

This paper considers the process of squeezing oil from melon seeds in a screw oil press, using the method of planning a full-factor experiment. To study the interaction of various factors affecting the process of squeezing oil from melon seeds, mathematical methods of experiment planning were applied. Melon seeds were used as the object of the study. The results of studying the physical and mechanical indicators of melon seeds are reported; the rational modes of pressing melon seeds have been determined; the aerodynamic indicators of melon seeds have been defined in order to design a cold-pressed press for melon seeds.

Ventilation modes have been substantiated; the soaring coefficient for melon seeds was derived. The coefficient of resistance for a melon seed is 1.54.

The highest critical velocity values for melon seeds were 6.4, for kernels 4.67, and for husks 3.94, respectively, with seed moisture content of 24.08 %.

The dependence of the oil yield on huskness has been determined. It is established that in the process of pressing there is a decrease in the oil content of the oil seed meal as it moves from the receiving chamber to the exit from the press, at the same time there is a compaction of the compressed product. Based on the study's results, a plant for squeezing oil from melon seeds was designed. As a result of solving the problem with the vector optimization criterion, optimal intervals of input parameters were obtained: the initial humidity of the raw material is 9.15...10.27 %, the speed of rotation of the oil press screw is 0.843...0.895 s⁻¹, the clearance for the yield of cake is 0.750...0.800, the oil seed meal temperature at pressing=87...89 °C, the huskness of the starting product is 7.13...7.23 %

Keywords: vegetable oil, melon seeds, statistical analysis, oil press design, optimization criteria

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DETERMINING OPTIMAL TECHNOLOGICAL MODES FOR PRESSING OIL FROM MELON SEEDS TO JUSTIFY RATIONAL ENGINEERING AND STRUCTURAL SOLUTIONS

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1. Introduction

Given the increasing volume of cultivation of melon crops in Kazakhstan, there is a need to design effective technological equipment for processing seeds of melon crops. The development of technological equipment requires reliable data on the physical, mechanical, aerodynamic, and other properties of both pumpkin seeds and products of their processing [1].

Melon seeds contain a number of biologically active substances and vitamins, which can be used in medicine for therapeutic and prophylactic purposes in the form of oil and cake. The task is to ensure that the oils and cake pro-

duced from the seeds retain biologically active substances and vitamins in their natural form.

The usefulness and effectiveness of melon oil, ways to obtain it are studied by scientists from all over the world. Many studies address the antioxidant, rejuvenating ability of melon oil.

The Sayarska region in northeastern Slovenia and southern Austria has a long tradition of growing pumpkin (*Cucurbita pepo L., Cucurbitaceae*) as an oil crop.

Seed oil is used for salad dressings but is also used in pharmacology and alternative medicine [2], especially when produced organically. The oil content in pumpkin seeds ranges from 40 % to 50 % depending on the genotype. The oil is dark

green and contains free fatty acids. The content of vitamin E, especially gamma-tocopherol, is very high [3]. Melon seeds, although less oilseed, are no less useful.

Study [4] found that honey melon seed oil could be a new source of edible oil because it contains high levels of polyunsaturated fatty acids. Iodine and saponifying numbers, the content of unsaponifiable substances and free fatty acids in freshly squeezed oil from melon seeds amounted to 153.4 g I₂/100 g of oil, 210.2 mg KOH/g of oil, 0.9 and 2.5 %, respectively. The oil had a color index of 1.6Y+0.4R and contained 10 fatty acids, of which 86.1 % were unsaturated. Linoleic acid prevailed (69.0 %), followed by oleic acid (16.8 %) and palmitic acid (8.4 %). The melting and crystallization temperatures were -5.12 and -59.01 °C, respectively. Electronic nasal analysis showed the presence of more volatile compounds compared to refined sunflower oil, which is also rich in linoleic acid.

Treatment with melon seed oil significantly improved the symptoms of polydipsia, reduced fibrinogen levels, increased plasma insulin levels, reduced plasma lipid levels, and protected against islet damage. The results also showed that melon seed oil mitigated oxidative stress and alleviated liver and kidney damage in diabetic mice. Melon seed oil also protected islet cells from apoptotic damage by inhibiting estrogen-mediated and mitochondrially-dependent apoptosis pathways. Further results of the analysis of the components showed that melon seed oil has rich natural resources that have a beneficial effect on the treatment and prevention of diabetes. That study showed that melon seed oil has an excellent antidiabetic effect and served as a scientific basis for the use of melon seed oils in the production of functional ingredients and food additives in the food and pharmaceutical industries [5]. Melon crops are increasingly attracting the attention of scientists and machine operators [6].

Melon is grown and eaten in West Africa and around the world. Melon seeds are a possible source of oil for biodiesel production in some parts of the world, making it a valuable crop of economic importance. Paper [7] provides an overview of mechanical and new methods of processing Egusi melon to extract valuable health-promoting compounds and lipids for use in food and biofuels. Manual processing of Egusi melon is difficult and dangerous to health, so mechanization is inevitable. To obtain high-quality products of melon processing, it is necessary to develop appropriate technologies and intelligent mechanization processes. In addition, the engineering properties of melon fruit, seeds, and kernels were presented as they are important for the design and manufacture of machines for the various stages of melon processing. Further research and more technological solutions are required to mechanize each stage of melon processing in order to significantly improve the production and competitiveness of this crop. The physical and mechanical properties of melons should be incorporated into the design of the machines for their mechanization, as this will further improve their efficiency.

A serious issue is that not every oil press is able to get oil from the seeds of melon crops. Unlike sunflower seeds and other traditional oilseeds, melon seeds have a dense husk and small seeds. As a result, in the prematrix zone of the oil press, hardening of lignin-containing raw materials occurs and the oil press does not cope with this task.

Therefore, research on the development of the design of new types of oil presses for pressing vegetable oil from melon seeds is relevant.

2. Literature review and problem statement

There are few documents related to the physical and mechanical properties of pumpkin crops in the literature. The technical (mechanical and physical) properties of melon seeds, kernels, and fruits, which are highly dependent on moisture, are crucial for the design of machines and equipment for peeling, storage, drying, transportation, planting, processing, and loading and unloading operations [8].

The study of effective ways of processing melon fruits is relevant for developing countries where this culture is mainly cultivated, given its nutritional value in the diet of residents of tropical and subtropical countries. However, the mechanical and physical properties of melon fruits, seeds, and kernels were not taken into consideration to a large extent in the development of machines used in melon processing operations (fruits, seeds, and kernels). The resulting effect is associated with an increase in product losses and a decrease in efficiency [9].

