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Heat treatment of crushed oil seeds sunflower before pressing

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Abstract. The work investigates the process of preliminary heat treatment of oilcake of sunflower variety Dushko in the field of infrared irradiation before pressing. Based on the planning of experiments, a pattern of changes in the value of the output parameter - the residual oil content of the crushed oil seeds sunflower - was obtained from factors influencing the process: radiant flux density and duration of irradiation in intermittent mode. Using Response Surface Methodology, the optimal values of the influencing factors were determined: radiant flux density 7.2 kW/m^2 and irradiation duration 160 s, at which the residual oil content of sunflower oilcake will be within 9.5-10% after the first pressing.

1 Introduction

In the world practice of producing vegetable oils in general, and sunflower oil in particular, there are two fundamentally different ways of extracting oil from seeds: pressing, mechanically squeezing oil from seeds suitably prepared for pressing; extraction of oil with a highly volatile organic solvent (extraction method) [1-3].

The method of oil extraction is that grinding the raw material is necessary for partial destruction of the cellular structure, as well as to improve the process by further moisture-heat treatment.

If crushed oil seeds are sent after the roller machine to a press, then, despite the high pressure, only a small amount (about 10% to 15% of the total content) of the oil contained in the crushed oil seeds can be extracted in the press. This is due to the fact that the oil, distributed in the crushed oil seeds in the form of thin films on the surface of the crushed kernel, is held by enormous surface forces, the magnitude of which is much greater than the pressure developed by the best presses used to extract the oil. To effectively extract oil from crushed oil seeds, it is necessary to overcome or at least significantly reduce the surface forces holding the oil [4].

Moisture and heat treatment of crushed oil seeds is currently used for this purpose - preparing the pulp, or frying. This process is carried out in roasters consisting of five, six or seven vats working in series.

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At the same time, under the influence of heat on moistened crushed oil seeds , the activity of enzymes initially increases, deteriorating the quality of the oil - The hydrolysis of triacylglycerols with the formation of free fatty acids, the oxidation of unsaturated fatty acids increases, and a change in phospholipids occurs, making it difficult to separate them from the oil. Proteins undergo significant changes.

In recent years, to prepare oilseed raw materials for pressing, heat treatment of the material in an electromagnetic field in the infrared (IR) or microwave range has been used. A large number of studies have been carried out on the mechanism of heat and mass transfer during the processing of food products in the field of electromagnetic waves, including in the field of infrared radiation. Thus, the authors [5,6,7] studied the use of IR radiation for drying sunflower and cotton seeds, for heat treatment of almonds, sesame, and fruit seed kernels. Studies have shown that drying and heat treatment with infrared radiation have a positive effect on the intensity of processes.

The work [8] shows that the use of IR radiation as an effective method of thermal preparation of oilseed material before oil extraction, firstly, ensures the inactivation of anti-nutrients - trypsin inhibitor, which reduces the nutritional value of proteins and the urease enzyme ; secondly, it creates a short-term intense thermal effect, which makes it possible to obtain high-quality cake and oil; thirdly, it makes it possible to process oilseeds on farms and other agricultural enterprises, in lines for the production of low-power vegetable oil. Therefore, there is no need to build an expensive boiler house, which provides production with process steam.

As a result of studies devoted to the problem of drying sunflower seeds using the IR - convective method, the authors [9,10] proposed a radiation-convective drying mode that ensures heating of seeds to 70-750C at an air temperature of 700C, air speed 1.6 m/s, at an emitter temperature of 3000C and a distance between the IR generators and the product of 250 mm. The positiveness of the process is reduced by 1.3 times compared to convective drying. It is concluded that intermittent modes of sunflower drying are advisable from the point of view of reducing the heating temperature of seeds and reducing specific energy costs. The authors show the prospects of using IR radiation for drying (heat treatment) of grain and oilseeds.

The work [11] showed that microwave and infrared irradiation are promising among thermal pretreatment technologies, but they are not used on such a large production scale as frying. For most oilseeds, heat treatment increases the yield of extracted oil and the content of minor lipid compounds in the oil, such as polyphenols, tocopherols and phytosterols.

The purpose of work [12] was to determine the effect of infrared radiation in combination with heating on grape seeds and oil quality. The maximum reduction in microbiological activity was achieved after heating grape seeds with infrared radiation to 135°C and subsequent exposure at 75°C for 60 minutes. The crude oil yield of samples subjected to these conditions was 10.39%, significantly higher ($p<0.05$) than that of the control sample, and their final moisture content was 7.20%. In addition, an increase in the content of free fatty acids and the peroxide value of the oil was achieved.

These studies showed the promise of using IR radiation for heat treatment of oil seeds.

Based on this, the purpose of this research is to determine the optimal heat treatment regime for the crushed seeds of local sunflower in the field of infrared irradiation.

