a}	0.948^{abc}	0.404^{bc}	0.042^{b}	0.017^{a}	0.153^{ab}	1.455^{ab}	1.018^{a}	0.424^{a}	0.049^{c}	0.020^{a}	0.163^{abc}
4	3	20	1.414^{ac}	0.965^{cdf}	0.394^{ac}	0.041^{c}	0.018^{d}	0.154^{ae}	1.438^{ab}	1.014^{a}	0.425^{ab}	0.048^{c}	0.021^{ab}	0.164^{abc}
5	3	35	1.374^{bc}	0.955^{cdf}	0.390^{a}	0.041^{c}	0.017^{a}	0.153^{a}	1.456^{ab}	1.023^{a}	0.431^{bc}	0.049^{d}	0.021^{c}	0.163^{abc}
6	3	50	1.391^{abc}	0.944^{bcf}	0.386^{a}	0.039^{a}	0.017^{a}	0.150^{bd}	1.467^{a}	1.027^{a}	0.434^{ab}	0.050^{e}	0.021^{d}	0.166^{cd}
7	5	20	1.383^{bc}	0.948^{abe}	0.389^{a}	0.039^{a}	0.017^{a}	0.152^{ab}	1.459^{ab}	1.026^{a}	0.418^{a}	0.049^{d}	0.021^{bc}	0.165^{bc}
8	5	35	1.358^{b}	0.936^{ae}	0.390^{a}	0.039^{a}	0.017^{a}	0.149^{cd}	1.463^{a}	1.029^{a}	0.440^{bc}	0.050^{e}	0.022^{g}	0.169^{d}
9	5	50	1.358^{b}	0.929^{e}	0.390^{a}	0.040^{a}	0.017^{a}	0.147^{c}	1.477^{a}	1.060^{a}	0.439^{c}	0.050^{e}	0.023^{d}	0.169^{d}

Legend: *Different letters written in superscript within the same column in the table show significantly different means of observed data (at $p<0.05$); 0 - control sample; n = 3.

samples and changes of the same indicators in samples during OD, as a function of process parameters (t and T), varied according to the adopted experimental plan.

The treated celery leaves, after OD with the highest values of process parameters, remains about 95.36%, 94.79%, 94.20%, 86.96% and 89.47% of the total antioxidant activity, for FRAP, ABTS, DPPH, HPMC and MRAP methods, respectively. At lower temperatures and shorter immersion times, retention of total antioxidant was achieved in even higher percentages, up to 99%.These results are in agreement with the results of research by Tonnon *et al.*, [18], that the total carotenoid content in tomatoes was maintained after 6 hours of OD in an aqueous solution of sucrose and sodium chloride. Good preservation of the antioxidant potential of the samples is a consequence of the incorporation of sucrose and salt from the solution, which potentially prevent damage to the surface layers of treated tissue cells and enable the creation of a barrier that hinders the transport of bioactive substances from the product into solution. In addition, the penetration of the osmotic solution into plant tissue prevents oxidation of antioxidant compounds through enzymatic activity, due to the limited concentration of oxygen and moisture in the current enzyme environment. Inhibition of possible enzymatic action contributes to the preservation of the present antioxidants [15, 19].

However, based on the results in Table 2, it is observed that OD in ternary solution resulted in a more obvious decrease in antioxidant activity and phenolic content of nettle leaves samples during the process.

