UDC 66.061

O.M. Fedoryshyn, R.O. Petrina, A.S. Krvavych, K.S. Kniazieva, Z.V. Hubrii, V.M. Atamanyuk

RESEARCH ON ASPECTS OF THE EXTRACTION KINETICS OF METABOLITES OF *CARLINA ACAULIS* WHILE MIXING

Lviv Polytechnic National University, Lviv, Ukraine

This study reports the features of the mass transfer kinetics during the extraction of phenolic compounds and flavonoids from the *Carlina acaulis* roots. The extraction process of target compounds was optimized and the mathematical model was selected, which implies that the mass transfer of target compounds occurs during the extraction of the solid phase (plant cells) into the liquid phase (extractant). The most effective hydrodynamic conditions for the production of phenolic compounds and flavonoids were determined. An experimental verification of the kinetic equation was carried out by extracting the target compounds from the studied object of various sizes in a vessel with a stirrer using 40% and 70% ethanol as an extractant. The results of the experiment indicated that the target compounds extraction process, namely phenolic compounds and flavonoids from the *Carlina acaulis* roots, proceeds more efficiently under stirring conditions when using particles with a diameter of 2 mm and 70% ethanol as an extractant. The experimental data are in good agreement with the theoretically calculated results, which confirms the appropriateness of using the selected mathematical model. Studies of the kinetics of *Carlina acaulis* roots extraction process will allow minimizing the losses of target compounds, and improving the extraction process and the quality of final product.

Keywords: extraction, kinetics, phenolic compounds, flavonoids, mass transfer coefficient, diffusion, *Carlina acaulis.*

DOI: 10.32434/0321-4095-2023-146-1-3-10

Introduction

Currently, there is a great need to produce drugs based on plant raw material (PM) under industrial conditions. It is important not only to develop a calculation and isolation of biologically active substances (BASs) methodology, as well as to ensure optimal conditions for their isolation from extract, which means to achieve equilibrium of all components that are removed from a mixture. Phytodrugs, obtained by the methods of extraction, such as concentrated extracts from PM and its biomass cultivated *in vitro* have become an industrial significant [1]. Extraction of BASs from PM is an important technological operation used in the chemical, pharmaceutical, food and other industrial fields [2,3]. Therefore, it is important to study aspects of extraction kinetics, mass transfer process intensification, and equipment modernization, that can solve the problem of zero waste technology of the drugs production[1].

Studies of BASs extraction kinetics from *Carlina acaulis* are extremely relevant today, since this medicinal crop has a wide spectrum of pharmacological activity due to the content of phenolic compounds and flavonoids [4−6] and it is used for drugs production. It is necessary to know the equilibrium states and the mechanism of the extraction process in order to implement a certain extraction technology into industry and provide the process with appropriate equipment [7,8].

BASs are dissolved in a cytoplasm that is why its extraction is different from the extraction from mineral raw material. First, there is an internal transfer to the phase contact surface, then an external transfer of BASs from the phase contact surface in the bulk.

BASs pass through a cell wall, which is the main barrier to penetration of an extractant into the intercellular space, and then there is diffusion in the intercellular space to the phase boundary (the particles surface).

The low content of target components (0.05–3%) is the special feature of BAS extraction from PMs (leaves, stems, flowers, bark, and fruits). Due to the cellular structure of these objects, the extraction process is very slow, as the internal diffusion is a rate-determining step. Therefore, in order to accelerate this process there is a need to increase the surface of contact between the phases (grinding the material), select a certain type and concentration of the extractant, etc. [9].

Mathematical models of extraction process are based on the fact that the extraction of the solid phase (plant cells) by the liquid phase (extractant) is the mass transfer of BAS which takes place in three stages: target substances diffusion through the cell membrane into the intercellular space; diffusion in the intercellular space to the solid surface; the transition from solid to the extractant medium. These processes are described by the equation to establish the mass transfer coefficient [10]:

$$k = \left(\frac{\delta}{D_c} + \frac{d}{D_m} + \frac{1}{D_e} \right)^{-1}, \quad (1)$$

where D_c is the coefficient of target substances diffusion through the cell wall; D_m is the coefficient of diffusion in the intercellular space to the solid surface; D_e is the coefficient of diffusion in the extractant medium; δ is the thickness of cell wall; and d is the average particle diameter.

The total coefficient value is equal to:

$$k = \left(\frac{1}{k_c} + \frac{d}{k_m} + \frac{1}{k_e} \right)^{-1}, \quad (2)$$

where k is the total value of the mass transfer coefficient; k_c is the mass transfer coefficient through the cell wall; k_m is the mass transfer coefficient in the intercellular space; and k_e is the mass transfer coefficient in the extractant medium [11].

