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The physicochemical evaluation of oils used for frying chips in the aspect of biofuel production

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Summary. Plant oils used for frying food in industrial or household conditions undergo degradation resulting from multi directional physicochemical transformations. Post-frying fat may be utilized for production of FAME type biofuel. Goal of this paper were analysis of physicochemical changes taking place in sunflower and rapeseed oil during course of potato chips frying process, and answer to a question concerning effect of type of oil, number of frying cycles and addition of chips on above mentioned changes, when compared with fresh oil. This answer will provide information concerning suitability of investigated post frying oils for production of biofuels. With rapeseed and sunflower oils used for frying chips as examples, verification of hypothesis of lack of significance of intergroup factors effects: oil and additions of chips, was conducted. Significance of frying cycle and its interactions with intergroup factors was also verified. Influence of type of oil and chips addition on four chosen oil quality parameters: acid number, peroxide number, fatty acids oxidation products, photometric colour index, was compared. Moreover, interactions between investigated factors and frying cycle were analysed. In order to verify hypotheses of lack of significance of intergroup factors effects, univariation variance analysis was used, in spite of strong linear dependence between investigated parameters of oil: acid number (AN), peroxide number (PN), oxidation products (OP) and photometric colour index (PCI). Number of oil samples was too small when compared to number of dependent variables, what lead to necessity of using univariation test. It must be noted that dependence between these variables is not cause and effect one. Values of particular variables depended on cycle of heating, while they did not depend on other variable investigated in the research. Significance of factor of repeated measurements and its interactions with intergroup factors were verified by means of multivariation variance analysis and univariation tests F.

Key words: post-frying oils, biofuels, acid number, peroxide number, PCI, variance analysis.

INTRODUCTION

Plant oils used for frying food in industrial or home conditions are subject to degradation resulting from multi directional physicochemical changes caused by high temperature, water and atmospheric oxygen. Reactions taking place in fat subjected to prolonged heating depend on conditions in which frying is conducted, initial quality of utilized oil, type of food and its surface, content of water and antioxidants as well as concentration of oxygen and type of fryer. High temperature of frying, number of cycles, content of free and unsaturated fatty acids, ions of heavy metals, food additives with remnants of agents for cleaning and washing equipment, lower oil's resistance to oxidation and are factors increasing pace of disadvantageous oil quality changes [1, 3]. Volatile and non-volatile substances are products of the reactions. Most of them evaporate with water vapour and remaining ones take part in reactions of oxidation and polymerization or are absorbed by food. Some, formed during frying, volatile compounds (1,4-dioxane, benzene, toluene) do not contribute to obtaining desirable taste and are toxic [14, 4]. High temperature and sunlight accelerate formation of free radicals and, as result of it, affect free-radical chain transformations. Water, weak nucleophile, attacks ester bounds of triglycerides and and this way di- and monoacylglycerides, glycerol and free fatty acids are formed. Thermal hydrolysis is observed mainly in oil phase. Products of hydrolysis reactions undergo secondary oxidation transformations [19]. Oxidation leads to formation of hydroperoxides and volatile, low particular weight, compounds such as aldehydes, ketones, carboxylic acids, alkanes and short chain alkenes, and high temperature favours processes of cyclization [4, 14].

In deeper layers of oil, where access of oxygen is limited, transformations leading to formation of free radicals, which are precursors of polymerization transformations of oil, prevail. Formation of polymers results in changes of density, viscosity and consistence of fat [22]. Polymers, formed in frying oil as a result of oxidation and thermal transformations, directly contribute to intensification of hydrolytic changes, for they cause detergency of oil, this way promoting accumulation of water vapour in frying oil. Detergency of frying oil favours also reactions of free fatty acids with, present in fried product, cations of sodium and potassium [4, 8]. As a result of fat degradation, surfactants, which increase time of contact of food and oil, are formed. Therefore quantity of fat absorbed by food increases, what causes decrease of heat transfer rate and decrease of heat transport factor [2].

