The study of edible vegetable oils rheological properties

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Abstract. The study of technological media rheological properties in the food industry is of primary importance for innovative food products development. This kind of research results can be recommended for reconstructing the suspensions, solutions, and mixtures properties and behavior. The objects of testing are the following types of edible vegetable oils: sunflower, mustard, linseed, camelina, rapeseed, milk thistle. The aim is to determine the rheological properties of the studied oils and to find out their dependence on temperature. Tests at shear rates $\gamma = 100 \div 1000\ s^{-1}$ in the temperature range of 20 - 120°C were carried out in this work. The viscosity was determined with the Brookfield DV-II + PRO viscometer. The data analysis showed that the dynamic coefficient for the studied samples of oils changed insignificantly in the range of the shear rate values $\gamma = 600 \div 800\ s^{-1}$. This can be explained by the structure strengthening due to the formation of additional intermolecular bonds. The nature of the rheological curves was established. The data obtained are recommended for use in the implementation of methods of hydromechanical and thermal processes intensification in the studied oils obtaining.

1 Introduction

Most foods behave like non-Newtonian liquids. Empirical and semi-empirical equations characterizing foods viscosity were published in the works [1]. Currently, the study of elastic-plastic products that can be the basis of functional food is relevant [2, 3]. The rheological characteristics of non-Newtonian edible vegetable oils were given in the form of stress and shear rate curves, as well as in the form of dynamic characteristics - the dependence of time on viscosity at a constant shear rate. At the same time, various authors brought it together [4, 5]. The study of rheological characteristics is important for the process of oils pressing, for hydromechanical and thermal processes, etc. [6].

One of the most promising experimental research methods is the study of edible vegetable oils physical properties under the influence of various factors. Depending on the types of vegetable oils, their properties are manifested in different ways under the influence of external forces [7]. Viscosity is one of the main parameters in blends developing [8]. In this regard, the main task is to study rheological laws and determine rheological constants,

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under the influence of which various transformations occur that affect the quality of edible vegetable oils during storage.

The operation of technological equipment is known to depend on the modes used in the production of edible vegetable oils. The objects studied go through various stages of heating, stirring, etc. from the dosing device [9]. As a result, their rheological properties undergo changes that affect the equipment operation [10].

Predicting of oils rheological properties based on fatty acid composition is also promising. A preliminary analysis of published vegetable oil data suggests a potential relationship between rheological properties and carbon number and unsaturation levels in fatty acids. A number of studies on the effect of temperature on the absolute viscosities of vegetable oils have already been published [11].

The objects of testing are the following types of edible vegetable oils: sunflower, mustard, linseed, camelina, rapeseed, milk thistle. The aim is to determine the rheological properties of the oils studied and to find out their dependence on temperature.

2 Materials and methods

Determination of viscosity was carried out with the Brookfield viscometer DV-II+PRO (Figure 1).

Fig. 1. Brookfield viscometer DV-II+PRO.

It was equipped with an SS adapter allowing the use of a small oil amount for each analysis. Viscosity was measured with a spiral movement stand (Helipath Stand) and T-shaped spindles (T-Bar spindles). The temperature was controlled with an error of ±0.1°C. The analysis was carried out in the temperature range from 20°C to 120°C.

The operation of this device is the following. The spindle moved by the drive, is immersed in edible vegetable oils. The viscous resistance with a change in the drive speed determined by the rotation sensor is measured with a viscometer. The measurement interval in the spindle rotation can be found with the device. In this case, it is necessary to use a low Griffin beaker with a volume of 600 ml for testing the samples under study. To measure the viscosity, it is necessary to determine the modes of time to control the stopping time and determine the torque.

Thus, the device is configured with a spindle and speed detection, followed by the readings recorded. An internal controller linked with a computer is also used to control the viscosity measurement. The RS-232C serial port is used to connect a printer or a computer, and the Centronics parallel port is used to connect a printer.

Physico-chemical characteristics of oils are determined in accordance with the requirements for vegetable oils TR CU 024/2011 "Technical regulations for oil- and fat products" dated by 09.12.2011, obtained by "cold pressing". Analysis of oils fatty acid composition was carried out in accordance with GOST R 32190-2013 "Vegetable oils. Acceptance Rules and Sampling Methods" with gas chromatography method on the Kristall-5000.1 apparatus.

Office Excel 2013 software was used to obtain linear regressions. Each test sample was subjected to a 5-fold analysis. The confidence interval was less than 0.5% of the obtained values. The data obtained are statistically reproducible and reliable

Samples of the above mentioned oils obtained by cold pressing were chosen as the objects of research (Figures 2-4).