It is known that phenolic compounds and flavonoids are hydrophilic and soluble in polar solvents. In addition, viscosity and surface tension have a significant effect on the rate of diffusion process. Therefore, the use of ethanol solutions with different concentrations as the extractant for the extraction of phenolic compounds and flavonoids is the most expedient [12]. The optimal concentration of ethanol is in the range from 40 to 70% [13].

The research of the extraction kinetics of *Carlina acaulis* will allow minimizing the losses, improving the process. This, in turn, will improve the quality of the final product.

The purposes of the work are to study the kinetics of mass exchange in the process of extraction of phenolic compounds and flavonoids from the roots of *Carlina acaulis* needle, to optimize the process of extraction of target compounds and to prove the most effective hydrodynamic conditions for the production of phenolic compounds and flavonoids.

Experimental

The study on BASs release kinetics, such as phenolic compounds and flavonoids from the roots of *Carlina acaulis*, was carried out in a vessel with a stirrer. Ethanol solutions with different concentrations (40% and 70%) were used as extractants. Dried roots of *Carlina acaulis* (moisture content – 10%) were used for the experiment. Previously, they had been ground in a laboratory grinder type LMT-2 and sifted through a sieve type SLM-1. The particle size of dried roots was in the range from 2 to 5 mm. The shape of the sifted particles is considered to be spherical [11].

10 g of crushed *Carlina acaulis* roots were loaded into a flask with a volume of 0.250 l and 0.1 l of extractant was added to the raw material, extractant ratio being 1 to 10. The extraction process was performed in the vessel with a stirrer at the temperature of 20±2^{0}C for 2 hours. Samples for analysis were taken from the vessel with a certain periodicity (every 10 minutes), then they were filtered and used for determination of the phenolic compounds and flavonoids content using standard methods with «Sigma-Aldrich» and «Merck» reagents. The total content of phenolic compounds was determined by spectrophotometry method with Folin-Ciocalteu reagent on a spectrophotometer type U Lab 108UV, and flavonoids were determined with silver chloride AgCl reagent [10].

Results and discussion

Hydrodynamic conditions essentially affect the extraction process of plant raw material, especially the process of mass transmission in a diffusive sublayer

[1] Handa S.S., Khanuja S.P.S., Longo G., Rakesh D.D. Extraction technologies for medicinal and aromatic plants. International centre for science and high technology, Trieste. 2008; 21-25. Available from: https://www.morningmystbotanics.com/wp-content/uploads/Extraction_technologies_for_medicinal_and_aromatic_plants.pdf#page=25.

and in an external extractant. As the mixing speed increases, the molecular transfer mechanism changes into the convective one and the size of the diffusive layer decreases [14].

The results of the study on kinetics of extraction in the vessel with the stirrer for the content of phenolic compounds and flavonoids are presented as the dependences BAS content vs. extraction time in Fig. 1 and Fig. 2, respectively. The results of the experiment indicate that the equilibrium concentration of phenolic compounds for particles with a size of 2 mm is reached in 80–90 min (Fig. 1); it is equal to 0.62 kg/m^3 and 0.86 kg/m^3 in 40% EtOH and 70% EtOH, respectively. For particles with a size of 3 mm, the equilibrium concentration of phenolic compounds is reached in 100 min. For the largest particles with a size of 5 mm, the equilibrium concentration of phenolic compounds is reached in 110–120 min. Therefore, the most optimal parameters for extraction are observed for particles with a size of 2 mm after 90 min of extraction in the vessel with the stirrer when using 70% EtOH as the extractant. In this case, maximum concentration of phenolic compounds is 0.86 kg/m^3. As the particle size decreases to 2 mm, the equilibrium concentration establishes faster.

