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Quality indicators of extracted sunflower and rapeseed oil obtained with hexane and ethyl alcohol solvents

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Abstract. The relevance of the conducted research is conditioned by the increase in demand for oilseeds with improved and environmentally friendly qualities, namely, the replacement of a dangerous solvent in the extraction process of processing oilseeds. In this regard, this paper is aimed at investigating the use of an organic solvent, such as ethanol, in extraction technology that is safer for human health. The leading approach to studying this problem is Soxhlet extraction and microwave extraction using hexane and ethanol solvents. The fatty acid composition of the resulting product was analysed by gas chromatography. In the proposed microwave method of oil extraction with a "green" solvent, which is ethyl alcohol, physical and chemical parameters were studied and compared with those obtained by the Soxhlet method. The efficiency of microwave processing is related to the heating process, which significantly increases the internal pressure of cells, which causes their destruction. A barodiffusion flow is created, which contributes to a significant increase in the yield of the extraction oil concentration by 1.4-1.8 times over the same time period and a decrease in the extraction process time by almost 3 times. The oil obtained by extraction of raw materials in a microwave

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field with a solvent ethyl alcohol is more resistant to oxidation, as evidenced by a decrease in the numbers: peroxide from 4.8 to 3.8, and anisidine from 0.25 to 0.2. The acid number, which characterises the degree of freshness of the resulting oil, also decreased from 2.5 to 2.1. The research results show that the use of microwave extraction with a polar solvent, which is ethyl alcohol, was effective in improving the quality properties of the extracted oil. The use of a "green" solvent does not degrade the quality of the finished product, unlike hexane, which is harmful to human health. The materials of the study are of practical value for the fat and oil industry, namely, in the technology of extraction of oilseeds

Keywords: solvents; extraction; hexane; ethyl alcohol; microwave energy; fatty acid composition

Introduction

The energy crisis and the growing demand for products with ecological and harmless properties for human health are priorities for the development of the latest technologies in the extractive production of materials (in particular, oilseeds).

The volume of oilseeds, namely sunflower seeds, is one of the oilseeds that are mass-produced in Ukraine. According to the State Statistics Service, in the 2021/22 season, Ukrainian farmers collected a record harvest of oilseeds: sunflower – 16.4 million tonnes, soybeans – 3.4 million tonnes, and rapeseed – 2.96 million tonnes. Of these, processors produced 6.87 million tonnes of vegetable oil: sunflower – 6.45 million tonnes, rapeseed – 265 thousand tonnes and soy – 163 thousand tonnes (Latifundist Media..., 2022). The strategy for the development of food industry exports and ensuring the quality of food products for the population, as well as the ecology of living systems, indicates the regularity of manufacturing and implementing energy-saving, resource-efficient, and harmless ("green") technologies (On the approval of the Strategy ..., 2020).

Improving the technology of oil production in order to increase the yield of finished products while maintaining their good quality is one of the main tasks of developing scientific and technical progress in the industry and intensifying mass transfer processes. When determining innovative methods of conducting the extraction process, it is worth considering the practice of using conventional solvents such as hexane and exploring non-traditional methods of "green technologies" for extracting substances from oilseeds with ethanol solvent.

Ukraine occupies a leading position in terms of gross sunflower harvest in the world (Agro Polit..., 2020). At the same time, the bulk of sunflower seeds are processed into oil, feed cake, and meal. The oilseed market of Ukraine is one of the main ones in the agricultural sector. The Ukrainian fat and oil industry has held a leading position in the world over the past five years. However, in the context of a full-scale invasion of the Russian Federation, it operates in conditions of a shortage of raw materials and energy resources. This determines the areas of finding solutions to improve existing technologies and develop new ones that allow obtaining high-quality products with high technical and economic indicators. According to statistics, since the beginning of the full-scale invasion (March-June 2022), Ukraine has exported more than 700 thousand tonnes of sunflower oil, which is almost 50% lower than the data for the current period of the past season (APK-Inform ..., 2022).

According to the results of the 2021/22 marketing year (ended August 31, 2022), Ukraine exported a significant amount of sunflower – 1.63 million tonnes (APK-Inform …, 2022). The increase in sunflower exports was conditioned by the suspension of sunflower oil exports and a significant decrease in domestic processing. Even in the state of a full-scale invasion of the Russian Federation on the territory of Ukraine, the country has a leading position in the rating for the production and export of sunflower seeds and its processed products on the world market. Therefore, the development and implementation of the latest technologies for oil production, in particular from sunflower seeds, remains relevant.