Fig. 2. Oil samples: mustard, linseed, milk thistle.

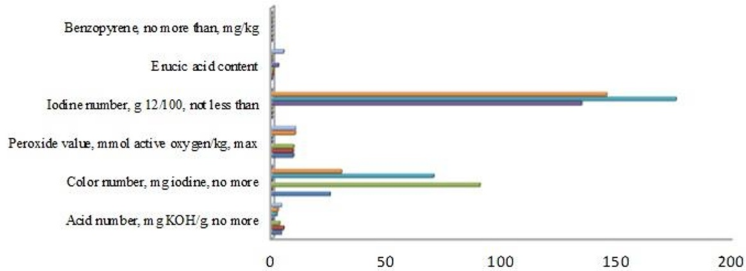
Fig. 3. Oil samples: sunflower, rapeseed, camelina.

Fig. 4. Device for cold pressing MPL-1.

3 Results

All oils were stored at room temperature (about 20°C) in the dark prior to analysis. The physicochemical properties of oils were found to vary depending on the plant location and the agricultural practices applied to the raw materials (Figure 5).

The composition of vegetable oils is shown in figure 6: monounsaturated fatty acids (MUFAs), polyunsaturated fatty acids (PUFAs), and saturated fatty acids (SFAs).



	Acid number, mg KOH/g, no more	Color number, mg iodine, no more	Peroxide value, mmol active oxygen/kg, max	Iodine number, g 12/100, not less than	Erucic acid content	Benzopyrene, no more than, mg/kg
According to TR CU 021/2011	4	0	10	0	5	0,002
Milk thistle oil	2,5	30	10	145	0,1	0
Linseed oil	2	70	0	175	0,1	0
Camelina oil	0,2	0	0	134	2,7	0
Mustard oil	3,2	90	9,3	0	0,6	0
Rapeseed oil	5	0	9,1	0	0,4	0
Sunflowerseed oil	4	25	9,2	0	0	0

Fig. 5. Physical- and chemical properties of vegetable oils.

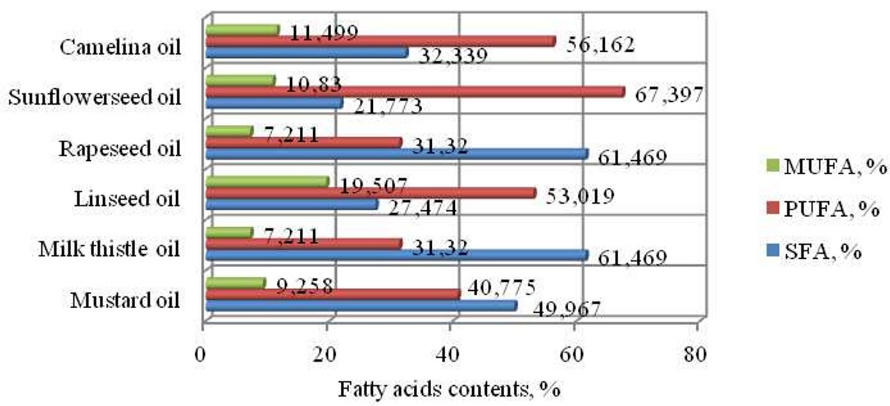


Fig. 6. Fatty acids contents of vegetable oils.

The determination of edible vegetable oils viscosity was carried out at the following temperatures: 20, 40, 60, 80, 120°C. In the literature references such a parameter as viscosity is proved to have a significant effect on hydrodynamic and thermal processes [12-13].

The experimental results of rheological properties for the studied oil samples in the specified temperature ranges are presented in Tables 1 and 2.

Table 1. Results of structural and rheological properties for edible oils.

Temperature, °C	Shear rate, γ, s^{-1}	Sunflower seed oil		Rapeseed oil		Linseed oil	
		Shear stress, $\tau\times10^{-2}$, Pa	Dynamic viscosity index, $\mu\times10^{-6}$, Pa·s	Shear stress, $\tau\times10^{2}$, Pa	Dynamic viscosity index, $\mu\times10^{-6}$, Pa·s	Shear stress, $\tau\times10^{2}$, Pa	Dynamic viscosity index, $\mu\times10^{-6}$, Pa·s
20	100.0	6.3	58.40	8.6	70.19	7.8	64.75
40	200.0	12.3	28.30	16.8	31.57	15.3	29.04
60	400.0	24.2	16.27	33.2	19.18	30.2	17.64
80	600.0	36.2	10.15	49.7	11.87	45.2	10.12
100	800.0	45.2	9.87	61.9	10.18	56.3	9.32
120	1000.0	55.4	5.14	75.8	6.02	69.0	5.49

