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Improving the Technology of Refining the Safflower Oil Using the Flax Fiber for the Primary Purification

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Abstract: The safflower oil is a very valuable product for the body and human health. It is rich in macro- and microelements, vitamins and minerals, and also has antioxidant properties. Primary purification of safflower oil is an important stage in production, as it directly affects the quality of the final product and its storage. To purify safflower oil, the combination of filtration and sedimentation processes in an experimental cone-shaped centrifuge is a new direction for this technology. The purpose of this study was to determine the effects of flax fiber as a filter material on safflower oil. The results showed that the quality indicators of safflower oil before and after filtration through flax fiber suffered changes. The amount of unsaturated fatty acids such as oleic (18.31±0.874%) and cis-linoleic acid (82.52±1.854%) increased, and there was also a significant increase in the content of arginine (2.1), tyrosine (0.57), methionine (0.4), cystine (2.5), tryptophan (2.6) and other amino acids in the unit of measurement oil g per 100 g of protein. There is an increase in the total amount of phenols (322.12±6 mgEAG/kg of oil), which directly affected the increase in the antioxidant activity (42.65±8%) of safflower oil. These results are proof of the enrichment of safflower oil with flax fiber. To find the optimal parameters of the process of centrifugation of safflower oil on a cone-shaped sedimentary-filtering centrifuge, the thickness of the flax fiber and the distance between the inner and outer perforated filter rotor were changed. The optimal and effective for the yield of safflower oil and the separation factor is the thickness of the flax fiber $1.5*10^7$ nm, and the thickness of the sediment is $0.5*10^7$ nm.

Keywords: safflower oil; refining; antioxidant; purification; enrichment; filter material; sediment; centrifuge

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1. Introduction

Vegetable oils are an indispensable factor in human health, not only as a source of energy but also as a plastic material that is part of cell membranes. Lipids in the human body play a role in important biochemical processes [1,2]. The uniqueness of vegetable oils is due to their nutritional value. They are the main suppliers of carbohydrates, proteins and fats necessary to replenish energy in the human body, and in many respects, they are also carriers of essential (not produced by the body) fatty acids [3,4].

Among oilseeds, safflower (Carthamustinctorius) is growing in popularity. Safflower is one of the oldest oilseeds and has been cultivated since ancient times mainly for its flowers for the production of paint. Currently, safflower is mainly used as an oilseed. In recent years, there has been growing interest in the beneficial effects of this oil on human health. Potential therapeutic properties are anti-carcinogenic and anti-atherosclerotic effects and growth activation with a slight increase in body weight [5-7]. And according to Liu et al., the oil content of safflower seeds ranges from 20 to 45%, and the oil is rich in linoleic acid, an unsaturated fatty acid that helps lower blood cholesterol levels [8].

Safflower oil is a very useful vegetable oil because it has a high concentration of linoleic and oleic acid [9,10]. They are a source of beneficial unsaturated fatty acids. They normalize the level of cholesterol and glucose and therefore are of great importance for people who have obesity, diabetes, and diseases of the cardiovascular system [11,12]. The use of safflower oil in food helps to strengthen the immune system, and experts recommend introducing the herbal composition into the diet of people prone to the development of diseases of the liver, genitourinary system and gallbladder [13,14].

The oxidative instability of raw safflower oil prevents it from being stored for long periods before processing. Typically, the induction period, which can be used as an indicator of oxidative stability, including storage, of raw safflower oil without the use of antioxidants ranges from 4 to 8 hours immediately after receipt and decreases to 1-3 hours after 2-4 months of standard storage conditions [15,16]. That is, safflower oil does not have high resistance to oxidation [17-19].

Primary purification of vegetable oils, which primarily involves the removal of mechanical impurities, is one of the important stages of food production since it affects quality indicators and reduces losses during production, transportation and storage [20]. Primary treatment includes such processes as filtration, settling, and separation. They are physical methods for cleaning vegetable oils, resulting in a natural product. Of all the above processes, filtration is of high importance, as it directly affects the subsequent purification processes. During the purification process, a precipitate is created at the initial stage, which must then be filtered out [21-23].

It should be noted that it is the accompanying substances and impurities, and not triglycerides, that determine the color, taste and smell of fats. At the same time, some of them (for example, phospholipids, and vitamins) increase the nutritional value of fats [24,25]. The presence of other substances (waxes, gossypol, etc.) - on the contrary, worsens the quality of fats and complicates their technological processing [26].

After pressing, safflower oil is a multicomponent polydisperse liquid system, which, in addition to glycerols and related substances, contains protein and non-protein mechanical impurities. These impurities contribute to the development of various spoilage processes, so their removal immediately after receipt is critical. For these purposes, methods such as sedimentation, centrifugation and filtration are used [27,28]. Currently, there is no equipment for the simultaneous filtration and settling of safflower oil. Therefore, the development and justification of equipment that allows primary purification from mechanical impurities after pressing by centrifugation, combining the processes of filtration and settling, is an urgent task for the industry and the purpose of the research of the authors [29].

Currently, centrifuges, pressure sheets, bags, polishing, cartridge, frame, membrane, vacuum filters, etc. are used to filter vegetable oils, including safflower oil. In all of the above and other equipment, fabric and non-fabric materials, porous ceramics, sand, sintered glass or metal, membranes, and others are used as filtering materials [30-32]. Each piece of equipment and material has its advantages and disadvantages and is also used at different stages of cleaning. For example, for primary purification of vegetable oil after pressing or for purification of vegetable oil after hydration and neutralization. However, all filter materials are intended only for cleaning vegetable oils from mechanical impurities that worsen their taste, and presentation and promote the oxidation process (me-

chanical impurities, heavy fats, paraffin, wax, hydrophobic fractions and soapy substances) [33,34].

From the foregoing, it should be noted that the by-products of processing grains and oilseeds are not used as a filtering material. Potentially, these filter materials can not only be purified vegetable oils, but vegetable oils can also be enriched with macro- and microelements, vitamins, etc. beneficial for human health. It should be noted the nutritional value of safflower oil for human health in the fight, prevention and treatment of hyperlipemia, atherosclerosis and coronary heart disease, and this is only a small part of the ailments [35-37].