2 Materials and methods

The object of study was sunflower hydride, included in the State Register of Agricultural Crops Recommended for Sowing in the Republic of Uzbekistan. To conduct the research, Dushko sunflower seeds from the 2023 harvest were used. Oil content of seed kernels is 50-52%, protein content is 20.7-23.2% DM.

The oil content of sunflower seed kernels was determined according to the standard “Oil seeds. Methods for determining oil content. Uz State standard 2438:2012". In laboratories, this indicator is analyzed both in raw materials and in finished products. To determine the amount of oil, extractors that implement the Soxhlet method are used. Diethyl ether is used as a solvent.

The initial moisture content of oil seed kernels was determined according to the interstate standard “Oil seeds. Method for determining humidity. State standard 10856-96".

The acid number characterizes the presence of free fatty acids in the oil and is expressed by the amount of potassium hydroxide (mg) necessary to neutralize the free fatty acids and alkali-neutralized triacyl glyceride- related substances contained in 1 g of oil (mg KOH/g oil). This indicator was determined according to the standard “Vegetable oils. Methods for determining acid number. Uz State standard 203:2015".

To determine the optimal values of factors affecting heat treatment, Response Surface Methodology (*RSM*) was used. *RSM* examines the relationships between several independent variables and one or more response variables [13]. The advantage of the *RSM* is that it can extract a large amount of information from a small number of experiments, and it will take less time to determine the optimal process parameters.

The study of the process of infrared heat treatment of sunflower seed mince was carried out on a laboratory installation (Fig. 1), which consists of a working chamber, a control panel with instrumentation, control and alarm equipment.

Inside the working chamber *2* in its upper part there are IR emitters *3*. Quartz halogen lamps of *the KGT 220 -1000 type* were used as IR emitters. Quartz halogen lamps of the KGT type are a type of halogen lamps with a low incandescent temperature that serve as a source of infrared waves. They are a quartz tube with a heating coil filled with halogen. The lamps are mounted in such a way that it is possible to change the distance between them. Above the IR emitters there is a screen *4*, which can be moved vertically. The voltage in the filament of IR lamps varies within 0-250 V using a voltage regulator *RNO-250-10 11*.

The internal surfaces of the working chamber are made of polished aluminum, which has a high reflectivity in the infrared region of the spectrum.

Measuring and recording the temperature in the layer of fruit seed petals and the drying chamber environment during heat treatment is carried out using a *UNI-T UT-39C+* digital multimeter 7 with primary measuring transducers in the form of thermocouples *8*. Sensitive elements and thermocouple wires are protected by screens *9* and heat-resistant protective shells made of asbestos fabric *10* from directly incident IR radiation.

Mesh bed *1* is installed on screw supports mounted on the frame. Four emitters are installed on top of the chamber, which are connected to electrical command devices with a time relay designed to regulate the duration of irradiation and “sleep” - the time without irradiation.

An observation window is provided for visual observation of the heat treatment process. In order to comply with safety standards, grounding of all control and measuring devices, a lock is provided that is activated when the working chamber door is opened, and the entire installation automatically turns off.

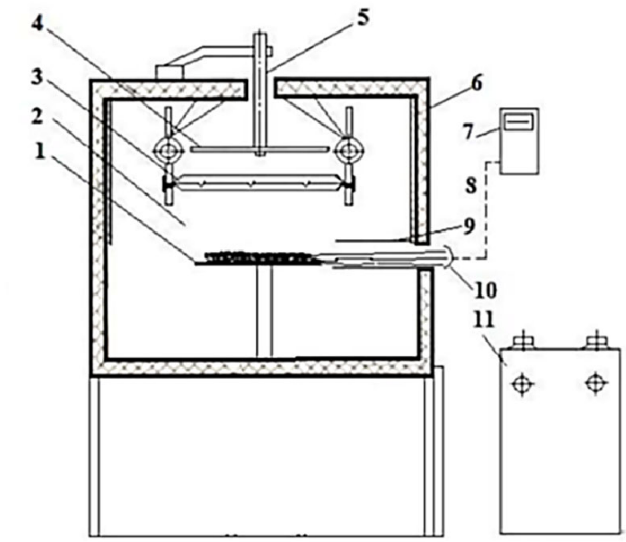
We calculate the irradiation density for the case of emitters (lamps) located in parallel using the formula [14]:

$$E = \frac{P \cdot U_э \cdot a}{l^2}, \ \ kW/m^2 \quad (1)$$

where E is the irradiation density, W/m$^{2;}$ P – power of each lamp, W; U_e is a coefficient that characterizes the efficiency of the source used. $U_e = 0.70 \div 0.85$; l – distance from one lamp to another, m; a is the coefficient of multiple reflections. It is determined by the formula [14]:

$$a = \frac{1}{1 - \rho_К \cdot \rho_П \cdot \psi} \quad (2)$$

where ρ_k≈0.2 is the reflection coefficient of the working chamber; ρ_p=0.5 - product reflection coefficient; ψ is the fraction of the ray flux that is reflected by the camera. This value is taken to be from 0.7 to 0.8.



