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ANALYSIS OF MASS TRANSFER RATE AND EFFICIENCY OF OSMOTIC DEHYDRATION OF WILD GARLIC

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Abstract

The availability period of fresh wild garlic is very limited, only during the spring season. After harvest, the leaves quickly lose their sensory, nutritious and functional properties. The stability and availability of this valuable herb material can be extended by adequate drying technique. The aim was to evaluate the influence of used osmotic solution, process duration, temperature and mixing on the mass transfer rate and the efficiency of process on wild garlic.

The paper describes a study of osmotic dehydration of wild garlic (*Allium ursinum* L.) in sugar beet molasses and aqueous solution of sodium chloride and sucrose, at three different temperatures (20, 35, and 50 ^{0}C), with and without manual stirring in every 15 minutes. For this purpose, rate of water loss-RWL, rate of solid gain - RSG, rate of weight reduction - RWR and dehydration efficiency index - EI, were determined after 1, 2.5, and 4 hours of dehydration. In order to follow the mass transfer during the process, three key process variables were measured: moisture content, change in weight and change in dry matter, in accordance with Official Methods of Analysis (AOAC). Based on the obtained parameters RWL, RSG, RWR and EI were calculated. Principal component analysis (PCA) was applied to separate the samples according to the process parameters and characterize the observed samples.

Higher values of the observed parameters was achieved when the process was performed with agitation. Mass transfer was the most intensive at the beginning of the process, at temperature of 50 ^{0}C. RWL, RSG, RWR and EI decreased continuously from the first to the fourth hour, and after 2.5 hours showed a tendency to slow down. The highest value of EI was obtained by using molasses as osmotic solution, at 20 ^{0}C, after 2.5 hours of process, performed with agitation (5.59), and without agitation (5.27), which was also observed on the PCA biplot.

Mass transfer was the most intensive at the beginning of the process, decreased continuously from the first to the fourth hour, and after 2.5 hours showed a tendency to slow down. Therefore, processing time can be limited to 2.5 hours.

***Key words**: Osmotic dehydration, Wild garlic, Efficiency of dehydration, Mass transfer rate, PCA analysis.*

1. Introduction

Wild garlic (*Allium ursinum* L.), a perennial herbs, grow wild in the forest, at an altitudes of up to 1,900 m, and on shady river banks [1]. The herbaceous plants grow to a height of 20 - 50 cm and bulbs up to 6 cm long. During blooming wild garlic species form umbel-like white flowers, and black seed gather in trichotomic capsules [1, 2]. Its whole vegetation cycle begins in early spring and ends at beginning of summer. Leaves of wild garlic are edible, with a long tradition of use, as a salad or a spice. Besides culinary uses, their fresh and dried leaves have been used in traditional medicine for centuries [3, 4]. Lately, wild garlic has become increasingly popular, especially when some studies have shown that *Allium ursinum* has more active substances and a stronger therapeutic effect than *Allium sativum* (regular garlic) [5]. High amounts of volatile sulphur-containing compounds (allin, allicin and other) and flavonoids are responsible for cardioprtotective, antioxidant, cytostatic, antidiabetic, antiplatelet and antimicrobial properties [2, 6]. The fresh wild garlic's availability is limited only to the spring months, and after harvesting its leaves wither very quickly and lose their sensory, nutritional and functional characteristics [7]. This short period of its availability is further shortened by the fact that it is best to use young fresh leaves harvested before the time of flowering, when the quality and quantity of valuable compounds are greatest [1]. The application of appropriate drying technique opens a possibility of greater stability and availability of wild garlic for the needs of food and pharmaceuticals industries [8].

The goal of drying wild garlic is to preserve as much as possible the volatile components responsible for its inherent smell and taste and for its health benefits. Therefore, a good selection of adequate drying temperature and total drying time in order to avoid the negative influence of temperature is crucial [7, 8].

