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EFFECT OF INDUSTRIAL CONDITIONS OF HEAT TREATMENT OF RAPE, MUSTARD, FLAX AND CAMELINA SEEDS ON THE QUALITY OF OILS INTENDED FOR BIODIESEL PRODUCTION*

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K e y w o r d s: rapeseed, mustard, flax, camelina, pressing, oils, quality.

A b s t r a c t

The aim of the study was to determine the effect of industrial conditions of heating rape, mustard, flax and camelina seeds on the pressing efficiency and quality of oil intended for biodiesel production. The research was conducted on rape, mustard, fibre flax and camelina seeds. Oils were pressed from seeds heated at 60, 70 and 80°C using the Kocibórz Biorefinery production line equipment. The quality of oils was assessed on the basis of the value of indicators affecting the course and the efficiency of transesterification and the stability of esters, i.e. the content of water and volatile compounds, the content of chlorophyll pigments and carotenoids, the content of phosphorus, degree of hydrolysis and oxidation and the composition of fatty acids.

It was found that the temperature of seed treatment positively affected pressing efficiency, but it had a negative effect on the quality of oils. The quality of oils deteriorated with an increase in temperature, which was indicated by a higher rate of hydrolysis and oxidation and an increased content of chlorophyll pigments and phosphorus. On the other hand, heat treatment temperature did not bring about any significant changes in the composition of fatty acids. In the case of rape and mustard seeds, the optimum pressing temperature on the production line in the Kocibórz Biorefinery for good pressing efficiency and oil quality was 70°C. For flax and camelina seeds, it was established that heat treatment of seeds under industrial conditions should be carried out at 60°C.

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WPŁYW PRZEMYSŁOWYCH WARUNKÓW OGRZEWANIA NASION RZEPAKU, GORCZYCY, LNU I LNIANKI NA JAKOŚĆ OLEJÓW PRZEZNACZONYCH DO PRODUKCJI BIODIESLA

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S ł o w a k l u c z o w e: rzepak, gorczyca, len, lnianka, tłoczenie, oleje, jakość.

A b s t r a k t

Celem pracy było określenie wpływu przemysłowych warunków ogrzewania nasion rzepaku, gorczycy, lnu i lnianki na wydajność tłoczenia i jakość olejów przeznaczonych do produkcji biodiesla. Badania wykonano na nasionach rzepaku, gorczycy, lnu włóknistego i lnianki. Oleje tłoczono z nasion ogrzewanych w temperaturach 60, 70 i 80°C w urządzeniach linii technologicznej Agrorafinerii Kocibórz (UWM Olsztyn). Jakość olejów oceniono na podstawie wartości wyróżników, które mają wpływ na przebieg i wydajność przeestryfikowania oraz stabilność estrów, tj. zawartości wody i związków lotnych, zawartości barwników chlorofilowych i karotenoidów, zawartości fosforu, stopnia hydrolizy i stopnia utlenienia oraz składu kwasów tłuszczowych.

Wykazano, iż temperatury ogrzewania nasion miały korzystny wpływ na wydajność tłoczenia, natomiast negatywny na cechy olejów. Wraz ze wzrostem temperatury następowało pogorszenie jakości olejów, na co wskazał podwyższony stopień hydrolizy i utlenienia oraz zwiększona zawartość barwników chlorofilowych i fosforu. Temperatura ogrzewania nie spowodowała natomiast istotnych zmian w składzie kwasów tłuszczowych. W przypadku nasion rzepaku i gorczycy za optymalną temperaturę tłoczenia na linii technologicznej w Agrorafinerii Kocibórz, z uwagi na dobrą wydajność tłoczenia i równocześnie dobrą jakość oleju, uznano 70°C. Z kolei w przypadku nasion lnu i lnianki stwierdzono, iż ogrzewanie nasion w warunkach przemysłowych powinno być prowadzone w temperaturze 60°C.

Introduction

Biocomponents and liquid biofuels, as an alternative for traditional fuels, have started to play an increasingly more important role in the energy policy of the European Union. The growing demand of the economy for fuels and energy, in view of the diminishing resources of fossil fuels has prompted interest in the use of biocomponents, liquid fuels and other renewable fuels. The need for such activities in our country results from legal acts adopted by the European Union and which are also applicable in Poland. They include, e.g. the Green Paper (2000), European Union directives (Directive... 2001, 2003a,b) and the Kyoto protocol (1997).