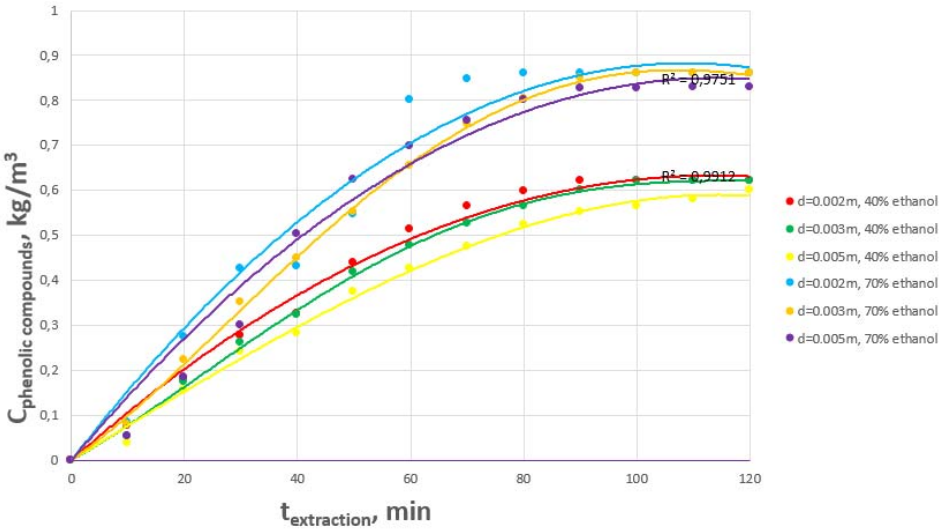

Fig. 1. Time dependence of the phenolic compounds content during extraction in the vessel with the stirrer for *Carlina acaulis* roots particles with different sizes in 40% and 70% EtOH

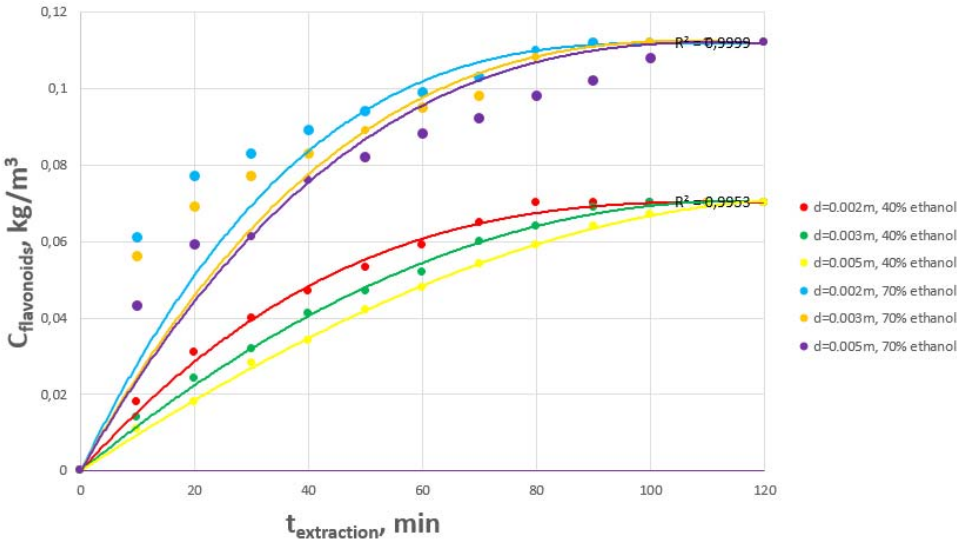

Fig. 2. Time dependence of the flavonoids content during extraction in the vessel with the stirrer for *Carlina acaulis* roots particles with different sizes in 40% and 70% EtOH

The results of the study on flavonoid content changes (Fig. 2) show that the maximum concentration of flavonoids is observed when using 70% EtOH; it equals 0.122 kg/m^3 while it is 0.07 kg/m^3 when using 40% EtOH. Equilibrium flavonoid concentration is reached in 90−100 min for particles of all sizes when using 40% EtOH extractant and in 90 min for 2−3 mm particle sizes and 70% EtOH as an extractant. Therefore, the most optimal parameters for extraction are observed for particles with a size of 2−3 mm after 90 minutes of extraction in the vessel with the stirrer when using 70% EtOH as the extractant. In this case, maximum concentration of flavonoids is 0.112 kg/m^3.

The experimental results of the study on phenolic compounds and flavonoids extraction from *Carlina acaulis* in the vessel with the stirrer allow us to perform mathematical processing experiment, considering the solid phase is a living object (plant) that consists of cells that contain these BASs. In the course of extraction, target components pass through the cell wall into intercellular space, and then there is diffusion in the intercellular space to the interface (the surface of the particle). We use the following designations in this study: C_{IC} is the isolated compound (IC) concentration (phenol compounds or flavonoids) in the cell; V_c is the cell volume, a constant value regardless of the BASs content in the cell; t is the time; and C_1 is the IC concentration in the extraction volume, this value being much smaller than the concentration in the cell space since solid particles of PM consist of a large number of cells and have a spherical shape.

