https://doi.org/10.17221/316/2021-PSE

Oil content and fatty acid profile of selected poppy (*Papaver somniferum* L.) landraces and modern cultivars

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Citation: Satranský M., Fraňková A., Kuchtová P., Pazderů K., Capouchová I. (2021): Oil content and fatty acid profile of selected poppy (*Papaver somniferum* L.) landraces and modern cultivars. Plant Soil Environ., 67: 579–587.

Abstract: The oil content and fatty acid composition were determined in the seed of 19 poppy genotypes (both landraces and modern cultivars) grown in three-year field trials. The total oil content ranged from 34.56–44.76%. The oil content in white-seeded genotypes (40.73–44.76%) exceeded the oil content in blue-seeded genotypes (34.56–40.34%) and ocher-seeded genotypes (38.36–42.69%). Linoleic acid (71.41–74.02%), oleic acid (12.35–15.51%) and palmitic acid (8.95–10.29%) were the most abundant fatty acids in the evaluated seeds of poppy genotypes. A significant negative correlation (–0.7574**) was found between linoleic and oleic fatty acids. The sum of polyunsaturated (PUFA), monounsaturated (MUFA) and saturated (SFA) fatty acids ranged from 72.43–74.91%, 12.90–16.14% and 10.99–12.46% of the total fatty acids, respectively. Both the total oil content and the content of individual fatty acids were mainly affected by the crop year (weather conditions); however, the effect of genotype and year × genotype interaction was also significant. Due to the favourable composition of fatty acids, the evaluated poppy genotypes can be a good source of nutritionally valuable oil.

Keywords: linoleic acid; oleic acid; human nutrition; tempratures; rainfalls

Poppy is one of the oldest cultural crops, and for medicinal and food purposes, it has been used for many centuries. At present, the Czech Republic and Turkey belong to the main poppy growers, to a lesser extent France, Spain, Hungary, Germany and some others, which, however, focus on the production of pharmaceutical technical poppy cultivars (FAOSTAT 2021). On the other hand, poppy cultivation for the food industry has a long tradition, especially in Central Europe (Fejer 2007).

Poppy seeds contain almost no opium alkaloids. Contamination of the final product with opium alkaloids may occur as a result of inappropriate harvesting practices or the use of poppy seed that is a by-product of the cultivation of technical poppy cultivars intended for the pharmaceutical industry (López et al. 2018).

Poppy seeds are a source of valuable omega-6 fatty acids, contain a lot of minerals (Na, K, Mg, Ca), and the amount of protein exceeds 20% (Levent et al. 2020, Senila et al. 2020). The poppy seed oil also contains significant amounts of β-sitosterol (663.9–3 244.4 ppm), α-tocopherol (22.0–45.8 ppm), γ-tocopherol (195.4–280.9 ppm) (Erinç et al. 2009), and β-tocopherol (309.5–567.3 ppm) (Özcan and Atalay 2006).

The oil content of poppy seeds ranges from 28–52% depending on cultivar, seed colour, growing technology and environmental conditions (Erinç et al. 2009, Ghafoor et al. 2019, Dąbrowski et al. 2020, Luhmer et al. 2021). Fatty acids perform a number of functions in the body. They are important as components of biological membranes that are precursors of various molecules, participate in the process of energy stor-

https://doi.org/10.17221/316/2021-PSE

age and transport of vitamins (Petrović et al. 2010, Labdelli et al. 2019). PUFA (polyunsaturated fatty acids) are prevailing fatty acids in poppy seed oil, mainly linoleic fatty acid, the amount of that ranges from 56.4–74.8% of all fatty acids (Bozan and Temelli 2008, Rahimi et al. 2011, Lančaričová et al. 2016). PUFA are one of the basic building blocks of human nutrition, and their intake is important for the proper functioning of the human body in terms of prevention of cardiovascular diseases, heart attacks and inflammatory diseases (Hlinková et al. 2012). Due to the high PUFA content, poppy seeds and poppy products are prone to autooxidation, which can lead to unpleasant odours and bitter tastes (Lančaričová et al. 2016). As far as to the other fatty acids, poppy seed oil contains MUFA (monounsaturated fatty acids), mainly oleic acid (13.2–17.8%) (Erinç et al. 2009, Rahimi et al. 2011) and palmitoleic acid (0.17–0.40%) (Hlinková et al. 2012, Özbek and Ergönül 2020). Saturated fatty acids are represented mainly by palmitic acid (8.7–16.3%) (Rahimi et al. 2011, Özbek and Ergönül 2020) and stearic acid (1.9–2.3%) (Valizadeh et al. 2014, Dąbrowski et al. 2020).