The main oil production raw material cultivated in Polish conditions is rapeseed, used both for food and for fuel purposes. The factors determining its usefulness for the production of methyl esters of higher fatty acids include its cultivar, seed yield and the fat content in seeds (HEIMANN 2002, KACHEL-

-JAKUBOWSKA and SZPRYNGIEL 2009). Seeds used in processing, both for food and for energy purposes, should originate from cultivars of double low rapeseed, characterised by a minimum oil content of 40%, a minimum percentage of oleic acid of 56%, acid value for oil ≤ 3.0 mg KOH · g^{-1}, erucic acid percentage < 1.0% and the content of alkenyl glucosinolates < 25 μmol · g^{-1} defatted dry matter (*Rośliny przemysłowe oleiste*... PN-90/R-66151).

Own research concerning the composition of fatty acids of seeds of various rape cultivars has demonstrated that winter, open pollinated and hybrid cultivars of rapeseeds, characterised by high oil content (> 40%) and optimum composition of fatty acids (≥ 56% oleic acid ≤ 12% linolenic acid) were the best raw material for biodiesel production (AMBROSEWICZ et al. 2012).

Because of the growing demand for seeds and rapeseed oil both for fuel purposes and, to a lesser extent, for consumption purposes, it is increasingly more difficult, year-by-year, to provide the required amount of these raw materials. As results from the report presented in *Rynek Rzepaku – stan i perspektywy* (2012), the demand for rapeseed oil intended for food purposes will grow very slowly, due to the high variety of vegetable oils in the market. On the other hand, it was found that an obligation to increase the share of biocomponents in liquid fuels imposed on the fuel sector (National Index Target in 2013 – 7.10%) has contributed to the growing demand for this raw material. It was estimated, for instance, that as much as two million tonnes of rape seeds should be provided for production of esters carried out exclusively on the base of rapeseed oil only. Consequently, the use of other oil raw materials grown in Poland (e.g. flax, camelina and mustard seeds) is considered necessary.

Oils from seeds are extruded by pressing and/or extraction. Oil intended for biodiesel production is extruded by pressing, the efficiency of which depends highly on the method of seed conditioning (heat treatment) (RADZIEMSKA et al. 2009). Seed heating results in decomposition of all cell structures, thus releasing both reserve and structural fat (TAŃSKA and ROTKIEWICZ 2003). The results of own research (TAŃSKA et al. 2013a,b) showed that good pressing efficiency and a relatively good quality of oil was obtained when seeds were heated at 60°C and 80°C. A similar range of temperatures is used in domestic agricultural biorefineries. These conclusions provide a basis conducting further research under industrial conditions of Kocibórz Biorefinery (UWM in Olsztyn).

Material and Methods

The research material included seeds of winter oilseed rape, white mustard, flax and camelina and oils pressed from those seeds. Samples of seeds harvested in 2011 were obtained from the Plant Production and Experimental

Station in Bałcyny. Samples were characterized in terms of moisture content (*Oznaczenie zawartości wody*... PN-62/R-66163), fat content (*Nasiona oleiste*... PN-EN ISO 659:2009) and content of impurities (*Rośliny przemysłowe oleiste*... PN-91/R66160) – Table 1.

Table 1

Characterization of the experimental material

Discriminants	Rapeseed	Mustard	Flax	Camelina
Moisture [%]	$7.20^{a} \pm 0.45$	$8.51^{c} \pm 0.68$	$8.20^{b} \pm 0.42$	$7.40^{a} \pm 0.21$
Content of fat [% d.wt]	$47.52^{d} \pm 0.58$	$31.72^{a} \pm 1.45$	$39.15^{c} \pm 0.98$	$36.72^{b} \pm 1.23$
Total content of impurities [%]	$4.28^{b} \pm 0.51$	$4.48^{b} \pm 0.32$	$10.92^{c} \pm 0.59$	$1.12^{a} \pm 0.32$
– useful impurities [%]	$2.99^{c} \pm 0.21$	$2.39^{b} \pm 0.12$	$2.40^{b} \pm 0.14$	$0.00^{a} \pm 0.00$
– useless impurities [%]	$1.29^{a} \pm 0.21$	$1.09^{a} \pm 0.01$	$8.52^{b} \pm 0.52$	$1.12^{a} \pm 0.31$
The presence of mites [number of pieces · kg of seeds^{-1}]				
– live	trace	trace	trace	trace
– dead	trace	trace	trace	trace

Explanation: *a, b*... – mean values in lines marked with the same letter are not significantly different ($p \leq 0.05$)

Oil pressing under industrial processing conditions in Kocibórz Biorefinery (UWM in Olsztyn) was preceded by heat treatment of seeds in a conditioner, at 60°C, 70°C and 80°C. Pressing was carried out in a ET 996 expeller with a capacity of about 3500–4000 kg/24h (with conditioning) and about 1.800 kg/24h with cold pressing.