The purpose of this study is to improve the technology of filtration of safflower oil on a cone-shaped sedimentary filter centrifuge. As a filter material, secondary products of processing of the grain processing and oil and fat industries were used for deep purification and enrichment of safflower oil. This work is the only one of its kind since there are no studies in the field of combining the processes of filtration and settling of the centrifuge, as well as the filtration of vegetable oils through natural by-products of processing grains and oilseeds. The results of these studies will give a great impetus and interest to the process of primary purification, that is, to filtering and settling not only safflower oil, but also other vegetable oils, and will also provide an opportunity to enrich vegetable oils using filter materials from secondary products of processing grains and oilseeds.

2. Materials and Methods

2.1. Materials

2.1.1.The material for extraction of safflower oil

For pressing, safflower seeds of the Akmai variety were used, which was researched and described by Aknur Turgumbayeva, Ardak Jumagaziyeva and other authors, and this safflower variety was grown in the Akmola region of Kazakhstan in the experimental sown areas of the S. Seifullin Kazakh Agrotechnical Research University in Astana (Latitude and longitude coordinates are: 51.169392, 71.449074.). Akmai variety safflower is the most popular in Kazakhstan because it has a high yield, and is resistant to diseases and climatic conditions, for this reason, it is grown in Aktobe, Almaty, Zhambyl, Kyzylorda, South Kazakhstan, Akmola regions of Kazakhstan. The fat content in absolutely dry seeds is 36-37%, and in the kernel 55-55.7% [38].

2.1.2. Experimental cone-shaped sediment filter centrifuge

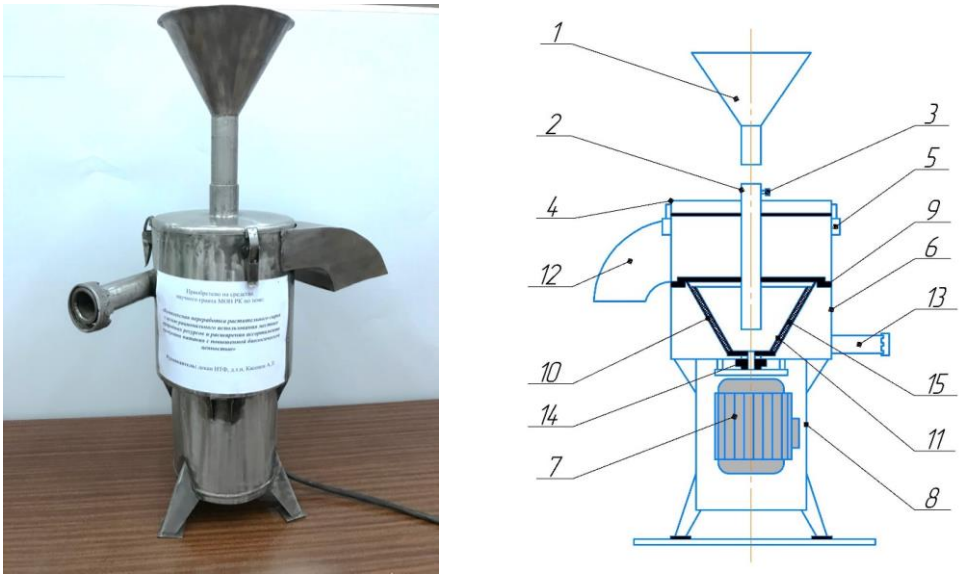
Centrifuges are widely used equipment for the purification of vegetable oils, because they have several advantages, such as high productivity, simple structure and maintainability, the ability to adjust the differential speed, and the implementation of adjustment following the implementation of various technological tasks.

In a cone-shaped sediment-filter centrifuge, the process of purification, settling and enrichment of safflower oil, which is a complex dispersed system, will take place in a centrifugal field. The centrifugal field is the space where, under the action of centrifugal force, heterogeneous, dispersed liquid systems are separated into fractions.

This cone-shaped sediment filter centrifuge is a development of Iskakov Bauyrzhan, Kakimov Mukhtarbek, Tokhtarov Zhaiyk, Mursalykova Maygul, Sataeva Zhuldyz which is designed for deep purification of vegetable oils from mechanical impurities, the result of this work is a patent for invention No. 36262 of the Republic of Kazakhstan dated 15.09.2023.

The experimental cone-shaped sediment filter centrifuge has undergone improvements based on the YA7-OCM model produced in Russia, the city of Barnaul (Fig. 1). The experimental cone-shaped sediment-filtering centrifuge is equipped with a funnel (1) for loading safflower oil, which is connected to the main body of the centrifuge through

the loading fitting (2) and fixed with a bolt (3) [39]. The funnel 1 for loading safflower oil is connected to the main body of the centrifuge through the loading fitting (2), which is separated from flange (9) of the main body. The main working bodies are located in the separator body, these are external perforated rotors for filtration (10) and an internal perforated rotor for settling (11) safflower oil, and filter material (15) is placed between them for additional filtration and enrichment of safflower oil. Perforated means that there are holes on the surface of the rotor, it should be noted that the holes on the outer (0.3 mm) and inner (0.5 mm) rotor are different. The holes of the inner rotor should be larger to avoid plugging the hole and also to make it easier to clean the safflower oil through the filter media. After the filter material, all impurities are deposited, purified and enriched safflower oil exits through the outer rotor. The rotors are placed by a drive coupling and a seal (14) on the drive motor shaft (7), which is protected by a casing (8) to minimize the noise in the workplace. In the process of sedimentation and filtration of safflower oil, the dehydrated fraction, that is, the sediment passes through the tray (12) to the outside, while the purified safflower oil exits through the lower fitting (13). The centrifuge body is closed with a cover (4) and secured with locks (5).



(**a**) (**b**)

Figure 1. Experimental cone-shaped sediment filter centrifuge; **(a)** picture of a centrifuge; **(b)** centrifuge drawing; 1 - load funnel; 2 - boot fitting; 3 - bolt for fastening the loading funnel; 4 - lid centrifuge; 5 - locks for fastening the centrifuge cover; 6 - separator body; 7 - drive motor; 8 - the protective casing of the electric motor; 9 - separating flange; 10 - external perforated filter rotor; 11 - internal filtering rotor; 12 - tray output of the dehydrated fraction; 13 - pipe oil outlet fitting; 14 - drive coupling and seal; 15 - filter material.

The rotors are the main components of the centrifuge for purifying, settling and enriching safflower oil. Because the centrifugal force created by the rotation of the rotor throws the safflower oil against the perforated rotors and the filter media. Purification from colloidal and mechanical impurities takes place due to deposition in a centrifugal field on the inner and outer perforated filtering rotors. The productivity of the centrifuge is 900 kg/h, the capacity of the working chamber is 9 liters and is made of stainless steel grade 12X18H10T, the size of the filter mesh openings is 0.5 mm, the rotation speed of the rotor shaft is 2850 RPM. Figure 2 shows the process of refining safflower oil, as well as the principle of operation of the main part of the sediment filter rotor.