In terms of process duration and lower temperatures, osmotic dehydration (OD) is one of the best method for food preservation, with minimal processing. OD implies a simple immersion of fresh plant or animal material in concentrated osmotic solution, where the difference in concentration of water in the raw material and hypertonic solution is the driving force for the dehydration process. The complex cellular structure of plant tissue conduct as a semi-permeable membrane, which allows two main opposite flows: water from the plant material diffuses into the osmotic solution whereas osmotic solutes flow from the solution to the immersed material [9, 10]. Sugar beet molasses, by-product from sugar processing, has been reported to be a very good solution for OD process, primarily due to the high dry matter content (over 80%), which provides intensive mass transfer during the OD [11].

The objective of this study was to investigate the influence of osmotic solution type, process duration, temperature and manual agitation on the mass transfer rate and process efficiency during osmotic dehydration of wild garlic.

2. Materials and Methods

The samples (leaves of *Allium ursinum* L.) were collected during April in the forest of the mountain Fruška Gora (Serbia). Initial moisture content of the fresh plant material was 93.04%. Prior to the osmotic dehydration, wild garlic leaves were washed with running water, dried with paper towels and cut into squares, dimensions of 1 x 1 cm. Sugar beet molasses, with an initial dry matter content of 85.04%, was obtained from the sugar factory Crvenka, Serbia. The second solution used in this work as hypertonic medium was made from sucrose in the amount of 1.200 g/kg water, NaCl in the amount of 350 g/kg water and distilled water, a total of 60% of dry matter (in further text indicated as ternary solution). The dry matter content of osmotic solutions was determined refractometrically, using Abbe refractometer, Carls Zeiss, Jena, Germany. The samples (leaves of wild garlic) were measured and immersed in laboratory vessels with osmotic solutions, whose mass were 20 times higher than mass of samples, in order to reduce excessive dilution of the solutions. Osmotic dehydration processes were performed at temperatures of 20 ^{0}C, 35 ^{0}C, and 50 ^{0}C which maintained constant in heat chamber (Memmert IN160, Schwabach, Germany), with manual stirring in every 15 minutes and without manual agitation. After 1, 2.5 and 4 hours samples from solutions were taken out, lightly rinsed and gently blotted with towels, and then weighed.

The dry matter content of the fresh and osmodehydrated samples was determined by kept samples in an oven (Instrumentaria Sutjeska, Serbia) at 105 ^{0}C until constant mass was attained. In order to follow the mass transfer during the process, three key process variables were measured: moisture content, change in weight and change in dry matter, in accordance to AOAC methods (2000) [12]. Use of these values allow calculation of the following parameters: weight reduction (WR), water loss (WL) and solid gain (SG), rate of weight reduction (RWR), rate of water loss (RWL), rate of solid gain (RSG) and dehydration efficiency index (EI), as described by Koprivica *et al.*, [13]. Principal component analysis (PCA) was applied to separate the samples according to the process parameters and characterize the observed samples [9]. These analysis was performed using StatSoft Statstica, for Windows, ver. 10 program [14].

3. Results and Discussion

By monitoring the change of RWR, RSG, RWL and EI in Tables 1 and 2, the change in mass transfer kinetics, as the basic drive mechanism during the process of OD was monitored. In this way, the rate and the efficiency of the process were directly observed and compared.

Table 1 provides an overview on the average values of these parameters as a function of the type of used osmotic solution, process temperature and duration, when OD was performed without agitation, while in Table 2 are shown the values of the same parameters, when agitation was involved in the process. It is obvious that all observed parameters, without exception, were slightly higher when the process was performed with agitation. It can be explained by the fact that agitation affect on recovery of water layer diffused from sample, providing constant contact of the sample surface with

Table 1. Mass transfer rate and efficiency of the osmotic dehydration of wild garlic without agitation