In work [10], a solution was proposed for peeling melon seeds. The performance of a melon seed cleaning machine operating at a constant speed of 1500 rpm and designed without taking into consideration physical and mechanical properties, except for the moisture content, was investigated. The study used two varieties of melon with a humidity of 13.07 % and 12.16 %, respectively. When feeding seeds of both varieties to the machine, the peeling efficiency was 64.1 %, 61.52 %, and 64.1 %, as well as 54.6 %, 51.4 %, and 52.5 % with a seed weight of 100 g, 200 g, and 300 g, respectively. In addition, damage efficiencies of 0.66 %, 0.05 %, and 0.04 %, and 0.95 %, 0.49 %, and 0.36 % were evaluated for seeds of Bara and Sewere varieties, using weights of 100 g, 200 g, and 300 g, respectively.

To produce vegetable oils, the press technique is used, which involves the following sequential technological operations – cleaning seeds from impurities, separating shells, grinding, heat (moisture-thermal) treatment, pressing; it remains almost unchanged for centuries. However, the use of alternative oilseeds implies refining the optimal intervals of pressing parameters for each specific crop, in order to simplify the process under industrial conditions and reduce material and energy costs [11].

To preserve all valuable substances in vegetable oils obtained by cold pressing, it is necessary to choose the right rational parameters for their extraction [12].

To study the interaction of various factors affecting the process of squeezing oil from pumpkin seeds, mathematical methods of experiment planning were applied. Pumpkin seeds (oil content, 32–36 %) were used as the object of the study. There are results of studies to assess the effect of moisture content on some of the physical and mechanical properties of seed melon seeds and their kernels. The average length, width, thickness, weight, and hardness of 100 seeds were 12.42, 7.80, 2.37 mm, 0.097 g, and 64.8 N, respectively, the moisture content in the seeds was 9.53 % (w. b.), for the kernel: 10.5, 6.50, 1.64 mm, 0.061 g, and 14.0 N. An increase in the number of seeds at a moisture content from 9.53 to 24.08 % leads to an increase in the volume density of seeds and kernels from 490 to 600 and from 510 to 640 kg/m³, respectively. However, the true density of seeds decreased from 1160 to 1000 kg/m³. Porosity decreased from 58 to 41 % for seeds and from 50 to 40 % for the kernel, respectively. The highest critical velocity values were 6.4 for seeds, 4.67 for the kernel, and 3.94 for the husk, respectively, with a seed moisture content of 24.08 %. At the same time, the

increase in the moisture content of the seeds increased the static friction coefficient of the seeds from 0.24 to 0.65, 0.23 to 0.80, and 0.34–0.90 for galvanized metal, stainless steel, and plywood, respectively. While the initial values of the static coefficient of friction of the kernels ranged from 0.23 to 0.68, from 0.27 to 0.75 and from 0.33 to 0.80 for surfaces. The rest angle increased from (27 to 43 degrees) for seeds and from 31 to 41 degrees for kernels with an increase in moisture content from 9.53 to 24.08 (w. b.) [13].

Our review [8–15] reveals the prospects of studying both the process of squeezing oil from melon seeds and solving the task of providing technical solutions. An unsolved issue is the lack of cold-pressed oil presses for melon seeds.

3. The aim and objectives of the study

The purpose of this study is to devise optimal technological modes of squeezing oil from melon seeds for the selection of rational engineering and design solutions for the implementation of the process. This will make it possible to design a cold-pressed oil press to extract good quality oil from the seeds of melon crops.

To accomplish the aim, the following tasks have been set:

- to investigate the mechanical properties of melon seeds and determine the structure of a mechanical model;
- to determine the aerodynamic indicators of melon seeds for equipment design;
- to build a mathematical model for the design of a cold-pressed oil press;
- to substantiate the structure of the oil press.

4. The study materials and methods

The object of this study was the technological processes of pressing seeds for vegetable oil, melon seeds of various varieties. The main hypothesis of the study assumed that oil presses for small-scale enterprises do not squeeze oil from melon seeds by cold pressing because of the high content of lignin, improperly selected huskness. In the current study, the following assumptions and simplifications were adopted: the yield of oil from melon seeds is affected by the pressing process, the temperature inside the oil press chamber, the percentage of huskness, and the design of the oil press.

Melon seeds were chosen as materials. For research, the seeds from the 2021 harvest were selected.

Before the start of the experiment, the working chamber and the press cage chamber of the press PSHU «Maslyachok» were heated.

To this end, crushed sawdust weighing 0.3 kg, brought to a humidity of 12...18 %, was loaded into the loading device of the press.

The press with a screw speed of 25 rpm was turned on, while all exit holes were closed. The temperature in the chamber and body was brought to values close to working values (55...70 °C). Next, sawdust was unloaded and the initial product weighing 5 kg was loaded.

The product was processed under the established mode at a certain value of the moisture content of the raw material and the speed of rotation of the screw, the length of the press cage chamber, and the area of the channel for the output of oil and cake. Sensors are mounted in the oil press that provide for the readings of the screw speed, the temperature in the oil seed meal. After the hopper was emptied, sawdust weighing 0.1 kg was again filled in to push through the remnants of the previous load and the process was repeated.

At the same time, in each experiment, the values of the pressure in the press cage chamber, the temperature of the product inside the chamber, the speed of rotation of the screw were recorded. After entering the established mode of operation, the press was stopped and the press cage chamber was partially disassembled in order to take samples for oil content, humidity, and pulp density.

Linear seed sizes were measured with a caliper at the rate of 100 seeds and arithmetic mean data were obtained. The mass fraction of fat and the mass fraction of moisture were determined by a standard method.

The basis of the process of extracting oil from melon seeds is the deformation of the latter under the influence of the compressive force. To establish specific values, the installation is assembled, the main working bodies of the device are a punch, a matrix, and a cup. Whole and crushed melon seeds were alternately poured into the matrix with the initial density. Under the action of the jack, the samples were deformed. The strain force was recorded with a model dynamometer pre-calibrated according to the standard procedure; the movement of the punch was recorded; the data were displayed on the monitor screen as a pressure dependence on deformation (Fig. 1). After deformation, the samples were removed from the matrix and weighed.

Fitting the experimental data with the theoretical curve has made it possible to establish that the relationship between the pressing pressure and the density of melon seeds is expressed by the following empirical dependence:

$$P = c\rho^m, \tag{1}$$

where P is the pressing pressure; ρ is the density of melon seeds, kg/m^3 ; c , m are the coefficients characterizing the physical and mechanical properties of melon seeds: density, elasticity, seed size, seed shape.