Analysis of literature data shows that extraction processes for substances in solid and liquid systems form the basis of a number of important enterprises of the chemical, petrochemical, food, microbiological, and other branches of the industrial industry (Puertolas *et al.*, 2016; Tan *et al.,* 2016; Mwaurah *et al.*, 2020), and require modern approaches, one of which is the use of microwave energy in the process of extracting oilseeds and switching to safe solvents.

The development of new methods is because traditional methods have various disadvantages, such as more energy, more time, low yield, and less environmental friendliness. Physical methods of oil extraction can only extract about 80% of the oil present in the oil material; therefore, a different technology must be used to extract the remaining 20% (Puertolas *et al.*, 2016).

Solvent extraction is widely used due to the simplicity and cost-effectiveness of the process (Mwaurah *et al.*, 2020). Typically, the solvents are hexane and n-hexane, as they provide the highest yield (95%) (Tan *et al.*, 2016). In particular, n-hexane is preferred because of its properties such as easy extraction, low latent heat of evaporation (330 KJ/kg), narrow boiling point range (63 to 69°C), high solubility, and nonpolarity. The disadvantages of using these solvents are their harm to human health, safety, and the environment, and therefore, despite their high extraction efficiency, their use is not only harmful and toxic, but also leads to air pollution (Konopka *et al.*, 2016; Kumar *et al.*, 2017). In addition, although hexane is approved for the food industry by the European Commission and the Food and Drug Administration (FDA) (Commission Implementation Regulation (EU)…, 2022), it is still considered and classified as dangerous and not the best for some international organisations (Castejon *et al.*, 2018). However, the extraction of vegetable oil consumes large amounts of hexane, and therefore, there is a need to investigate environmentally friendly technologies.

The purpose of the study is to determine the quality indicators of extracted oil with "green solvent" ethanol under the influence of an electromagnetic field in comparison with conventional technologies.

Literature Review

One of the methods of oil extraction in industrial conditions is mechanical pressing. The resulting product after pressing is characterised by high quality. Screw presses are mainly used to ensure this process. However, between 8% and 14% of the oil remains in the cake (Ionescu *et al.*, 2013). The advantage of solvent extraction is a more complete extraction (up to 95% of the oil contained in the raw material) (Topare *et al.*, 2011) and can be used for seeds with low oil content, as well as for complete extraction of oil from cake after pressing.

The research paper by S. Hussain *et al.* (2018) presents the results of using both pure solvents and mixtures. The researchers investigated the potential of less dangerous binary mixtures of ethyl acetate (EA) and dichloromethane (DCM) for rice from bran oil extraction. Nine solvent mixtures with different volume EA/DCM ratios in the range from 0.11 to 9 were used. A mixture of solvents with a volume factor of 4 (S8) provided a maximum oil recovery of 88.04%. The oil yield increases from 76.41% to 89.7% by increasing the preheating temperature from 40°C to 65°C. Other optimised parameters for increasing oil extraction: bran particle size < 125 microns (obtained by Sieve), solvent-to-bran ratio 5 ml/g, and mixing time 15 min. The minimum mixing speed to prevent agglomeration in the mixture and optimise oil extraction is 80 rpm.

Oil extraction takes place by mass transfer. Mass transfer is the process of mass transfer on the surface of particles and diffusion inside (Bandura *et al*, 2021). Recent studies on the improvement of extraction processes that can reduce the amount of energy consumed, use harmless alternative solvents, and ensure the production of a safe, benign extract product and the feasibility of using microwave technology are reported by the authors (Grasso *et al.*, 2012). Microwave extraction is a new method that can reduce extraction time and solvent consumption (Burdo *et al.*, 2017; Bandura *et al.*, 2018).

Replacing toxic organic solvents from fossil sources with non-toxic ones from bio-renewable sources in large-scale processes has been an object of research by M.C. Ferreira *et al.* (2022). Although ethanol is being investigated as a hexane substitute for vegetable oil extraction, most studies are conducted on a laboratory scale. The initial parameters of the continuous and countercurrent extractor, which indicates the technical feasibility of a large-scale operation, are still scarce. Here, a continuous-action extractor consisting of columns with a fixed layer connected in series (resembling the so-called simulated movable layer extractor) for the extraction of soybean oil with anhydrous ethanol was experimentally reproduced using a multi-section solid-liquid extraction system. After 5-step extraction, the residual oil in the solid phase was 0.17% with an extraction yield of 99.2%, confirming that ethanol was able to exhaust the solid matrix with the maximum extraction yield. Food safety technologies and less environmental impact confirm that ethanol is a safe and promising solvent for the extraction of vegetable oils in continuous equipment (Ferreira *et al.*, 2022).