Pressing efficiency [%] was calculated as the relative relation to the oil content in the oil cake and seeds, according to the following formula:

$$\frac{A - B \cdot 100}{A}$$

where:
A – fat content in seeds [%] determined by the Soxhlet method;
B – fat content in the cake [%] determined by the Soxhlet method.

The quality of oils was evaluated by assaying: the water and volatile compounds content (*Oleje i tłuszcze*... PN-EN ISO 662:2001), acid value (*Oleje i tłuszcze*... PN-ISO 660:1998), peroxide value (*Oleje i tłuszcze*... PN-ISO 3960:2005), anisidine value (*Tłuszcze roślinne jadalne*... PN-93/A-86926), content of chlorophyll pigments (BEUTNER i in. 2001), the content of carotenoid pigments (FRANKE et al. 2010), phosphorus content (*Tłuszcze roślinne*

jadalne... PN-88/A-86930) and the fatty acids composition. The fatty acids composition was estimated acc. PN-EN-ISO-5508:1996 (*Analiza estrów*... PN-EN-ISO-5508:1996), preparing methyl esters by the method described by ZADERNOWSKI and SOSULSKI (1978). The separation of methyl esters were carried out applying GC 8000 series FISONS Instrument Gas Chromatograph equipped with a flame-ionization detector using a column type DB-225 (30 m x 0.25 mm x 0.15 μm) and helium as a carrier gas. Fatty acids were identified according to retention time determined for fatty acid standards.

Statistical Analysis

For each sample the arithmetic mean and standard deviation were determined. Obtained results of researches were statistically analyzed using the Statictica 9.0 PL (StatSoft Poland) program. In order to indicate significance of differences between seeds and oils analysis of variance (ANOVA) with Tukey's test of $p \leq 0.05$ significance level was used.

Results and Discussion

Heat treatment of seeds before pressing had an effect on the effectiveness and quality of oils. The highest efficiency was obtained when oil was pressed from seeds of various species heated at 80°C. For rapeseed oil, the pressing efficiency amounted to 74%, for mustard – 57%, while flax and camelina revealed a similar level of about 67%. The lowest and the similar pressing efficiency, 62–64%, was obtained at 60°C for rapeseed, flax and camelina seeds. For mustard seeds, oil pressing efficiency was only 52% (Table 2).

It was also found that the growth rate of pressing efficiency was differentiated for seeds of individual species, which was closely related to the oil content of these raw materials. Seeds with a higher fat content (rapeseed), heated at 80°C, were characterized by the highest pressing efficiency (Table 2). An increase in the temperature from 60°C to 80°C improved the pressing efficiency for seeds with the highest oil content (rapeseed) by 11 percentage points and the lowest oil content (mustard) by 5 percentage points. On the other hand, in the case of seeds of medium oil content, namely flax and camelina, a growth in pressing temperature increased oil efficiency by only 4 and 2 percentage points, respectively (Table 2).

Oil quality was closely related to the species and parameters of seed heating (Table 3, Table 4). The results of research demonstrated that the content of water and volatile substances in oils pressed at various temperatures ranged