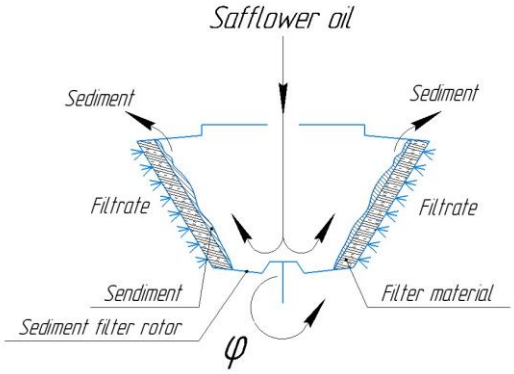


Figure 2. Sediment filter rotor.

In Figure 2, safflower oil enters the working chamber and is thrown onto the inner filter rotor due to centrifugal force and the settling process takes place, after which the safflower oil passes through the filter material and the outer rotor. The filter material is 15 mm thick and is placed between the outer and inner rotors to filter the safflower oil. In the end, the sediment exits through the top of the rotor and is discharged through the tray, and the filtrate, in our case, safflower oil, exits through the fitting. Data on the effect of sediment thickness, filter material thickness, rotor shaft speed on output and safflower oil separation factor were determined experimentally, analyzed in the form of graphs and discussed.

Based on the above, the main idea of using centrifuge safflower oil filtration technology is two rotors, these are the inner and outer rotors, and the filter material is placed between the rotors. Filter material for the production of secondary raw materials, which acts as a filter material for purifying and enriching safflower oil.

2.1.3.Filter material

As a filter material, secondary processing products of the grain processing and oil and fat industries, such as wheat bran (Fig. 3), rye bran (Fig. 4), oat bran (Fig. 5), as well as flax fiber (Fig. 6), were used. All data were obtained from bran producers of LLP "AL and KS", information about flax fibers were obtained from the developers of NJSC National Agrarian Scientific and Educational Center.

Table 1. Chemical composition of secondary products of agricultural processing.

Secondary products	Protein, g	Fats, g	Carbohydrates, g	Alimentary fiber, g	B1, %	B6, %	E, %	Fe, %	Zn, %
Wheat bran	14.7	4.1	23.5	43.6	50	65	69	78	61
Rye bran	15.5	3.8	17	43.6	36	21	10	56	36
Oat bran	17.3	7	50.8	15.4	78	8.3	6.7	30	26
Flax fibers	16	4.3	64.5	43.6	50	9	69	78	59

All of the above secondary products in Table 1 are rich in proteins, fats, carbohydrates and dietary fiber, as well as vitamins B, E and minerals such as iron, zinc and others. These secondary products are useful for the human body, for example, wheat bran is for the gastrointestinal tract and reduces the risk of developing cardiovascular diseases (CVD), cancer and metabolic diseases, rye bran due to the high content of dietary fiber contributes to the growth of beneficial bacteria in the large intestine, which means prevent the development of dysbacteriosis, oat bran, due to the high content of fiber in the form of β-glucan, reduces cholesterol levels by a third and prevents the occurrence of atherosclerosis, etc.

As a result of comparative analysis, it was revealed that the maximum protein content in oat bran, in second place is flax fiber, the smallest amount of protein in wheat bran. The maximum amount is also in oat bran, and the minimum is in rye bran. The carbohydrate content ranges from 17.0 g to 64.5 g. Based on the data in the table, wheat bran, rye bran and flax fiber (Fig. 3) have the largest amount of dietary fiber. It should also note that these filter materials have a high content of vitamins, due to which the oil, after filtering through the secondary products of these crops, will be enriched with nutritional properties and vitamins.

Next, a comparative analysis of the materials used to filter safflower oil was conducted. According to preliminary data, flax fiber was chosen as the most optimal material for filtering safflower oil.



Figure 3. Secondary products of agricultural processing; **(a)** wheat bran; **(b)** rye bran; **(c)** oat bran; **(d)** flax fiber NJSC "National Agrarian and Scientific Educational Center".

2.2. *Methods*

2.2.1. Density and specific gravity of safflower oil

Density and specific gravity were determined on the AON-1 hydrometer of the JSC "Steklopribor" company (Zavodskoe, Ukraine). The refractive index of safflower oil was determined on an Atago PAL-RI series refractometer (Tokyo, Japan). Method of determination according to GOST 18848-2019 Vegetable oils. Organoleptic and physicochemical indicators. The essence of the method for determining the density is to immerse the hydrometer in the test product, take readings on the hydrometer scale at the determination temperature and convert the results to the density at a temperature of 20°C.

2.2.2. Determination of the viscosity of safflower oil

To measure the viscosity of safflower oil, a Brookfield model DV-E viscometer (Milwaukee, USA) was used and the analyzes were carried out according to GOST 33768-2015 Method for deter-mining kinematic viscosity and calculation of dynamic viscosity of transparent and opaque liquids. Method for determining the kinematic viscosity and calculating the dynamic viscosity of transparent and opaque liquids. The essence of the method is to measure the time of expiration of a certain volume of the tested oil product under the influence of gravity with a glass capillary viscometer.

2.2.3. Chemical properties of safflower oil

The chemical properties have been determined according to AOAC (2005) and are iodine value, acid value, peroxide value and saponification value of safflower oil.

2.2.4. Composition of fatty acids

The fatty acid composition of safflower oil was determined according to GOST 30623-2018 Vegetable oils and blended fat products. Falsification detection method, where method is based on the gas chromatographic determination of the fatty acid composition of vegetable oils and the fatty phase of products with a mixed composition.

2.2.5. Composition of inorganic substances

The composition of inorganic substances was investigated by the following regulatory documents:

GOST 30538-97 Raw materials and food products. Atomic absorption method for the determination of toxic elements. This standard applies to food raw materials and finished products and establishes a method for the determination of lead, cadmium, copper, zinc, iron, tin and arsenic in them by the atomic emission method.

GOST R 51766-2001 Raw material and foodstuffs. Atomic absorption method for determination of arsenic. The method is designed to determine the amount of arsenic in food products by the atomic absorption method.