In fats subjected to prolonged heating, changes of colour, intensifying with time that frying oil is used, occur. Main cause of colour changes are oxidation reactions, leading to accumulation of non-volatile compounds in fryer - mainly polymers. Maillard compounds, formed of remains of food present in frying oil, are also reason for frying oil darkening. Moreover, all fried products may affect colour of fat, by releasing into frying oil coloured substances and lipids [8, 7, 12]. Changes of colour can be used as indicator helping to control course of the process.

Increase of production of post-frying wastes from households and from industrial production becomes more and more significant problem both in Poland and the world. Unfortunately, this waste is often dumped into sewer system, what creates problem for waste water treatment plants and leads to loses of energy. Obtained, by means of properly organised and selective collection, post-frying oil can be utilized for production of FAME (Fatty Acid Methyl Esters) and can be used as biofuel. Elaboration of criteria enabling determination of: when oil is not suitable for use, and what its maximal save degree of "wear out" is, poses a great challenge for producers of fried food. Similar problem concerns used frying oils intended for transesterification reaction. Such oils shall characterize with specified values of acid and peroxide number and of free fatty acids [6].

Fuels for diesel engines, obtained from edible oils are changing electricity markets. To decrease production costs more and more often used vegetable and animal fats additives are used as raw materials. Quality requirements for these materials, pertaining to the content of free fatty acids, water, phosphatides and solid impurities depend on the kind of catalyst used. In FAME production these are alkaline catalysts, acidic catalysts or enzymes. With acidic catalysts usage even a 50 % or higher content of free fatty acids (FFA) in oils is accepted. With alkaline catalysts this should not exceed 0.5 – 1 % [9, 21]. High FFA content in fat causes significant loses in catalyst reaction, as in KOH due to potassium soaps formation. Post-frying oils quality parameters such as unsaturated fatty acids products colour and quantity are degradation degree indicators. Esters obtained from strongly degraded fats can be used as an additive to fuel oil.

Aim of this paper were analysis of physicochemical changes taking place in sunflower and rapeseed oil during course of chips frying process, and answer to question concerning effect of type of oil, number of frying cycles and addition of chips on above mentioned changes, when compared with fresh oil. This answer will provide information on suitability of investigated post-frying oils for production of biofuels. With rapeseed and sunflower oils used for frying chips as examples, verification of hypothesis of lack of significance of intergroup factors effects: oil and additions of chips, was conducted. Significance of frying cycle and its interactions with intergroup factors was also verified.

Characteristics of post-frying oils properties can be a basis for elaboration of model of these changes. Above mentioned research will enable elaboration and suggesting easy to conduct and cheap method of determination of quality of oil used for gastronomical purposes with regard to feasibility of its utilization for FAME production.

MATERIALS AND METHODS

Sunflower and rapeseed oils were objects of this investigation. For the purpose of which 5 litres of each, obtained from batch in trade, were used. Content of individual containers was poured into a single container and mixed. Obtained mixture was called raw sunflower oil or raw rapeseed oil. Next, oil was heated in the container to temperature enabling proper frying of chips, which were made of raw potatoes. After frying and separation of potato chips, oil had been left in the container in room temperature for 24 hours. Collected sample was marked as frying I. After 24 hours remaining oil was heated again and all described above actions were repeated – yielding another sample marked as frying II. Whole process of heating, cooling and sampling was repeated until it yielded samples marked with numbers III, IV, V, VI and VII. In order to investigate effect of frying on properties of sunflower or rapeseed oil, similar cycles of heating and cooling, but without frying chips, were conducted yielding samples marked as heating I – VII.

Each of collected samples was subject to a laboratory testing and following properties were determined: peroxide number (PN) [15], acid number (AN) [16], photometric colour index (PCI) [14] and composition of higher fatty acids [18].