The mathematical model described elsewhere [13] was used for this extraction process. The first equation of the system describes the change of the target substance concentration in the cell volume over time:

$$\frac{dC_C}{dt} = -k_C\left(C_C - C\right) \quad (3)$$

The second equation describes the change of the target substance content in the intercellular space over time:

$$\frac{dC}{dt} = k_C\left(C_C - C\right) - k_M\left(C - C_C\right) \quad (4)$$

The third equation is the material balance equation:

$$V_\varepsilon C_{IC} = V_\varepsilon C_C + V\left(1-\varepsilon\right)C + WC_1, \quad (5)$$

$$t = 0; C = 0; Cc = C_{IC}; C_1 = 0$$

where k_c is the mass transmission coefficient through the cell wall; W is the volume of extract; k_M is the mass transmission coefficient in the intercellular space to the particles surface; V is the volume of extract that is contained in the free space of the solid particle (phase), in the cell and in the intercellular space; and ε is the porosity of the raw material layer.

Subsequently, kinetic constants determined based on experimental data are used. The extraction process kinetics is described by the following equation:

$$C = C_P\left(1 - Ae^{-kt}\right), \quad (6)$$

where C is the instantaneous IC concentration in the extract; C_p is the equilibrium IC concentration in the extract; A is the logarithmic constant (leaching coefficient); k is the mass transmission coefficient; and t is the time of extraction.

Note that Ae^{-kt} is a small quantity that can be neglected when $t=t_p=\infty$, $C=C_p$; here t_p is the time of achieving the equilibrium.

If we find the logarithm for the equation, we obtain the equation in the following form:

$$\ln\left(1 - \frac{C1}{C1p}\right) = \ln(A) - kt \quad (7)$$

The calculation *ln(1−C1/C1p)* was performed at different points in time while isolating phenolic compounds and flavonoids. Based on the data, the following dependence was constructed: $\ln\left(1 - \frac{C1}{C1p}\right) vs.\, t$.

This dependence gives us an opportunity to determine the leaching coefficient *(A)* and the total mass transmission coefficient *(k)* for each value of the solid particles size (phase) when using different extractant concentrations.

The equation of a linear function for particles size may be written as:

$$y_i = \ln\left(1 - \frac{C_i}{C_{1p}}\right)$$

Based on the obtained dependences (Figs. 3 and 4), set of equations for phenolic compounds and flavonoids were obtained (Table 1), that describe the approximated logarithmic lines in the second extraction period, which makes it possible to accurately determine the mass transmission coefficient.

Using the basic extraction equation and determining the mass transmission coefficient k and

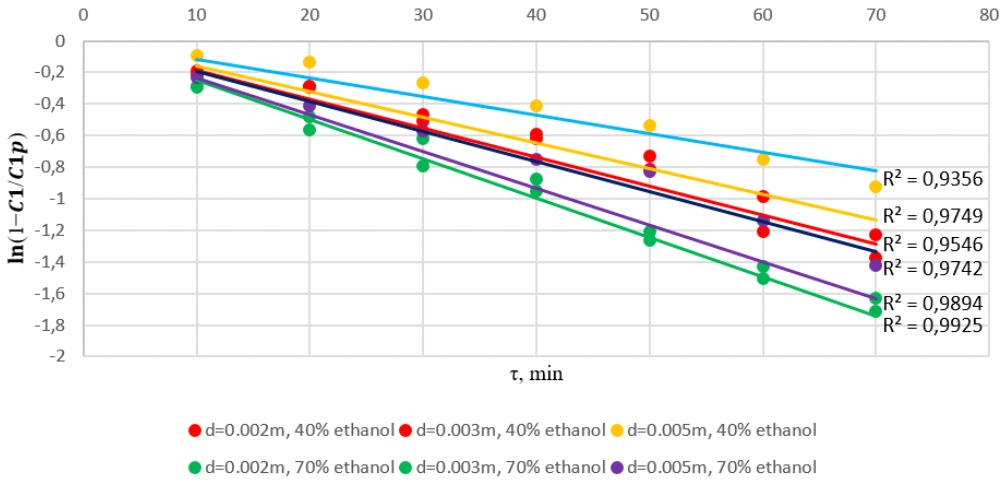

Fig. 3. Dependence $\ln\left(1-\frac{C1}{C1p}\right) vs. t$ for the extraction of phenolic compounds from different sized solid particles of *Carlina acaulis* roots in the vessel with the stirrer

