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Nutritional quality and phytochemical contents of cold pressed oil obtained from chia, milk thistle, nigella, and white and black poppy seeds

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SUMMARY: Cold pressed oils obtained from chia (*Salvia hispanica* L.), milk thistle (*Silybum marianum* L.), nigella (*Nigella sativa* L.), and white and black varieties of poppy (*Papaver somniferum* L.) seeds were characterized. The nutritional quality was determined based on the analysis of fatty acids, tocochromanol and phytosterol contents, as well as antioxidant activity and general physico-chemical properties. Among the oils analyzed the fatty acid composition most beneficial for health was found in chia seed oil, with 65.62% of α-linolenic acid and the n-6:n-3 fatty acid ratio of 1:3.5. Other oils studied were rich sources of linoleic acid (18.35-74.70%). Chia seed oil was also distinguished by high contents of phytosterols, mainly β-sitosterol (2160.17 mg/kg oil). The highest content of tocochromanols was found in milk thistle oil with dominant α-tocopherol (530.2 mg/kg oil). In contrast, the highest antioxidant activity was recorded for nigella oil (10.23 μM Trolox/g), which indicated that, in addition to tocopherols, other antioxidants influenced its antioxidant potential.

***KEYWORDS*:** *Chia; Cold-pressed oil; Milk thistle; Nigella; Nutritional quality; Phytosterols; Poppy; Tocopherols*

RESUMEN: ***Calidad nutricional y contenido fitoquímico de aceites prensados en frío de semillas de chía, cardo mariano, nigella, y amapola blanca y negra.*** Se caracterizaron aceites prensados en frío obtenidos de semillas de chía (*Salvia hispanica* L.), cardo mariano (*Silybum marianum* L.), nigella (*Nigella sativa* L.) y de variedades blancas y negras de amapola (*Papaver somniferum* L.). La calidad nutricional se determinó en base al análisis de ácidos grasos, el contenido de tococromanoles y fitosteroles, así como la actividad antioxidante y las propiedades fisicoquímicas generales. Entre los aceites analizados, la composición de ácidos grasos más beneficiosa para la salud se encontró en el aceite de semilla de chía, con un 65,62% de ácido α-linolénico y una relación de ácido graso n-6:n-3 de 1:3,5. Los demás aceites estudiados fueron ricos en ácido linoleico (18,35-74,70%). El aceite de semilla de chía también se distinguió por el alto contenido de fitosteroles, principalmente β-sitosterol (2160,17 mg/kg de aceite). El mayor contenido de tococromanoles se encontró en el aceite de cardo mariano con α-tocoferol dominante (530,2 mg/kg de aceite). Por el contrario, se registró la mayor actividad antioxidante para el aceite de nigella (10,23 μM Trolox/g), lo que indica que, además del tocoferol, otros antioxidantes influyeron en su potencial antioxidante.

PALABRAS CLAVE: *Aceite prensado en frío; Amapola; Calidad nutricional; Cardo mariano; Chia; Fitosteroles; Nigella; Tocoferoles*

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1. INTRODUCTION

Increased consumer awareness concerning healthy nutrition is related to the development of science as well as the interpretation of science for the general audience, which have been popularized in magazines, television programs and on the Internet. In addition to sensory properties, consumers expect food to positively affect their health, well-being and quality of life (Obiedzińska and Waszkiewicz-Robak, 2012). More and more often they choose minimally processed food without synthetic additives. Cold pressed vegetable oils are becoming increasingly popular (Makała 2015). The manufacturing of those products is simple, it does not require the use of chemicals or high temperature, and are therefore considered high-quality products (Wroniak and Łukasik, 2007). Cold pressed oils contain a wide range of bioactive compounds such as essential fatty acids, vitamins, glycolipids, carotenoids, phospholipids and sterols. In cold pressed oils the refining process is not carried out, which means that they also contain prooxidant substances, such as heavy metals and chlorophylls. (Skwarek and Dolatowski, 2012). Amphiphilic compounds present in cold pressed oils may also influence autoxidation processes by forming association colloids (Kittipongpittaya *et al*., 2014).