By Baümler *et al.* (2016) investigated the ethanol extraction of sunflower oil and compared it with previous data, where hexane was used as the extraction solvent. Soxhlet first determined the extractive power of ethanol. This gave a higher yield of the extracted material, the content of soluble components of hexane (oil phase) was similar to that obtained with n-hexane. When ethanol was used as a solvent, 70% less crystallising waxes and at least 38% more tocopherols and phospholipids were extracted. The kinetics of ethanol extraction at 50 and 60°C in a periodic reactor were then investigated. Under equilibrium conditions, it was observed that extraction can be limited by the solubility of the extracted material. From the standpoint of the quality of the resulting products, this study demonstrated the feasibility of using ethanol as a solvent, an alternative to hexane, in the extraction of oil from sunflower cake.

O. Burdo *et al.* (2018) emphasised that the most important problems of human development (energy, ecology, food) are typical for the food industry, and their solution is associated with the search for new approaches to thermal processing of raw materials. The prospects of electrical technologies for targeted energy supply for individual elements of food raw materials using microwave processing are substantiated. Hypotheses of energy-efficient processes of dehydration, extraction and inactivation of microorganisms are formulated.

Microwave extraction is a popular extraction method that has high extraction performance and efficiency compared to other conventional methods. Microwave radiation interacts with the dipoles present in the sample matrix, causing them to oscillate in response to changing electromagnetic fields. Vibrations or rotation of dipoles during movement lead to the friction of molecules, which turns into heat and is transferred inside the material due to thermal conductivity. In addition to the dipoles from the solvent used in the extraction process, this heat leads to the formation of water vapour and electroporation effects that destroy the cell wall of oilseeds and enhance the effective extraction of intracellular metabolites (Mwaurah *et al.*, 2020).

Nonpolar solvents, when used by microwave extraction, show poor synergy between the solvent and microwave radiation due to their low permittivity. In addition, the microwave heating mechanism is based on the rotation of molecules or dipoles in combination with ionic conductivity. For these reasons, polar solvents are best suited for microwave extraction because they have a high dielectric constant, absorb more microwave radiation, and promote conductivity. Moreover, polar solvents showed better results than nonpolar solvents in most cases (Khan & Rathod, 2018). Ethanol has excellent microwave absorption properties, while the commonly used hexane is inert to microwave radiation.

Materials and Methods

The research presented in the paper was conducted from 2020 to 2022. Sunflower seeds from the batch of seeds received by the Vinnytsia fat and oil plant were used. The moisture content of sunflower seeds was determined in accordance with the DSTU ISO 10565-2003 standard "Oilseeds. Simultaneous determination of oil and moisture content. Spectrometry method using pulsed nuclear magnetic resonance" (2005). Sunflower seeds were processed by the press in accordance with the technology of sunflower oil production approved at the enterprise. Samples of cake that remained after pressing were taken for further studies of the extraction process. Rapeseed of the "Chempion" variety of the 2021 harvest was used. Seed moisture was determined according to the current standard DSTU 8175:2015 "Rapeseed oil. Technical specifications" (2017).

Solvents. Hexane, as an extractive solvent, was obtained from Antekom LLC (Ukraine). Ethyl alcohol – from the manufacturer of the state enterprise SpirtLux (Ukraine).

Materials. Laboratory equipment: laboratory sieve, thermostat TS-80 M2, thermometer TL-2K, electronic scales PS 750/c/1 RADWAG®, desiccators, containers, flasks, weighing cups, drying cabinet SPT-200, drying cabinet 2B-151, analytical scales of the AS 310x series, experimental stand of microwave action (developed by Odesa National Technological University), gas chromatograph Agilent 8890 (manufacturer – Alsi Chrome (USA)).

Soxhlet extraction methods. Soxhlet extraction was carried out in accordance with DSTU 4492:2017 "Sunflower oil. Technical specifications" (2019). When using this method, 40 g of crushed sunflower cake (or crushed rapeseed) was weighed and transferred to the Soxhlet extractor. Extraction was completed in 22-24 hours at a maximum temperature of 50….68.7°C (boiling point of n-hexane). After the extraction process, the solvent residue was removed at 50°C and reduced pressure using a rotary evapourator (Heidolf, Germany). To further reduce the amount of solvent, the extracted oil was transferred to a TS-80 M2 thermostat (Ukraine) at a temperature of 50°C until a constant mass was reached. The resulting oil was weighed and the oil yield was calculated.

The same experiments were conducted with the ethyl alcohol solvent. Extraction was completed in 22-24 hours at a maximum temperature of 50....78.3°C (boiling point of ethyl alcohol). Determination was carried out in triplicate for individual solvents. Investigation of physical and chemical parameters of sunflower extraction oil obtained by Soxhlet extraction and oil extraction under the influence of a microwave field, were carried out by generally accepted methods of analysis, which are set out in the relevant standards and reference books on techno-chemical control of production, and by methods described in the state standards of Ukraine (Table 1). Testing of rapeseed oil was carried out in accordance with the standard DSTU 8175:2015 "Rapeseed oil. Technical specifications" (2017). Table 1 shows methods of sunflower oil testing.