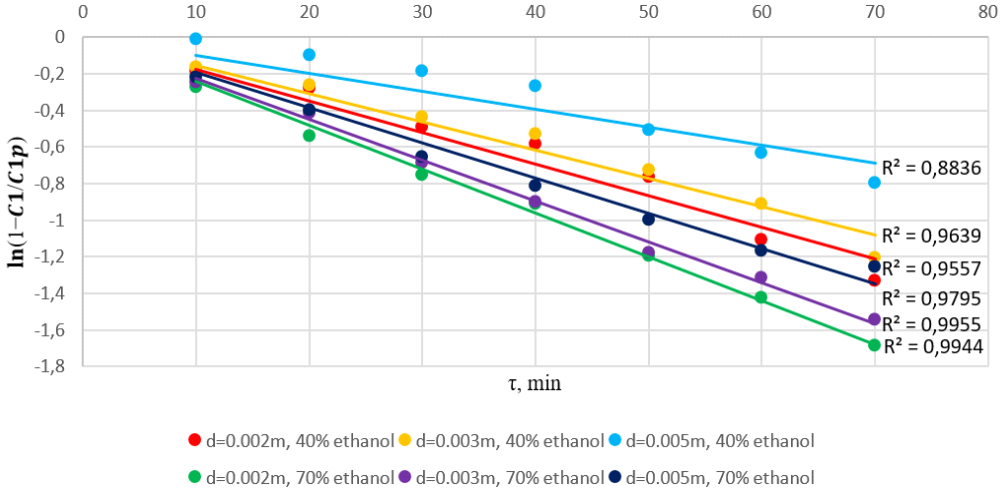

Fig. 4. Dependence $\ln\left(1-\frac{C1}{C1p}\right) vs. t$ $\ln\left(1-\frac{C1}{C1p}\right) vs. t$ for the extraction of flavonoids from different sized solid particles of *Carlina acaulis* roots in the vessel with the stirrer

the leaching coefficient A, the change in phenolic compounds and flavonoids concentrations depending on time were described.

Mass transmission coefficients and leaching coefficients depend on the particle diameter. The dependence k vs. d is described by the following equations for phenolic compounds and flavonoids extraction depending on the PM particle size:

$$k=-0.1478\cdot10^{-4}d+3.76\cdot10^{-4} \quad (8)$$

$$k=-0.1495\cdot10^{-4}d+3.68\cdot10^{-4} \quad (9)$$

The dependence A vs. d is also described by the following equations for phenolic compounds and flavonoids extraction depending on the PM particle size:

$$A=0.0108d+0.8954 \quad (10)$$

$$A=0.0086d+0.8991 \quad (11)$$

The calculated values of k and A are summarized in Tables 2 and 3.

The final kinetic equations were obtained by substituting equations (10) and (11) into the main equation (6). Thus, we have obtained kinetic equations for determining the target extraction products depending

Table 1

Systems of equations for phenolic compounds and flavonoids that describe the approximated logarithmic lines in the second extraction period

Concentration of EtOH	Systems of equations
for phenolic compounds:	
40%	y_1=0.00032t–0.11025
	y_2=0.00028t–0.10853
	y_3=0.00025t–0.07320
70%	y_1=0.00036t–0.16621
	y_2=0.00032t–0.12642
	y_3=0.00028t–0.10568
for flavonoids:	
40%	y_1=–0.00027t–0.10388
	y_2=0.00025t–0.05672
	y_3=0.00022t–0.04287
70%	y_1=–0.00030t–0.14528
	y_2=0.00028t–0.12542
	y_3=0.00022t–0.10857

Table 2

Kinetic constants of the extraction process of phenolic compounds from the *Carlina acaulis* roots in the vessel with the stirrer at different concentrations of EtOH

Parameters	Values					
	40% EtOH			70% EtOH		
d, mm	2.0	3.0	5.0	2.0	3.0	5.0
$k\cdot10^{-4}$, 1/s	3.4	3.0	2.2	3.5	3.2	2.6
A	–0.835	–0.868	–0.924	–0.882	–0.984	–0.992

Table 3

Kinetic constants of the extraction process of extraction of flavonoids from the *Carlina acaulis* roots in the vessel with the stirrer at different concentrations of EtOH

Parameters	Values					
	40% EtOH			70% EtOH		
d, mm	2.0	3.0	5.0	2.0	3.0	5.0
$k\cdot10^{-4}$, 1/s	3.4	28	2.3	3.5	3.0	2.6
A	–0.844	–0.872	–0.887	–0.894	–0.976	–0.934

on the particle size, time and the extractant concentration:

– for the phenol compounds extraction in the vessel with the stirrer:

$$C=0.86(1-(0.0108d+0.8954)\cdot \cdot\exp(-(3.76\cdot10^{-4}-0.1478\cdot10^{-4}d)t)); \quad (12)$$

– for the flavonoids extraction in the vessel with the stirrer:

$$C=1.112(1-(0.0086d+0.8991)\cdot \cdot\exp(-(3.68\cdot10^{-4}-0.1495\cdot10^{-4}d)t)). \quad (13)$$

The obtained equations allow determining the phenolic compounds and flavonoids concentrations at any time t for a given size of solid phase particles or to calculate the required size of solid phase particles for achieving equilibrium concentration during the given time.