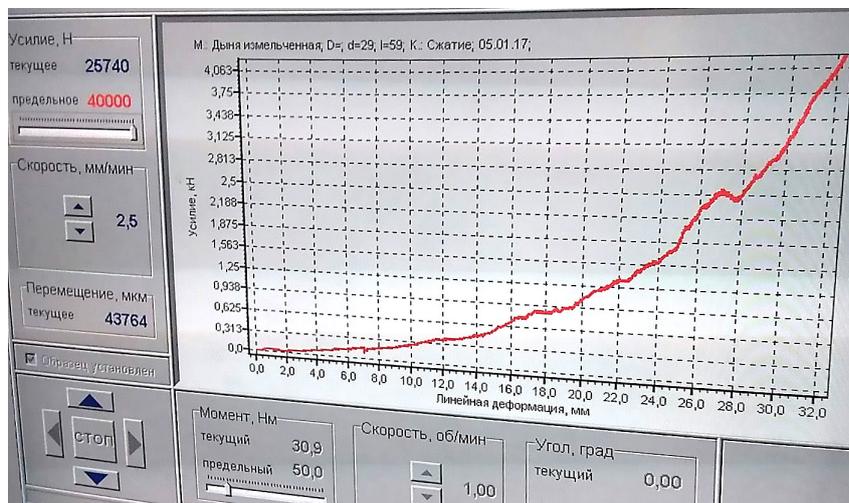


Fig. 1. Dependence of pressure on deformation

The study of the rate of soaring of melon and pumpkin seeds was carried out at a bench installation consisting of a vertical glass tube, a measuring scale, and a fan connected by air ducts in a closed loop. To equalize the air flow rate in the glass tube, meshes are installed on its lower and upper flange connections (Fig. 2). The air flow rate and temperature were recorded with the thermoanemometer VT 100 (KiMO instruments, France) with an accuracy of ± 0.1 m/s and ± 0.2 °C, respectively. The thermoanemometer probe was placed in the center of the air pipe and rigidly fixed with a rubber seal. The object of research was melon seeds, 100 pcs.; humidity, 5.2 %; grown in the Republic of Kazakhstan, Almaty region, Ili district.

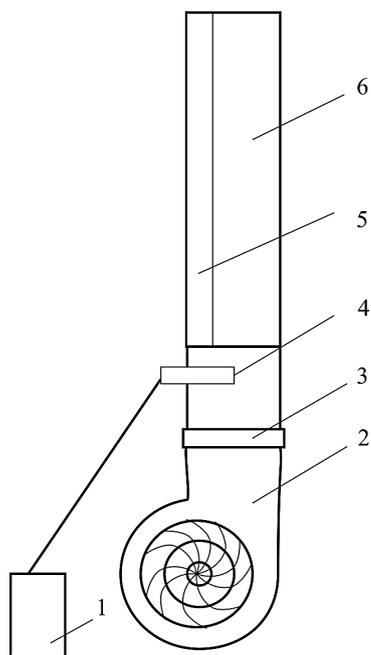


Fig. 2. Experimental installation:
1 – thermoanemometer VT100; 2 – fan; 3 – tee; 4 – probe;
5 – ruler; 6 – glass tube ($L=1$ m)

The principle of operation of the experimental installation is as follows. Fan 2 is switched on and, due to the supply of air through tee 3, the fluidization of the material layer begins in tube 6. Using a sensor located at the end of probe 4, the air velocity of fan 2 is determined. Using ruler 5, the level of the material arrangement in tube 6 is registered.

The granular layer of the material located on the gas permeable supporting lattice, depending on the speed of the upward flow of the gas, can enter a suspension state or remain stationary (filtering). A suspended layer, for external similarity with the behavior of an ordinary drip fluid (fluidity, the ability to take the shape of the vessel in which it is placed, etc.) is called fluidized. The phenomenon of fluidized bed, in this case, can be described as follows.

Suppose that the flow of air (gas, water) moves through the layer as shown in Fig. 3. At low speeds, the flow is simply filtered through the voids between the particles; in this state, they constitute the so-called fixed (filtering) layer (Fig. 3, a). If the flow rate increases above some critical value, the layer would enter a suspended state. Moreover, its structure may be different. At relatively low speeds, a suspended layer with a uniform distribution of the solid phase can be obtained, regardless of the duration of the process and the size of the

apparatus. Such a layer is called homogeneous. It is usually easily organized at the same particle sizes, as well as the absence of large bubbles of gas passing through the layer. Thus, the state of the gas-solid fine-grained particles system can be considered homogeneous only if the upward flow is free from external disturbances (Fig. 3, b, c). In this region, the friction between the particle and the flow is compensated by the weight of the particle, the vertical component of the cohesion force of neighboring particles decreases, and the pressure difference in any section of the layer will be equal to the weight of the flow with the particles in this cross-section.

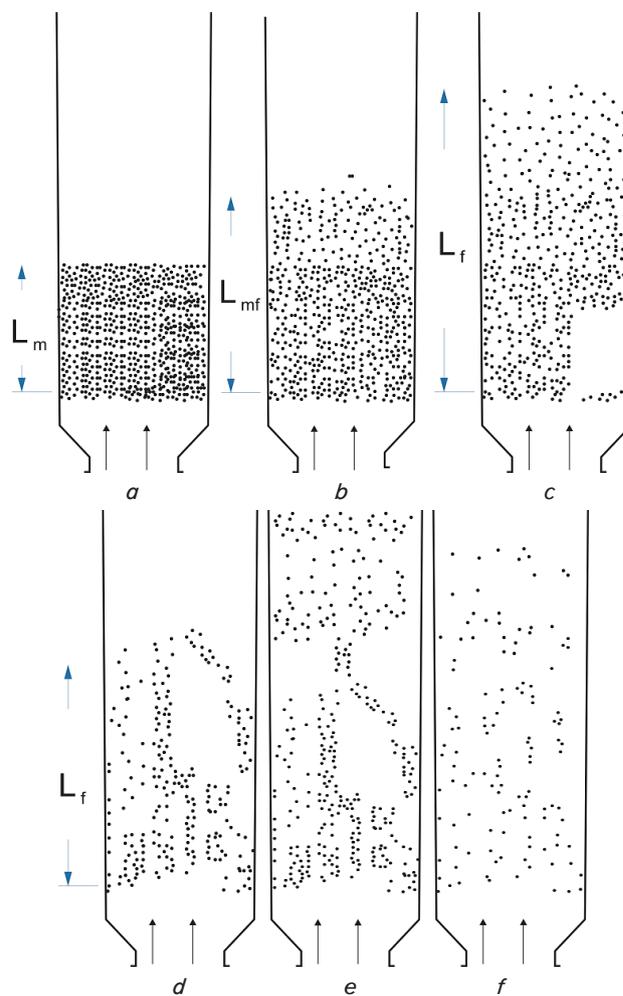


Fig. 3. Schemes of pseudo-fluidization modes:
a – fixed (filtering) layer at a low flow rate of gas or liquid;
b – pseudo-fluidization by fluid flow; c – homogeneous pseudo-fluidization by gas flow; d – heterogeneous (with bubbles) pseudo-fluidization by gas flow; e – piston mode; f – the diluted phase of the fluidized bed with pneumatic transport at a high flow rate of gas or liquid

With a further increase in the flow rate, large inhomogeneities are observed in the form of bubble formation or channel formation. When moving through a layer of large bubbles, the outer surface of the layer breaks, and groups of particles move along with the bubbles along the height of the layer, contributing to intensive mixing of the solid phase (Fig. 3, d).