Photometric colour index (PCI) was determined by means of spectrophotometric method measuring absorbency for four lengths of light waves: 460 nm, 550 nm, 620 nm and 670 nm. Photometric colour index (PCI) was calculated as follows:

$$PCI = 1,29 \cdot (Ab_{460}) + 69,7 \cdot (Ab_{550}) + \\ + 41,2 \cdot (Ab_{620}) - 56,4 \cdot (Ab_{670}),$$

where: $Ab_{(460)}$, $Ab_{(550)}$, $Ab_{(620)}$, $Ab_{(670)}$ are values of absorbency measured for four lengths of light waves: 460 nm, 550 nm, 620 nm and 670 nm respectively [14]. After each heating, each oil sample (with and without chips) was analysed in six repetitions.

Determination of fatty acids composition was conducted by means of gas chromatography. Extracted fat was subjected to alkaline hydrolysis with sodium hydroxide solution in anhydrous methanol, and than released fatty acids were transformed into methyl esters with hydrogen chloride in methanol. Obtained esters were separated in a chromatographic column and than their participation in a sum of fatty acids was determined [18]. Relying on obtained chromatograms amount of oxidation products (OP) after each of seven frying cycles was calculated.

Investigation was conducted in randomised, complete design, according to two-factor, crossed classification scheme with repeated measurements. Crossed classification was used for two intergroup factors: oil and additives. Cycles of frying in temperature enabling preparation of potato chips were factor of repeated measurements. Statistical calculations were conducted by means of Statistica 6.0 program.

RESULTS AND DISCUSSION

In this paper, characteristics of chosen physicochemical changes of sunflower and rapeseed oil after each of the seven heating cycles, were evaluated. Analysed changes of acid number (AN), peroxide number (PN), photometric colour index (PCI) and oxidation products (OP) were presented in a graphic and tabular form in figures 1-4 and tables 1-3.

Raw sunflower and rapeseed oil characterized with typical properties meeting quality standards [17] of product being a subject to business trade; (rapeseed oil AN=0,192 mgKOH·g^{-1}t of fat, PN=33 meq·kg^{-1}, sunflower oil AN=0,111 mgKOH·$g^{-}$of fat, PN=33,3 meq·kg^{-1}). Oils were lucid, clear – no residuum was noted.

Influence of type of oil and addition of chips, on chosen oil quality parameters: AN, PN, OP and PCI, were compared. Moreover, interactions between investigated factors and frying cycle were analysed.

In order to verify hypothesis of insignificance of effects of intergroup factors univariation variance analysis was used, even though strong linear dependence between investigated parameters of oil: acid number (AN), peroxide number (PN), oxidation products (OP) and photometric colour index (PCI) was noted. Number of oil samples was too small when compared to number of dependent variables, what lead to necessity of using univariation test. It must be noted that dependence between these variables is not cause and effect one. Values of particular variables depended on cycle of heating, while they did not depend on other variable investigated in the research. Significance of factor of repeated measurements and its interactions with intergroup factors was verified by means of a few methods: multivariate variance analysis and univariate tests F.

ANALYSIS OF VARIABLE AN - ACID NUMBER

Results of multivariate Roy's test for repeated measurements factor - cycle of heating and its interactions with intergroup factors: type of oil and additives, leads to rejection of null hypotheses assuming insignificance of heating cycle influence and insignificance of interaction of heating cycle and intergroup factors on diversification of acid number of investigated oils (tab. 2).

Mauchley's test for sphericity does not reject null hypothesis assuming fulfilment of sphericity condition for acid number AN (tab. 3), what enables utilization of univariation tests for repeated measurements factor. At significance level of 0,01, significant diversification of acid number value, depended on type of oil, additives and heating cycle, was noted. Acid number of investigated oils was not changing identically with a change of additive and change of heating cycle (tab. 1).

Rapeseed oil with addition of chips maintained higher value of acid number AN throughout all heating cycles, while in pure rapeseed oil acid number levelled with AN of sunflower oil in the sixth heating cycle (fig. 1).