In addition to oils obtained from popular raw materials such as rapeseed or sunflower seeds, innovative vegetable oils play an increasingly important role due to their high nutritional value and have a positive effect on human health (Parry *et al*., 2006). Chia seed oil was used in ancient times to treat stomach disorders and eye infections. It contains high concentrations of polyunsaturated fatty acids, especially α-linolenic acid and other compounds with health benefits such as phytosterols and tocopherols (de Falco *et al*., 2017). Nigella (*Nigella sativa* L., also known as black cumin) is another rarely used raw material, known for thousands of years as a preservative and seasoning. Due to its content of biologically active substances, it has anti-inflammatory, anticancer, antibacterial, antidiabetic and analgesic properties. Most of these properties are due to the presence of thymoquinone (2-methyl-5-isopropyl-1,4-benzoquinone) (Abedi *et al*., 2017). In addition, this oil also contains many valuable fatty acids, mainly linoleic, which further increase their nutritional value (Solati *et al*., 2014). Another raw material, milk thistle, is classified as a medicinal plant. Its complex of flavonolignans (silymarin, silybin, silychristin and silidianin) is used to treat liver diseases (Abenavoli *et al*., 2010). Due to its antioxidant properties, the beneficial composition of fatty acids and high protein content, this plant is also increasingly used (Meddeb *et al*., 2017; Wierzbowska *et al*., 2013). Poppy is another plant providing innovative vegetable oil. This plant is a rich source of polyunsaturated fatty acids, especially linoleic acid. Thanks to this it may become an excellent alternative to traditional vegetable oils (Rahimi *et al*., 2015).

The popularity of cold pressed oils from various unconventional raw materials is constantly increasing. Due to the high nutritional value of the raw materials described, attempts have been made to use them in the production of cold pressed oils. The Absence of quality standards concerning such products results in the need for research aimed at characterizing the final product. The aim of the present research was to determine the physicochemical parameters of cold pressed oils: chia, milk thistle, black cumin and poppy seeds, as well as to specify the nutritional value, mainly on the basis of fatty acid composition. The contents of bioactive compounds and antioxidant activity were also determined. The results may be used to compare the nutritional value of oils obtained from these raw materials. They may also indicate their potential use in the food industry, taking into account the physicochemical parameters and antioxidant capacity of these oils.

2. MATERIALS AND METHODS

2.1. Materials

The seeds of five plants were selected for analyses: chia (*Salvia hispanica* L.) from Argentina, milk thistle (*Silybum marianum* L.) from Poland, nigella (*Nigella sativa* L.) from India, white and black poppy seeds (*Papaver somniferum* L.) from the Czech Republic. Plant seeds which were free from disease were purchased in retail (Poznań, Poland). A Farmet Uno expeller press (Farmet, Czech Republic) was used to obtain the oil from seeds (Siger *et al*., 2015).

2.2. Physical characteristics of cold pressed oils

The physical characteristics of the cold pressed oils included measurements of the refractive index (at 40 °C), density (at 20 °C) and the spectrophotometric properties of the oils dissolved in hexane (0.1, 1, 10%, v/vat 200–290, 290–400 and 400–800 nm, respectively) (Siger *et al*., 2017).

2.3. Chemical and quality parameters of oil

- Peroxide value (PV) was determined according to ISO 3960:2001 standard methods.
- Acid value (AV) was determined according to ISO 660:1996 standard methods.
- *P*-anisidine value was determined according to ISO 6885:2007 standard methods.
- Iodine value was determined according to ISO 3961:2018 standard methods.
- The Karl Fischer method (ISO 8534:2017) was used to determine the water content in the oils.

- GC-FID was used to determined the fatty acid composition. Fatty acid methyl esters were prepared following the AOCS Official Method Ce 1h-05 (AOCS Official Method, 2017).
- Pigments (total chlorophyll and β-carotene) were determined by the spectrophotometric method according to the AOCS method Cc13i-96 (AOCS Official Method, 2017) and Siger *et al.*, (2017)
- Vitamin E compounds (tocopherols and tocotrienols) were determined by normal-phase liquid chromatography. Oil samples were prepared and assayed according to Siger *et al.*, (2017). The vitamin E equivalent was determined by multiplying the amount (milligrams) of α-T by 1.0, ß-T by 0.5, γ-T by 0.1, α-T3 by 0.3 (Eitenmiller and Lee, 2004)
- Phytosterol contents and composition were determined by GC, following the procedure described by the AOCS Official Method Ch 6–91 (AOCS Official Method, 1994)
- the DPPH• radical-scavenging activity of the oil samples was measured according to Górnaś *et al.*, (2014). Antioxidant activity was expressed as the Trolox equivalent and the antiradical power (ARP) was determined (Siger *et al.*, 2008)

2.4. Nutritional quality index

The nutritional quality index was evaluated based on the fatty acid composition of the oils. The atherogenic index (AI), thrombogenic index (TI) and hypocholesterolemic: hypercholesterolemic ratio (HH) were calculated according to Guimarães *et al.*, (2013).