1 - mesh deck ; 2 - working chamber; 3 - infrared emitter; 4-screen; 5-screen holder; 6-camera body; 7- multimeter; 8- thermo-couples; 9- defender; 10-thermocouple protection shell; 11-voltage regulator

Fig. 1. Diagram of a laboratory setup for studying the process of IR heat treatment of oil seeds.

The work [15] shows that oilseed materials, using the example of stone fruit (apricot) kernels, in the wavelength range of 0.7-1.2 µm have the greatest transmittance, therefore, for effective heating throughout the entire thickness of the layer of petals of sunflower kernels, it is advisable to choose such an IR generator radiation, the maximum radiation intensity of which is in the range of 0.7-1.2 µm [15].

Based on this, a material 5 mm thick is subjected to heat treatment using IR emitters *KGT 220-1000*, emitting rays with a maximum wavelength of 1.1 microns.

Sunflower seed kernels, separated and cleared of husks, are flattened in a laboratory roller device. The resulting petals should be 0.3-0.35 mm thick.

To assess the homogeneity of the resulting crushed raw material, its fractional composition is determined using sieve analysis using a set of sieves.

Sieve analysis of crushed raw materials is carried out as follows: 200 g of raw materials are placed on the largest (upper) sieve and the entire set is shaken for 5 minutes. The sieves are then removed one by one, after which each sieve is again shaken separately over the receiver. Sifting is considered complete if the amount of material passing through the sieve with repeated additional shaking for 1 minute is less than 1 % of material remaining on the sieve. The screenings (passage) are added to the top sieve of the remaining set of sieves.

The quality of crushed oil seeds meat entering heat treatment should be characterized by the following indicators: humidity 5.5–6.5%; husk content no more than 15%; passage through a 1 mm sieve is at least 60%.

The sunflower seed pulp is weighed on an electronic scale with an accuracy of 0.01 g.

A sample of sunflower crushed oil seeds of known initial moisture content and weight is subjected to heat treatment in a chamber of an experimental setup (Fig. 1) under intermittent irradiation mode with a given duration of irradiation and “resting”. During heat treatment, the temperature of the sample was measured with chromel-copel thermocouples and recorded with a *UNI-T UT-39C+* multimeter.

After heat treatment, the sample is pressed in a laboratory hydraulic press. Maximum pressing pressure 25 MPa.

We select the main factors influencing the process. The first influencing factor is the radiant flux density, z_1, kW/m^2; the second factor is the duration of irradiation, z_2, s.

Variation intervals for factor values:

- radiant flux density $z_1^- = 6.5$ kW/m^2 ; $z_1^+ = 7.5$ kW/m^2 ;
- in the mode +60-120+30-120+30-120+30 irradiation duration z_2^- =150 s;
- with irradiation mode +60-120+30-120+30-120+30-120+30;
- irradiation duration z_2^+ =180 s;
- here "+" is the irradiation time; "-" exposure time without irradiation.

When encoding, all variables will take values from –1 to +1, i.e. $x_i \in [-1;+1], i = \overline{1,k}$[16,17].

The output parameter is the residual oil content of the cake, *y*, %.

To reduce the number of experiments with a given accuracy of the results obtained, compositional (sequential) plans were used. The compositional plan consists of experiments 2^k (k≤5), to which is added an experiment in the center of the plan, located on the axes of fictitious space, the coordinates of which are: (±1.0...,0), (0±1.0...,0), (0…, 0, ± 1) [16,17,18,19].

Results and discussion

We build a matrix for planning experiments, taking into account all interactions and average response values, which is shown in Table 1.

The results of the implementation of the plan (average response values, *y* in%) are given in Table 1.

Table 1. Experiment planning matrix.

Experiment number	x_0	x_1	x_2	x_1x_2	Average values response, *y* (%)
1	1	-1	-1	1	12.60
2	1	-1	1	-1	11.90
3	1	1	-1	-1	11.70
4	1	1	1	1	10.70
5	1	0	0	0	10.70
6	1	0	1	0	12.20
7	1	0	-1	0	13.37
8	1	1	0	0	11.57
9	1	-1	0	0	11.40

A mathematical model that takes into account the effect of paired interaction of factors is written in the form [16,17]:

$$y= b_0 +b_1x_1 +b_2x_2 + b_{12}x_1x_2 +b_{11}x_1^2 +b_{22}x_2^2 \quad (3)$$

The model coefficients are determined using the formulas [16]:

Mathematical and statistical data processing was carried out using the *MS Excel* 2013 application computer program.