In sunflower oil heated without chips, acid number (AN) was growing systematically while oil was being heated, reaching finally level almost five times higher than in raw oil. In analogous sample of oil heated with potato chips, two-time increase was noted (fig. 1). In rapeseed oil, increase of acid number was 2.96 and 1.92 respectively.

Similar tendency of changes of investigated oils properties was observed in earlier research by Szmigielski et

Table 1. Univariate analysis of variance analysis for investigated variables and factor of repeated measurements

Variable	Sources of variation	SS	Degrees of freedom	MS	F	p
AN	Absolute term	9.6587	1	9.6587	96093.82	0.000000
	Oil	0.2361	1	0.2361	2348.70	0.000000
	Additives	0.6424	1	0.6424	6390.76	0.000000
	Oil*additives	0.0171	1	0.0171	170.43	0.000001
	Error	0.0008	8	0.0001		
	Cycle	0.7197	7	0.1028	2465.72	0.000000
	Cycle*oil	0.0122	7	0.0018	41.91	0.000000
	Cycle*additives	0.1526	7	0.0218	522.88	0.000000
	Cycle*oil*additives	0.0359	7	0.0051	122.86	0.000000
	Error	0.0023	56	0.00004		

PN	Absolute term	50679.17	1	50679.17	298288.3	0.000000
	Oil	5541.31	1	5541.31	32615.1	0.000000
	Additives	252.33	1	252.33	1485.2	0.000000
	Oil*additives	573.89	1	573.89	3377.8	0.000000
	Error	1.36	8	0.17		
	Cycle	8031.86	7	1147.41	4830.9	0.000000
	Cycle*oil	826.15	7	118.02	496.9	0.000000
	Cycle*additives	557.89	7	79.70	335.6	0.000000
	Cycle*oil*additives	142.49	7	20.36	85.7	0.000000
	Error	13.30	56	0.24		
OP	Absolute term	91854.57	1	91854.57	169250.3	0.000000
	Oil	257.99	1	257.99	475.4	0.000000
	Additives	9612.67	1	9612.67	17712.2	0.000000
	Oil*additives	547.28	1	547.28	1008.4	0.000000
	Error	4.34	8	0.54		
	Cycle	9293.11	6	1548.85	3797.4	0.000000
	Cycle*oil	3410.56	6	568.43	1393.6	0.000000
	Cycle*additives	1117.02	6	186.17	456.4	0.000000
	Cycle*oil*additives	246.20	6	41.03	100.6	0.000000
	Error	19.58	48	0.41		
PCI	Absolute term	850492014	1	850492014	5254948	0.000000
	Oil	1106306	1	1106306	6836	0.000000
	Additives	23378872	1	23378872	144451	0.000000
	Oil*additives	844088	1	844088	5215	0.000000
	Error	1295	8	162		
	Cycle	128146166	7	18306595	196264	0.000000
	Cycle*oil	8358142	7	1194020	12801	0.000000
	Cycle*additives	22759271	7	3251324	34857	0.000000
	Cycle*oil*additives	4237936	7	605419	6491	0.000000
	Error	5223	56	93		

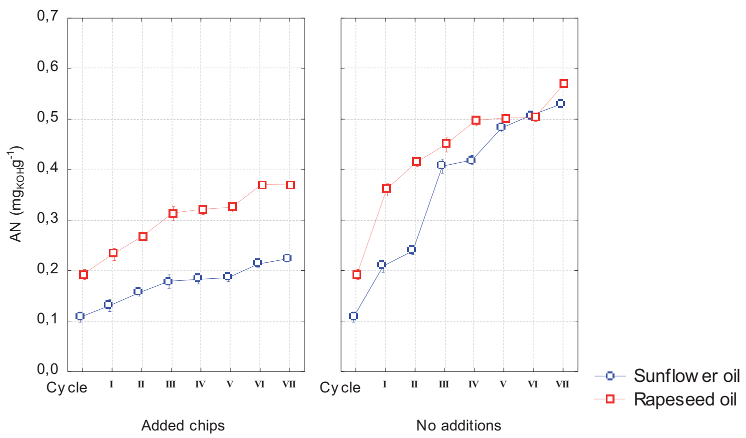

Fig. 1. Changes of acid number AN in subsequent heating cycles.F(7, 56)=122.86, p=0.0000. Vertical bars represent 0.95 confidence interval

