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STUDY OF THE EXTRACTION KINETICS OF FLAVONOIDS FROM THE FRUITS OF *SOPHORA JAPONICA L.* WITH SUNFLOWER OIL

Among the large number of biologically active substances contained in the fruits of Sophora japonica L., the extraction of flavonoids, substances of medium polarity, is particularly important. The process of extracting them with vegetable oil from fruits is quite complicated. The object of research is the kinetics of the process of extracting flavonoids from Sophora japonica L. fruits with sunflower oil. The influence of temperature, duration, and hydraulic modulus on the extraction process, as well as on the derivation of the equation of the mathematical model, is studied.

Mathematical modeling methods are used in the research. Processing of experimental data for the study of extraction kinetics in the vegetable oil:vegetable raw material system is carried out using the Statistica statistical package. In order to derive the equation of the mathematical model of the process of extracting flavonoids from Sophora japonica L. with sunflower oil, the influence of temperature, duration and hydromodulus on the process of transition of the target component – flavonoids to the extract – is investigated. A mathematical model of the dependence of flavonoids on the hydromodulus (H=10–25), temperature (t=25–45 °C) and the duration of the extraction process of Sophora japonica L. (τ=2–10 h) is obtained, which makes it possible to calculate the content of flavonoids with an average relative with an error within 5 %.

On the basis of the conducted experimental studies, basic technological schemes for obtaining unrefined sunflower oil of increased biological value are developed, which includes the following stages: preparation of raw materials, treatment of prepared raw materials with sunflower oil during dilution and mixing, separation of oil from raw materials by filtering. The proposed technology is promising, as its implementation is possible not only in food industry enterprises, but also in restaurant establishments, as it does not require expensive equipment, additional production premises and special training of personnel.

The mathematical models of the extraction process of Sophora japonica L. with unrefined sunflower oil proposed in the work allow to select the extraction parameters with a high degree of probability and offer the consumer flavonoid-enriched sunflower oil of increased biological value.

Keywords: *Sophora japonica L., sunflower oil, extraction, flavonoids, biologically active substances, kinetics, temperature, hydromodule.*

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1. Introduction

The scientific principles of nutritive science indicate the need for a new approach to the composition, properties and technology of food products, which should satisfy the human body's need for basic nutrients and energy. In addition, in order to prevent food-dependent diseases of consumers, it is advisable to enrich food products with functional micro-ingredients. Based on this, fatty products should be not only a source of energy and plastic material, but also an important supplier of functional ingredients [1–3].

Oils are a promising fatty product of increased biological value, which is confirmed by the significant attention paid to them by scientists from various countries around the world.

There are many ways to obtain oil of increased biological value, namely:

– obtaining blended oils with the aim of optimizing the fatty acid composition, extending their shelf life and increasing the content of useful substances [4–10];
– introduction of vitamins (E, D, A), macro- and microelements, phospholipids of natural and artificial origin [11–17];
– addition of essential oils [18–20];
– addition of oil, CO_2 or alcohol extracts obtained from vegetable and spicy-aromatic raw materials to oils in small quantities [10, 21–24];
– direct introduction of vegetable raw materials to the oil (powder of carrots, garlic, spices, spices, etc.) both in the crushed state and their individual parts [20, 25, 26];

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– extraction of vegetable raw materials (rowan, carrot, pumpkin, garlic, horseradish, medicinal plant raw materials, etc.) with traditional oils [1, 27–30].

One of the most popular and affordable ways to obtain oils of increased biological value is extraction. Since flavonoids are substances of medium polarity, the transition of which to vegetable oil is difficult, it is important to study the kinetics of the extraction process of flavonoids with sunflower oil.

There is a significant amount of scientific research devoted to the extraction of biologically active substances from vegetable raw materials with vegetable oils. But there are no studies on the process of extracting flavonoids from *Sophora japonica L.* with sunflower oil under conditions of dilution at low temperatures (below 50 °C), which emphasizes the relevance of the conducted research.

Therefore, *the aim of research* is to determine the influence of the temperature and duration of extraction on the process of extracting *Sophora japonica L.* flavonoids with sunflower oil, hydromodulus, as well as deriving the equation of the mathematical model.

2. Materials and Methods

The kinetics of the extraction process depends on the type of vegetable oil and raw material. As a vegetable oil, unrefined sunflower oil was chosen, since it is a product of the daily diet of the population of Ukraine. *Sophora japonica L.* was chosen as a plant material, as it is a source of flavonoid substances (rutin, quercetin kaempferol-3-sophoroside, quercetin-3-rutinoside, genistein-4-sophorobioside, narcissin, lycoside, genistein glucuronide, etc.) and contains a significant amount of biologically active substances [31–35].