Many factors affect the rate of mixing of particles, the size of the bubbles, and the degree of heterogeneity of the layer. These factors include the geometry of the layer, the flow rate of the gas, the type of gas distributor, and the internal structure

of the vessel; the presence of elements such as nets, partitions, heat exchangers. As an example, consider piston formation – a phenomenon that strongly depends on the geometry of the vessel. Under this regime, gas bubbles merge and grow as they rise; with a sufficient depth of the layer, they can become large enough to occupy the entire cross-section of the vessel. Therefore, the part of the layer above the bubble is pushed up like a piston. Particles are poured from the piston down, and it collapses. Almost during the same time, another piston is formed, and this pulsating unstable movement is repeated (Fig. 3, *e*). Most often, piston formation is undesirable because it poses a problem of carryover and reduces the potential for using such a layer as for the course of processes. Usually, piston formation occurs in high layers of small diameter.

It is believed that both gas and liquid layers are pseudo-fluidized in the dense phase since there is a well-defined upper boundary or surface of the layer. However, when the velocity of the particles increases at a sufficiently high flow rate, the upper boundary of the layer disappears, the entrainment becomes noticeable and the particles are carried out of the layer with the flow of the fluidized agent. In this case, we have a dispersed, diluted, or fluidized layer in the diluted phase with pneumatic transport of particles (Fig. 3, *f*).

The rate of soaring was defined as the average of 5 dimensions for each cotyledon with its steady oscillatory motion on a fixed length section of the glass tube. The relative error of the average measurement of the velocity of soaring in the series of measurements did not exceed $\pm 2.83\%$.

The wind coefficient (k) was calculated from a known relationship:

$$v = \sqrt{\frac{g}{k}}, \quad (2)$$

$g=9.8 \text{ m/s}^2$ is the acceleration of free fall; v is the average rate of soaring of melon seeds, m/s;

$$k = \frac{g}{v^2}. \quad (3)$$

Substituting values, we derived k values for melon seeds, 0.5 m^{-1} , for pumpkin seeds, $0.09\text{--}0.13 \text{ m}^{-1}$.

We determined the coefficients of aerodynamic drag of seeds according to [16–18].

The resistance force was determined from the formula:

$$R = k_c F \frac{\rho_a V^2}{2}, \quad (4)$$

where k_c is the coefficient of resistance; F is the area of the midsection, m^2 ; ρ_a is the density of air, kg/m^3 ; V is the critical velocity, m/s.

The area of the midsection is irregularly shaped, therefore, it is determined by dividing in triangles. Hence:

$$F = \frac{h}{2} a, \quad (5)$$

where a is the thickness of the seed; h is the width of the seed.

Then the resistance coefficient takes the form:

$$k_c = \frac{2mg}{\rho_a F v^2}. \quad (6)$$

The process of oil pressing is combined with grinding and thermal action on the material in sealed screw presses. The short duration of the temperature effect, the formation of water vapor, and their relaxation not only facilitates the extraction of oil but also improves its quality.

The greatest sealing of the material is achieved at the last turn of the screw. There are two zones there. A sealing zone in which the raw material does not move towards unloading but is compacted between the screw and the «plug» of the briquette. As well as the push zone, in which the material moves towards unloading, and the density of the material and the pressure are unchanged.

The width of the sealing and pushing zones depends on the required density of the briquette, the speed of rotation of the screw, the design parameters of the screw. In order to increase the push zone and, accordingly, the productivity, with a constant briquette density, it is necessary to increase the density of the material supplied to the compaction zone.

Work [19] reported a calculation procedure that makes it possible to determine the force acting on the screw in the zone of the last turn, the torque on the screw shaft, the required power spent on pressing. Our calculations of the screw turn were carried out according to that procedure. Melon seeds differ in structural and physical-mechanical properties from oilseeds. Most presses are not suitable for pressing oils from melon seeds. When choosing an inappropriate oil press, melon or pumpkin seed oil is heated and undergoes an oxidation process, the color of the vegetable oil changes, the oil yield is low. When using a given design to squeeze oil from the seeds of melon crops, these shortcomings are eliminated. The oil yield is 30–35 %.

5. Results of studying the technological modes and choosing the rational engineering and design solutions

5.1. Investigation of mechanical properties of melon seeds, determining a structurally mechanical model

The main physical and mechanical properties of melon seeds from a Kazakhstan producer, the harvest of 2021, were experimentally studied. The oil was squeezed with the help of the oil press PSHU «Maslyachok»; this oil press did not cope with the task of pressing the oil. Without heating the additional press cage chamber of the oil press PSHU «Maslyachok», no oil from peeled and unpeeled melon seeds was squeezed. With the additional installation of heaters and heating the prematrix zone, the oil yield from 1 kg of seeds was 20 ml. The oil came out dark brown in color. Next, the experiment was repeated under the same conditions at the DoLong oil press, manufactured in China. When operating this oil press, the yield increased to 50 ml, but the structure of this oil press includes heating elements along the press cage chamber. The oil at the outlet had a temperature of 65°C , the color of the oil was yellow (like sunflower oil).

Tables 1–3 give the basic physical and mechanical properties of melon seeds. Data on seeds grown in Kazakhstan, Almaty region, Ili district are provided. Also, for comparison, the seeds from melons of the variety «Asian oval», grown in Tajikistan, and melons «C. Edulis», «Egusi», «Sarakhi», grown in Africa.

When designing the main and auxiliary technological equipment intended for cleaning oilseeds from weeds, drying, and collapsing, reliable information on the basic physical and mechanical properties of seeds is required. Such indicators as linear dimensions and shape, volumetric mass, mass of a thousand seeds, coefficient of external friction, as well as information on the specific work of destruction are given [21].

Table 4 gives the physical and chemical indicators of melon seeds of the Torpedo variety, harvest of 2021.