The interest in the quality of poppy seed oil and its use in the food industry has been increasing in recent years. Therefore, the aim of the work was to determine the oil content and fatty acid profile in selected poppy landraces and modern cultivars grown in environmental conditions of the central part of the Czech Republic and to evaluate the effects of genotype and crop year on these characteristics.

Table 1. The terms of poppy sowing and harvest

Operation	2015	2016	2017
Sowing	April 7	April 5	March 29
Harvest	July 21–August 7	July 19–August 8	July 17–August 2

MATERIAL AND METHODS

Plant material. A collection of 19 poppy seed samples, including both landraces and modern cultivars, was obtained from the Gengel (organisation gathering and preserving genetic resources of the field crops) and cultivated in the exact field small-plot trials, carried out during the 2015–2017 growing seasons at the experimental base of the Czech University of Life Sciences in Prague – Suchdol (central part of Bohemia, 280 m a.s.l.). The collection involved 5 blue-seeded, 8 white-seeded and 3 ocher-seeded landraces and 3 modern cultivars (blue-seeded Major, white-seeded Orel and ocher-seeded Redy) – the list of genotypes is a part of Table 3. The small-plot field trials were established using random blocks; in 3 replicates, no fertilisers and pesticides were applied. The terms of poppy sowing and harvest are given in Table 1 (individual poppy genotypes were harvested gradually, depending on the achievement of full maturity).

Relatively large time spans were found between the beginning and the end of the harvest (Table 1). Figure 1 shows that there were differences between

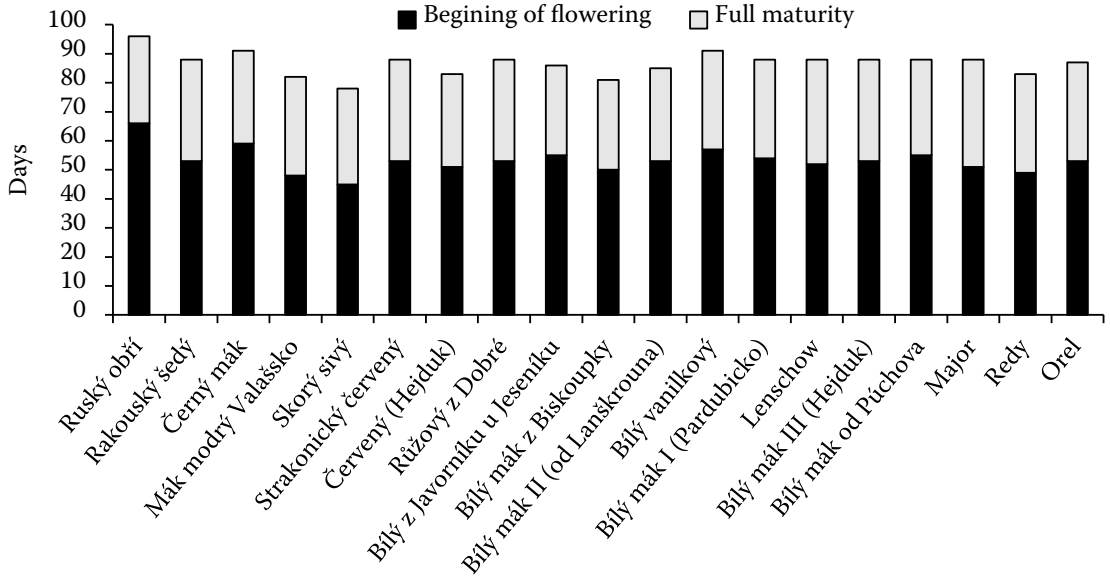

Figure 1. Number of days from plants emergence to the beginning of flowering and to the full maturity (average of 2015–2017)