The content of flavonoids in the obtained oils was determined by the spectrophotometric method using the reaction with aluminum chloride in the presence of acetic acid. Obtaining an alcoholic extract for analysis was carried out using the method proposed in [36]. The optical density was measured at a wavelength of 400 nm on a photocolorimeter KPhK-2 (concentration photoelectric colorimeter KPhK-2 ZOMZ, designed for measurement in separate sections of the wavelength range 315–980 nm). The results were evaluated according to the calibration graph constructed using quercetin as a standard sample (HC qualification, chemically pure, the content of the main component is more than 99 %).

Mathematical modeling and data processing were carried out using the Statistica statistical package.

3. Results and Discussions

Obtaining oil extracts from *Sophora japonica L.* included the following stages:

– preparation of raw materials (drying at a temperature of 20–25 °C, freezing for 72 hours at a temperature of –20±2 °C, grinding to a particle size of 0.5–1.5 mm, infusion in an alcohol-water solution);

– treatment of prepared raw materials with sunflower oil during dilution and mixing;

– separation of oil from raw materials by filtration.

In order to establish the optimal technological mode of processing *Sophora japonica L.* with sunflower oil, it is necessary to develop a mathematical model.

According to previously obtained experimental data, the parameters that affect the extraction process are determined: temperature (t), duration (τ), hydromodulus (H). During the experiment, the rarefaction and the stirring speed are constant values (the rarefaction is 3 mm Hg, the stirring speed is 129 rpm). The criterion of optimality in the finished extract was the quantitative content of flavonoids (C_{fl}, mg/100 g). Thus, the function of the content of flavonoids in the extract depends on temperature, duration and hydromodulus [37, 38].

The general scheme of the mathematical model is presented in Fig. 1.

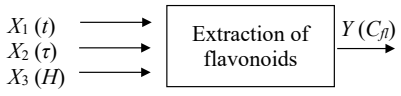

Fig. 1. General scheme of the mathematical and statistical model

The dependence of the output function on the input parameters was determined in the form of a second-order polynomial and the regression equation was drawn up:

$$Y=\beta_0+\beta_1X_1+\beta_2X_1^2+\beta_3X_2+\beta_4X_2^2+\beta_5X_3+\beta_6X_3^2+$$
$$+\beta_{12}X_1X_2+\beta_{14}X_1X_2^2+\beta_{23}X_1^2X_2+\beta_{15}X_1X_3+$$
$$+\beta_{16}X_1X_3^2+\beta_{25}X_1^2X_3+\beta_{35}X_2X_3+\beta_{36}X_2X_3^2+$$
$$+\beta_{45}X_2^2X_3+\beta_{45}X_2^2X_3+\beta_{46}X_2^2X_3^2, \quad (1)$$

where β_0, β_1, β_2, β_3, β_5, β_6, β_{12}, β_{14}, β_{23}, β_{15}, β_{16}, β_{25}, β_{35}, β_{36}, β_{45}, β_{46} – coefficients of the regression equation.

The plan of the experiment was drawn up according to the specified number of experiments and the limits of changing factors.

The required number of experiments is 27, which was determined using the formula:

$$N=3^n=3^3=27, \quad (2)$$

where n – the number of input factors.

Variation steps, upper and lower levels of influencing factors (temperature, duration, hydromodulus) are given in the Table 1.

To derive the regression equation in the original equation (1), it is possible to convert the variables X_i into dimensionless normalized z_i according to the formula:

$$z_i=\frac{X_i-X_{0i}}{\Delta X_i}, \quad (3)$$

where X_i – the value of the factor at the upper "+" or lower "–" level; X_0 – the value of the factor at the 0-level; ΔX_i – the variation step.

As a result, it is possible to obtain the above regression equation:

$$Y=\beta_0+\beta_1Z_1+\beta_2Z_1^2+\beta_3Z_2+\beta_4Z_2^2+\beta_5Z_3+\beta_6Z_3^2+\beta_{12}Z_1Z_2+$$
$$+\beta_{14}Z_1Z_2^2+\beta_{23}Z_1^2Z_2+\beta_{15}Z_1Z_3+\beta_{16}Z_1Z_3^2+\beta_{25}Z_1^2Z_3+$$
$$+\beta_{35}Z_2Z_3+\beta_{36}Z_2Z_3^2+\beta_{45}Z_2^2Z_3+\beta_{45}Z_2^2X_3+\beta_{46}Z_2^2Z_3^2. \quad (4)$$

The construction of the matrix of the complete three-factor experiment is shown in the Table 2.