Table 1
Seed linear size

Seed variety	Linear size, mm		
	length	width	thickness
Melon variety «Torpeda» RK	13.07	5.66	1.89
Melon variety «Asian oval»	10.36–14.35	4.58–6.16	1.11–2.49
Melon variety «C. Edulis» [20]	12.81	7.02	2.22
Melon variety «Egusi» [20]	13.20	7.92	1.85
Melon variety «Sarakhi» [20]	15.62–17.05	9.15–10.07	3.10–3.16

Table 2
Friction angle

Seed variety	Moisture content, %	Friction angle at rest, degree		
		Iron	sieve d=7 mm	sieve d=4 mm
Melon variety «Torpeda» RK	6.6	34.5	31.8	39.5
Melon variety «Asian oval»	5.3–23.1	26.5–51.8	28.3–54.5	27.6–52.2

Table 3
Weight of melon seeds

Seed variety	Mass of a thousand seeds, g	Weight of individual seeds, g
Melon variety «Asian oval»	54.14	0.03–0.08
Melon variety «Torpeda» RK	97.3	0.08–0.1

Table 4
Physical and chemical indicators of melon seeds of the «Torpedo» variety

Physical and chemical indicator	Result		
	peel	kernel	seed
mass fraction of fresh seed moisture	39.16	22.02	55.38
mass fraction of fresh seed fat	0.3	41.31	28.58
mass fraction of moisture of wet seeds	6.88	3.77	4.84
mass fraction of wet seed fat	1.03	42.27	34.74

Table 7
Technological characteristics of melon seeds

No.	Seed name	Moisture content, %		Batch weight, g				Batch weight for oil, ml	Volumetric mass, ml	Total, moisture content, %	
				Before drying		After drying					
1	Taisia	5.32	5.14	5.83	5.25	5.52	4.98	100.03	67.928	19	5.23
2	Zhansaya	5.34	5.12	5.05	5.27	4.78	5.0	100.04	67.950	24.6	5.23
3	Ethiopia	5.79	7.5	6.04	5.76	5.69	5.33	100.01	68.07	23.5	6.04
4	Prima	6.08	5.91	6.25	5.92	5.87	5.57	100.00	67.47	24.0	5.99
5	Altynochka	5.41	4.97	7.21	5.84	6.82	5.55	100.03	66.6	24.6	5.19
6	Kolkhoznitsa	5.44	5.13	5.33	6.63	5.04	6.29	100.00	65.18	26	5.28
7	Mayskaya	5.35	4.86	5.04	5.55	4.77	5.28	100.04	68.96	22.5	5.1
8	Muza	3.47	4.84	6.06	5.99	5.85	5.70	100.00	70.92	22.5	4.15
9	Iliyskaya	5.46	5.3	6.40	5.66	6.05	5.36	100.02	67.92	23.5	5.38
10	Medovaya	5.46	5.15	7.13	6.21	6.74	5.89	100.01	69.97	20.0	5.3

Taking into consideration the found coefficients c and m , the specific work of pressing seeds was determined (Table 5); the specific work was calculated from the formula:

$$A = \frac{c}{m-1} (\rho_2^{m-1} - \rho_1^{m-1}), \text{ J/kg.} \tag{7}$$

The degree of compaction for loose crushed seeds was calculated from the formula:

$$\beta = \frac{\rho}{\rho_0}, \tag{8}$$

where ρ is the density of the cake obtained; ρ_0 – of the bulk crushed seeds.

The results of our calculations are given in Table 6.

Table 5
Coefficients and density for melon seeds

Seed type	c	m	$\rho_1, \text{ kg/m}^3$	$\rho_2, \text{ kg/m}^3$
For crushed seeds	0.135	0.1	0.39	2.52
For whole seeds	0.16	0.1	0.4	1.95

Table 6
Theoretical specific work for crushed and whole melon seeds

Name	Quantity	
A, whole, J/kg	98.42689	$*10^{-2}$
A, crushed, J/kg	1255.908	$*10^{-2}$

As can be seen from Table 6, the theoretical specific work on pressing whole seeds is less than that on pressing crushed seeds peeled from husks.

5. 2. Aerodynamic indicators

For the experiment, melon seeds of selection from the «Kazakh Research Institute of Potato and Vegetable Growing» were used. Table 7 gives the technological characteristics with a batch weight of 100 g.

An increase in the amount of seed moisture from 9.53 to 24.08 % leads to an increase in the volume density of seeds and kernels from 500 to 620 and from 570 to 680 kg/m³, respectively. At the same time, there is a decrease in the true density of seeds from 1150 to 983 kg/m³ and its increase for kernels from 1005 to 1138 kg/m³. Table 8 gives the results of measurements of the aerodynamics of melon seeds.

Table 8

Results of measurements of aerodynamics of melon seeds of the variety «Taisia»

Experiment No.	Layer height, m	Airflow velocity, m/s	Pseudo-fluidized mode
1	0.11	0.1...0.4	stationary layer
2	0.14...0.16	0.44...0.48 (critical)	pseudo-fluidized by airflow
3	0.17...0.30	0.5...0.7	piston mode
4	from 0.30 to 1.0	0.8 and faster (carryover speed)	carryover of particles (seeds)

Table 8 demonstrates that the fluidization of melon seeds by the airflow occurs at an air flow rate of 0.44–0.48 m/s. This makes it possible to carry away the husk to a greater extent than the seeds. At the same time, it was experimentally established that at such a speed about 10 % of the huskness is achieved, which was required for the rational pressing of oil from melon seeds.

5. 3. Construction of a mathematical model for the design of a cold-pressed oil press

As the main factors affecting the pressing process, the following were chosen: x_1 is the initial humidity of raw materials, %; x_2 is the rotational speed of the oil press screw, s^{-1} ; x_3 is the size of the gap for the output of the cake, mm; x_4 is the temperature of the oil seed meal at pressing, $^{\circ}C$; x_5 is the huskness of the original product, %.

All these factors are compatible and not correlated with each other. The limits of change in the factors under study are given in Table 9.

Table 9

Limits of change in input factors

Planning condition	Limits of factor change				
	$x_1, \%$	x_2, s^{-1}	x_3, mm	$x_4, ^{\circ}C$	$x_5, \%$
Main level	10	0.8	0.5	80	6
Variation interval	1	0.1	0.2	5	1
Upper level	11	0.9	0.7	85	7
Lower level	9	0.7	0.3	75	5
Upper «star point»	12	1.0	0.9	90	8
Lower «star point»	8	0.6	0	70	4

The choice of intervals for changing factors is due to the technological conditions of the pressing process and the technical characteristics of the oil press. The following criteria for assessing the influence of various factors on the pressing process were chosen: y_1 is the specific energy costs for the pressing process, kJ/kg; y_2 is the residual oil content of the cake, %; y_3 is a comprehensive organoleptic quality index (COQI).