N°	τ(h)	T (°C)	RWL g/(gi x s x w x s) x 10^5	RSG g/(gi x s x w x s) x 10^5	RWR g/(gi x s x w x s) x 10^5	EI
Sugar beet molasses						
1.	1	20	10.02	1.69	7.93	5.16
2.	2.5	20	5.89	0.97	4.96	5.27
3.	4	20	4.11	1.01	3.08	3.45
4.	1	35	12.45	4.06	8.23	2.67
5.	2,5	35	6.28	1.46	4.79	3.51
6.	4	35	4.18	1.07	3.09	3.28
7.	1	50	15.92	4.37	11.09	3.24
8.	2.5	50	7.46	1.77	5.17	3.58
9.	4	50	5.21	1.13	3.98	3.69
Ternary solution						
10.	1	20	6.95	1.65	4.99	3.67
11.	2.5	20	3.94	1.03	2.58	3.12
12.	4	20	2.59	0.86	1.61	2.69
13.	1	35	8.04	2.01	5.43	3.39
14.	2.5	35	4.36	1.10	3.01	3.18
15.	4	35	2.99	0.94	1.87	2.54
16.	1	50	12.26	3.02	8.91	3.59
17.	2.5	50	6.05	1.69	4.42	3.38
18.	4	50	4.01	1.47	2.53	2.37

Table 2. Mass transfer rate and efficiency of the osmotic dehydration of wild garlic with agitation

N°	τ(h)	T (°C)	RWL g/(gi x s x w x s) x 10^5	RSG g/(gi x s x w x s) x 10^5	RWR g/(gi x s x w x s) x 10^5	EI
Sugar beet molasses						
19.	1	20	10.44	1.97	8.33	5.26
20.	2.5	20	6.29	1.12	5.11	5.59
21.	4	20	4.56	1.21	3.33	3.76
22.	1	35	12.85	4.33	8.52	2.97
23.	2.5	35	6.95	1.86	5.08	3.73
24.	4	35	4.70	1.32	3.39	3.58
25.	1	50	16.75	4.87	11.89	3.44
26.	2.5	50	7.85	2.08	5.77	3.78
27.	4	50	5.63	1.45	4.18	3.88
Ternary solution						
28.	1	20	7.05	1.83	5.22	3.85
29.	2.5	20	4.06	1.22	2.83	3.32
30.	4	20	2.83	1.01	1.84	2.83
31.	1	35	8.27	2.35	5.92	3.52
32.	2.5	35	4.56	1.34	3.21	3.38
33.	4	35	3.16	1.11	2.06	2.86
34.	1	50	12.53	3.31	9.21	3.78
35.	2.5	50	6.42	1.79	4.63	3.58
36.	4	50	4.30	1.68	2.62	2.56

concentrated osmotic solution, i.e. high concentration gradient on the contact surface of the sample/solution. Stirring in every 15 minutes recovers the thick diffusion layer of water from the wild garlic, homogenizing the surrounding osmotic solution, which results in higher values of mass transfer rate in obtained samples.

According to the presented results, OD was the most intensive in the first hour of the process, for all three applied temperatures. By increasing temperatures, higher values of parameters for mass transfer rate were achieved, so the best results were at 50 °C, after 1 hour of dehydration, for both solutions, regardless of agitation. Higher values of RWL, RSG and RWR in the samples osmodehydrated after the first hour were caused by a larger difference in concentration between plant tissue and surrounding hypertonic solutions, so a greater driving force at the beginning of the process. The mass transfer rate was gradually decreased from the first to the 2.5 hours, after which it showed a tendency to slow down.

In terms of the influence of the used osmotic solution on the observed parameters, the mass transfer rate was more intense when wild garlic samples were immersed in sugar beet molasses, compared to the ternary solution. This is reasonable, because the initial concentration of molasses (85.04%) was higher than in ternary solution (60%), which is a prerequisite for better mass transport during the OD process.