Table 1. *Metodics of sunflower oil testing*

Indicator	Principle of the research method
Oil sampling and preparation for analysis	According to DSTU 4349:2004 (2005)
Mass fraction of moisture and volatile substances, %	According to DSTU ISO 662:2004 (2006)
Mass fraction of insoluble impurities, %	According to DSTU EN ISO 663:2019 (EN ISO 663:2017, IDT; ISO 663:2017, IDT)
Acid number, mgKOH/g	According to DSTU EN ISO 660:2019 (EN ISO 660:2009, IDT; ISO 660:2009, IDT)
Peroxide number, mol ½O/kg	According to DSTU EN ISO 3960:2019 (EN ISO 3960:2017, IDT; ISO 3960:2017, IDT)
Flash point, °C	According to DSTU 4455:2005 (2006)
Mass fraction of phosphorus-containing substances in terms of stearooleolecithin, %	According to DSTU 7082:2009 (2011)
Anisidine number	According to DSTU EN ISO 6885:2019 (EN ISO 6885:2016, IDT)
Fatty acid composition of the oil	According to DSTU ISO 5508-2001 (2003)

Microwave extraction. A Samsung microwave oven (Korea, 425 W output power with a frequency of 2450 MHz) and a refrigerator connected to it were used (Fig. 1). For each cycle of the experiment, 40 g of sunflower cake (or crushed rapeseed) was weighed, a solvent (n-hexane, or ethyl alcohol) was added in the ratio of cake and solvent 1:3 in each cycle of experiments. Crushed sunflower cake or rapeseed was poured into a flask, filled with a solvent and exposed to an electromagnetic field for 10-20 minutes. Next, the kinetics of the process was studied.

The main elements of the experimental microwave stand were a chamber in which, due to the magnetron, a microwave field was created, and a container in which the actual process of extracting the objects of research took place: sunflower seed cake and winter rapeseed of the "Champion" variety.

The principle of operation of the experimental stand is as follows: in the container with the product, the extraction process takes place under the action of a microwave field in chamber 1. The extractant vapours enter the return refrigerator 2, condense, and flow back into the reaction tank with the test sample and solvent. A syringe is used to collect the seed for further study of the oil concentration.

Extraction was completed in 10-20 minutes. To further reduce the amount of solvent, the extracted oil was transferred to a TS-80 M2 thermostat (Ukraine) at a temperature of 50°C until a constant mass was reached. The resulting oil was weighed and the oil yield was calculated.

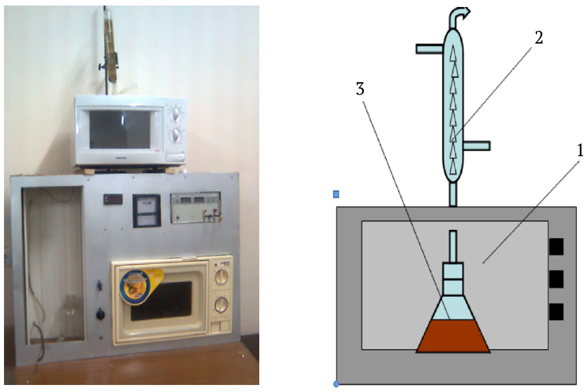

Figure 1. Photo and diagram of an experimental installation for extracting oil raw materials in a microwave field: 1 –microwave oven, 2 – return refrigerator, 3 – flask with raw material and solvent

Source: developed by the author

To obtain a control sample (sunflower and rapeseed oils), the authors used oils obtained at the Vinnytsia fat and oil plant using the current technology (extraction in a carousel extractor, hexane is used as a solvent.

To determine the fatty acid composition of the oil, an Agilent 8890 gas chromatograph (manufacturer – Alsi Chromium (USA)) was used. The fatty acid composition of the oil was analysed by gas chromatography using an HP-88 100 m*0.25 mm*0.2 mkm column. Experimental laboratory studies of extracted oils were conducted. The prospect of using the oil for food purposes was approved by conducting trial laboratory experiments to study and determine changes in physicochemical data for the storage period of 3 months.

Statistical analysis. The study was repeated three times and mathematically processed using Microsoft Excel 2007 to ensure the accuracy of the results obtained. The statistical error did not exceed 5% (with a 95% confidence level).