2.5. Statistical analysis

All analyses were performed in triplicate. The Statistica 13.0 software (StatSoft, Inc., Tulsa, OK) was used for statistical analyses. Analysis of variance (ANOVA) was applied and the post-hoc analysis was performed using Tukey's test. All tests were considered significant at $p < 0.05$.

3. RESULTS AND DISCUSSION

The cold pressed oils were subjected to a series of physicochemical analyses (Table 1). All the oils obtained were yellow in color and were in the liquid state at 4 °C. Color may have been influenced by the presence of carotenoids, as confirmed by the spectrum analysis (Figure 1). In all oil samples the absorption band in the UV-Vis spectrum was characteristic of carotenoids (in the wavelength range of approx. 350-500 nm). The refractive index for all oils measured was in the range of 1.4720-1.4825 at 20 °C. There were no significant differences in oil density. This value was about 0.92 g/ml at 20 °C. The water content in individual oils was significantly different. The highest water content (831 ppm) was detected in black poppy oil; while the lowest (358 ppm) was found in nigella oil. Water is usually present in cold pressed oils in larger quantities compared to refined oils, where its concentration was around 300 ppm (Siger *et al.*, 2017). The presence of water plays an important role in the formation of association colloids and autooxidation processes. The contents of chlorophyll and carotenoid pigments are important, not only because they affect the color of the oil, but also due to their technological and nutritional functions, in particular their anti- and pro-oxidant

Table 1. Physical and chemical properties of cold pressed oils obtained from chia, milk thistle, nigella, and white and black poppy seeds

	Oils				
Component	**chia**	**milk thistle**	**nigella**	**white poppy**	**black poppy**
Colour	Yellow	Yellow	Yellow	Yellow	Yellow
Physical state at 4 °C	Liquid	Liquid	Liquid	Liquid	Liquid
Index of refraction at 20°C	1.4825	1.4720	1.4735	1.4750	1.4745
Density at 20 °C (g/ml)	0.929	0.916	0.920	0.921	0.919
Water (ppm)	437 ± 15^{b}	779 ± 22^{d}	358 ± 41^{a}	583 ± 32^{c}	831 ± 29^{e}
β-Carotene (mg/kg)	2.88 ± 0.14^{b}	3.45 ± 0.36^{c}	8.37 ± 0.24^{d}	1.35 ± 0.22^{a}	1.37 ± 0.19^{a}
Chlorophyll (mg/kg)	nd	4.82 ± 0.13^{a}	6.69 ± 0.21^{b}	nd	nd
Iodine value (g/100 g)	218.41 ± 0.24^{d}	119.30 ± 0.12^{a}	128.04 ± 0.32^{b}	148.80 ± 0.11^{c}	145.16 ± 0.51^{c}
Peroxide value (meq O_2/kg)	0.10 ± 0.18^{a}	1.17 ± 0.12^{c}	65.4 ± 0.20^{d}	0.30 ± 0.18^{a}	0.78 ± 0.15^{b}
Acid value (mg KOH/g)	0.68 ± 0.16^{a}	2.15 ± 0.11^{c}	1.99 ± 0.07^{c}	1.03 ± 0.05^{b}	3.05 ± 0.16^{c}
p-Anisidine value	0.421 ± 0.022^{b}	0.091 ± 0.002^{a}	3.591 ± 0.032^{d}	0.561 ± 0.012^{c}	0.581 ± 0.012^{c}

nd – not detected.
* Values (means ± SD; n = 3) bearing different superscripts are statistically significantly different ($P < 0.05$). ANOVA with Tukey's test was applied.