The processing of the received data and the derivation of the equation of the mathematical model of extracting the fruits of *Sophora japonica L.* with sunflower oil and the construction of its response surfaces were carried out using the Statistica statistical package.

Table 1

Variation levels and factor variation steps

Factor	Units of measurement	0-level	Variation step	Upper level "+"	Lower level "–"
$X_1(t)$	°C	35	10	45	25
$X_2(\tau)$	h	6	4	10	2
$X_3(H)$	–	17.5	7.5	25	10

Table 2

Matrix of a complete three-factor experiment

No. of research	z_0	z_1	z_2	z_3	$\bar{y}$	No. of research	z_0	z_1	z_2	z_3	$\bar{y}$	No. of research	z_0	z_1	z_2	z_3	$\bar{y}$
1	+	+	+	+	2.92	10	+	0	+	+	2.5	19	+	–	+	+	0.55
2	+	+	+	0	14.5	11	+	0	+	0	9.15	20	+	–	+	0	2.9
3	+	+	+	–	17.25	12	+	0	+	–	14.9	21	+	–	+	–	6.9
4	+	+	0	+	2.17	13	+	0	0	+	2.15	22	+	–	0	+	0.43
5	+	+	0	0	10.1	14	+	0	0	0	8.21	23	+	–	0	0	1.31
6	+	+	0	–	16.4	15	+	0	0	–	13.7	24	+	–	0	–	5.34
7	+	+	–	+	1.2	16	+	0	–	+	0.62	25	+	–	–	+	0.215
8	+	+	–	0	6.62	17	+	0	–	0	3.7	26	+	–	–	0	0.92
9	+	+	–	–	8.3	18	+	0	–	–	5.03	27	+	–	–	–	3.05

According to the results of calculations, the equation of the mathematical model of extracting *Sophora japonica L.* fruits with sunflower oil has the following form:

$$C_{fl}=9.991-0.744t+0.006t^2-9.889\tau+0.645\tau^2+$$
$$+0.157H-0.044H^2+1.009t\tau-0.07t\tau^2-0.013t^2\tau-$$
$$-0.028tH-0.001tH^2+0.002t^2H-0.662\tau H+$$
$$+0.014\tau H^2+0.055\tau^2H-0.001\tau^2H^2. \quad (5)$$

The image of the response surface of the complete second-order mathematical model of the dependence of the content of flavonoid derivatives in the extract of Sophora japonica fruits on the duration of the process, temperature, and hydromodulus are shown in Fig. 2–4.

On the basis of experimental studies, a technology for obtaining unrefined sunflower oil of increased biological value was developed, which includes the following stages:

– drying of the fruits of *Sophora japonica L.* at a temperature of 20–25 °C to a humidity of 6–7 %;
– freezing of *Sophora japonica L.* fruits at a temperature of –20–25 °C;
– grinding of frozen Sophora japonica fruits to a particle size of 0.5–1.5 mm;
– infusion of crushed *Sophora japonica L.* fruits for 2–3 hours in an alcohol-water solution with a concentration of 96±1 %;
– addition of *Sophora japonica L.* fruits to sunflower oil in the amount of 10 %;
– treatment of *Sophora japonica L.* fruits with sunflower oil for 6–7 hours with dilution and mixing at a temperature of 30–35 °C;
– separation of oil from *Sophora japonica L.* fruits by filtration.

The resulting unrefined sunflower oil, processed with Sophora japonica fruits, has increased antioxidant properties, exhibits bactericidal properties against pathogenic microflora and increased stability during the storage process [39–41].

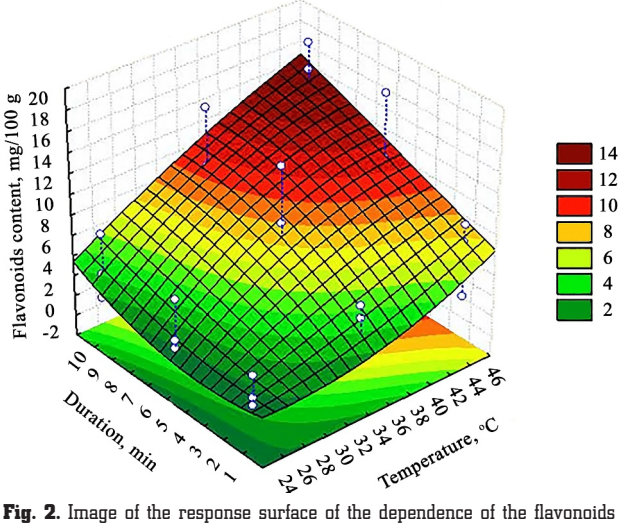

Fig. 2. Image of the response surface of the dependence of the flavonoids content in the extract of *Sophora japonica L.* fruits on duration and temperature at a hydromodulus 17.5