The highest values of RWL, RSG and RWR were achieved after 1hours, in sugar beet molasses as osmotic solution, at process temperature of 50 ^{0}C, when the process was performed with agitation: 16.75 g/(gi x s x w x s)·10^5, 4.87 g/(gi x s x w x s) x 10^5 and 11.89 g/(gi x s x w x s) x 10^5, respectively. On the other hand, the lowest values were obtained after 4 hours of dehydration, at temperature of 20 ^{0}C, using ternary solution in the process without agitation: 2.59 g/(gi x s x w x s) x 10^5 for RWL, 0.86 g/(gi x s x w x s) x 10^5 for RSG and 1.61 g/(gi x s x w x s) x 10^5 for RWR.

The parameter EI (WL/SG ratio) is the most valuable indicator of effectiveness of OD. High EI values point to intensive water removal with minimal solid gain [13]. The highest values of EI were obtained by using molasses as osmotic solution, at 20 ^{0}C, after 2.5 hours of process, performed with agitation (5.59), and without agitation (5.27). In the case of ternary solution, the highest EI were observed at 20 ^{0}C, after 1 hours of process with agitation (3.85), and without agitation (3.67).

The principal component analysis, a mathematical procedure used as a central tool in exploratory data analysis, was introduced in this study to explore the experimental data and to separate observed samples [9, 15]. The PCA, applied to the given data set of 36 samples in Tables 1 and 2, has shown a differentiation between the samples according to the observed process parameters. The sample score biplot reveal that the first two principal components, accounting for 86.41% of the total variability for osmodehydrated wild garlic samples, which can be considered sufficient for data representation.

Considering the map of the PCA performed on the data, the variables that contributed positively according to the first principal component were: RWL (which explained 26.6% of the total variance, based on the correlations), RSG (23.2%) and RWR (26.2%). The positive contribution to the second principal component calculation was observed for EI (48.1% of the total variance, based on the correlations). Dehydration time, parameter Ʈ, showed the negative impact on the first principal component (19.4% the total variance), while temperature, parameter T, showed the positive impact on the second principal component (39.8% the total variance) (Figure 1).

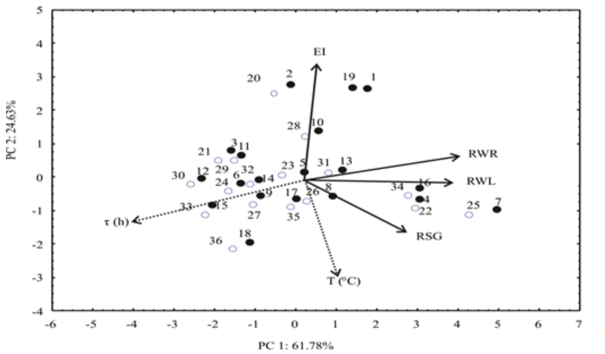

Figure 1. Biplot graphic of osmotically dehydrated wild garlic samples

The first group of osmotically dehydrated wild garlic samples (1h 20 ^{0}C, 1h 35 ^{0}C, and 1h 50 ^{0}C) were located at the right part of the graph. These samples are characterised as the samples with highest values of mass transfer rate and efficiency of OD process. Other samples were located at the left part of the graph, and they are caracterized as samples with lower RWR, RSG, RWR and EI values.

According to PCA analysis, the first principal coordinate describes the difference between samples, based on variances in the temperature coordinate, while the second principal component showing the variations between samples caused by the dehydration time.

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4. Conclusions

- The highest value of dehydration efficiency index was obtained by using molasses as osmotic solution, at 20 ^{0}C, after 2.5 hours of process, performed with agitation (5.59), and without agitation (5.27), which was also observed on the PCA biplot.

- Based upon the presented results, the process was more efficient when it was performed with agitation, due to the better homogenization of the applied osmotic solution.
- Concerning osmotic solution impact on rate and efficiency of dehydration process, sugar beet molasses proved to be a better choice. Additionally, the use of molasses as an osmotic agent is more reasonable from economic, environmental and energetic aspects.
- It can be concluded that the mass transfer rate was the most intensive in the first hour of the process, and after 2.5 hours showed a tendency of slowing down. Therefore, osmotic dehydration time of wild garlic can be limited to 2.5 hours, which could contribute to significant energy savings.

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