Conclusions

1. The process of phenolic compounds and flavonoids extraction from the *Carlina acaulis* roots in the vessel with the stirrer has been optimized based on the experimental and calculation investigations. The main parameters of optimization were particle size and extractant concentration.

2. The results showed that the optimal particle size is 2 mm, and the extractant (EtOH) concentration is 70%. The small size of particles and this extractant concentration contribute to an increase in the

effectiveness of phenolic compounds and flavonoids extraction. A technique, that was used to establish the process mechanism, is comparable with experimental data on kinetics.

3. The kinetics of extraction was experimentally investigated and the kinetic equations of the extraction process of phenolic compounds and flavonoids from the *Carlina acaulis* roots in the vessel with the stirrer were derived. The obtained equations allow determining the phenolic compounds and flavonoids concentrations in the extract at a certain point in time with a particle size of the solid phase of 2−3 mm.

4. The obtained results adequately describe the extraction process of phenolic compounds and flavonoids from the *Carlina acaulis* roots in the vessel with the stirrer. Moreover, these results make it possible to predict the extraction process in a production environment.

REFERENCES

1. *Kinetics* and mechanism of the extraction of biologically active substances from wild species *G. imbricatus* / Krvavych A.S., Konechna R.T., Mylianych A.O., Petrina R.O., Fedoryshyn O.M., Mykytyuk O.M., et al. // Voprosy Khimii i Khimicheskoi Tekhnologii. − 2018. − No. 5. − P.111-115.

2. *Research* of complex of *Calendula officinalis* extract−hydrogel for application in cosmeceuticals / Petrina R.I., Kurka I.S., Holubovska Ya.I., Suberlyak S.A., Fedorova O.V., Hrytsenko I.M. // Voprosy Khimii i Khimicheskoi Tekhnologii. − 2022. − No. 3. − P.53-59.

3. *Pavliuk I.V., Stadnytska N.Ye., Novikov V.P.* Doslidzhennia kinetyky ekstrahuvannia flavonoidiv zi shrotu shyshok khmeliu // East. Eur. J. Adv. Technol. − 2015. − Vol.5/11. − No. 77. − P.36-41.

4. *Biolohichni* osoblyvosti rostu i rozvytku vydiv rodu *Carlina L.* ex situ / Yefremova O.O., Skybitska M.I., Meleshko I.H., Han T.V. // Lisnytstvo i Ahrolisomelioratsiya. − 2009. − No. 115. − P.245-249.

5. *Carlina acaulis* exhibits antioxidant activity and counteracts Aβ toxicity in Caenorhabditis elegans / Link P., Roth K., Sporer F., Wink M. // Molecules. − 2016. − Vol.21. − No. 7. − Art. No. 871.

6. *Bioactivity* assays on *Carlina acaulis* and *C. acanthifolia* root and herb extracts / Dordevic S., Tadic V., Petrovic S., Kukic-Markovic J., Dobric S., Milenkovic M., et al. // Dig. J. Nanomater. Biostruct. − 2012. − Vol.7. − No. 3. − P.1213-1222.

7. *Vyshnevska L.I.* Tekhnolohichni doslidzhennya likarskoyi roslynnoyi syrovyny ta yiyi kompozytsiyi u stvorenni novykh preparativ // Visn. Farm. − 2008. − No. 4. − P.33-38.

8. *Optymizatsiya* oderzhannya flavonoidiv ta fenolnykh spoluk z ekstraktiv biomasy *Carlina acaulis* / Fedoryshyn O.M., Kniazieva K.S., Khomiak S.V., Petrina R.O. // Vcheni zapysky Tavriiskoho natsionalnoho universytetu imeni V.I. Vernadskoho. − 2020. − Vol.31. − No. 70. − P.48-53.

9. *Diachok V.V., Malovanyi M.S.* Doslidzhennia mekhanizmu protsesu ekstrahuvannia iz tverdykh til klitynnoi budovy // Nauk. Pratsi ONAKhT. − 2011. − No. 39(2). − P.130-133.

10. *Diachok V.V., Yatchyshyn Yu.I.* Pro koefitsiienty dyfuzii pry ekstrahuvanni roslynnoi syrovyny // Voprosy Khimii i Khimicheskoi Tekhnologii. − 2013. − No. 1. − P.47-49.

11. *Semenyshyn Ye.M., Stadnyk R.V., Trotskyi V.I.* Eksperymentalne vyznachennia koefitsiientiv vnutrishnoi dyfuzii dlia umov ekstrahuvannia ridkykh ta tverdykh tsilovykh komponentiv / Nauk. Pratsi ONAKhT. − 2010. − No. 37. − Vol.1. − P.341.