GOST R 53183-2008 Foodstuffs. Determination of trace elements. Determination of mercury by cold-vapour atomic absorption spectrometry (CVAAS) after pressure digestion (MOD). The method is based on the determination of mercury using cold vapor atomic absorption spectrometry after acid mineralization of a pressure sample. All toxic elements were determined on the GTA120 Graphite Tube Atomizer (Agilent Technologies, Penang, Malaysia).

GOST R 52676-2006 Vegetable oils. Methods for determination of phosphorated substances. The method is based on the transfer of phosphorus, which is part of the phospholipids of vegetable oils, into a water-soluble state by ashing and its subsequent determination by the photometric method using the blue molybdenum complex.

GOST 31905-2012 This standard applies to the food additive calcium lactate E327, which is a calcium salt of lactic acid (hereinafter referred to as food calcium lactate) and intended for use in the food industry.

GOST R 55484-2013 The method is based on a comparison of the absorption of resonant radiation by free metal atoms formed in a flame when solutions of the analyzed products are introduced into it (complete destruction of organic substances) and calibration solutions with known concentrations of the metals to be determined, subjected to a similar procedure. Inorganic substances in safflower oil after filtration were determined on an Epsilon 1 X-ray fluorescent spectrometer (Malvern Panalytical Company, Almelo, Netherlands).

2.2.6. The Mass fraction of non-fat impurities and sediment

The mass fraction of non-fat impurities and sediment was determined by GOST 5481-2014. The method is based on the treatment of the sample with an excess amount of

hexane, petroleum ether or gasoline (nefras) followed by filtration of the resulting solution, washing the filter with sediment, drying the precipitate to a constant weight and weighing it.

2.2.7. Determining the amount of amino acids

The amino acid composition was determined using the Kapel-105 (LUMEX Company, Saint Petersburg, Russian) capillary electrophoresis system (MVI M 04-38-2004).

2.2.8. Total phenols

The total amount of phenols in safflower oil was analyzed according to the method described by Merouane et al. [40].

2.2.9. Determination of antioxidant activity

Determination of the antioxidant activity of safflower oil was carried out according to the method of Nogala-Kalucka et al. [41].

2.2.10. Filtration material thickness

The thickness of the filtration material directly impacts the physical and optical properties of the film, as well as the strength and barrier properties. In the laboratory, a spiral micrometer or a micrometer is often used to measure film thickness. Randomly select 5 points on the material for testing and measure them with a micrometer. The average reading is accurate to 0.001 mm.

3. Results and discussion

Qualitative physical and chemical parameters of safflower oil were determined, including fatty acid composition, content of tocopherols and antioxidants. All data obtained are summarized and discussed under the appropriate headings.

3.1. Physical indicators of safflower oil

We have determined various physical parameters of safflower oil, such as density, refractive index, moisture content and volatile substances, which are set out in Table 2 below.

Table 2. Physical characteristics of safflower oil.

Physical indicators		
Index	**Before filtration**	**After filtering through flax fiber**
Density (g/ml)	0.922±0.196	0.884±0.192
Specific gravity	0.931±0.197	0.965±0.201
Refractive index	1.4771±0.248	1.4812±0.485
Viscosity (cP)	46.6±1.393	46.8±1.397

* Each value is the average of three determinations.

From the results of Table 2, it can be seen that the density of safflower oil before filtration was 0.922±0.196 g/ml, and after filtration, a slight decrease in density to 0.884±0.192 g/ml can be seen. The density of a substance is the ratio of its mass to volume, and the specific gravity is the ratio of the mass of a certain volume of a substance to the mass of the corresponding volume of water at 20°C. Density and specific gravity depend on temperature. The specific gravity of vegetable oils is also affected by the quantitative content of polyunsaturated fatty acids. For example, the ratio of C18 polyunsaturated fatty acids in safflower oil may be the main factor in increasing its specific gravity. Thus,

the specific gravity of safflower oil before filtration was 0.931±0.197, due to oil purification and an increase in the proportion of polyunsaturated fatty acids, the specific gravity of safflower oil increased to 0.965±0.201. For quantitative identification, the determination of the specific gravity and refractive index of the oil does not provide enough information, however, these data are useful for determining adulteration and contamination of the oil [42]. From the research of Shevchenko N.V., it follows that the more linoleic and linolenic acids belonging to the group of polyunsaturated fatty acids, the higher the refractive index. And also, the refractive index reflects the quality, purity of the oil and the degree of its oxidation during storage. The refractive index of safflower oil before filtration was 1.4771±0.248, after filtration, it also increased to 1.4812±0.485. Slight changes were observed in the viscosity of safflower oil: before filtration, it was 46.6±1.393 cP, after filtration it was 46.8±1.397 cP.

3.2. Chemical indicators of safflower oil

The iodine value, acid value, saponification value and peroxide value of safflower oil were determined and the results are shown in Table 3.

Table 3. Chemical characteristics of safflower oil.

	Chemical indicators	
Index	**Before filtration**	**After filtering through flax fiber**
Acid number (mg KOH/g)	1.066±0.211	1.075±0.212
Iodine number (g in I2/100 g)	148.19±2.485	150.15±2.501
Peroxide value (mol/kg)	8.09±0.581	7.01±0.540
Saponification number (mg KOH/g)	160.7±2.588	161.5±2.594

* Each value is the average of three determinations.

The acid number is the amount of potassium hydroxide in milligrams, which contributes to the neutralization of free fatty acids. Table 3 shows that the acid number of safflower oil before filtration was 1.066±0.211 mg KOH/g, after filtration the acid number increased slightly to 1.075±0.212 mg KOH/g. The iodine number is a measure of the unsaturation of fatty acids in oils. Thus, the iodine number of safflower oil before filtration was 148.19±2.485 g in I2/100 g, while after filtration it was 150.15±2.501 g in I2/100 g, which confirms the increase in the amount of unsaturated fatty acids. The peroxide number before filtration was 8.09±0.581 mol/kg, after filtration it became 7.01±0.540 mol/kg, which is a good indicator of storage capacity. The saponification number also indicates the amount of potassium hydroxide; however, the saponification number determines the amount of ester bonds in the fat. The saponification number of safflower oil before filtration is 160.7±2.588 mg KOH/g and after filtration 161.5±2.594 mg KOH/g.

3.3. Fatty acid profile, total inorganic matter and tocopherols in safflower oil

Pressed safflower oil was chosen as a starting point, since it is more natural and richest in macro- and microelements, vitamins and other beneficial substances for the human body, if we do not take into account small and large mechanical impurities in the composition of the oil that is removed in the process of primary oil purification through filtration and settling.