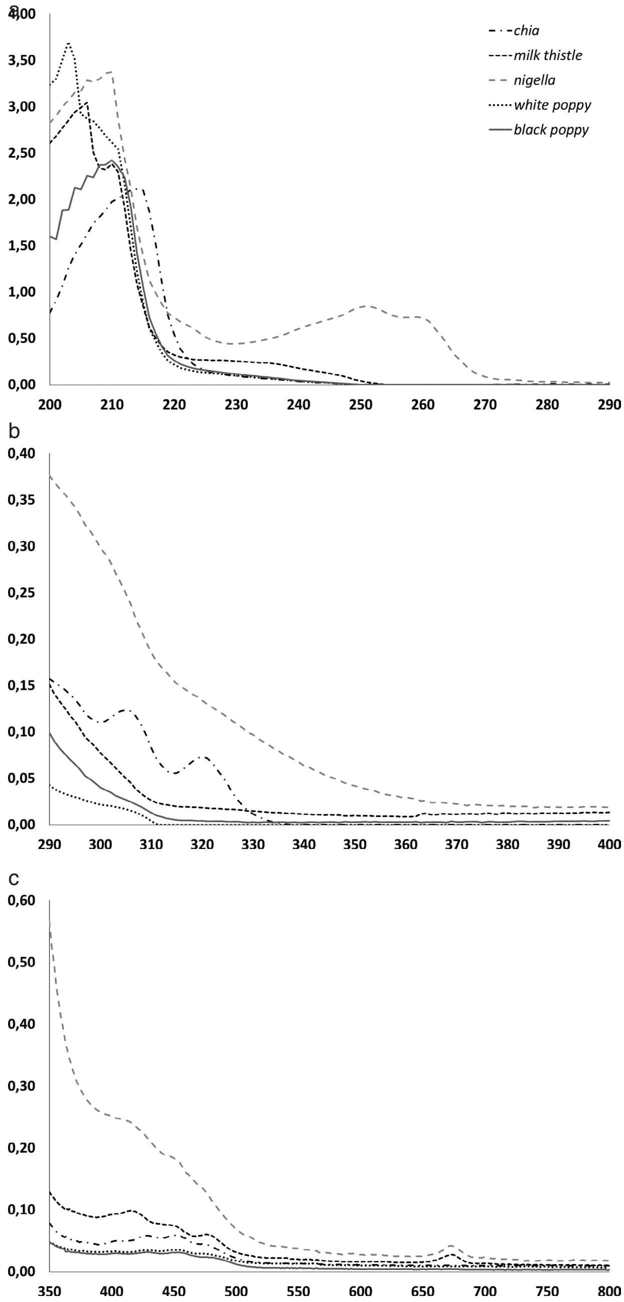

FIGURE 1. UV spectra of cold pressed oils obtained from chia, milk thistle, nigella, and white and black poppy seeds diluted in n-hexane (0 1, 1, 10%, v/v) measured at $l_{200–290}$, $l_{290–400}$, $l_{400–800\ nm}$; respectively.

activities. Chlorophyll pigments largely affect the increased rate of fatty acid oxidation, because they act as photosensitizers (Wroniak *et al.*, 2006). The highest contents of β-carotene (8.37 mg/kg) and chlorophyll (6.69 mg/kg) were detected in nigella oil. This was also confirmed by the analysis of the UV-Vis absorption spectra of the investigated oils (Figure 1). In the case of nigella oil, the absorption band at a wavelength of 400-500 nm was characteristic of carotenoids and a wavelength of 675 nm, typical of chlorophyll, clearly exceeded the bands observed in other oils. The lowest contents of β-carotene were detected in white and black poppy (1.35 mg/kg and 1.37 mg/kg respectively, Table 1). Apart from nigella, chlorophyll was found only in milk thistle (4.82 mg/kg).

Another parameter that determines the nutritional value of oil is the iodine value. It reflects the content of unsaturated bonds in one gram of oil (Kyriakidis and Katsiloulis, 2000). By far the highest iodine value (218.41 g/100 g oil) was recorded for chia oil. Gas chromatography (GC) analyses of the fatty acid composition (Table 2) confirm the highest contents of unsaturated fatty acids, mainly α-linolenic acid, in chia oil. On the contrary, the lowest iodine value was determined in milk thistle oil (119.30 g/100 g oil). In the case of nigella this value amounted to 128.04 g/100 g oil; while it was very similar for both types of poppy seed oil (148.80 g/100 g and 145.16 g/100 g for white and black poppy seeds, respectively; Table 1). The susceptibility of oil to oxidation processes grows with increasing contents of unsaturated fatty acids (Yun and Surh, 2012).