The structure of the quality indicator is considered as a set of the main organoleptic properties of the product and is defined as the product of differentiated (single) indicators according to the formula:

$$y_3 = K_1 K_2 K_3 K_4 K_5, \tag{9}$$

where K_1 is the taste of the product under study; K_2 is the color of the product under study; K_3 is the smell of the product under study; K_4 is the appearance of the product under study; K_5 is the transparency of the product under study.

The overall rating of the resulting product was determined as the arithmetic mean score from the ratings of five independent experts on a 100-point scale.

For the study, central compositional rotatable uniform planning was applied and a complete factor experiment 2^{5-1} with a fractional replica $x_5 = x_1 x_2 x_3 x_4$ was chosen. The order of the experiments was randomized by means of a table of random numbers, which excluded the influence of uncontrolled parameters on the results of the experiment:

$$y_1 = 0.132 - 0.039x_1 + 0.043x_2 - 0.078x_3 + 0.054x_4 + 0.019x_5 - 0.028x_1x_2 + 0.054x_1x_3 + 0.065x_1x_4 - 0.018x_1x_5 + 0.008x_2x_3 + 0.009x_2x_4 - 0.017x_2x_5 - 0.013x_3x_4 - 0.054x_3x_5 + 0.042x_4x_5 + 0.017x_1^2 - 0.017x_2^2 - 0.024x_3^2 + 0.066x_4^2 + 0.044x_5^2, \tag{10}$$

$$y_2 = 5.912 - 0.128x_1 + 0.184x_2 + 0.312x_3 - 0.390x_4 - 0.245x_5 - 0.344x_1x_2 - 0.026x_1x_3 + 0.041x_1x_4 + 0.584x_1x_5 - 0.223x_2x_3 + 0.675x_2x_4 - 0.159x_2x_5 + 0.146x_3x_4 + 0.148x_3x_5 - 0.266x_4x_5 - 0.083x_1^2 - 0.017x_2^2 + 0.135x_3^2 + 0.132x_4^2 + 0.165x_5^2, \tag{11}$$

$$y_3 = 9.365 + 0.037x_1 + 0.022x_2 + 0.386x_3 + 0.026x_4 + 0.018x_5 - 0.029x_1x_2 + 0.007x_1x_3 + 0.012x_1x_4 - 0.017x_1x_5 + 0.005x_2x_3 + 0.012x_2x_4 - 0.017x_2x_5 - 0.024x_3x_4 - 0.012x_3x_5 - 0.011x_4x_5 - 1.669x_1^2 - 1.456x_2^2 - 0.306x_3^2 - 1.032x_4^2 - 1.181x_5^2. \tag{12}$$

The optimization task is stated as follows: it is required to find such modes of operation of the oil press under which, in a wide range of changes in the input parameters of the raw material, there would be the minimum specific energy consumption, the minimum oil content of the cake, and the maximum comprehensive organoleptic quality index. The general mathematical statement of the optimization problem is represented in the form of the following model:

$$q = q(y_1, y_2, y_3) x \in D \xrightarrow{opt} \\ D: y_1(x_1, x_2, x_3, x_4, x_5) x \in D \xrightarrow{\min} \\ y_2(x_1, x_2, x_3, x_4, x_5) x \in D \xrightarrow{\min} \\ y_3(x_1, x_2, x_3, x_4, x_5) x \in D \xrightarrow{\min} \\ v_i > 0, i = 1.3; x_i \in [-2; 2], j = 15. \tag{13}$$

Table 10 gives the recommended intervals of values of output variables as a variant of the solution of the problem of compromise optimization.

Table 10

Recommended intervals of values of output variables that provide a solution to the problem of compromise optimization

y	x ₁ , %		x ₂ , s ⁻¹		x ₃ , mm		x ₄ , °C		x ₅ , %	
	min	max	min	max	min	max	min	max	min	max
y ₁	7.31	11.72	0.843	0.940	0.64	0.78	74	89	4.95	7.23
y ₂	8.15	10.27	0.790	0.895	0.75	0.80	82	92	6.52	7.67
y ₃	9.15	10.61	0.798	0.866	0.72	0.90	87	90	7.13	8.0

At each point of the experiment, 3 parallel experiments were conducted, our results matched the calculated confidence intervals in terms of all quality criteria.

At the same time, the standard error for all control results did not exceed 4.3 %.

5. 4. Rationale for the design of the oil press

In the study, the method of cold pressing from peeled dried seeds of melon fruits was used. The method of cold pressing makes it possible to get a lively, useful, high-quality delicacy oil. The main disadvantage of this method is the low oil yield. The basis for choosing this method is the preservation of natural vitamins, lipids, and minerals. When heated above 80 degrees, the oil loses its stability during oxidation; the shelf life of this oil is reduced and useful properties are lost; given this, the method of cold pressing was chosen. The method for obtaining oil from the seeds of melon crops includes cleaning from weeds, sorting, crushing, drying, and pressing crushed seeds. In this case, drying is carried out in a screw-type device for heat treatment of oilseeds. First, at a temperature of 100 °C to 110 °C for 2–3 minutes, and then at a temperature not higher than 60 °C for 20–23 minutes at a humidity of 3 % to 5 %. Next, the seeds are fed to the installation where the grinding apparatus is mounted; sequentially, crushed seeds enter a globular aero separator. Pressing of crushed melon seeds is performed on an auger press assembled in the laboratory (Fig. 4).

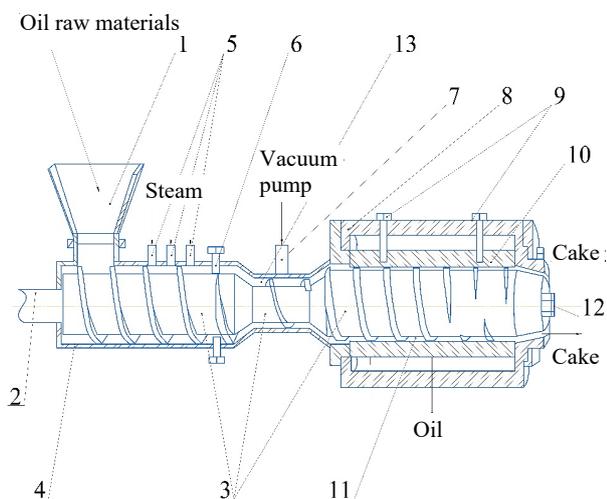


Fig. 4. General view of a press for obtaining oils from vegetable raw materials

The press for oil production from vegetable raw materials, which includes an extrusion chamber, is designed to adjust the temperature. Temperature adjustment is carried out by four screws located in the extrusion chamber. In the extrusion chamber, preliminary preparation of raw materials for pressing is carried out (thermal moisture treatment of raw materials, extrusion). In the zone where the raw material passes into a molten state, an intermediate section is provided, which is necessary for the removal of vapors (formed as a result of extrusion). The zone of direct pressing of oil is represented in the form of trapezoidal cage plates, and there is a small chamfer on the ribs of the plates, designed to form a gap in order to carry out the release of oil.