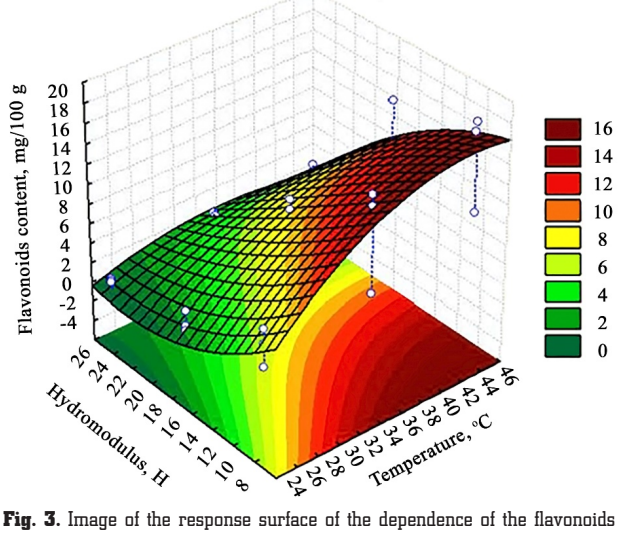

Fig. 3. Image of the response surface of the dependence of the flavonoids content in the extract of *Sophora japonica L.* fruits on the extraction temperature and the hydromodulus with an extraction duration of 6 h

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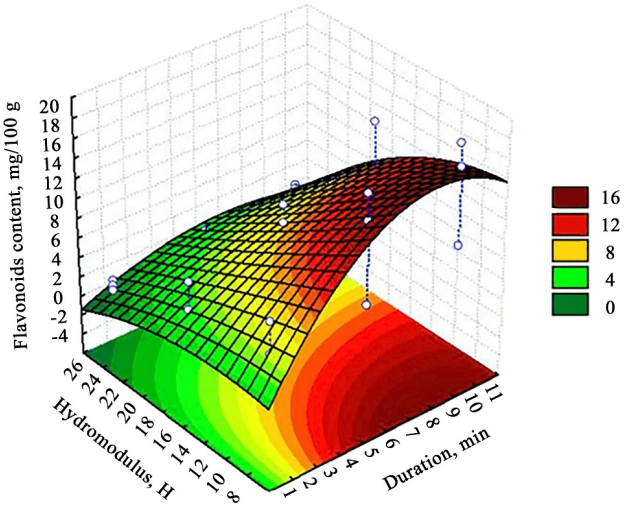

Fig. 4. Image of the response surface of the dependence of the flavonoids content in the extract of *Sophora japonica L.* fruits on the duration of extraction and hydromodulus at a temperature of 35 °C

Considering a number of advantages of the extraction process when extracting biologically active substances from plant raw materials, it remains quite time-consuming and requires considerable time.

Since the process of extracting flavonoids from *Sophora japonica L.* with vegetable oil has not been studied much, it is advisable to further study it. For example, research on the influence of physical factors and the extraction process (influence of cavitation, microwave or other processing) or selection of raw material preparation methods, etc. Further research will contribute to a more in-depth study of the influence of external factors on the process of the transition of biologically active substances of *Sophora japonica L.* to vegetable oil and will allow obtaining a new high-quality product with an improved qualitative composition.

The proposed mathematical models can be implemented in the production of sunflower oil processed with prepared *Sophora japonica L.* fruits under conditions of dilution (3 mm Hg) and stirring (129 rpm) at a temperature of 25–45 °C for 2–10 h at a hydromodule 10–25.

The implementation of the research results and the production of oil treated with *Sophora japonica L.* requires the availability of special equipment (which makes it possible to simultaneously heat, mix and create liquefaction).

4. Conclusions

In the course of the study, the extraction kinetics in the vegetable oil:vegetable raw material system was studied. In order to derive the equation of the mathematical model of the process of extracting *Sophora japonica L.* flavonoids with sunflower oil, the influence of temperature, duration and hydromodulus on the process of transition of the target component to the extract was investigated.

The obtained mathematical model of the dependence of the flavonoids content in the extract of *Sophora japonica L.* fruits on hydromodulus (H=10–25), temperature (t=25–45 °C) and duration (τ=2–10 h) makes it possible to calculate the content of flavonoids with an average relative error up to 5 %.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this study, including financial, personal, authorship, or any other, that could affect the study and its results presented in this article.

Financing

The study was conducted without financial support.

Data availability

The paper has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating this work.

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