Results and Discussion

In the proposed extraction method, a thermal effect occurs on the processed product through the penetration of microwave energy into the material molecule, where radiation interacts with opposite molecules with the assistance of ionic conductivity and dipole rotation, accompanied by the release of heat. The degree of heating of raw materials depends on the dielectric constant of the material. The efficiency of microwave processing is related to the heating process, which significantly increases the internal pressure of cells, which causes their destruction. Extractives are mixed with a solvent after the destruction of the cell membrane.

In the conducted studies of the extraction process without the use of microwave energy, only under the influence of temperature, the solvent hexane is more effective than ethyl alcohol (Fig. 2).

Conducting studies using microwave energy allows increasing the yield of the extraction oil concentration over the same period of time by 1.4-1.8 times while reducing the process time by almost 3 times. A study with the solvent polar ethyl alcohol proves that the intensity of oil extraction under the influence of ultrahigh-frequency action increased to the efficiency of hexane (Fig. 3). This is probably conditioned by the rupture of the cell structure of the material under the influence of microwave heating, which leads to an increase in the degree of solvent penetration into the internal structure of the material.

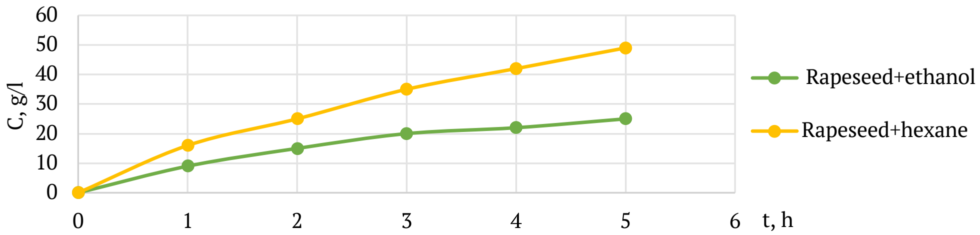

Figure 2. Change in oil concentration over time during oil extraction with solvents hexane and ethyl alcohol at a temperature of 50°C

Source: developed by the author

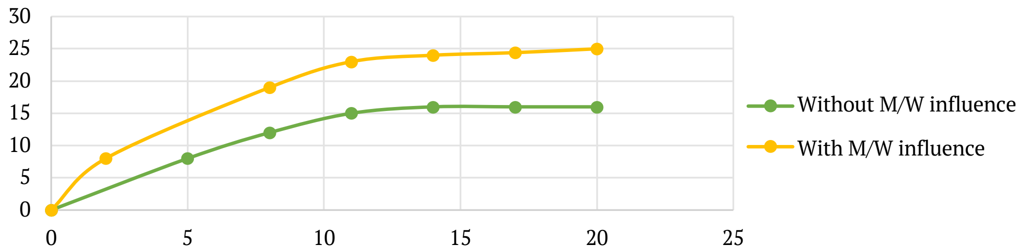

Figure 3. Change in the oil concentration from time during extraction of crushed rapeseed with ethanol at the boiling point of 78.3°C

Source: developed by the author

The results of the study of sunflower extraction oil obtained by Soxhlet extraction and under the influence of a microwave field are shown in Table 2.

Table 2. *Physical and chemical parameters of sunflower extraction oil were obtained after extraction with solvents: hexane samples No. 1, No. 3, and alcohol samples No. 2, No. 4*

Indicator	Soxhlet Method		Under the influence of a microwave field	
	Solvent hexane	Solvent ethyl alcohol	Solvent hexane	Solvent ethyl alcohol
Test sample	No. 1	No. 2	No. 3	No. 4
Mass fraction of moisture and volatile substances, %	0.18	0.17	0.19	0.16
Mass fraction of non-fat impurities, %	0.05	0.04	0.05	0.03
Acid number, mgKOH/g	3.1	2.5	2.8	2.1

Table 2. Continued

Indicator	Soxhlet Method		Under the influence of a microwave field	
	Solvent hexane	Solvent ethyl alcohol	Solvent hexane	Solvent ethyl alcohol
Peroxide number, mol ½O/kg	5.0	4.8	4.3	3.8
Mass fraction of phosphorus-containing substances in terms of stearooleolecithin, %	0.45	0.41	0.43	0.38
Anisidine number, c.u.	0.3	0.25	0.28	0.2
Flash point, °C	226	227	226	225

Source: developed by the author

The obtained data from studies of the peroxide and anisidine numbers confirm the best indicators of the oil obtained by extraction of raw materials in a microwave field (solvent – ethyl alcohol). The oil obtained by extraction of raw materials in a microwave field with a solvent ethyl alcohol is more resistant to oxidation, as evidenced by a decrease in the numbers: peroxide from 4.8 to 3.8, and anisidine from 0.25 to 0.2. The acid number, which characterises the degree of freshness of the resulting oil, also decreased from 2.5 to 2.1.