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the evaluated genotypes in the number of days from plants emergence (BBCH 11) to the beginning of flowering (BBCH 61) and to harvest (full maturity – BBCH 89). The earliest was the blue-seeded genotype Skorý sivý; the latest was the blue-seeded genotype Ruský obří. The harvest time varied slightly depending on the climatic conditions of each observed year. To the earlier genotypes were also included, for example, blue-seeded Mák modrý Valašsko and white-seeded Bílý mák z Biskoupky, to the later genotypes, for example, white-seeded Bílý vanilkový and blue-seeded Černý mák (Figure 1).

The survey of average monthly temperatures and sums of precipitation during the evaluated years of 2015–2017 in comparison with long-term standard gives Table 2.

The average temperature in all evaluated years exceeded the long-term standard. With regard to precipitation, evaluated years were under the long-term standard. Regarding to the growing season (from March to August), especially the year 2015 was very dry, and July, which is decisive for poppy seed formation, reached in 2015 only 36% of precipitation compared to the long-term standard.

As already mentioned, the harvest was carried out at the full maturity of the individual genotypes. The moisture content of seed at the time of harvest varied depending on the weather conditions and ranged from 7.6–9.1% (on average).

After the field experiments harvest, the yield of poppy seeds was determined and obtained seed samples were used for analyses.

Oil content determination. Poppy seeds were ground using a laboratory grinder, and the obtained meal was used for analyses. The accelerated Soxhlet method on a Velp SER 148/6 Soxhlet Extractor (Velp Scientifika, Usmate Velate, Italy) was used for total oil content determination. Approximately 6 g of homogenised sample was weighed into the extraction thimble and extracted using petroleum ether (VWR Chemicals, Czech Republic) by a three-step procedure. Firstly, the meal was for 120 min immersed and then for 90 min rinsed by the solvent. In the last phase, the solvent was evaporated for 20 min. The temperature of the plate was constant (110 °C) during the whole extraction process. The obtained oil was weighed to the nearest ± 0.0001 g. Results were calculated on a dry matter basis. Seed samples were dried at 103 ± 2 °C to the constant weight (ISO 665, 2000). Analysis of each sample was performed in triplicate.

Determination of fatty acid (FA) composition. Prior to GC analysis, the poppy samples were derivatised by alkaline transesterification. Approximately 300 mg of homogenised poppy seed was weighed into a 10 mL volumetric flask. Next, 0.5 mL of petroleum ether (VWR Chemicals, Czech Republic), 0.5 mL of benzene (Lachner, Neratovice, Czech Republic) and 1 mL of

Table 2. The survey of average monthly temperatures and sums of precipitation during the years of 2015–2017 in comparison with long-term standard

Month	Average temperature (°C)				Σ of precipitation (mm)			
	2015	2016	2017	long-term standard	2015	2016	2017	long-term standard
January	2.4	0.2	–4.2	–2.0	20.6	25.2	11.3	44
February	1.2	3.9	2.3	´0.9	2.6	28.2	9.8	38
March	5.6	4.5	7.5	2.9	32.9	23.7	35.0	48
April	9.1	8.9	8.2	7.9	26.4	20.0	57.6	42
May	13.7	14.8	15.2	13.0	31.9	72.5	50.4	69
June	16.8	18.2	19.4	15.8	38.6	108.7	95.0	79
July	21.6	19.8	19.9	17.8	31.6	81.6	71.4	88
August	22.9	18.8	19.8	17.3	59.7	50.0	80.3	80
September	13.9	17.4	13.0	12.8	7.7	26.5	21.5	58
October	8.7	8.6	10.8	8.1	50.6	45.6	54.2	43
November	7.1	3.5	4.9	2.9	44.3	17.3	28.6	49
December	5.6	1.1	2.2	–0.9	9.7	24.7	21.7	50
Average temperature	10.71	9.97	9.91	7.97				
Σ of precipitation					356.6	524.0	536.8	688