Table 2. Multivariate Roy's test for factor of repeated measurements and for investigated variables

	Sources of variation	Value	F	Effect df	Error df	p
Variable AN	Cycle	62936.27	17981.79	7	2	0.000056
	Cycle*oil	729.35	208.39	7	2	0.004784
	Cycle*additives	16450.86	4700.25	7	2	0.000213
	Cycle*oil*additives	3421.34	977.53	7	2	0.001022
PN	Cycle	73906.36	21116.10	7	2	0.000047
	Cycle*oil	38132.80	10895.08	7	2	0.000092
	Cycle*additives	7240.41	2068.69	7	2	0.000483
	Cycle*oil*additives	1554.84	444.24	7	2	0.002248
OP	Cycle	23783.68	11891.84	6	3	0.000001
	Cycle*oil	9055.49	4527.75	6	3	0.000005
	Cycle*additives	2997.96	1498.98	6	3	0.000027
	Cycle*oil*additives	1053.61	526.81	6	3	0.000128
PCI	Cycle	6681140	1908897	7	2	0.000001
	Cycle*oil	505382	144395	7	2	0.000007
	Cycle*additives	1203929	343980	7	2	0.000003
	Cycle*oil*additives	173356	49530	7	2	0.000020

al. [20] and Maniak et al. [10]. This data suggests similar character of oil properties changes, of both rapeseed and sunflower oil, taking place during frying chips. In research of Chung [5] and Naz [13] it was showed that acid number and content of free fatty acids in oil sampled from frying pan was increasing with each frying cycle, while time of frying did not influence oil hydrolysis. Oxidation transformations seem to be a major profile of investigated oils changes. Samples in which chips were fried characterised with lower values of AN, when same number of frying cycle is taken into consideration, than samples heated without chips. It may result from minor influence of hydrolytic transformations of oil, taking place in presence of water from chips, as well as absorption of hydrolysis products on porous surface of potatoes.

ANALYSIS OF VARIABLE PN - PEROXIDE NUMBER

Peroxide number in sunflower oil was higher than in rapeseed oil regardless if chips were added or no addition of chips to heated oil was done. Addition of chips caused significantly slower increase of PN in rapeseed oil, while it only slightly slowed increase of this parameter in sunflower oil, hence, greater span between PN values in investigated oils (fig. 2). Similar trend was observed in case of properties of post-frying rapeseed and sunflower oils by Szmigielski [20] and Maniak [10].

It is characteristic in case of oxidation changes that initial high decrease of unsaturated fatty acids content is accompanied by simultaneous increase of products

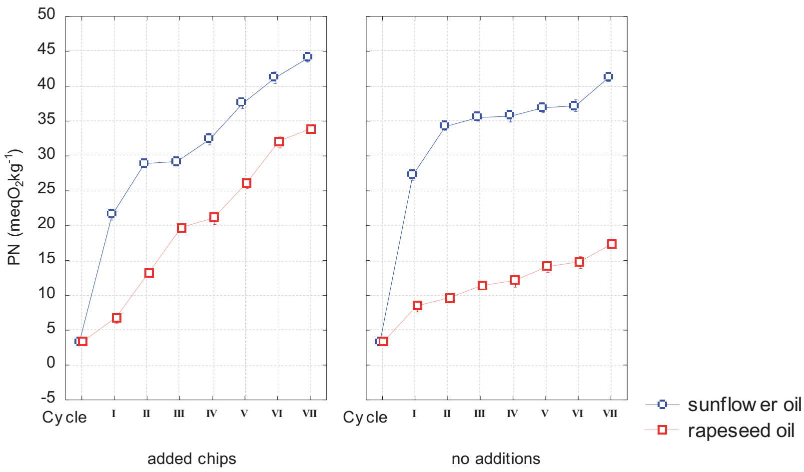

Fig. 2. Changes of peroxide number PN in subsequent heating cycles. F(7, 56)=85.701, p=0.0000. Vertical bars represent 0.95 confidence interval

of partial fat oxidation content and increase of peroxide number. Above mentioned transformations are also probably affected by sorption of oxidation products by chips, what is suggested by lower peroxide number of samples heated with the product [4, 14, 19].