Notably, the main guarantee of the nutritional value of oil is the fatty acid composition (Ivanov *et al*., 2013). Together with the generally accepted oil parameters, the fatty acid composition of sunflower extraction oil was studied. The results are shown in Tables 3-6.

Table 3. *Fatty acid composition of sunflower extraction oil (sample No. 1)*

Conditional sign acids	Name of the acid according to the trivial nomenclature	Mass fraction of fatty acid (% to total fatty acids)
$C_{6:0}$	Caproic	0.07
$C_{14:0}$	Miristic	0.07
$C_{16:0}$	Palmitinic	6.49
$C_{16:1}$	Palmitooleic	0.09
$C_{18:0}$	Stearic	3.69
$C_{18:1}$	Oleic	28.37
$C_{18:2}$	Linoleic	59.23
$C_{20:0}$	Arachic	0.21
$C_{20:1}$	Eikosanoic	0.11
$C_{18:3}$	Linolenoic	0.16
$C_{21:0}$	Heneicosanic	0.18
$C_{22:0}$	Begenic	0.69
$C_{24:0}$	Lignoceric	0.17

Source: developed by the author

Table 4. *Fatty acid composition of sunflower extraction oil (sample No. 2)*		
Conditional sign acids	**Name of the acid according to the trivial nomenclature**	**Mass fraction of fatty acid (% to total fatty acids)**
$C_{16:0}$	Palmitinic	6.87
$C_{16:1}$	Palmitooleic	0.09
$C_{17:0}$	Margaric	0.06
$C_{18:0}$	Stearic	3.67
$C_{18:1}$	Oleic	25.84
$C_{18:2}$	Linoleic	59.54
$C_{20:0}$	Arachic	0.68
$C_{20:1}$	Eikosanoic	0.30
$C_{18:3}$	Linolenoic	0.22
$C_{21:0}$	Heneicosanic	0.15
$C_{22:0}$	Begenic	0.82

Source: developed by the author

Table 5. *Fatty acid composition of sunflower extraction oil (sample No. 3)*		
Conditional sign \acids	**Name of the acid according to the trivial nomenclature**	**Mass fraction of fatty acid (% to total fatty acids)**
$C_{14:0}$	Miristic	0.08
$C_{16:0}$	Palmitinic	6.88
$C_{16:1}$	Palmitooleic	0.11
$C_{18:0}$	Stearic	3.27
$C_{18:1}$	Oleic	30.09
$C_{18:2}$	Linoleic	57.42
$C_{18:3}$	Linolenoic	0.25
$C_{20:1}$	Gondoinic	0.10
$C_{24:0}$	Lignoceric	0.21

Source: developed by the author

Table 6. *Fatty acid composition of sunflower extraction oil (sample No. 4)*		
Conditional sign acids	**Name of the acid according to the trivial nomenclature**	**Mass fraction of fatty acid (% to total fatty acids)**
$C_{6:0}$	Caproic	0.19
$C_{8:0}$	Caprylic	0.05
$C_{14:0}$	Miristic	0.08
$C_{16:0}$	Palmitinic	7.18
$C_{16:1}$	Palmitooleic	0.17
$C_{17:0}$	Margarine-oleic	0.41
$C_{17:1}$	Margaric	0.19
$C_{18:0}$	Stearic	3.53

Table 6. Continued

Conditional sign acids	Name of the acid according to the trivial nomenclature	Mass fraction of fatty acid (% to total fatty acids)
$C_{18:1}$	Oleic	26.44
$C_{18:2}$	Linoleic	57.12
$C_{20:0}$	Arachic	0.19
$C_{20:3}$	Eicosatrienoic	0.67

Source: developed by the author

The composition of fatty acids of sunflower oil, in general, should include the following fatty acids: miristic (up to 0.2%), palmitinic (up to 5.0 to 7.6%), palmitooleic (up to 0.3%), stearic (from 2.7 to 6.5%), oleic (from 14.0 to 39.4%), linoleic (from 48.3 to 74.0%), linolenoic (up to 0.3%), arachic (from 0.1 to 0.5%), gondoinic (up to 0.3%), begenic (from 0.3 to 1.5%), lignoceric (up to 0.5%).

Thus, after conducting laboratory tests, it can be argued that sunflower oil extraction, obtained by the method of extraction of raw materials in a microwave field, meets the requirements of DSTU 4492-2017 (2017). A study of the fatty acid composition of rapeseed oil was also conducted (Tables 7 and 8) obtained by extraction in a microwave field with solvents hexane and ethyl alcohol of rapeseed meal.