Table 2

Efficiency of pressing and fat content in seeds and pressed pulp

Samples	Efficiency of pressing [%]	Fat content [%]
Rapeseed	–	47.52 ± 0.85
preseed pulp 60°C	63^{a} ± 0.57	17.36^{c} ± 0.82
preseed pulp 70°C	70^{b} ± 0.46	14.39^{b} ± 0.57
preseed pulp 80°C	74^{c} ± 0.54	12.42^{a} ± 0.76
Mustard	–	31.72 ± 0.66
preseed pulp 60°C	52^{a} ± 0.58	15.14^{c} ± 0.72
preseed pulp 70°C	55^{b} ± 0.00	14.20^{b} ± 0.60
preseed pulp 80°C	$57^{b,c}$ ± 0.65	13.73^{a} ± 0.61
Flax	–	39.15 ± 0.52
preseed pulp 60°C	64^{a} ± 0.85	14.21^{c} ± 0.30
preseed pulp 70°C	65^{b} ± 0.45	13.64^{b} ± 0.33
preseed pulp 80°C	68^{c} ± 0.32	12.66^{a} ± 0.30
Camelina	–	36.72 ± 0.37
preseed pulp 60°C	62^{a} ± 0.85	14.06^{b} ± 0.37
preseed pulp 70°C	62^{a} ± 0.54	14.02^{b} ± 0.23
preseed pulp 80°C	$64^{a,b}$ ± 0.57	13.11^{a} ± 0.25

Explanation as in Table 1

from 0.07 for a sample obtained from rapeseeds heated at 60°C to 0.25% for a sample of flax seeds heated at 70°C. According to BUCZEK and CZEPIRSKI (2004), as well as KOTOWSKI (2004), the threshold content of those compounds should not exceed 0.50% (Table 3). An excessive water content in oil intended for biodiesel production contributes to an undesired reaction of triacylglycerol hydrolysis, resulting in the formation of significant amounts of free fatty acids, and consequently soaps after adding an alkaline catalyst (MATHIYAZHAGAN and GANAPATHI 2011).

It was found that the chlorophyll pigment content depended on species and seed treatment temperature (Table 3). It was proven that oils pressed from seeds conditioned at the highest temperature were characterized by the highest content of chlorophyll pigments, while those heated at 60°C and 70°C contained a comparable content of those compounds (Table 3).

Generally, it was found that oils pressed from mustard seeds were characterized by the highest content of chlorophyll pigments (from 17.22 $mg \cdot kg^{-1}$ in the case of oil obtained from seeds heated at 60°C, to 26.12 $mg \cdot kg^{-1}$ for oil of seeds heated at 80°C). Rapeseed oil samples had a similar content of chlorophyll pigments, between 16.80 $mg \cdot kg^{-1}$ and 25.40 $mg \cdot kg^{-1}$. The lowest content of chlorophyll pigments was found in flax oil samples: from 5.16 $mg \cdot kg^{-1}$ (sample from seeds heated at 60°C) to 11.50 $mg \cdot kg^{-1}$ (sample from seeds heated at 70°C) – Table 3.

Table 3

Characteristics of oils obtained from seeds heated at different temperatures

Discriminants	Rapeseed			Mustard			Flax			Camelina		
	temperature of heating											
	60°C	70°C	80°C	60°C	70°C	80°C	60°C	70°C	80°C	60°C	70°C	80°C
The water and volatile compounds content [%]	0.07^a ± 0.07	0.15^c ± 0.12	0.13^b ± 0.15	0.20^b ± 0.21	0.12^a ± 0.20	0.24^c ± 0.00	0.24^b ± 0.24	0.25^b ± 0.20	0.20^a ± 0.25	0.21^a ± 0.21	0.22^a ± 0.22	0.23^a ± 0.23
The content of chlorophyll pigments [mg · kg^{-1}]	16.80^a ± 0.12	19.42^b ± 0.12	25.40^c ± 0.00	17.22^a ± 0.00	17.85^b ± 0.07	26.12^c ± 0.00	5.16^a ± 0.00	6.18^b ± 0.00	11.50^c ± 0.37	10.12^a ± 0.24	10.89^a ± 0.12	16.33^b ± 0.12
The content of carotenoid pigments [mg · kg^{-1}]	11.7^b ± 0.11	10.6^a ± 0.04	10.3^a ± 0.00	10.4^b ± 0.01	9.0^a ± 0.08	10.6^c ± 0.01	18.0^a ± 0.08	17.9^a ± 0.04	25.7^b ± 0.28	21.6^a ± 0.08	25.9^b ± 0.06	31.7^c ± 0.00
Phosphorus content [mg · kg^{-1}]	4.22^b ± 0.14	3.64^a ± 0.18	5.56^c ± 0.33	1.13^a ± 0.19	2.33^b ± 0.15	10.12^c ± 0.14	11.92^a ± 0.48	25.27^b ± 0.67	26.18^b ± 0.62	4.75^a ± 0.42	$7.15b$ ± 0.28	25.55^c ± 0.82