One of the main quality indicators of vegetable oils is their fatty acid composition. On an Agilent 7890A chromatograph (Agilent Technologies, Penang, Malaysia), the fatty acid composition of pressed safflower oil (Tab. 4) was studied by gas chromatography of the mass fraction of fatty acid methyl esters. To measure the amount of α-, β-, γ-, δ-tocopherols, the method of high-performance liquid chromatography was applied. The inorganic composition of pressed safflower oil was determined following the relevant state standards of the Republic of Kazakhstan.

Table 4. Fatty acid composition of safflower oil.

The name of the indicators	Characteristics and norms, %	Results before filtering, %	Results after filtering through flax fiber, %
Saturated fatty acids			
Caprylic acid C8:0	not standardized	0.94±0.198	-
Myristic acid C14:0	up to 1.0	0.35±0.121	0.07±0.054
Palmitic acid C16:0	2.0-10.0	7.6±0.563	4.34±0.425
Stearic acid C18:0	1.0-10.0	2.56±0.327	1.81±0.275
Monounsaturated fatty acids			
Palmitoleic acid C16:1	up to 0.5	0.08±0.058	0.05±0.046
Oleic acid C18:1	7.0-12.2	12.13±0.711	18.31±0.874
Arachic acid C20:0	up to 2.5	0.33±0.117	0.30±0.112
Behenic acid C22:0	up to 0.5	0.1±0.065	0.24±0.100
Cis-10-heptadecenoic acid C17:1	not standardized	0.1±0.065	0.23±0.098
Gadoleic acid C20:1	not standardized	0.06±0.050	0.11±0.068
Polyunsaturated fatty acids			
Cis-linoleic acid 18:2 A-linolenic acid C18:3	55.0-81.0	74.82±1.766	82.52±1.854
Cis-linoleic acid 18:2 A-linolenic acid C18:3	up to 1.0	0.95±0.199	0.22±0.096
Inorganic composition: (mg/kg, no more)			
Iron	5.0	0.024±0.032	0.045±0.043
Phosphorus	not standardized	0.067±0.053	0.346±0.120
Silicon	not standardized	0.066±0.052	0.249±0.102
Sulfur	not standardized	0.085±0.059	-
Chlorine	not standardized	0.091±0.062	0.466±0.139
Calcium	not standardized	0.107±0.067	0.236±0.099
Tocopherols (mg/kg)	230-660	508.26±4.602	556.7±4.816

Based on the results of the analysis of the fatty acid composition of safflower oil, the following conclusions can be drawn: of saturated fatty acids in safflower oil, C16:0 palmitic acid prevails (7.6±0.563%), followed by C18:0 stearic acid (2.56±0.327%), C8:0 caprylic acid (0.94±0.198%) and C14:0 myristic acid (0.35±0.121%). However, after filtration of safflower oil, a decrease in the amount of saturated fatty acids by almost two times is seen, and C8:0 caprylic acid is completely absent. If we dwell on each fatty acid, then the content of C16:0 palmitic acid is 4.34±0.425%, C18:0 stearic acid 1.81±0.275% and C14:0 myristic acid 0.07±0.054%.

Table 4 shows a clear quantitative advantage of unsaturated fatty acids over saturated fatty acids, and most importantly, after filtration, the concentration of unsaturated fatty acids increased significantly. However, there are exceptions where the content of individual fatty acids has decreased. If we dwell on each group of unsaturated fatty acids in more detail, then it will be necessary to consider mono- and polyunsaturated fatty acids separately.

Let's start with monounsaturated fatty acids, where the content of C16:1 palmitoleic acid (0.05±0.046%) and C20:0 arachidic acid (0.30±0.112%) decreased. Whereas, the second group of monounsaturated fatty acids such as C18:1 oleic acid (18.31±0.874%), C22:0 behenic acid (0.24±0.100%), C17:1 cis-10-heptadecenoic acid (0.23±0.098%) and C20:1 gadoleic acid (0.11±0.068%) doubled in content.

Polyunsaturated fatty acids predominate over others before and after filtration, for example, the content of C18:2 cis-linoleic acid before filtration was 74.82±1.766%, while after it became 82.52±1.854%. However, the concentration of C18:3 a-linolenic acid decreased from 0.95±0.199% to 0.22±0.096%. These results are quite similar to those of M.B. Katkade, H.M. Syed and others [43].

The inorganic composition of safflower oil before and after filtration changed in that the concentration of many elements increased greatly, even though the amount of sulfur was 0.085±0.059 mg/kg, after filtration, it was not found in the composition of safflower oil. If we dwell on the rest of the inorganic substances, then the content of iron (0.024±0.032 mg/kg) 0.045±0.043 mg/kg, phosphorus (0.067±0.053 mg/kg) 0.346±0.120 mg/kg, silicon (0.066±0.052 mg/kg) 0.249±0.102 mg/kg, chlorine (0.091±0.062 mg/kg) 0.466±0.139 mg/kg and calcium (0.107±0.067 mg/kg) 0.236±0.099 mg/kg increased at least twice.

Additionally, from the table, you can see the total content of α-tocopherols in safflower oil, which is 508.26±4.602 mg/kg, after filtration, it is 556.7±4.816 mg/kg. This indicator indicates the high resistance of safflower oil to oxidation, despite the significant amount of linolenic acid. The amount of tocopherols in safflower oil is consistent with the results of a study by Elif Aksoz and other scientists [44].

3.4. The Mass fraction of non-fat impurities and sludge

Non-fat impurities and sludge are contaminants that must be removed during processing to prevent adverse reactions or undesirable changes in the appearance of the oil from occurring. The study data are shown in Table 5.

Table 5. Mass fraction of non-fat impurities and sludge in safflower oil.

The name of the indicators	Characteristics and norms	Results before filtering	Results after filtering through flax fiber
Mass fraction of non-fat impurities and sludge: (%, no more)	0.1±0.06	0.45±0.13	0.02±0.02

The mass fraction of non-fat impurities and sludge according to the results before filtration is 0.45±0.13% and after filtration 0.02±0.02%, which is within the normal range and an indicator of high-quality filtration of pressed safflower oil.