The press extruder works as follows: an electric motor with a frequency converter is turned on, which drives shaft 2 with bushings with screw windings 3. Oilseeds are fed through loading funnel 1 to extrusion chamber 4. There, there is an intensive grinding of the raw materials, as well as thermal and humid treatment with steam by the installed nozzles 5. Then there is a gradual increase in pressure and compaction of the mass of the product due to a sharp decrease in the size of the screw channel of the screw. There, the bulk mass is converted into a homogeneous melt due to an increase in pressure, while a melt is formed, homogeneous in structure and temperature.

With the help of 4 screws installed in the extrusion chamber, an intense mechanical effect occurs, which also contributes to the additional heating of the homogeneous melt.

Next, the molten product enters vacuum chamber 13, where air is sucked out of the product through nozzle 7. Due to this, there is a decrease in the oxygen content in the pressed raw materials, which makes it possible to achieve greater compaction of raw materials.

From the vacuum chamber, the feedstock enters press cage chamber 11, where direct pressing of the oil is carried out. The design of the screw makes it possible to reduce the free volume in the course of movement of the material throughout the entire press cage chamber, thereby subjecting the raw materials to compression. Compression of raw materials entails an increase in pressure, at which the oil is squeezed. The squeezed vegetable oil exits the press cage chamber through the gaps between cage plates 10, and the squeezed material (cake) exits through the annular gap at the outlet of press cage chamber 11.

The oil output from the oilseeds is regulated by means of screws 9 installed in housing 8. When twisting these screws, the cage plates are wedged, which leads to a decrease in the gap between them. Reducing the clearance makes it possible to reduce the amount of pulp that falls into the oil, and it also makes it possible to optimize the operation of the press extruder when extracting oil from small crops.

Fig. 5 shows a general technological scheme for obtaining vegetable oil from melon seeds by cold pressing. According to this scheme, oilseed raw materials are weighed upon arrival, prepared for processing, cleaned of impurities, dried to a moisture content for melon seeds of 7–11 %, then conditioned and sent for grinding.

Grinding is carried out on a disc crusher to obtain a heterogeneous mixture of grains.

Fig. 6 shows a schematic structure of the cold-pressed oil press for melon seeds designed during our study, based on the results of the experimental data obtained.

The main physical and chemical indicators of the melon oil obtained from melon seeds by pressing are given in Table 11.

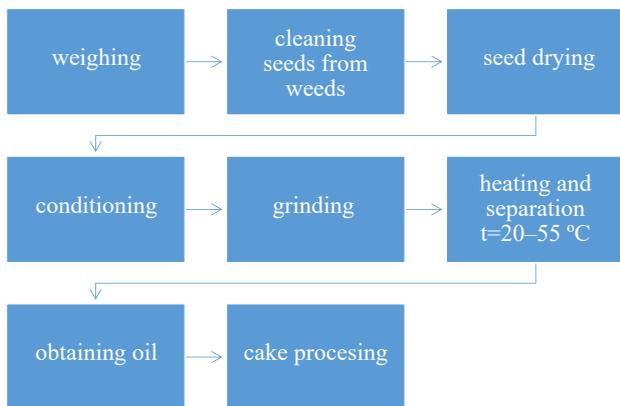


Fig. 5. General technological scheme for obtaining oil from seeds of melon crops

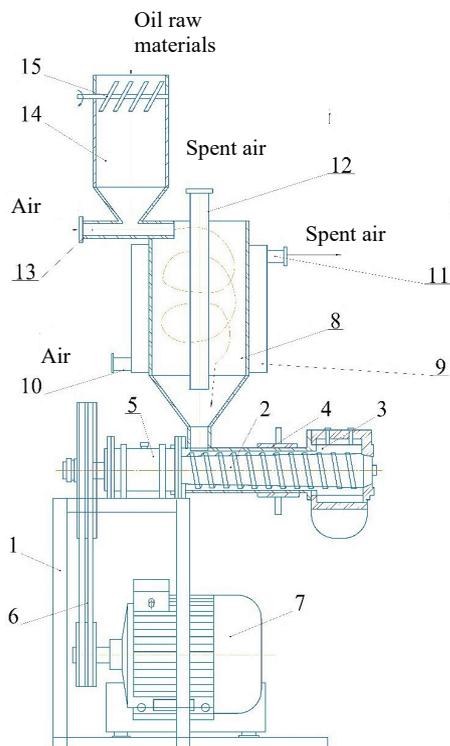


Fig. 6. Schematic diagram of the oil press structure. Designation of positions: 1 – oil press frame; 2 – screw; 3 – press cage chamber; 4 – adjustment nut (tightening); 5 – bearing unit; 6 – belt transmission; 7 – electric motor; 8 – cyclone; 9 – jacket; 10 – fitting for hot air inlet; 11, 12 – fitting for exhaust air outlet; 13 – air inlet fitting; 14 – loading hopper; 15 – chopper

Table 11 gives the qualitative characteristics of vegetable oil obtained from melon seeds on the designed oil press.

Studies were carried out on the dependence of the density of oil seed meal and the acid number of oilseeds on the pressing depth in the screw press (Fig. 7).

Our treatment of experimental data (Fig. 7) has made it possible to derive the following equation for determining the acid number (A.n.) of the resulting vegetable oil:

$$A.n. = 0.31e^{-0.05M} + A.n._0 \tag{14}$$

where A.n.₀ is the average value of the acid number of the oil seed meal entering the oil press.