Explanation as in Table 1

The content of carotenoid pigments in rapeseed and mustard oils was about two times lower than in flax and camelina oils, and it did not show any clear relation to the temperature of seed treatment (Table 3). On the other hand, in the case of oils obtained from flax and camelina, it was found that the higher the temperature of seed treatment, the higher was the content of these pigments (Table 3). The total growth in the content of carotenoids in flax and camelina oils, calculated on the basis of a difference between the content of carotenoid pigments in oils pressed at 60°C and 80°C, amounted to 7.7 mg · kg^{-1} for flax, and 10.1 mg · kg^{-1} for camelina.

Pigments of vegetable oils, including carotenoid and chlorophyll pigments, demonstrate pro-oxidant or antioxidant activity (ROTKIEWICZ et al. 2002, STROBEL et al. 2005). BEUTNER et al. (2001) found that the activity of carotenoids consisted in deactivation, i.e. chemical and physical "quenching" of singlet oxygen. It is also claimed that carotenoids can delay the process of lipid autoxidation, among others, by scavenging free radicals. In turn, chlorophyll pigments (chlorophyll a and b and their derivatives) are pro-oxidative compounds, which in the presence of light initiate reactions consisting in the generation of highly reactive singlet oxygen from triplet oxygen, strengthening autoxidation of lipids (RAWLS and VAN SANTEN 1970, MIŃKOWSKI 2008).

The phosphorus content in oil, like the pigment content, depended both on the species and the temperature of seed treatment (Table 3). Generally, it was found that flax and camelina were characterised by a significantly higher content of phosphorus than rapeseed and mustard oils. Generally, a significant growth in the phosphorus content was observed in oils pressed from seeds heated in increasing temperatures. Although the growth in the phosphorus content in flax, camelina and mustard oils was of a linear nature, for rapeseed oils a significantly higher content of this compound was found in a sample obtained from seeds heated only at 80°C. Rapeseed oils heated at 60°C and 70°C revealed comparable phosphorus content. The highest content of phosphorus in oils obtained in the research, amounting to 25.55–26.18 mg · kg^{-1} (sample of camelina and flax oil from seeds heated at 80°C) does not exceed the internationally recognised threshold value of 50 mg · kg^{-1} for oil intended for biodiesel production (WALISIEWICZ-NIEDBALSKA 2004).

Phosphorus compounds in oils include mainly phospholipids which impede the transesterification process. It is believed that their presence reduces the activity of catalysts, inhibits the rate of reaction and makes it difficult to separate the ester phase from the glycerine (PODKÓWKA 2004, VAN GERPEN 2005).

The degree of oil hydrolysis (determined by acid value) depended on the species and the seed heating temperature. Oils obtained from flax seeds were characterised by the highest and significantly varied acid values

(11.45–14.49 mg KOH · g^{-1}). Oils produced from rapeseed and mustard seeds were characterised by the lowest, comparable values (1.79–2.13 mg KOH · g^{-1}) (Table 4). An increase in the temperature of seed treatment before pressing affected the growth of the acid value for all oils, although this value was significant only in the case of flax and camelina oils. Differences in the acid value of oils obtained from seeds heated at extreme temperatures (60–80°C) amounted to only 0.21 mg KOH · g^{-1} and 0.25 mg KOH · g^{-1} for rapeseed and mustard oil and 3.04 mg KOH · g^{-1} and 3.15 mg KOH · g^{-1} for flax and camelina (Table 4).

The acid value of oils intended for transesterification with the use of alkaline catalyst should not be too high. Literature sources provide different values; from ≤ 1 mg KOH · g^{-1} (WALISIEWICZ-NIEDBALSKA 2004) to 6 mg KOH · g^{-1} (BUCZEK and CZEPIRSKI 2004, KOTOWSKI 2004, RAMADHAS et al. 2005, RADZIEMSKA et al. 2009). In the case of transesterification with the use of acid catalyst, higher values of this indicator are acceptable ≤ 10 mg KOH · g^{-1} (BUCZEK and CZEPIRSKI 2004).