The results show that at higher process temperatures, there is less retention of the antioxidants in the samples, and this negative effect of temperature on antioxidant retention increases with the duration of the process. The greatest retention of antioxidant potential occurs at the lowest temperatures, because an increase in temperature accelerates cell collapse, causing a decrease in membrane permeability and selectivity and favoring water diffusion, and thus loss of water-soluble antioxidants [16]. Moreover, high temperatures reduce the viscosity of the osmotic solution, and thus the external resistance to mass transfer, so the process is accelerated. By prolonging the immersion time, regardless of the applied process temperature, the retention of the initial antioxidant activity is less, probably due to the loss of the integrity of the cell walls [31]. These results are in agreement with the results of researchers Nowicka *et al.*, [32], who state that osmotic dehydration promotes a negative effect on the composition of total phenols and antioxidant capacity in fruit. Also, Devic *et al.*, [17], found that the concentration of some bioactive compounds decreases at higher OD temperatures, and that the main mechanism responsible for the reduction of antioxidant compounds is water diffusion. Another mechanism that can take place during OD and favors the reduction of the total antioxidant product, is the hydrolysis of molecules. Hydrolysis of molecules reduces the degree of polymerization of some antioxidant compounds, resulting in molecules of lower molecular weight which diffuse more easily through the cell membrane into the surrounding solution. This mechanism depends much more on the duration of the process than on the temperature [17]. The observed parameters consider the total antioxidant activity, so it is not known which antioxidant compounds participate in mass transport during OD, as well as these results do not provide precise information on what possible antioxidant reactions occur during the osmotic process.

On the other hand, OD in sugar beet molasses leads to the constant increase in antioxidant capacity for all observed process conditions and assays, in all samples of celery and nettle leaves (Tables 1 and 2). The increase of antioxidant indicators of treated samples is proportional to the increase in process

Table 2. Antioxidant indicators for OD of nettle leaves in ternary solution and sugar beet molasses, [14]

Solution			Ternary solution						Sugar beet molasses					
No	t	T	FRAP	ABTS	DPPH	HPMC	MRAP	FC	FRAP	ABTS	DPPH	HPMC	MRAP	FC
	Min	°C	mM Fe(II)	mM Trolox	mM Trolox	% mL	% mL	mg GAE/L	mM Fe(II)	mM Trolox	mM Trolox	% mL	% mL	mg GAE/L
0	0	20	1.321^{g}	0.965^{g}	0.388^{h}	0.017^{d}	0.016^{a}	0.143^{f}	1.321^{a}	0.965^{a}	0.388^{a}	0.017^{a}	0.016^{a}	0.143^{a}
1	30	20	1.109^{f}	0.754^{f}	0.317^{g}	0.017^{cd}	0.015^{a}	0.117^{e}	1.323^{a}	0.937^{a}	0.396^{a}	0.019^{b}	0.016^{ab}	0.145^{a}
2	30	35	1.009^{e}	0.677^{e}	0.281^{e}	0.016^{bc}	0.015^{a}	0.107^{d}	1.357^{a}	0.940^{a}	0.388^{a}	0.021^{c}	0.017^{cde}	0.145^{a}
3	30	50	1.033^{e}	0.704^{e}	0.294^{f}	0.017^{cd}	0.015^{a}	0.108^{d}	1.327^{a}	0.933^{a}	0.395^{a}	0.021^{c}	0.016^{bcd}	0.144^{a}
4	60	20	0.926^{d}	0.641^{d}	0.266^{d}	0.016^{bcd}	0.015^{a}	0.098^{c}	1.333^{a}	0.958^{a}	0.392^{a}	0.021^{c}	0.016^{bc}	0.146^{a}
5	60	35	0.867^{bc}	0.591^{bc}	0.245^{bc}	0.016^{ab}	0.015^{a}	0.091^{b}	1.338^{a}	0.957^{a}	0.396^{a}	0.023^{d}	0.017^{cde}	0.146^{a}
6	60	50	0.885^{cd}	0.604^{c}	0.255^{cd}	0.016^{bcd}	0.015^{a}	0.092^{b}	1.359^{a}	0.935^{a}	0.400^{a}	0.024^{e}	0.017^{cde}	0.147^{a}
7	90	20	0.876^{bc}	0.608^{c}	0.246^{bc}	0.016^{ab}	0.015^{a}	0.092^{b}	1.348^{a}	0.937^{a}	0.390^{a}	0.022^{d}	0.017^{cde}	0.144^{a}
8	90	35	0.834^{b}	0.565^{b}	0.237^{b}	0.016^{abc}	0.015^{a}	0.089^{b}	1.358^{a}	0.957^{a}	0.388^{a}	0.024^{e}	0.017^{de}	0.146^{a}
9	90	50	0.711^{a}	0.473^{a}	0.197^{a}	0.015^{a}	0.015^{a}	0.078^{a}	1.335^{a}	0.935^{a}	0.392^{a}	0.024^{e}	0.017^{e}	0.146^{a}