Table 11

Physical and chemical parameters of melon oil

The name of indicators	Indicator value
Density at 20 °C, g/cm	0.93±0.001
Refractive index, n _{20 D}	1.35±0.01
Saponification number, KOH (in mg)	220.0±2.9
Acid number, mg KOH/g	0.32±0.01
Iodine number	127.0±1.5
Oxidation index	5.01±0.07
The content of unsaponifiable substances, %	0.61±0.01
Content of free fatty acids, %	0.17±0.029
Total content of carotenoids in terms of β-carotene, mg %	13.22±0.04
Total content of tocopherols in terms of α-tocopherols, mg %	20.81±0.16

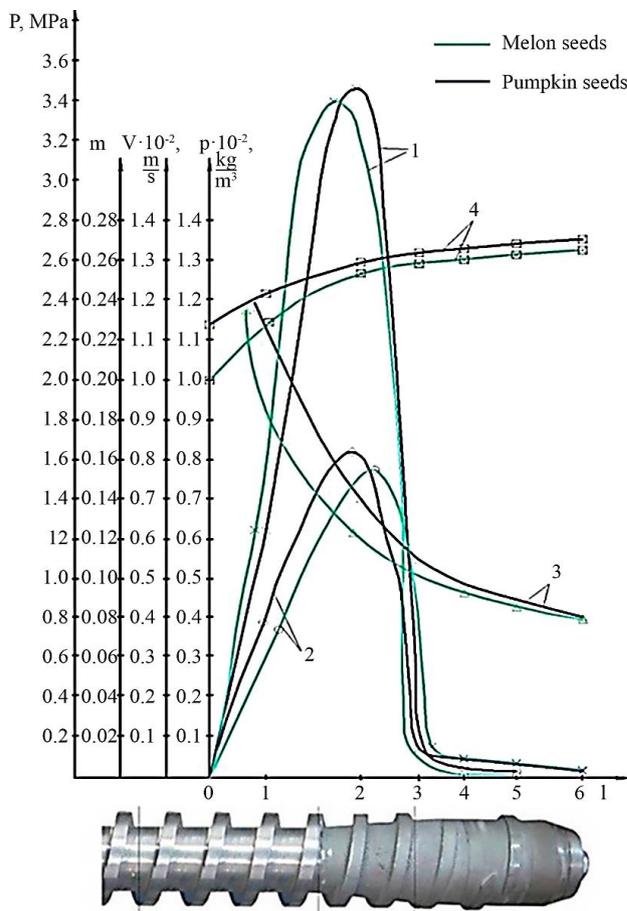


Fig. 7. Change in the pressure, pressing speed, and characteristics of the oil seed meal from melon and pumpkin seeds along the length of the working chamber of the oil press: 1 – pressure in the oil press chamber; 2 – average speed of the pressed oil; 3 – porosity of the oil seed meal; 4 – oil seed meal density [22]

Thus, our study into the kinetics of the pressing process allows a deeper assessment of the processes occurring in the raw materials, making it possible to establish optimal technological modes and optimize the design of the oil press for cold pressing of alternative oilseed raw materials.

6. Discussion of results of the analysis and justification of the design of the oil press

The specific work on squeezing whole melon seeds is less than that for crushed seeds (Table 6). Our experiment on the pressing of oil from purified whole seeds showed that the oil press does not squeeze the oil while lignin-containing raw materials are collected in the prematrix zone. The oil press is heated, the prematrix zone is clogged, the lignin-containing oil seed meal is plasticized under the influence of pressure. In the area closer to the matrix, the temperature is lower, so the lignin-containing oil seed meal solidifies there. Experiments have shown that unpeeled and crushed seeds provide a greater yield of oil (1). Based on this, the crushing process was included in the installation.

The rate of soaring of melon seeds ranges from 8.1–10.7 m/s, the critical velocity of melon seeds (transition from rest to suspension) is 0.44–0.48 m/s, the entrainment rate is 0.8 m/s at a humidity of 5.23 %. The coefficient of resistance for melon seeds is 1.54.

The highest critical velocity values for melon seeds were 6.4, for kernels 4.67, and for husks 3.94, respectively, with a seed moisture content of 24.08 %.

Statistical analysis of the pressing process revealed that the main influence on the pressing process is exerted by the huskness and rotation speed of the screw, at a controlled temperature inside the chamber (Table 10). As a result, a cyclone was included in the installation to provide the right amount of husk when pressing oil from melon seeds. To this end, we conducted studies of the aerodynamic properties of seeds and husks, and determined the mode of cleaning from excess husks.

Our experiment with unpeeled seeds showed that the cake comes out with residual oil. Providing a husk content of 7–10 % ensures maximum oil yield but increases the pressure inside the chamber (Fig. 7). Accordingly, it was decided to maintain the content of husks at 10–15 %. The higher the temperature in the pressing chamber, the better the oil yield, but the greater the likelihood of an increase in the acid number, which results in a short shelf life of the oil.

The indicators for the vegetable oil obtained at the optimal point of the experiment are given in Table 11 and show that the oil obtained in this way is not inferior in quality to vegetable sunflower oil. Our results are limited to the considered area of experiment planning (Table 9).

The disadvantages of this study are that with different seed moisture, we have different unit costs, specific work.

In the future, it is planned to study the processes of squeezing vegetable oil from melon seeds, depending on the

moisture content of the seeds and improving the design of the oil press.

7. Conclusions

1. An experiment was conducted to determine the relationship between the pressure and density of melon seeds, which has made it possible to establish an empirical relationship in the form of an indicative function. In this case, both crushed and whole seeds were studied. It is revealed that the theoretical specific work on pressing whole seeds is less than that on pressing crushed seeds peeled from husks.

2. The values of the aerodynamic characteristics of pumpkin and melon seeds make it possible to assess the possible limits of their changes. Aerodynamic characteristics can be used to design pneumatic separation equipment to refine the technological modes of operation when designing technological lines for the processing of melon crops. Our study showed that the humidity and weight of seeds significantly affect the aerodynamic properties; on average, with the same seed humidity, different varieties show approximately the same coefficient, the spread is ± 0.8 –1.

3. Regression equations have been constructed, the analysis of which has made it possible to identify the factors that most affect the considered process of pressing oilseeds, using melon seeds as an example. It was established that the initial humidity of the product was 9.10...10.23 %, the remaining independent variables (screw rotation frequency, the value of the gap for the output of the cake, the temperature of the pulp during pressing, the huskness of the initial product) conflict with each other regarding the optimization criteria. It is concluded that when entering the oil press, melon seeds should possess a humidity from 7–11 % and a seed temperature from 50–55 °C.

4. Our design justifies the presence of a crusher, aero separation, and related processes. The huskness should be 7.13 from the peeled seeds – this percentage of huskness contributes to the construction of a certain frame when pressing the oil and forms the porosity of the model, as well as reduces the amount of lignin in the prematrix zone. According to the technology, the oilseed raw materials are first crushed when entering the oil press, the excess husk is removed through the cyclone. Next, it enters the working chamber already heated to the required temperature. It is established that the longer the raw material stays in the matrix zone, the greater the acid number, therefore, the worse the quality of vegetable oil.

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