An increased content of free fatty acids in oils intended for basic transesterification is undesirable since this contributes to a saponification reaction, and consequently, an increase in viscosity, gel and foam formation, which hinders the course of the process, as well as the separation of phases (MA and HANNA 1999, ZHANG et al. 2003, MATHIYAZHAGAN and GANAPATHI 2011). As WALISIEWICZ-NIEDBALSKA et al. (2005) also reported, the saponification reaction of FFA involves the release of reaction water, which hydrolyses fat and creates another portion of free fatty acids. During acid catalysis, on the other hand, FFA reacts with alcohol, forming esters and also, unfortunately, water, which impedes the transesterification of glycerides (CANAKCI 2007).

The peroxide value, determining the content of primary oxidation products, ranged from 0.46 mEq O_2 · kg^{-1} (flax oil obtained from seeds heated at 60°C) to 1.38 mEq O_2 · kg^{-1} (flax oil obtained from seeds heated at 80°C) (Table 4). Seed treatment resulted in a significant, although small, growth in the content of peroxides in oils from all species (Table 4).

The content of secondary oxidation products, as determined by the anisidine value, did not reveal any clear relation, either to a species of seeds or the temperature of seed treatment. Generally, the values of this determinant were low and did not exceed the following levels: for rapeseed oil obtained from seeds heated at 80°C – 0.85, for mustard oil from seeds heated at 60°C – 2.67, for flax oil from seeds heated at 70°C – 2.57 and for camelina oil from seeds obtained at 60°C – 1.31 (Table 4).

The low peroxide and anisidine values observed in the study indicate a low level of oil oxidation, which indicates the good quality of seeds. Although those factors are not mentioned in the quality assessment of oils intended for

Table 4

Characteristics of oils obtained from seeds heated at different temperatures

Discriminants	Rapeseed			Mustard			Flax			Camelina		
	temperature of heating											
	60°C	70°C	80°C	60°C	70°C	80°C	60°C	70°C	80°C	60°C	70°C	80°C
Acid value [mg KOH · g^{-1}]	1.92^a ± 0.05	2.06^b ± 0.04	2.13^c ± 0.03	1.79^a ± 0.08	1.95^b ± 0.07	2.04^c ± 0.02	11.45^a ± 0.00	13.21^b ± 0.01	14.49^c ± 0.06	3.02^a ± 0.08	2.95^c ± 0.07	6.17^b ± 0.05
Peroxide value [mEq O_2 · kg^{-1}]	0.89^a ± 0.01	0.96^b ± 0.02	1.07^c ± 0.01	0.62^a ± 0.06	0.77^b ± 0.03	0.99^c ± 0.03	0.46^a ± 0.05	0.55^b ± 0.00	1.38^c ± 0.01	1.07^a ± 0.02	1.23^b ± 0.07	1.08^a ± 0.01
Anisidine value [–]	0.56^a ± 0.01	0.73^b ± 0.02	0.85^c ± 0.04	2.67^b ± 0.09	2.00^a ± 0.06	2.60^b ± 0.01	1.40^a ± 0.09	2.57^c ± 0.09	2.05^b ± 0.09	1.31^c ± 0.05	1.06^b ± 0.03	0.88^a ± 0.09

Explantation as in Table 1

Table 5

Fatty acids composition [%]