At significance level of 0.05 Mauchley's test for sphericity does not reject null hypothesis assuming fulfilment of sphericity condition for peroxide number - PN, while it rejects this hypothesis at significance level of 0,01 (tab. 3), therefore univariate test for repeated measurements factor shall be used with caution.

Results of multivariate Roy's test for repeated measurements factor - heating cycle and its interactions with intergroup factors, type of oil and additives, lead to rejection of null hypotheses assuming lack of significance of heating cycle influence and lack of significance of interactions of heating cycle with intergroup factors on diversification of peroxide number value PN in investigated oils (tab. 2). Univariate tests also reject null hypotheses for factor of repeated measurements and interactions of this factor with type of oil and additive (tab. 1). Therefore, at significance level of 0.01 significant diversification of PN level, with regard to type of oil, additives, heating cycle and interaction between these factors, was noted.

ANALYSIS OF VARIABLE OP - OXIDATION PRODUCTS

Heating sunflower and rapeseed oil in laboratory conditions (small size of container used for the experiment, and easy access of air), caused increase of content of partial fat oxidation products (OP), as a result of, characteristic mainly for oxidation processes, changes of composition of higher fatty acids (fig. 3). In investigated oils, amount of products of fatty acids oxidation (OP) was from 6.88% to 65.2% for sunflower oil heated without chips and from 4.8% to 62.2% for sunflower oil heated with chips, while respective values for rapeseed oil were from 27.24% to 49.48% and from 14.8% to 22.97%. Catalytic effect of present in heated oil potato chips (fig. 3), as well as sorption of oxidation products on surface of fried chips, are possible.

Autoxidation is radical chain reaction. It is greatly affected by food compounds like, for example: proteins, saccharides, food dyes and water as well as catalysts, which influence course and kinetics of autoxidation. Formed during oxidation of lipids hydroperoxides are very unstable, and hydrocarbons, aldehydes, ketones, alcohols and ethers are secondary products of their degradation [19].

At significance level of 0.05 Mauchley's test for sphericity does not reject null hypothesis assuming fulfilment of sphericity condition for oxidation products - OP, while it rejects this hypothesis at significance level of 0,01 (tab. 3), therefore univariate test for repeated measurements factor shall be used with caution. While at significance level of 0,01, significant diversification of oxidation products, with regard to type of oil, additives and heating cycle, was observed. It should be noted that content of oxidation products in investigated oils was not

Table 3. Mauchley's sphericity test for investigated variables

Variable	Effect	W	Chi-kw.	df	p
AN	Cycle	0,001225	36,55609	27	0,103656
PN	Cycle	0.000269	44.82426	27	0.016968
OP	Cycle	0,001766	36,62489	20	0,012974
PCI	Cycle	0,001788	34,49470	27	0,152153