12. *Phytochemical* screening and extraction: a review / Tiwari P., Kumar B., Kaur M., Kaur G., Kaur H. // Int. Pharm. Sci. − 2011. − Vol.1. − No. 1. − P.98-106.

13. *Dyachok V., Malovanyy M., Ilkiv I.* Some kinetic regularities of intracellular substance extracting // Chem. Chem. Technol. − 2011. − Vol.5. − No. 4. − P.469-472.

14. *Krvavych A.S., Konechna R.T., Novikov V.P.* Vyvchennia biolohichno aktyvnykh rechovyn kosarykiv cherepytchastykh (*Gladiolus imbricatus)* // Visn. Lviv Polytechn. Nat. Univ. Ser. Chem. Technol. Subst. Appl. − 2014. − No. 787. − P.217-220.

Received 08.07.2022

ДОСЛІДЖЕННЯ ОСОБЛИВОСТЕЙ КІНЕТИКИ ЕКСТРАГУВАННЯ МЕТАБОЛІТІВ *CARLINA ACAULIS* ПРИ ПЕРЕМІШУВАННІ

О.М. Федоришин, Р.О. Петріна, А.С. Кравич, К.С. Князєва, З.В. Губрій, В.М. Атаманюк

Здійснено дослідження кінетичних закономірностей масообмінного процесу при екстракційному вилученні фенольних сполук і флавоноїдів з коренів *Carlina acaulis*. Оптимізовано процес екстрагування цих цільових продуктів та обрано математичну модель, яка ґрунтується на тому, що в процесі екстрагування твердої фази (рослинні клітини) у рідку фазу (екстрагент) відбувається масоперенесення цільових компонентів. Визначено найефективніші гідродинамічні умови одержання фенольних сполук та флавоноїдів. Проведено експериментальну перевірку кінетичного рівняння екстракцією цільових компонентів з досліджуваного об'єкту різних розмірів в апараті з мішалкою за використання 40% і 70% етанолу. Результати експериментальних досліджень вказують на те, що процес виділення цільових компонентів, а саме фенольних сполук і флавоноїдів з коренів *Carlina acaulis*, перебігає ефективніше в умовах перемішування при використанні частинок діаметром 2 мм та 70% етанолу. Дослідні дані задовільно узгоджуються з теоретично розрахованими, що підтверджує доцільність застосування обраної математичної моделі. Дослідження кінетики процесу екстракції коренів *Carlina acaulis* дозволять мінімізувати втрати, удосконалити процес, що в свою чергу покращить якість кінцевого продукту.

Ключові слова: екстрагування, кінетика, фенольні сполуки, флавоноїди, коефіцієнт масоперенесення, коефіцієнт масовіддачі, дифузія, *Carlina acaulis.*

RESEARCH ON ASPECTS OF THE EXTRACTION KINETICS OF METABOLITES OF *CARLINA ACAULIS* WHILE MIXING

O.M. Fedoryshyn, R.O. Petrina*, A.S. Krvavych, K.S. Kniazieva, Z.V. Hubrii, V.M. Atamanyuk

Lviv Polytechnic National University, Lviv, Ukraine

***e-mail: romanna.o.petrina@lpnu.ua**

This study reports the features of the mass transfer kinetics during the extraction of phenolic compounds and flavonoids from the *Carlina acaulis* roots. The extraction process of target compounds was optimized and the mathematical model was selected, which implies that the mass transfer of target compounds occurs during the extraction of the solid phase (plant cells) into the liquid phase (extractant). The most effective hydrodynamic conditions for the production of phenolic compounds and flavonoids were determined. An experimental verification of the kinetic equation was carried out by extracting the target compounds from the studied object of various sizes in a vessel with a stirrer using 40% and 70% ethanol as an extractant. The results of the experiment indicated that the target compounds extraction process, namely phenolic compounds and flavonoids from the *Carlina acaulis* roots, proceeds more efficiently under stirring conditions when using particles with a diameter of 2 mm and 70% ethanol as an extractant. The experimental data are in good agreement with the theoretically calculated results, which confirms the appropriateness of using the selected mathematical model. Studies of the kinetics of *Carlina acaulis* roots extraction process will allow minimizing the losses of target compounds, and improving the extraction process and the quality of final product.

Keywords: extraction; kinetics; phenolic compounds; flavonoids; mass transfer coefficient; diffusion; *Carlina acaulis.*

REFERENCES

1. Krvavych AS, Konechna RT, Mylianych AO, Petrina RO, Fedoryshyn OM, Mykytyuk OM, et al. Kinetics and mechanism of the extraction of biologically active substances from wild species G. imbricatus. *Voprosy Khimii i Khimicheskoi Tekhnologii.* 2018; (5): 111-115.