3.5. Amino acids in safflower oil

The amino acid composition of safflower oil before and after filtration is shown in Figure 4. In general, safflower oil is not rich in amino acids, but they are still present in the composition. After filtration, one can see a significant increase in the level of amino acids in safflower oil, for example, the level of arginine 1.16, tyrosine 0.17, methionine 0.17, glutalic acid 0.15 and aspartic acid 0.11 increased two or more times, that is, to 2.1, 0.57, 0.4, 0.32, 0.41 respectively. Other amino acids also increased quite a lot and this shows the positive effect of flax fiber not only as a filter material, but also as a means of enrichment. If we analyze the results of the work of Funda Arslanoğlu and Selim Aytaç, then flax is rich in amino acids from which we can assume that some components were transferred during the filtration process [45]. In addition, it is necessary to pay attention to the high content of cystine 2.5 and tryptophan 2.6; after filtration, arginine 2.1 caught up with their level.

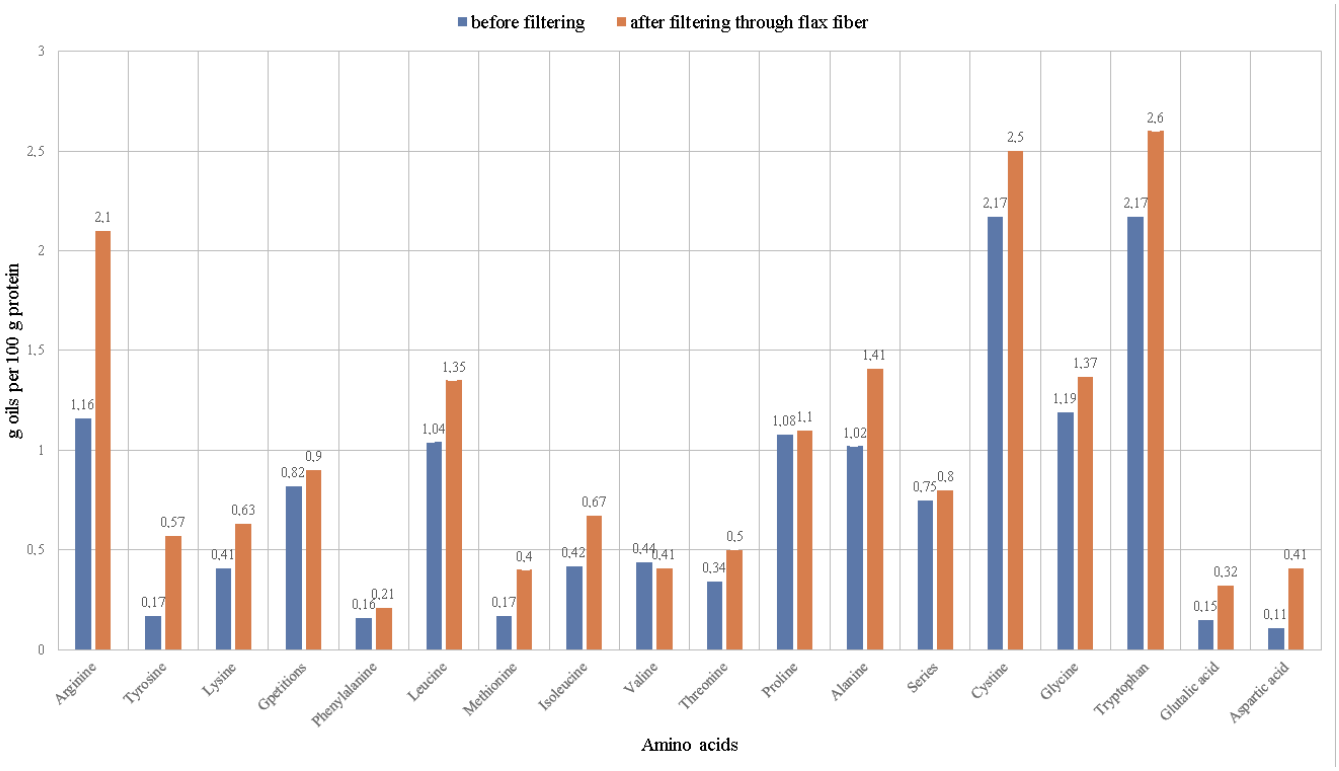


Figure 4. Amino acid composition of safflower before and after filtration (g oils per 100 g protein).

3.6. Total phenols and antioxidant activity of safflower oil

To determine the antioxidant activity of safflower oil, an analysis of the total amount of phenols was carried out (table 6). Since the amount of phenols, unsaturated fatty acids and vitamins directly affect the antioxidant activity of safflower oil in the human body, that is, the higher the indicators, the higher the antioxidant activity [46].

Table 6. Total polyphenols and antioxidant activity of safflower oil.

Vegetable oil	Total phenols before filtration (mgEAG/kg of oil)	Antioxidant activity (%) before filtration	Total phenols after filtration (mgEAG/kg of oil)	Antioxidant activity (%) after filtration
Safflower oil from Akmay seeds	310.5±8.4	41.12±2.7	322.12±6	42.65±8

In the same column for each year, means with the same letter were not significantly different at $p < 0.05$.

The antioxidant activity of the safflower oil extract before filtration was in the region of 41%, after filtration we can see a slight increase up to 42% (Table 6). This is a fairly high indicator for the antioxidant activity of safflower oil, since for comparison in the scientific works of Kamel Zemour, Amina Labdelli and other authors, the highest total phenols and antioxidant activity were 412.8±1.3 and 68.9±0.4b in the Syrian safflower oil of 2017 harvest, and the lowest is 168.1±7.1b and 24.7±0.7b for 2015 Algerian safflower oil. In the scientific work of these authors, the direct effect of the total amount of phenols on the antioxidant activity of safflower oil, as well as a direct positive effect on human health, was clearly described.

3.7. Analysis of data dependences of the technological process of centrifugation of safflower oil on a cone-shaped sedimentary-filtering centrifuge

To simplify the mathematical description of the purification process in a cone-shaped sediment-filtering centrifuge, it is advisable to consider it as consisting of two processes:

1) the centrifugation process, that is, the purification of the liquid when it is displaced by particles of impurities along the radius to the inner shell of the cone;

2) the process of liquid (oil) movement in the direction along the generatrix of the cone, while impurities are deposited in the pores of the filter material, as well as on the walls of the inner part of the rotor.

The nature of the flow of centrifugal filtration is determined by the centrifugation mode, i.e., the centrifuge speed, given by the thickness of the filter layer in the rotor, the method of loading the rotor with a suspension, the ratio between the solid and liquid phases in the material being processed, and the physicochemical properties of the latter.