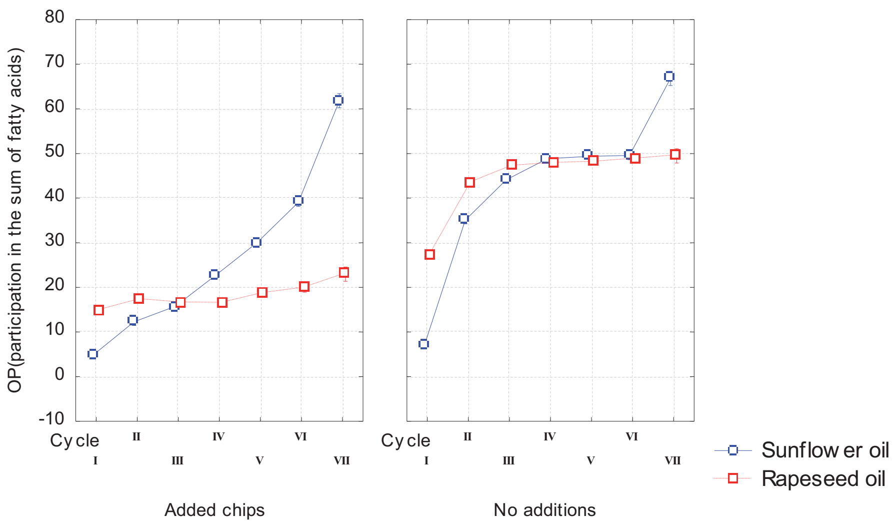

Fig. 3. Changes of oxidation products OP in subsequent heating cycles. F(6, 48)=100.60, p=0.0000. Vertical bars represent 0.95 confidence interval

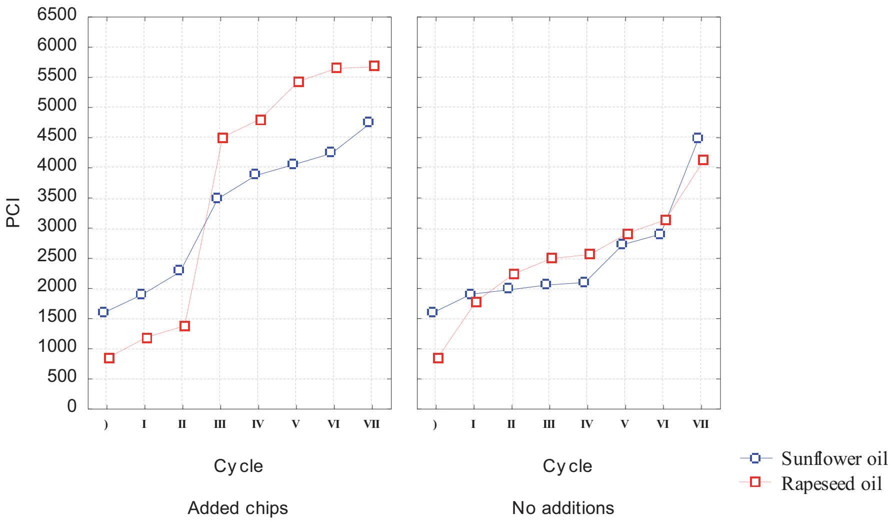

Fig. 4. Changes of photometric colour index PCI in subsequent heating cycles. F(7, 56)=6490.7, p=0.0000. Vertical bars represent 0.95 confidence interval

changing in the same manner in samples with and without addition of chips, and with each consecutive heating cycle.

In sunflower oil with addition of chips, content of oxidation products was increasing fast, while, in case of rapeseed oil with chips addition, slower increase was observed. Heating investigated oils without chips addition caused similar changes of content of oxidation products in cycles III-VI, while in second and seventh cycle of heating much greater increase of OP in rapeseed oil than in sunflower oil was observed (fig. 3).

Results of multivariate Roy's test for repeated measurements factor - heating cycle and its interactions with intergroup factors: type of oil and additives, lead to rejection of null hypotheses assuming lack of significance of heating cycle influence and lack of significance of interactions of heating cycle with intergroup factors on diversification of oxidation products of investigated oils (tab. 2). Univariate tests also reject null hypotheses for factor of repeated measurements and interactions of this factor with type of oil and additive (tab. 1). Therefore, at significance level of 0.01 significant diversification of OP level, with regard to type of oil, additives, heating cycle and interaction between these factors, was noted.

ANALYSIS OF PCI - PHOTOMETRIC COLOUR INDEX

Visual and instrumental effect of changes taking place in subjected to heating seven times oils was their darkening progressing with time of their utilization. Main reasons for colour changes were oxidation reactions leading to accumulation of polymers in the fryer, as well as Maillard reactions in which simple and complex carbohydrates, proteins and amino acids, products of peroxides degradation were substrates [19, 11, 8].