Table 7. *Fatty acid composition of rapeseed oil (sample No. 1, hexane solvent)*

Conditional sign acids	Name of the acid according to the trivial nomenclature	Mass fraction of fatty acid (% to total fatty acids)
$C_{16:0}$	Palmitinic	7.53
$C_{16:1}$	Palmitooleic	0.14
$C_{18:0}$	Stearic	3.15
$C_{18:1}$	Oleic	27.66
$C_{18:2}$	Linoleic	60.08
$C_{18:3}$	Linolenoic	0.16
$C_{20:0}$	Arachic	0.22
$C_{20:1}$	Gondoinic	0.12
$C_{22:0}$	Begenic	0.46
$C_{22:1}$	Erucic	0.48

Source: developed by the author

Table 8. *Fatty acid composition of rapeseed oil (sample No. 2, ethyl alcohol solvent)*

Conditional sign acids	Name of the acid according to the trivial nomenclature	Mass fraction of fatty acid (% to total fatty acids)
$C_{14:0}$	Miristic	0.1
$C_{16:0}$	Palmitinic	7.3
$C_{16:1}$	Palmitooleic	0.16
$C_{18:0}$	Stearic	2.98
$C_{18:1}$	Oleic	28.79

Table 8. Continued

Conditional sign acids	Name of the acid according to the trivial nomenclature	Mass fraction of fatty acid (% to total fatty acids)
$C_{18:2}$	Linoleic	58.56
$C_{18:3}$	Linolenoic	0.23
$C_{20:0}$	Arachic	0.19
$C_{20:1}$	Gondoinic	0.16
$C_{22:0}$	Begenic	0.48
$C_{22:1}$	Erucic	0.5

Source: developed by the author

The findings show that microwave technologies are a powerful tool for implementing food nanoenergy technologies. They will, in comparison with conventional technologies, significantly increase the concentration for the same time period by 1.4 -1.8 times, as well as reduce the time of the process by almost 3 times, to create technologies for processing food raw materials that fully meet modern requirements of resource and energy efficiency, environmental safety, and market economy requirements. Since ethanol is non-toxic and safe, but extracts extractives more slowly than n-hexane, it is advisable to perform extraction in a microwave field.

Ethanol is one of the alternative solvents because it is cheap and can be produced by fermentation from a wide variety of biological materials using a simple technology, and is therefore designated as "natural" or "bio-renewable". The discrepancy for some target components is conditioned by the fact that they are insoluble in ethyl alcohol, which is a polar solvent. The choice of polar solvents is justified for microwave devices by the dipole shift effect. Therefore, if the main target component in extraction is those fatty acids that are insoluble in alcohol, a combined or other extraction method should be considered.

In the studies by Baümler *et al.* (2016) ethanol was used as the solvent, with 70% less crystallising waxes and at least 38% more tocopherols and phospholipids extracted. From the standpoint of the quality of the resulting products, this study demonstrated the feasibility of using ethanol as a solvent, an alternative to hexane, in the extraction of oil from sunflower cake. These studies confirm the relevance and results are presented.

Ying Li *et al.* (2014) evaluated the effectiveness of five alternative solvents (alcohols: ethanol, isopropanol, and terpenes: d-limonene, α-pinene, and n-cymol) compared to n-hexane in rapeseed oil extraction. The extracted oils were quantitatively and qualitatively analysed to compare solvent characteristics in terms of kinetics, fatty acid composition, lipid yield, and grades. In addition, the trace elements in the extracted oils were also quantified by high-performance liquid chromatography and gas chromatography, respectively. In addition, the interaction between alternative solvents and rapeseed oil was theoretically studied using the Hansen solubility methodology to better understand the dissolution mechanisms. The results showed that n-cymol may be the most promising solvent for replacing n-hexane with a higher lipid yield and good selectivity, despite the relatively low content of trace elements. But the authors did not specify that n-cymol is an organic compound, belongs to aromatic hydrocarbons and is highly toxic, which is dangerous for use in food technologies.

Candidate and doctoral theses have been published based on the results of studies on the efficiency of using the microwave field in extraction processes. According to the topic of the dissertation work (Levtrynska, 2017), coffee extraction was performed under the influence of a microwave field in a rarefaction chamber. During production tests of the device, coffee extract concentrate was obtained. According to the tasting reports, the resulting product has high quality, flavouring properties that are superior to ordinary instant coffee. No more than 0.65% of extractives remain in the spent solid phase, which confirms the effectiveness of the microwave field.

In the dissertation (Bandura, 2021), the results of oil extraction under the influence of a microwave field increase by 30%, and electricity costs decrease significantly. The recommended solvent for extraction in MX is poly-ethyl alcohol, as polar, safe, non-toxic and 1.5 times more intense than hexane in a microwave field environment. This is confirmed by the authors' research on the energy-efficient use of microwave technologies in ethyl alcohol extraction processes.