2. Petrina RO, Kurka MS, Holubovska YaI, Suberlyak SA, Fedorova OV, Hrytsenko OM. Research of complex of Calendula officinalis extract−hydrogel for application in cosmeceuticals. *Voprosy Khimii i Khimicheskoi Tekhnologii.* 2022; (3): 53-59. doi: 10.32434/0321-4095-2022-142-3-53-59.

3. Pavliuk IV, Stadnytska NYe, Novikov VP. Doslidzhennya kinetyky ekstraguvannia flavonoidiv zi shrotu shyshok khmeliu [Study of the kinetics of extraction of flavonoids from the meal of hop cones]. *East Eur J Adv Technol.* 2015; 5/11(77): 36-41. doi: 10.15587/1729-4061.2015.50965.

4. Yefremova OO, Skybitska MI, Meleshko IH, Han TV. Biolohichni osoblyvosti rostu i rozvytku vydiv rodu Carlina L. ex situ [Biological features of growth and development of species of Carlina L. ex situ]. *Lisnytstvo i Ahrolisomelioratsiya.* 2009; (115): 245-249. (*in Ukrainian*).

5. Link P, Roth K, Sporer F, Wink M. Carlina acaulis exhibits antioxidant activity and counteracts Aβ toxicity in Caenorhabditis elegans. *Molecules*. 2016; 21(7): 871. doi: 10.3390/molecules21070871.

6. Dordevic S, Tadic V, Petrovic S, Kukic-Markovic J, Dobric S, Milenkovic M. Bioactivity assays on Carlina acaulis and C. acanthifolia root and herb extracts. *Dig J Nanomater Biostruct.* 2012; 7(3): 1213-1222.

7. Vyshnevska LI. Tekhnologichni doslidzhennya likarskoi roslynnoyi syrovyny ta yiyi kompozytsii u stvorenni novykh preparativ [Technological studies of medical plant raw materials and other compositions in the creation of new drugs]. *Visn Farms.* 2008; (4): 33-38. (*in Ukrainian*).

8. Fedoryshyn OM, Kniazieva KS, Khomiak SV, Petrina RO. Optymizatsiia oderzhannia flavonoidiv ta fenolnykh spoluk z ekstraktiv biomasy Carlina acaulis [Optimization of preparing flavonoids and phenolic compounds from biomass extracts of Carlina acaulis]. *Vcheni Zapysky Tavriiskoho Natsionalnoho Universytetu imeni V.I. Vernadskoho.* 2020; 31(70): 48-53. (*in Ukrainian*).

9. Diachok VV, Malovanyi MS. Doslidzhennya mekhanizmu protsesu ekstraguvannya iz tverdykh til klitynnoyi budovy [Study of the mechanism of the process of extraction from solid bodies of cellular structure]. *Naukovi Pratsi ONAKhT.* 2011; 39(2): 130-133. (*in Ukrainian*).

10. Diachok VV, Yatchyshyn YuI. Pro koefitsiienty dyfuzii pry ekstraguvanni roslynnoyi syrovyny [On the diffusion coefficient during the extraction of plant raw materials]. *Voprosy Khimii i Khimicheskoi Tekhnologii.* 2013; (1): 47-49. (*in Ukrainian*).

11. Semenyshyn YeM, Stadnyk RV, Trotskyi VI. Eksperymentalne vyznachennya koefitsiientiv vnutrishnoyi dyfuzii dlya umov ekstraguvannia ridkykh ta tverdykh tsilovykh komponentiv [Experimental determination of internal diffusion coefficients for the conditions of extraction of liquid and solid target components]. *Naukovi Pratsi ONAKhT.* 2010; 7(1): 341. (*in Ukrainian*).

12. Tiwari P, Kumar B, Kaur M, Kaur G, Kaur H. Phytochemical screening and extraction: a review. *Int Pharm Sci.* 2011; 1(1): 98-106.

13. Dyachok V, Maljovanyj M, Ilkiv I. Some kinetic regularities of intracellular substance extracting. *Chem Chem Technol.* 2011; 5(4): 469-472. doi: 10.23939/chcht05.04.469.

14. Krvavych AS, Konechna RT, Novikov VP. Vyvchennya biolohichno aktyvnykh rechovyn kosarykiv cherepytchastykh (Gladiolus imbricatus) [Study of biologically active substances of gladiolus (Gladiolus imbricatus)]. *Visn Lviv Polytechn Nat Univ Ser Chem Technol Subst Appl.* 2014; 787: 217-220. (*in Ukrainian*).