The peroxide value and the anisidine value are important parameters for determining the oxidation quality of oil. In all the oils tested, except for nigella oil (*Nigella sativa* L.), the peroxide value was very low and did not exceed 1.17 meq O_2/kg. It was much lower than the standard recommended for cold pressed oils by Codex Alimentarius (15 meq O_2/kg) (CODEX-STAN: 210-1999). Similarly, for the same oils low anisidine values were recorded (in the range 0.09 to 0.58, with the exception of nigella oil), which confirmed the good oxidative quality of the cold pressed oils obtained.

Nigella oil was an exception in the group of oils tested, because it was characterized by very high peroxide and anisidine values (65.4 meq O_2/kg and 3.59, respectively; Table 1). A relatively high peroxide value of solvent extracted nigella seed oil amounting to 11.4 meq O_2/kg was reported by Gharby *et al.*, (2015). According to those authors such a peroxide value results either from extraction-associated oxidative processes or from insufficient oxidation protection immediately after extraction. However, no such phenomenon was observed in the case of the cold pressed oil. A more likely explanation for the high oxidative quality parameters of nigella oil may be the presence of large amounts of thymoquinone. Mohammed *et al.*, (2016) reported that this compound is one of the primary constituents in *Nigella sativa* cold pressed oil (NSO) and its content is 1.78 mg/ml. Thymoquinone belongs to quinone compounds and as an electron acceptor possesses oxidizing properties. Therefore, it may act as an interfering substance during peroxide value

Table 2. Fatty acid composition and nutritional quality index of cold pressed oils obtained from chia, milk thistle, nigella, and white and black poppy seeds

	Oils				
Fatty acid (%)	**chia**	**milk thistle**	**nigella**	**white poppy**	**black poppy**
C16:0	6.68 ± 0.11[a]	8.02 ± 0.15[b]	12.02 ± 0.11[d]	8.90 ± 0.17[c]	8.70 ± 0.15[c]
C16:1	0.131 ± 0.012[a]	0.182 ± 0.091[a]	0.381 ± 0.062[b]	-	-
C18:0	2.72 ± 0.09[b]	5.15 ± 0.21[c]	2.60 ± 0.14[b]	1.94 ± 0.08[a]	1.77 ± 0.09[a]
C18:1 (n-9)	6.03 ± 0.12[a]	32.31 ± 0.32[e]	24.07 ± 0.22[d]	13.57 ± 0.19[b]	19.00 ± 0.21[c]
C18:2 (n-6)	18.35 ± 0.21[a]	48.12 ± 0.22[b]	58.28 ± 0.43[c]	74.70 ± 0.44[e]	69.60 ± 0.38[d]
C18:3 (n-3)	65.62 ± 0.41[c]	0.15 ± 0.08[a]	0.16 ± 0.08[a]	0.51 ± 0.08[b]	0.77 ± 0.14[b]
C20:0	0.221 ± 0.081[a]	3.163 ± 0.072[b]	0.131 ± 0.073[a]	-	-
SFA	9.62	16.33	14.75	10.84	10.47
MUFA	6.16	32.49	24.45	13.57	19.00
PUFA	83.97	48.27	58.44	75.21	70.37
U/S	9.37	4.95	5.62	8.19	8.54
n-6/n-3	0.28	320.80	364.25	146.47	90.39
Nutritional quality index					
AI	0.074	0.099	0.145	0.100	0.097
TI	0.045	0.323	0.349	0.237	0.225
HH	13.5	10.0	6.9	10.0	10.3

U/S: unsaturated/saturated fatty acids; SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; AI: atherogenic index; TI: thrombogenic index; HH: the hypocholesterolemic: hypercholesterolemic ratio.
* Values (means ± SD; n = 3) bearing different superscripts are statistically significantly different ($P < 0.05$). ANOVA with Tukey's test was applied.

determination, which leads to an overestimation of the final result.

The acid value, which depends on the amount of free fatty acids, was relatively low in most of the samples tested (0.68 – 3.05 mg KOH/g) and lower than the values accepted for cold pressed oil by the international food standard Codex Alimentarius (4 mg KOH/g) (CODEX-STAN:210-1999). The highest acid value was found for black poppy seed oil (*Papaver* L.) (3.05 mg KOH/g), which may be associated with its high water content (831 ppm). Hydrolytic processes in oils, leading to an increase in their free fatty acid contents, may be affected by water and enzymes. That is why it is important to choose a high-quality raw material and to store the final product appropriately (Wroniak *et al*., 2006). Bodoira *et al*., (2017), when analyzing chia seed oil, also reported low levels for the acid and peroxide values and a high iodine value (212 g/100 g oil), close to the results recorded in this study (218.41 g/100 g).