A. Binello *et al*. (2014) conducted a comparative study of classical hydrodistillation (HD), microwave hydrodistillation (MGH), and microwave hydrodiffusion and gravity (MHG) used in the extraction of four plant species cultivated in Piedmont (Italy): lavender, oregano, basil, and sage. Both microwave treatments yielded excellent results; in particular, the essential oils obtained with MHG were very similar to those obtained with HD. In MGH, the polarity and physicochemical properties of the extracted compounds caused large differences in the composition of the essential oil. The authors confirmed the effective effect of microwave energy in the hydrodistillation process.

Using basic research in the field of studying the action of the microwave field, an innovative technique is created (Burdo *et al.*, 2018). To intensify and increase the energy efficiency of extraction processes, the principles of directed energy action and microwave action at the capillary level of the product are used. The main difference in this study is a more in-depth examination of the use of different solvents for oil extraction.

The research deepens the understanding of the feasibility of using a microwave field for various solid-liquid systems, the use of a green solvent improves the quality characteristics of the finished product and environmental safety, and is recommended for further implementation of these technologies in production.

Conclusions

The results of the conducted studies have shown that the use of microwave technologies increases the efficiency of the oil extraction process, oil density, oxidative stability, and oil colour index. Based on the results obtained, it can be argued that the use of microwave extraction with a polar solvent, which is ethyl alcohol, was effective in improving the quality properties of the extracted oil.

Since the obtained data from studies of peroxide (3.8), anisidine (0.2), and acid numbers (2.1) are lower in the oil values obtained by microwave extraction methods, they indicate a greater resistance of the oil to oxidation.

The use of a microwave field in the process of extracting oil raw materials with a polar solvent (ethyl alcohol) leads to a gradient-free wave supply of electromagnetic energy to polar molecules. It is due to this effect that a powerful diffusion flow of extract is obtained from the raw material, which is supplemented by the flow of a whole complex of components and does not degrade the quality of oils.

The results obtained confirm the improvement of the extraction process of oil materials using microwave energy, which increases the yield of the final product and speeds up the extraction process, ensuring high quality of the product, through the use of "green technologies" and environmentally friendly solvents.

Accordingly, the results obtained allow the recommendation of the microwave method for introducing vegetable oils with ethyl solvents into production. Promising areas of research are patenting this method and developing technological conditions for the production of vegetable oils. Since a more detailed investigation of the effect of the microwave field on the product is required and microbiological and technological studies of the finished product obtained using the new technology are necessary.

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Conflict of Interest

None.

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Показники якості екстрагованої соняшникової та ріпакової олії отриманої розчинниками гексаном та етиловим спиртом

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Анотація. Актуальність проведених досліджень зумовлена збільшенням попиту на олійну продукцію з покращеними та екологічно безпечними якостями, а саме заміною небезпечного розчинника в екстракційному процесі переробки олійного насіння. У зв'язку з цим дана стаття спрямована на застосування в технології екстрагування більш безпечного для здоров'я людини органічного розчинника, яким є етанол. Провідним підходом до дослідження цієї проблеми є екстракція за методом Сокслета та мікрохвильового екстрагування із застосуванням розчинників гексан та етанол. Дослідження жирно-кислотного складу отриманого продукту проводили методом газової хроматографії. У запропонованому мікрохвильовому методі екстракції олії «зеленим» розчинником, яким є етиловий спирт, досліджували фізико-хімічні показники та порівнювали їх із показниками отриманими за методом Сокслета. Ефективність мікрохвильового оброблення пов'язана з процесом нагрівання, що значно підвищує внутрішній тиск клітин, який викликає їх руйнування. Створюється бародифузійний потік, який сприяє вагомому, за однаковий період часу, у 1,4-1,8 рази збільшенню виходу концентрації екстракційної олії та зменшенню часу процесу екстрагування майже в 3 рази. Олія, отримана методом екстракції сировини в мікрохвильовому полі розчинником етиловим спиртом більш стійка до окислення про це свідчать зменшення чисел: пероксидного з 4,8 до 3,8, анізидинового з 0,25 до 0,2. Кислотне число, яке характеризує ступінь свіжості отриманої олії, також зменшилось з 2,5 до 2,1. Результати досліджень свідчать, що застосування мікрохвильового екстрагування полярним розчинником, яким є етиловий спирт, було ефективним для покращення якісних властивостей екстрагованої олії. Застосування «зеленого» розчинника не погіршує якості готового продукту на відміну гексану, який є шкідливим для здоров'я людини. Матеріали статті становлять практичну цінність для олієжирової промисловості, а саме в технології екстрагування олійної сировини

Ключові слова: розчинники; екстракція; гексан; етиловий спирт; мікрохвильова енергія; жирно-кислотний склад