In the process of theoretical and practical research, we noticed the relationship between oil yield, separation factor, filter media thickness and sediment thickness. The last three factors directly affect the yield of refined safflower oil. In the process of centrifugation, the separation factor takes a special place and is one of the main indicators. Based on the above studies, flax fiber was used as the filter material.

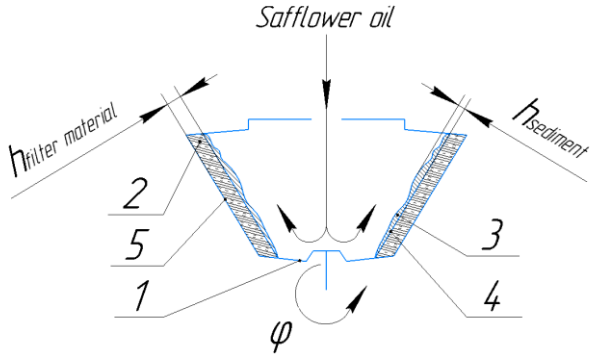


Figure 5. Sediment-filtering rotor: 1-sedimentary-filtering rotor; 2-filter material (flax fiber); 3-precipitate; 4-inner perforated filter rotor; 5-external perforated filter rotor.

In Figure 5, we can see the sedimentation filter rotor where the safflower oil is filtered and settled. On this rotor, we can change the thickness of the filter material, i.e., flax fiber, as we wish by adjusting the distance between the inner and outer perforated filter rotors. Through this function, we can change the filtration path, which affects the filtration quality, safflower oil yield and separation factor. In addition, these parameters are directly affected by the thickness of the sediment that is deposited on the internal perforated rotor. By adjusting the distance between the inner and outer perforated rotors, as well as the thickness of the flax fiber, we can obtain safflower oil from a primary to a highly refined grade. At the same time, the quality of the incoming press oil, which can facilitate or complicate the filtration process, cannot be ignored.

When studying the technological process of centrifugation on a cone-shaped centrifuge, the data presented in Figure 6 were obtained.

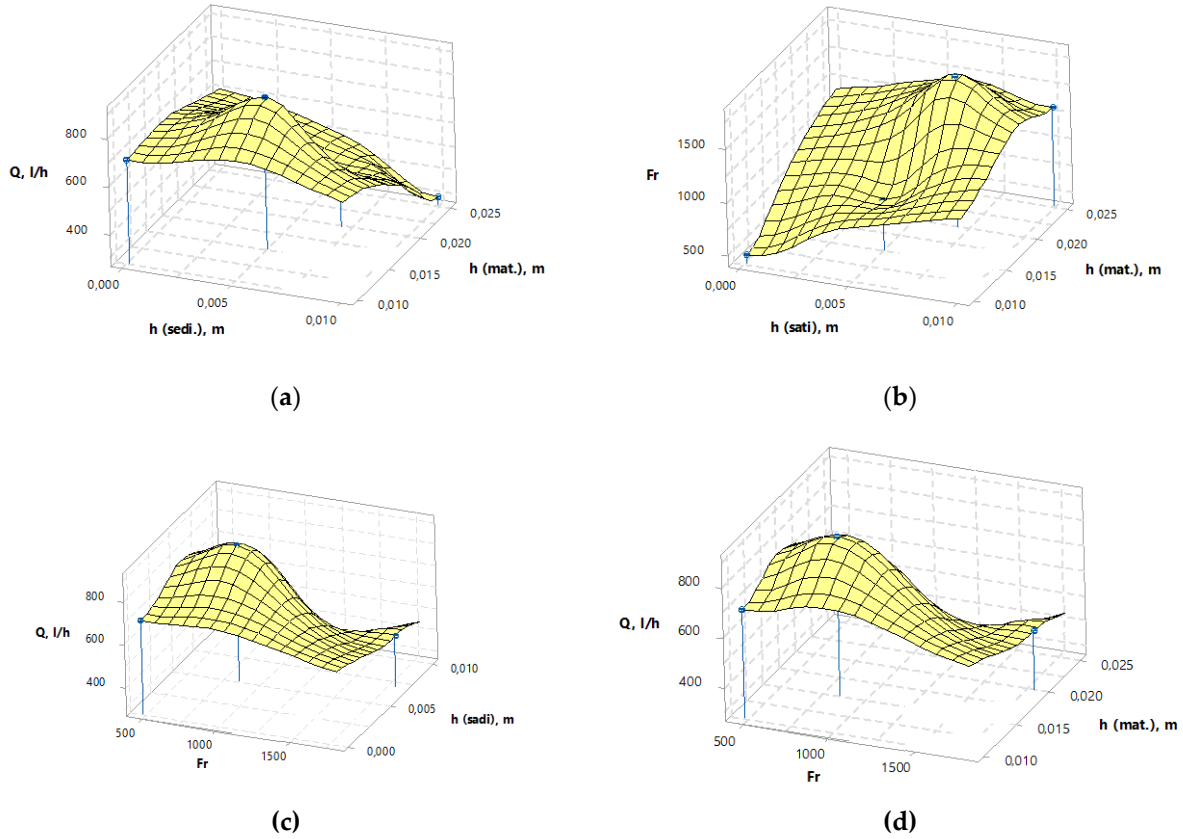


Figure 6. Safflower oil yield graph; **(a)** Influence of sediment thickness (h_{sadi}) and filter material thickness (F_{mat}) on oil yield (Q); **(b)** Influence of sediment thickness (h_{sadi}) and filter material thickness (h_{mat}) on the separation factor (Fr); **(c)** effect of separation factor (Fr) and sediment thickness (h_{sadi}) on oil yield (G); **(d)** effect of separation factor (Fr) and filter material thickness (h_{mat}) on oil yield (G); **Note:** Graphs were built in meters, while the thickness of the filter material and sediment were measured according to the method.

In Figure 6 (a, b) one can see the effect of flax fiber thickness and sediment on safflower oil yield and separation factor. In Figure 11(a), the yield of safflower oil rises from 700 L/h to 800 L/h, after which it begins to fall. While the thickness of the flax fiber decreases, and the thickness of the sediment increases in direct proportion, thereby reducing the oil yield. We had a low oil yield, which is equal to 300 l/h, with a flax fiber thickness of $2.5*10^7$ nm, and a draft of $1*10^7$ nm. Whereas, a high oil yield is observed with a flax fiber thickness of $1.5*10^7$ nm and $0.5*10^7$ nm of sediment. In the following figure 9 (b), at the beginning of the cleaning process, the separation factor was low in the region of 500, after which it begins to grow to 1500. The highest separation factor, as we can see, is at a thickness of $2*10^7$ nm while a low separation factor is observed at a flax fiber thickness of $1*10^7$ nm, $0.1*10^7$ nm of sediment.