In order to characterize the nutritional value of the obtained oils, a fatty acid analysis was carried out (Table 2). The content of saturated acids (SFA) ranged from 9.62 g/100 g (chia oil) to 16.33 g/100 g (milk thistle oil). Similar results were obtained by Bodoira *et al*., (2017). As in chia seed oil, the content of saturated fatty acids was 10.44 g/100 g. In turn, Parry *et al*., (2006) reported that milk thistle oil contained 13.8 g/100 g of SFA. A high concentration of α-linolenic acid (C18:3 n-3) was detected in chia seed oil at 65.62 g/100 g; whereas in other oils it was 0.15-0.77 g/100 g. The second most abundant fatty acid in chia oil was linoleic acid (18.35 g/100 g). This is in line with the results obtained by Bodoira *et al*., (2017) for cold pressed oil from chia seeds, where the α-linolenic acid content was 61.8 g/100 g oil and linoleic acid 20.1 g/100 g of oil. Ixtaina *et al*., (2012) obtained similar results (64.7 g/100 g of α-linolenic acid and 19.1 g/100 g of linoleic acid). In the other oils analyzed the dominant fatty acid was linoleic acid, with contents amounting to 74.70 g/100 g (white poppy seed oil), 69.60 g/100 g (black poppy seed oil), 58.28 g/100 g (nigella oil) and 48.12 g/100 g (milk thistle oil). Kola (2015), also noted a high content of linoleic acid (73.35%) and low content of linolenic acid (0.68%) in poppy seed oil. A similar quantitative composition of fatty acids in nigella oil was recorded by Gharby *et al*., (2015). According to those authors, the content of linoleic acid was 58.5%, while linolenic acid amounted to 0.4%. In the oils obtained from both poppy cultivars no palmitoleic or arachidonic acid were found (Table 2). Unsaturated fatty acids are highly valuable compounds in the human diet, but their qualitative indicator is, above all, the n-6 to n-3 fatty acid ratio, which in the appropriate diet should be around 2:1 (Simopoulos *et al*., 1999). However, the intake of these acids in the western diet is far from the accepted standard and is often manifested by an excessively high supply of n-6 fatty acids

Table 3. Contents of vitamin-E compounds in cold pressed oils obtained from chia, milk thistle, nigella, and white and black poppy seeds

	Oils				
Tocochromanol contents (mg/kg)	**chia**	**milk thistle**	**nigella**	**white poppy**	**Black poppy**
α-T	5.11 ± 0.81[a]	530.2 ± 2.4[d]	7.5 ± 1.2[a]	44.4 ± 1.1[c]	33.1 ± 1.4[b]
α-T3	-	-	69.8 ± 1.6[a]	-	-
β-T	-	23.2 ± 2.0[a]	-	-	-
β-T3	-	-	247.9 ± 1.4[a]	-	-
γ-T	453.7 ± 0.81[e]	31.3 ± 1.6[b]	15.2 ± 1.1a	271.6 ± 0.6[d]	207.3 ± 1.1[c]
Δ-T	17.00 ± 0.41[c]	2.13 ± 0.32[b]	1.31 ± 0.51[a]	2.22 ± 0.91[b]	2.33 ± 0.21[b]
Total	475.9 ± 1.1[d]	586.7 ± 3.2[e]	341.7 ± 2.4[c]	318.2 ± 3.6[b]	242.7 ± 2.7[a]
Vitamin E equivalent	50.5	544.9	30.0	71.6	53.8

T – tocopherol; T3 – tocotrienols.
* Values (means ± SD; n = 3) bearing different superscripts are statistically significantly different (P < 0.05). ANOVA with Tukey's test was applied.