Legend: *Different letters written in superscript within the same column in the table show significantly different means of observed data (at $p < 0.05$); 0 - control sample; n = 3.

parameters. After five hours of treatment at the highest temperature (50 ^{0}C), the treated celery leaves showed the best rise in antioxidant activity: from the initial 1,424 to 1,477 mM TE (3.72%), for the FRAP method; from 0.980 to 1.026 mM TE (4.69%), for the ABTS method; from 0.414 to 0.439 mM TE (6.03%), for the DPPH method; from 0.046 to 0.051 mL (10.86%), for the HPMC method and from 0.019 to 0.023 ml (21.05%) for the MRAP method, and total phenolic content was increased for 4.32%. In the case of nettle samples the increase was constant but less pronounced compared to celery leaves, possibly due to the shorter duration of the OD process (maximum 90 min). The enhancement of the antioxidant potential of the osmotically dehydrated celery and nettle most probably be attributed to the influence of sugar beet molasses, as an osmotic solution during the treatment. This is in accordance with the claim that sugar beet molasses possesses strong antioxidant potential, confirmed by several studies [23, 24, 28, and 29]. The type of osmotic solution directly affects the retention of bioactive compounds and the overall antioxidant content of the material immersed in it. During the OD, dissolved substances (phenolic compounds, antioxidants, minerals, organic acids, sugars) are transported from the osmotic solution to the plant material. This transfer is essential for the nutritional and functional quality of the dehydrated product [20, 31]. Sugar beet molasses is a rich source of antioxidants [24], and it is certain that some of them diffuse during osmotic treatment into the herbs tissue, contributing to the improvement of its overall antioxidant properties.

At higher process temperatures, and by prolonging the immersion time, the permeability of cell membranes increases, and the viscosity of the sugar beet molasses decreases, making mass transfer faster and easier. Therefore, at higher temperatures and with longer exposure of the sample to OD, better transport of active compounds from molasses to celery and nettle is achieved, causing higher antioxidant potentials of the treated samples. This assumption is in agreement with the experimental data (Tables 1 and 2). It can also be assumed that a higher concentration of molasses solution (over 80%), compared to ternary solution (60%), contributes to its better effect on antioxidant activity of treated herbs. Almeida et *al.*, [16], observed that a higher concentration of osmotic solution favors better preservation of antioxidant capacity. The incorporation of solutes from the osmotic solution into the tissue of the treated material has a protective effect and creates a barrier to the release of water-soluble substances from the sample, especially those that are carriers of antioxidantivity [15]. It is expected that sugar beet molasses, due to its complex composition and heterogeneity in molecules size, forms a stronger barrier than the solution of sucrose and sodium chloride. Therefore, during the OD, molasses penetrates in the herbs tissue, enriching it with antioxidants, and at the same time creating a protective barrier for the transport of antioxidants from celery leaves.

At the same time, it is possible that there is a loss of some antioxidants from celery and nettle, as observed with OD in ternary solution. Qualitative assessment of the antioxidant profile of dehydrated plants is complicated, given the large number of compounds that contribute to overall antioxidancy. Therefore, the influence of OD on the overall antioxidant profile of the treated sample was observed, where sugar beet molasses showed a significant advantage over ternary soultion.

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3. Conclusions

- Although the OD process has been examined to a large extent, more studies aimed to understand the effect of this process on the antioxidant properties of osmodehydrated products are required. Based on the previous investigations, the most commonly used osmotic solutions can, at best, preserve antioxidant capacity of food at lower temperatures, but generally reduce its overall antioxidant content.

- According to the findings in this review, sugar beet molasses as osmotic solution may provide osmodehydrated foods with improvement antioxidant activity. This finding opens a new perspective in which an agroindustrial side-product gained useful value in the food processing.

- Osmodehydrated herbs enriched in health-promoting antioxidants from molasses have potential to be use as an ingredient in complex food such as bakery, confectionary, dairy and cereal products, thus helping promote the consumption of molasses in the human diet.

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