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0.4 mol/L methanolic solution NaH (Sigma Aldrich, Czech Republic) were added. The volumetric flasks were stoppered and allowed to stand at room temperature for 20 min. After that, distilled water was added. The contents of the flask were shaken and then allowed to stand for 10 min. The organic solvent fraction was collected and analysed. The FA relative quantification was performed by gas chromatograph Agilent 7890A (Agilent, Santa Clara, USA) equipped with FID – Flame ionisation detector (Agilent, Santa Clara, USA). The separation of FA was performed on Restek (Restek, Bellefonte, USA) capillary column (100 m, 25 µm ID). The carrier gas was nitrogen at a flow rate of 1.2 mL/min. Injection 1.0 µL, split – split ratio 250:1, injection temperature was 250 °C. The detector temperature was 260 °C, the flow of the detector gases H_2: 30 mL/min, air: 400 mL/min, and make-up flow: 30 mL/min. The temperature conditions of the analysis were as follows: 70 °C 2 min, increase 5 °C/min to 225 °C, hold 9 min, increase 5 °C/min to 240 °C, hold 25 min (the duration of the analysis for each sample was 36 min). Analysis of each sample was performed in triplicate.

The identification of individual fatty acids was performed by gas chromatograph Agilent 7890A equipped with a quadrupole mass spectrometer 5975 C (Agilent, Santa Clara, USA). The duration of the analysis was 70 min. The GC conditions of the analysis were the same; the helium was used as carrier gas instead of nitrogen. The temperature of the ion source and quadrupole were 230 °C and 150 °C, respectively. Mass spectra were acquired in a scan mode (range: 40–400 m/z). Identification of the analysed fatty acids were done by comparing their spectra with the spectra of available standards and/or by comparing their retention indices with the NIST database NIST (National Institute of Standards and Technology) mass spectral library ver. 2.0f.

The following fatty acids have been labelled: C14:0 – myristic acid; C16:0 – palmitic acid; C16:1 – palmitoleic acid; C17:1 – heptadecenoic acid; C18:0 – stearic acid; C18:1w9 – oleic acid; C18:1w7 – cis-vaccenic acid; C18:2 – linoleic acid; C18:3 – linolenic acid; C20:0 – arachidic acid and C20:1 – gadoleic acid. But those listed here – C14:0, C17:1, C20:0 and C20:1 have been omitted due to their low content (and therefore the sum of the acids in the Table 5 is not equal to 100%).

Statistical analysis. The data obtained were statistically analysed using two-factor ANOVA – "year" (Y) and "genotype" (G) with interaction in the SAS programme (SAS Institute, Cary, USA), version 9.4, at a level of significance $P = 0.05$. The differences between means were evaluated using Tukey's *HSD* (honestly significant difference) test. The Pearson's correlation coefficients between individual fatty acids at a level of significance $P = 0.01$ were calculated as well.

RESULTS AND DISCUSSION

The results of ANOVA related to the 19 poppy genotypes grown over three trial years are given in Table 3. The results show that both contents of evaluated fatty acids, total oil content and yield of seeds were affected mostly by the crop year. However, significant effects of genotype and interaction (Y × G) on the evaluated traits were also found, except the effect of Y × G on the content of palmitic and linolenic acids and the effects of genotype and interaction (Y × G) on the content of SFA that were insignificant.

Table 3. The effect of genotype and year on the oil content, yield and evaluated fatty acids in the poppy seed (ANOVA, Fisher's *F*-values)

Factor	C16:0	C16:1	C18:0	C18:1w9	C18:1w7	C18:2
Year (Y)	99.75**	942.88**	134.24**	467.36**	219.42**	148.38**
Genotype (G)	4.15**	59.63**	34.48**	68.86**	12.94**	7.33**
Y × G	1.99^{ns}	35.03**	3.68**	57.32**	5.60**	8.53**
	C18:3	SFA	MUFA	PUFA	yield	oil content
Year	578.66**	14.17**	469.21**	84.09**	34.98**	429.99**
Genotype	2.11*	1.07^{ns}	66.93**	7.32**	5.77**	82.26**
Y × G	1.6^{ns}	0.55^{ns}	50.23**	7.89**	5.03**	17.74**