(Materac *et al.*, 2013). Among the oils analyzed chia seed oil had the best n-6 to n-3 fatty acid ratio (1:3.5; Table 2). The other oils were far from the optimum value (n-6:n-3 ratio from 90.39:1 in the case of black poppy seed oil to 364.25:1 for nigella oil; Table 2). In order to determine the biological activity of the fatty acids present in the obtained oils in relation to cardiovascular diseases, values were calculated for the atherogenic index (AI), thrombogenic index (TI) and the hypocholesterolemic:hypercholesterole mic ratio (HH). From the nutritional point of view, low AI and TI values are required (Bruno *et al.*, 2017). In the cold pressed oils studied, the AI and TI values were at similar low levels (AI 0.07-0.15 and TI 0.04-0.35; Table 2). This may indicate that the fatty acids contained in the analyzed oils may prevent the development of cardiovascular diseases. In contrast, according to literature data, oils with a relatively high HH index are preferred in the human diet (Bruno *et al.*, 2017). Among the oils studied, the highest HH index value was recorded for chia seed oil (13.47; Table 2).

The oil oxidation rate is influenced by the quality of the raw material used, the content of natural antioxidants and the composition of lipids (fatty acids) (Wroniak *et al.*, 2006). The DPPH radical-based method was used to determine the total antioxidant activity of the oils. Table 5 shows the antioxidant activity of the studied oils (expressed as µM of Trolox equivalent/g of oil and antiradical power (ARP)). The lowest antioxidant activity was detected in the case of both poppy cultivars, for which the values were 0.73-1.36 µM Trolox/g; while for chia seed oil it was 1.53 µM Trolox/g. Prescha *et al.*, (2014) obtained a similar antioxidant activity (0.72 µM Trolox/g) for poppy seed oil. In their study they also analyzed the antioxidant activity of milk thistle oil and recorded 1.70 µM Trolox/g, which was a lower value compared to the result obtained in our research (4.29 µM Trolox/g). The highest antioxidant activity, amounting to 10.23 µM Trolox/g, was found in nigella oil.

Tocochromanols, classified as compounds exhibiting vitamin E activity, are considered the most important lipophilic natural plant antioxidant. Oilseed crops are particularly rich in tocochromanols, as they contain about 10 times higher concentrations of these compounds than other plants (Eitenmiller and Lee, 2004). The contents of individual tocochromanols in the oils studied are presented in Table 3. The highest total content of tocochromanols was found in milk thistle oil (586.7 mg/kg); while the lowest content was observed in black poppy seed oil (242.7 mg/kg). The oil obtained from milk thistle was rich in α-tocopherol (530.2 mg/kg), which is the most biologically active compound in the vitamin E family (Power and Koutsos, 2019). For comparison, in cold pressed oils obtained from traditional raw materials such as rapeseed or sunflower the content of α-tocopherol is about 110-178 mg/kg (Krygier *et al.*, 1998). Similarly, Parry *et al.*, (2006) found that α-tocopherol was the dominant homologue of tocopherols in cold pressed oil from milk thistle. In turn, Zaborowska and Przygoński (2016) obtained similar results for α-tocopherol content (590 mg/kg) in their studies on milk thistle. The content of γ-tocopherol in their studies was found to be 32 mg/kg. They also analyzed the contents of tocochromanols and found the concentration of γ-tocopherol to be 459 mg/kg, which was comparable to the results obtained in our studies (453.7 mg/kg; Table 3). In a study by Dąbrowski *et al.*, (2017; 2018) it was stated that γ-tocopherol is the dominant homologue of tocopherol; however, its content was higher and amounted to 611 mg/kg. Different homologues of tocopherols are characterized by different biological activity; therefore, their contents were converted into the vitamin E equivalent (Table 3). The highest vitamin E equivalent was recorded in milk thistle oil (544.9 mg/kg). It was one order of magnitude higher

Table 4. Phytosterol contents in cold pressed oils obtained from chia, milk thistle, nigella, and white and black poppy seeds

Phytosterols (mg/kg)	Oils				
	chia	milk thistle	nigella	white poppy	black poppy
Sitostanol	-	210.15 ± 0.68[c]	-	102.57 ± 0.26[a]	39.40 ± 0.44[a]
Lanosterol	-	-	110.12 ± 0.70[a]	-	-
Campesterol	401.92 ± 0.82[a]	135.23 ± 0.48[b]	244.23 ± 0.29[b]	313.85 ± 0.29[c]	224.48 ± 0.54[c]
β-Sitosterol	2160.17 ± 0.17[c]	1142.24 ± 0.59[d]	1025.13 ± 0.72[f]	1032.03 ± 0.55[e]	934.27 ± 1.19[f]
Δ5-Avenasterol	-	-	980.21 ± 0.26[e]	145.37 ± 0.31[b]	68.08 ± 0.26[b]
Cycloartenol	-	110.14 ± 0.59[a]	-	332.57 ± 0.26[d]	615.53 ± 0.68[e]
Stigmasterol	1989.08 ± 1.23[b]	217.42± 0.97[c]	302.51± 0.79[c]	329.28 ± 0.68[d]	341.84 ± 1.19[d]
Δ7-Avenasterol	-	-	789.09± 0.36[d]	-	-
Total	4551.17	1815.18	3451.29	2255.67	2223.60

* Values (means ± SD; n = 3) bearing different superscripts are statistically significantly different (P < 0.05). ANOVA with Tukey's test was applied.