For the residual oil content of the cake, the results of calculating the coefficients are as follows:

b_0=11.76; b_1= -1.29; b_2= -0.54; b_{11}= -0.88; b_{22}= -0.5; b_{12}= -0.53.

Let's perform a regression analysis of the model. The main task of regression analysis is to obtain a mathematical model of the process, check the adequacy of the resulting model and assess the influence of each factor on the process.

To check the homogeneity of variances, the Cochran criterion was used, which showed that all measurements of response values at all points of the plan are equally accurate [18,19].

The obtained coefficients of the regression equation were checked for significance using the Student's test, which showed that all coefficients are significant.

Then model (3) looks like this:

$$y_1=11.76-1.29\,x_1-0.54\,x_2-0.53\,x_1x_2-0.88\,x_1^2-0.53\,x_2^2 \quad (4)$$

3 Conclusion

Let us carry out the interpretation (interpretation) of the results of model (4), which can only be done when it is written in coded variables. Only in this case the coefficients are not affected by the size of the factors, and we can judge by the size of the coefficients the degree of influence of a particular factor on the change in the output parameter [17]:

1. Coefficient b_0 included in equation (4) shows the value of the residual oil content of the cake y at the main level (i.e. at the factor space point with coordinates $x_1=x_2=...=x_n=0$).
2. Based on the absolute value of the coefficients b_j, we establish the extent to which each of the factors influences the process output, and hence the optimization parameter. For equation (4) $b_1 > b_2$ therefore $x_1 > x_2$ (the density of the radiant flux has a stronger effect on the process than the duration of irradiation).
3. The nature of the influence of the factor is also indicated by the sign of the coefficient. In our case, the optimization parameter tends to a minimum. Coefficients b_1 and b_2 have a negative sign, which means that with an increase in the values of factors x_1 and x_2, the value of the residual oil content of the cake, %, will decrease.
4. We check the mechanism of action of the factors. Here we consider the effects of interaction of factors. In our case, the coefficient b_{12} is significant for the interactions of factors x_1 and x_2: b_1 =-1.29; b_2 =-0.54. Since the coefficients b_1, b_2 and b_{12} in equation (4) have the same signs, the effect of the interaction of factors is enhanced here. It can be assumed that with mutual influence, *x_1 has a greater impact on the process*, because the signs for b_1 and b_{12} coincide. Consequently, to obtain a product with lower oil content, the radiant flux density (x_1) and irradiation duration (x_2) *should be increased.*

We checked the adequacy of the resulting empirical mathematical model using the Fisher criterion [16,17,19].

We write out the mathematical model in the form of regression equation (4) in natural variables, substituting their expressions through z_i *instead of* x_i. Having carried out arithmetic operations, we obtain an equation in natural values of the influencing factors:

$$Y_1=-238.35+46.60\,z_1+1.196\,z_2-0.070\,z_1z_2-2.68\,z_1^2-0.002\,z_2^2 \quad (5)$$

The dependence of the response function on the number of influencing factors can be depicted discretely or continuously, using axonometric constructions *Response Surface Methodology.*

Using the *MATLAB platform* and model (5), we construct a response surface [13], taking into account the dependence of the residual oil content of sunflower seed cake on influencing factors (Fig. 2).

Analyzing the graph shown in Fig. 2, we can conclude that with a radiant flux density E =7.2 kW/m^2 and irradiation duration τ=160 s, the residual oil content of the cake will be in the range of 9.5-10%, and the acid content the amount of oil obtained is in the range of 1.5-1.6 mg KOH, which is a good result after the first "cold" pressing.

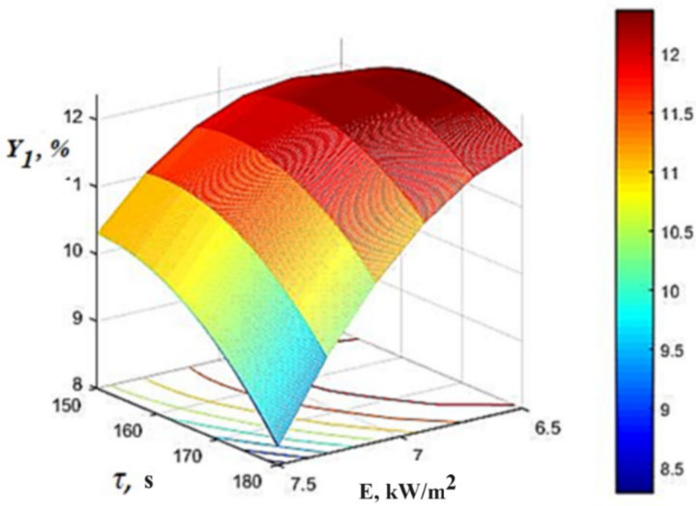


Fig. 2. Dependence of the residual oil content of sunflower seed cake on the radiant flux density, E and irradiation duration, τ.

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