*$P < 0.05$; **$P < 0.01$; ns – non-significant; C16:0 – palmitic acid; C16:1 – palmitoleic acid; C18:0 – stearic acid; C18:1w9 – oleic acid; C18:1w7 – cis-vaccenic acid; C18:2 – linoleic acid; C18:3 – linolenic acid; SFA – saturated fatty acids; MUFA – monounsaturated acids; PUFA – polyunsaturated acids

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The chemical composition of poppy seed is influenced by many factors, including genotype, climate, location and year of cultivation (Ghafoor et al. 2019). Lančaričová et al. (2016) concluded that the quality of poppy seeds depends on their genotype and especially on the locality of growing, that is, climatic conditions. The authors assumed, in line with our conclusions, that lower temperatures and greater precipitation can cause increased accumulation of oil. The results of Rahimi et al. (2015) suggested that the effect of location (climatic conditions) on the content of oil in the seed of four Turkish poppy cultivars was higher compared to the effect of the cultivar. The results of the same authors also showed the strong effect of location on the content of unsaturated fatty acids in poppy cv. Ofis 95. Hlinková et al. (2012) concluded on the basic of their results that oleic acid content was significantly affected by the year of cultivation. In addition, the linoleic and alpha-linolenic acid contents were also found slightly affected by the year of cultivation. Sethi et al. (1990) found the statistically significant effect of both locality and genotype on the yield and oil content of poppy seeds.

Total oil content. In the conducted experiment, both significant and non-significant differences were claimed between the evaluated genotypes (Table 4). The total oil content in the conducted experiment ranged from 34.56–44.76%, and this is in agreement with the results of other authors who reported oil content in poppy seeds in the range of 27.71–52.70% (Özcan and Atalay 2006, Erinç et al. 2009, Ghafoor et al. 2019, Dabrowski et al. 2020).

Based on our results, the oil content of white-seeded genotypes (40.73–44.76%) exceeded that of blue-seeded genotypes (34.56–40.34%) and was similar

Table 4. The oil content and yield of seeds in poppy genotypes and years – Tukey's *HSD* test at the level of $P < 0.05$

Genotype	Seed color	Type of genotype	Yield (t/ha)	Total oil content (%)
Ruský obří	blue	landrace	0.61^{cd}	39.38^{gh}
Rakouský šedý	blue	landrace	0.88^{abc}	40.34^{gf}
Černý mák	blue	landrace	0.78^{bcd}	38.46^{h}
Mák modrý Valašsko	blue	landrace	1.15^{a}	35.49^{ij}
Skorý sivý	blue	landrace	0.54^{d}	34.56^{j}
Strakonický červený	ocher	landrace	0.78^{bcd}	41.27^{def}
Červený (Hejduk)	ocher	landrace	0.76^{bcd}	42.69^{bcd}
Růžový z Dobré	ocher	landrace	0.79^{bcd}	38.36^{h}
Bílý z Javorníku u Jeseníku	white	landrace	0.79^{bcd}	40.73^{efg}
Bílý mák z Biskoupky	white	landrace	0.77^{bcd}	41.82^{def}
Bílý mák II (od Lanškrouna)	white	landrace	0.78^{bcd}	44.76^{a}
Bílý vanilkový	white	landrace	0.65^{cd}	42.69^{bcd}
Bílý mák I (Pardubicko)	white	landrace	0.77^{bcd}	43.98^{ab}
Lenschow	white	landrace	0.89^{abc}	43.96^{ab}
Bílý mák III (Hejduk)	white	landrace	0.68^{cd}	41.84^{def}
Bílý mák od Púchova	white	landrace	0.78^{bcd}	42.15^{cde}
Major	blue	cultivar	1.13^{a}	36.80^{i}
Redy	ocher	cultivar	1.01^{ab}	41.16^{def}
Orel	white	cultivar	0.78^{bcd}	43.44^{abc}
$HSD_{0.05}$			0.33	1.54
2015			0.67^{b}	37.29^{c}
2016			0.98^{a}	42.11^{a}
2017			0.68^{b}	40.90^{b}
$HSD_{0.05}$			0.09	0.39