Fatty acids	Rapeseed		Mustard		Flax		Camelina	
	temperature of heating							
	60°C	80°C	60°C	80°C	60°C	80°C	60°C	80°C
Palmitic	$4.97^{b} \pm 0.02$	$4.80^{a} \pm 0.04$	$3.85^{a} \pm 0.67$	$3.81^{a} \pm 0.43$	$6.08^{a} \pm 0.23$	$6.06^{a} \pm 0.21$	$5.38^{a} \pm 0.21$	$5.52^{b} \pm 0.33$
Palmitoleic	$0.24^{a} \pm 0.01$	$0.22^{a} \pm 0.00$	$0.19^{a} \pm 0.02$	$0.18^{a} \pm 0.00$	< 0.10	< 0.10	$0.11^{a} \pm 0.00$	$0.10^{a} \pm 0.02$
Stearic	$1.31^{a} \pm 0.02$	$1.30^{a} \pm 0.04$	$2.01^{a} \pm 0.12$	$2.09^{b} \pm 0.11$	$4.46^{a} \pm 0.36$	$4.42^{a} \pm 0.43$	$2.33^{a} \pm 0.25$	$2.27^{a} \pm 0.25$
Oleic	$62.32^{a} \pm 1.23$	$62.52^{a} \pm 0.89$	$63.38^{a} \pm 0.98$	$64.30^{b} \pm 0.77$	$23.57^{b} \pm 0.54$	$23.39^{a} \pm 0{,}21$	$15.77^{b} \pm 0.76$	$15.62^{a} \pm 0.69$
Linoleic	$20.26^{a} \pm 0.78$	$20.34^{a} \pm 0.65$	$9.85^{b} \pm 0.67$	$9.46^{a} \pm 0.98$	$14.65^{a} \pm 0.54$	$14.94^{b} \pm 0.32$	$16.51^{a} \pm 0.11$	$16.67^{b} \pm 0.24$
Linolenic	$\mathbf{9.51}^{a} \pm 0.45$	$\mathbf{9.40}^{a} \pm 0.23$	$\mathbf{14.74}^{b} \pm 1.05$	$\mathbf{14.28}^{a} \pm 0.78$	$\mathbf{51.24}^{a} \pm 0.65$	$\mathbf{51.19}^{a} \pm 0.76$	$\mathbf{37.32}^{a} \pm 0.87$	$\mathbf{37.44}^{a} \pm 0.99$
Arachidic	$0.45^{a} \pm 0.00$	$0.43^{a} \pm 0.05$	$0.59^{b} \pm 0.03$	$0.46^{a} \pm 0.01$	< 0.10	< 0.10	$1.33^{a} \pm 0.06$	$1.37^{a} \pm 0.08$
Eicosenoic	$0.94^{a} \pm 0.08$	$0.99^{a} \pm 0.04$	$2.58^{a} \pm 0.00$	$2.58^{a} \pm 0.04$	< 0.10	< 0.10	$15.32^{a} \pm 0.65$	$15.36^{a} \pm 0.76$
Eicosadienoic	$0.00^{a} \pm 0.00$	$0.00^{a} \pm 0.00$	$0.00^{a} \pm 0.00$	$0.00^{a} \pm 0.00$	$0.00^{a} \pm 0.00$	$0.00^{a} \pm 0.00$	$2.16^{a} \pm 0.04$	$2.04^{a} \pm 0.03$
Homo-γ-linolenic	$0.00^{a} \pm 0.00$	$0.00^{a} \pm 0.00$	$0.00^{a} \pm 0.00$	$0.00^{a} \pm 0.00$	$0.00^{a} \pm 0.00$	$0.00^{a} \pm 0.00$	$1.74^{a} \pm 0.08$	$1.64^{a} \pm 0.07$
Behenic	< 0.10	< 0.10	$2.81^{a} \pm 0.03$	$2.84^{a} \pm 0.01$	< 0.10	< 0.10	$0.26^{a} \pm 0.04$	$0.23^{a} \pm 0.00$
Erucic	< 0.10	< 0.10	$0.00^{a} \pm 0.00$	$0.00^{a} \pm 0.00$	$0.00^{a} \pm 0.00$	$0.00^{a} \pm 0.00$	$1.77^{a} \pm 0.02$	$1.74^{a} \pm 0.04$

Explanation as in Table 1

biodiesel production, they are still important indicators of the degree of oxidative changes affecting durability.

The composition of fatty acids in all samples under examination was typical for oils obtained from seeds of those species. It was found that seed treatment at 80°C did not result in any significant changes in the share of individual fatty acids (Table 5).

According to PN-EN 14214:2012, one of the main characteristics that qualify oil for biodiesel production is the percentage of linolenic acid, which should not exceed 12% (PN-EN 14214:2012). Among the examined oils, this requirement was satisfied only by rapeseed oil (from 9.40% oil of seeds heated at 80°C to 9.51% oil from seeds heated at 60°C).

The share of linolenic acid in mustard, flax and camelina oil exceeded the threshold value by 2.5, 39.2 and 25.3 percentage points, respectively. These oils should not be used as raw materials for biodiesel production on their own, but they should be used in mixes with fats characterised by a low share of linolenic acids, e.g. palm oil or animal fats.

Summary

The results of the research performed made it possible to claim that the optimum temperature of heating rape and mustard seeds in the Kocibórz Biorefinery was 80°C, and for flax and camelina it was 60°C. The oils extracted from seeds conditioned at the above specified temperatures were characterised by good pressing efficiency and good quality, understood as a low content of non-triacylglycerol compounds hindering transesterification and reducing the durability of esters.

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