Value of PCI for sunflower oil ranged from 1588 to 4730 for oil in which chips were fried, while for oil with no chips addition they were from 1588 to 4479. In case of rapeseed oil values were 842 – 5658 and 842 - 2543 respectively (fig. 4). Photometric colour index of oil was increasing faster in oil with chips addition than in pure oil. It must also be noted that the increase was faster in rapeseed oil than in sunflower oil. Course of changes of the index in oil without chips addition was similar. After seventh heating cycle value of PCI in rapeseed oil with chip addition was significantly higher than in same oil but without chips, while in case of sunflower oil, differences between PCI value of oil with and without chips were much smaller (fig. 4).

At significance level of 0,01, significant diversification of photometric colour index, with regard to type of oil, additives and heating cycle, was observed. Photometric colour index of investigated oils was not equally affected by addition of chips and by consecutive heating cycles (tab. 1). Relying on results of Mauchley's test, it was stated that sphericity condition for photometric colour index is fulfilled, therefore, univariate tests can by used for analysis of heating cycle effect (tab. 3).

Results of multivariate Roy's test for repeated measurements factor - heating cycle and its interactions with intergroup factors, type of oil and additives, lead to rejection of null hypotheses assuming lack of significance of heating cycle influence on diversification of photometric colour index of investigated oils, and lack of significance of interactions of heating cycle with intergroup factors (tab. 2). Univariate tests also reject null hypotheses for factor of repeated measurements and interactions of this factor with type of oil and additive (tab. 1). Therefore, at significance level of 0.01, significant diversification of PCI level, with regard to type of oil, additives, heating cycle and interaction between these factors, was noted.

CONCLUSIONS

1. Type of oil, additives (oil with or without chips) and frying cycles significantly diversify physicochemical properties of post-frying oils.

2. Changes of value of investigated parameters (AN, PN, OP, PCI) in investigated oils do not have same course, when changes of addition or heating cycle are taken into consideration.
3. Values of investigated parameters AN, PN, and OP in case of rapeseed oil with chips addition were at higher level than in sunflower oil.
4. Photometric colour index (PCI) of rapeseed oil with addition of chips increased significantly after third frying cycle, exceeding value of PCI recorded for sunflower oil with chips addition.
5. Course of changes of physicochemical properties of pure oils was similar for both investigated oils. Only in case of sunflower oil peroxide number PN increased significantly after first heating cycle and remained higher than in rapeseed oil throughout all subsequent heating cycles.
6. Results of conducted research may be a basis for elaboration of cheap and simple system of post-frying oils evaluation, when aspect of their use for biofuel production is considered.

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FIZYKOCHEMICZNA OCENA OLEJÓW UŻYWANYCH DO SMAŻENIA FRYTEK W ASPEKCIE PRODUKCJI BIOPALIW

Streszczenie. Oleje roślinne stosowane do smażenia w przemysłowych lub domowych warunkach ulegają degradacji wynikającej z wielostronnych fizykochemicznych transformacji. Tłuszcz pozostały po smażeniu może być wykorzystany do produkcji biopaliwa typu FAME.

Celem pracy była analiza fizykochemiczna zmian zachodzących w oleju słonecznikowym i rzepakowym podczas przebiegu procesu smażenia frytek ziemniaczanych, oraz ustalenie wpływu rodzaju oleju, liczby cyklów smażenia i dodatków do frytek na wyżej wymienione zmiany, w porównaniu ze świeżymi olejami. Wyniki badań pozwolą na wnioski dotyczące przydatności badanych olejów po smażeniu do produkcji biopaliw. Użyto olejów z rzepaku i słonecznika do smażenia frytek jako przykładów do weryfikacji założeń badawczych.

Słowa kluczowe: oleje po smażeniu, biopaliwa, liczba kwasowa, liczba nadtlenkowa, PCI, analiza wariancji.