Table 5. Antioxidant activity of cold pressed oils obtained from chia, milk thistle, nigella, and white and black poppy seeds

Oils	Antioxidant activity	
	DPPH• μM Trolox/g	ARP x 10^{-3}
chia	1.53 ± 0.11[c]	8.77 ± 0.16[c]
milk thistle	4.29 ± 0.14[d]	15.72 ± 0.32[d]
nigella	10.23 ± 0.23[e]	32.96 ± 0.21[e]
white poppy	1.36 ± 0.06[b]	6.98 ± 0.25[b]
black poppy	0.73 ± 0.09[a]	5.81 ± 0.42[a]

ARP – antiradical power.
* Values (means ± SD; n = 3) bearing different superscripts are statistically significantly different (P < 0.05). ANOVA with Tukey's test was applied.

than in the other oils (Table 3). Tocotrienols were detected only in nigella oil (69.8 mg/kg α-tocotrienol and 247.9 mg/kg γ-tocotrienol).

The contents of individual phytosterols are presented in Table 4. Sitostanol, lanosterol, campesterol, β-sitosterol, Δ5-avenasterol, cycloartenol, stigmasterol and Δ7-avenasterol were detected in the oils analyzed. Phytosterols are valuable compounds in the human diet, because they are able to reduce blood cholesterol levels, especially the LDL fraction, thanks to the reduction in its absorption from the intestinal lumen. The dominant sterol in plants is β-sitosterol, which may reduce the risk of heart diseases and inhibit the proliferation of breast, prostate and colon cancer cells (Obiedzińska and Waszkiewicz-Robak, 2012). Cold pressed oil from chia seeds had the highest content of total phytosterols (4551.17 mg/kg; Table 4), mainly β-sitosterol (2160.17 mg/kg), stigmasterol (1989.08 mg/kg) and campesterol (401.92 mg/kg). Dąbrowski *et al.*, (2017; 2018) confirmed the presence of mainly β-sitosterol at the concentration of 2905.5 mg/kg in the oil from chia seeds. Significant amounts of sterols were also found in nigella oil (3451.29 mg/kg), where β-sitosterol (1025.13 mg/kg) dominated (Table 4). Similar contents of β-sitosterol were found by Kostadinović Veličkovska *et al.*, (2015) as well as Kostadinović Veličkovska *et al.*, (2018) in nigella oil (828.72 mg/kg). Milk thistle oil also contained significant amounts of β-sitosterol (1142.24 mg/kg), which is a similar result to those obtained by Dabbour *et al.*, (2014) (1136.3 mg/kg). In the other oils analyzed, the total phytosterol content was in the similar range of 1815.18 - 2255.67 mg/kg (Table 4). For all the oils tested, β-sitosterol is the dominant sterol.

4. CONCLUSIONS

The analyzed cold pressed oils were characterized by high nutritional value. Chia seed oil proved to be the best from the nutritional point of view, mainly thanks to its fatty acid composition (especially its dominant α-linolenic acid belonging to the n-3 family) and the calculated n-6:n-3 fatty acid ratio of 1:3.5. The other oils studied were rich sources of linoleic acid (18.35-74.70%). Chia seed oil was also distinguished by high contents of phytosterols, mainly β-sitosterol. The highest content of tocochromanols was found in milk thistle oil with dominant α-tocopherol. In contrast, the highest antioxidant activity was recorded for nigella oil, which indicates that in addition to tocopherol, other antioxidants influenced its antioxidant potential. The oils from chia, milk thistle, and white and black poppy seeds were characterized by low peroxide values. The relatively high peroxide value of nigella oil was probably connected to the presence of large amounts of thymoquinone, which as an electron acceptor possess oxidizing properties. The unconventional oils here may become interesting and valuable ingredients to be used in the preparation of food.

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The authors declare that they have no conflicts of interest.

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