HSD – honestly significant difference

https://doi.org/10.17221/316/2021-PSE

to that of ocher-seeded genotypes (38.36–42.69%). The literature mentions higher oil content in white poppy genotypes (Lančaričová et al. 2016), which are characterised by a thin seed coat (Vašák 2010). Azcan et al. (2004) reported that there was 36.8% oil in white poppy seeds, according to Duman and Özcan (2015) – 46.15%, while in the conducted experiment, average oil content of 42.8% was obtained. In the own experiment, in the analysed genotypes with blue seeds, average oil content of about 37.5% was obtained, and this content was higher compared to the 33.6% obtained by Azcan et al. (2004), but lower compared to the results of Duman and Özcan (2015) – 44.50%.

Duman and Özcan (2015) determined the average oil content of yellow poppy seeds to be 45.93%. Also, Lančaričová et al. (2016) found that cultivars with ochre-coloured seeds contained the highest oil level, regardless of location.

Comparison of the evaluated modern and landrace cultivars showed that modern cultivars in oil content generally did not differ from their group in terms of seed colour and did not differ from landrace cultivars.

The results showed a statistically significant effect of the year, expressing in our case especially the effect of weather (average temperatures and sums of precipitation during the monitored vegetation seasons) on the oil content in evaluated poppy genotypes. The experimental year 2015, when the oil content was the lowest, was very dry; poppy genotypes were exposed to higher temperatures and especially lower precipitation compared to 2016 and 2017. In 2015, the lowest yield of seeds was also achieved (Table 4).

Fatty acid composition. Our results showed that linoleic (C18:2), oleic (C18:1w9) and palmitic (C16:0) acids were the most abundant fatty acids in evaluated poppy genotypes (Table 5). The linoleic acid content varied from 71.41–74.02%. Similar content of this acid was found by Valizadeh et al. (2014) with 72.70–74.66%. Slightly lower content of linoleic acid (69.36–73.92%) was detected by Erinç et al. (2009), while Rahimi et al. (2011) state the largest range in its accumulation level from 68.76–74.22%. The oleic acid content was in the range of 12.35–15.51%. The content of oleic acid (14.13–17.76%), reported by Erinç et al. (2009) was slightly higher in comparison with our results; Valizadeh et al. (2014) found a similar content of this acid (13.21–15.55%) and Rahimi et al. (2011) obtained the oleic acid content in the largest range of 13.30–17.80%. The palmitic acid content in the range of 8.95–10.29% was similar to its content reported by Rahimi et al. (2011) (7.96–10.19%), while the content of the same acid found by Valizadeh et al. (2014) and Erinç et al. (2009) slightly lower (8.25–8.85% and 7.67–9.91%, respectively). Despite some differences, it can be stated that our results are in principle in line with the findings of the above-mentioned authors, despite the fact that their results come from different environmental conditions and include the evaluation of poppy genotypes of Turkish origin.

However, various other fatty acids were also found in evaluated poppy genotypes in smaller amounts – they were stearic (C18:0), linolenic (C18:3), palmitoleic (C16:1) and cis-vaccenic (C18:1w7) acids (Table 5). The content of stearic acid ranged from 1.88–2.58% and was very similar to its content that was obtained by Rahimi et al. (2011) (1.84–2.40%). A slightly higher content of this acid (2.50–3.20%) was present by Azcan et al. (2004), while the range of this acid (0.60–1.80%) reported by Hlinková et al. (2012) was lower compared to our results. The content of linolenic acid was in the range of 0.80–1.19%. This range was higher compared to the other authors – Hlinková et al. (2012) reported that the content of this acid was in the range of 0.60–0.80%, Rahimi et al. (2011) showed the range of 0.55–0.75% and Azcan et al. (2004) 0.40–0.60%. The content of palmitoleic acid varied between 0.13–0.20%. This result was in line with the findings of Rahimi et al. (2011), who found palmitoleic acid content in the range of 0.13–0.25%, while Hlinková et al. (2012) reported the higher content of this acid compared to our results (0.30–0.40%). The content of cis-vaccenic (C18:1w7) acid was in the range of 0.35–0.56%. The occurrence of cis-vaccenic acid (C18:1w7) in poppy seed oil mention only some literary sources. Its content was present, for example, by Bozan and Temelli (2008) (on average of 1.09%) or Ghafoor et al. (2019) in the range of 0.61–0.93% (Table 5).