In Figure 6 (c, d), we observe the effects of flax fiber thickness and sediment thickness on oil yield and separation factor. In the figures, we noticed an almost similar result, that is, the thickness of the flax fiber and the thickness of the sediment have the same effect on the oil yield and the separation factor. With a flax wire thickness of $2*10^7$ nm and a sediment thickness of $7*10^6$ nm, in both figures, the oil yield is 700 l/h, while the safflower oil separation factor is 800. With the low oil yield of 400 l/h and the separation factor of 1600, we can see a flax fiber thickness of $2*10^7$ nm and a sediment thickness of $0.7*10^7$ nm.

From the above, the following conclusions can be drawn the thickness of the flax fiber and sludge directly affect the oil yield and separation factor. In addition, you should not prioritize the oil yield or the separation factor, this is what we need to find the opti-

mal parameters. As a result of our research, we came to the optimal option for centrifuging safflower oil to remove mechanical impurities. With a flax fiber thickness of $1.5*10^7$ nm and a sludge thickness of $0.5*10^7$ nm, our oil yield and separation factor are optimal and efficient.

4. Discussion

The presented study focused on the importance of filtration as a primary purification process to enhance the quality of safflower oil, a vegetable oil with growing demand in both food and technical applications. The high concentration of unsaturated fatty acids, such as linoleic and oleic acids, contributes to the nutritional value and healing properties of safflower oil, making it beneficial for immune enhancement and the prevention and treatment of various diseases.

The use of secondary processing products from the grain processing and oil and fat industries as filter material has emerged as a new and promising direction in improving safflower oil filtration technology. The preliminary studies revealed that flax fiber exhibited the most effective and optimal filtration properties, positively impacting the physical and chemical parameters, fatty acid composition, and antioxidant activity of safflower oil. This scientific groundwork opens avenues for further research on enriching vegetable oils using secondary products from the grain processing and oil and fat industries, as well as their utilization as filter materials.

Moreover, the investigation into the technical dependencies of the centrifugation process highlighted the significance of parameters such as the thickness of the flax fiber and sediment, which directly influenced the yield of safflower oil and the separation factor. By adjusting the distance between the inner and outer rotors, where the filter material is located, different parameter values (e.g., 1107 nm, 1.5107 nm, 2107 nm, and 2.5107 nm) were tested. These variations affected the separation factor, oil yield, and the thickness of the sediment formed on the inner rotor's walls. These findings contribute to the optimization of centrifugation processes for vegetable oils, facilitating the removal of mechanical impurities and the production of naturally enriched food products.

The graphs presented in the study demonstrate the interdependence of these parameters, emphasizing the pivotal role of oil yield and separation factor. These parameters significantly impact technological losses and the degree of safflower oil purification. Based on the collected data, optimal parameter values were determined, ensuring an efficient centrifugation process.

In conclusion, this study underscores the importance of filtration in improving the quality and shelf life of safflower oil. The use of secondary products from the grain processing and oil and fat industries as filter materials, particularly flax fiber, demonstrates promising results in enhancing the physical and chemical properties of safflower oil. Additionally, the investigation into centrifugation process parameters provides valuable insights for optimizing oil yield, separation factor, and the removal of impurities, facilitating the production of high-quality, naturally enriched safflower oil products. Further research in this direction can contribute to advancements in vegetable oil processing and product development.

5. Conclusions

Vegetable oils, including safflower oil, are currently a growing product for both food and technical purposes. The high concentration of unsaturated fatty acids such as linoleic and oleic acids enhance the nutritional value of safflower oil. The healing properties of safflower oil improve immunity and help in the prevention and treatment of various diseases.

Filtration is one of the important primary purification processes that improves the quality of safflower oil. This is one of the important stages of production technology, as it directly affects the quality indicators of the oil, as well as the duration of its storage. Sig-

nificantly facilitates subsequent purification processes of safflower oil, and therefore, will help reduce production costs and improve the quality of the final product.

The use of secondary processing products of the grain processing and oil and fat industries as filter material is a new and promising direction. In this connection, the use of secondary products of processing of the grain processing and oil and fat industries as filter material to improve the technology of filtration of safflower oil in an experimental sedimentary filter plant is urgent work. According to the results of preliminary studies, flax fiber is the most effective and optimal filter material. Which favorably influenced the physical and chemical parameters, fatty acid composition, the amount of tocopherols and phenols, respectively, on the antioxidant activity of safflower oil. These results can be a scientific groundwork and make it possible to conduct research in the direction of enrichment of vegetable oils with the help of secondary products of processing of the grain processing and oil and fat industries, as well as the use of these products as a filter material.

In addition to the technological part, the technical dependencies of the centrifugation process were investigated, as a result of which the thickness of the flax fiber and sediment directly affect important parameters, such as the yield of safflower oil and the separation factor. The parameters were changed by adjusting the distance between the inner and outer rotors where the filter material is located. The distance between the rotors and the thickness of the filter material was $1*10^7$ nm, $1.5*10^7$ nm and $2*10^7$ nm, $2.5*10^7$ nm these parameters directly affected the separation factor, oil yield and the thickness of the sediment that forms on the walls of the inner rotor. These results can help in optimizing the centrifugation process of vegetable oils to remove mechanical impurities and obtain naturally enriched food products.

6. Patents

Iskakov Bauyrzhan Myrzabekovich, Kakimov Mukhtarbek Mukanovich, Tokhtarov Zhaiyk Khamitovich, Mursalykova Maygul Taurzhanovna and Sataeva Zhuldyz Isakovna. Centrifuge for deep purification of vegetable oils from mechanical impurities. For invention patent No. 36262, filed 9th March 2022, and issued 15th September 2023.

Author Contributions: Conceptualization M.M, and M.K.; methodology I.B.; software I.B.; validation M.M., A.K. and K.S.; formal analysis M.B and Z.S.; investigation I.B.; resources B.S.; data curation K.Z.; writing—original draft preparation, I.B., M.B. and M.K.; writing—review and editing M.B., R.K., I.B., M.M. and Z.S.; visualization, I.B.; supervision, M.M. and M.B.; project administration, M.M., I.A. and M.B.; funding acquisition, A.M. All authors have read and agreed to the published version of the manuscript.

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