Table 2. Results of structural and rheological properties for edible oils

Temperature, °C	Shear rate, γ, s^{-1}	Mustard oil		Camelina oil		Milk thistle oil	
		Shear stress, $\tau\times10^{2}$, Pa	Dynamic viscosity index, $\mu\times10^{-6}$, Pa·s	Shear stress, $\tau\times10^{2}$, Pa	Dynamic viscosity index, $\mu\times10^{-6}$, Pa·s	Shear stress, $\tau\times10^{2}$, Pa	Dynamic viscosity index, $\mu\times10^{-6}$, Pa·s
20	100.0	8.2	67.98	8.4	70.02	8.3	69.33
40	200.0	16.1	30.49	16.5	31.40	16.4	31.09
60	400.0	31.7	18.52	32.7	19.07	32.4	18.90
80	600.0	47.4	10.60	48.8	10.74	48.5	10.79
100	800.0	59.1	9.72	60.9	10.02	60.3	9.91
120	1000.0	72.4	5.64	74.7	5.93	73.9	5.75

4 Discussion

However, such indicators as acid number and erucic acid content are normalized to 6% and 5%, respectively, for rapeseed oil according to TR CU 024/2011.

The results showed that the indicators norm for all the studied oils does not exceed the normative document.

Among the studied samples, sunflowerseed oil is distinguished by a higher content of PUFAs (53%) than oils from camelina, rapeseed, linseed, mustard, milk thistle (56%, 31%, 53%, 41% and 31%, respectively). This difference in the content of PUFAs will make it possible to obtain blends from the studied oil samples in the future.

5 Conclusion

The physicochemical parameters and fatty acid compositions of six edible vegetable oils, which are necessary for the relationship of the variability of the thermophysical properties of the components with structural properties such as molecular weight, were investigated in the work. The results showed that the norm of indicators does not exceed TR CU 024/2011 for all the studied oils. Among the studied samples, sunflowerseed oil is distinguished by a higher content of PUFAs (53%) than oils from camelina, rapeseed, linseed, mustard, milk thistle (56%, 31%, 53%, 41% and 31%, respectively).

It was found out that the studies of edible vegetable oils rheological properties indicate the belonging of these oils to the class of non-Newtonian liquids and they obey Bingham's

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law. The data obtained indicate that the oils studied can be attributed to pseudoplastic fluids, which have rheopectic properties. The conclusions made correlate with the literature data.

The conducted research on rheology is recommended to use for engineering calculations and equipment selection; for the development of models of various technological operations with a description of the modes of edible oils production using equipment with rotating and mixing devices to preserve the structure of the objects under study. The results of the study will make it possible to actualize the problems of thermal and hydromechanical processes of oil production at a given temperature.

As a result of experimental studies, a decrease in the dynamic coefficient of viscosity for linseed, mustard, sunflower, rapeseed, camelina and milk thistle oils is observed with an increase in the speed gradient up to 1000 s^{-1}. Viscosity changes insignificantly near the mentioned indicator. The effect of reducing of the studied oils viscosity with an increase in the shear rate is of great importance for the pressing process.

Analysis of Tables 1 and 2 showed that an intensive change in the numerical values takes place in the area within the shear rate from 100 to 400 s^{-1}. This can be explained by rheopectic properties in the liquid-phase oils. It can also be concluded that in the range of values of the shear rate $\gamma = 600 \div 800\ s^{-1}$, the dynamic coefficient for the studied oil samples changes insignificantly, which is explained by the strengthening of the structure due to additional intermolecular bonds.

From Tables 1 and 2, it can be seen that the values of the shear stress in the temperature range of 20 - 60°C increase 2 times. Therefore, the results for hydrodynamic and rheological calculations are recommended to use when designing equipment.

In the range of shear stress $\gamma = 600 \div 800\ s^{-1}$ quasi-Newtonian phase subspaces are formed [14-15]. This is due to the interaction of various chemical components of oils, oleic acid triglycerides in particular. The data obtained indicate that the media under study represent a pseudoplastic fluid belonging to the type of viscous non-Newtonian fluids [16].

Since the dependence of the viscosity on the shear rate is characteristic of a pseudoplastic fluid, it can be assumed that the flow index is $m < 1$. This is due to the fact that the orientation of the particles occurs when the fluid is in motion and the interaction between them weakens with the viscosity increase. This pattern of change can be observed in edible vegetable oils.

The results obtained are recommended for use in determining the ways of intensification of hydromechanical and thermal processes when obtaining edible vegetable oils.

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