In addition to the above-mentioned fatty acids, trace amounts (< 0.1%) of myristic (C14:0) acid, heptadecenoic (C17:1) acid, arachidic (C20:0) acid and gadoleic (C20:1) acid were found (the contents of these fatty acids are not included in Table 5). Trace amounts of these fatty acids in poppy seed oil are mentioned by many authors, e.g. Erinç et al. (2009), Rahimi et al. (2011), Lančaričová et al. (2016), Őzbek and Ergönül (2020) and others.

The results are given in Table 5 also showed significant differences in the content of the most of evaluated fatty acids between the monitored years. Hlinková et al.

https://doi.org/10.17221/316/2021-PSE

Table 5. Fatty acid composition of poppy seed (%) – Tukey's *HSD* test at the level of $P < 0.05$

Cultivar	C16:0	C16:1	C18:0	C18:1w9	C18:1w7	C18:2	C18:3	SFA	MUFA	PUFA
Ruský obří	10.22^{ab}	0.16^{fgh}	1.95^{hi}	13.43^{ghi}	0.49^{abcd}	72.45^{bcdef}	1.09^{a}	12.17^{a}	14.08^{fgh}	73.54^{bcdef}
Rakouský šedý	9.13^{cde}	0.13^{j}	2.20^{cde}	14.88^{bc}	0.49^{abcd}	72.15^{cdef}	0.93^{bc}	11.34^{a}	15.36^{b}	73.08^{cdef}
Černý mák	9.11^{de}	0.15^{ghi}	1.88^{i}	13.33^{ghij}	0.49^{abcd}	73.72^{ab}	1.19^{a}	10.99^{a}	13.97^{efgh}	74.91^{a}
Mák modrý Valašsko	9.62^{abcde}	0.16^{def}	2.12^{defg}	14.39^{cde}	0.35^{ef}	72.53^{bcdef}	0.80^{c}	11.73^{a}	14.92^{cde}	73.33^{cdef}
Skorý sivý	8.95^{e}	0.14^{ij}	2.58^{a}	14.78^{bcd}	0.28^{f}	71.79^{ef}	1.14^{a}	11.54^{a}	15.09^{cd}	72.93^{cdef}
Strakonický červený	9.65^{abcde}	0.15^{ghi}	2.13^{defg}	12.35^{k}	0.40^{de}	74.02^{a}	1.05^{a}	11.78^{a}	12.90^{j}	75.07^{a}
Červený (Hejduk)	9.75^{abcde}	0.14^{ij}	2.14^{defg}	12.73^{jk}	0.35^{ef}	73.68^{ab}	0.91^{bc}	11.89^{a}	13.23^{ij}	74.59^{ab}
Růžový z Dobré	9.98^{abcd}	0.19^{ab}	2.48^{ab}	13.88^{efg}	0.41^{de}	71.96^{ef}	0.94^{bc}	12.46^{a}	14.48^{def}	72.90^{def}
Bílý z Javorniku u Jeseníku	9.99^{abc}	0.17^{cd}	2.12^{defg}	13.73^{fgh}	0.53^{ab}	71.92^{ef}	1.17^{a}	12.11^{a}	14.43^{def}	73.11^{def}
Bilý mák z Biiskoupky	9.47^{abcde}	0.18^{bc}	2.15^{def}	13.67^{fgh}	0.56^{a}	72.67^{bcdef}	1.07^{a}	11.62^{a}	14.41^{efg}	73.82^{abcde}
Bilý mák II (od Lanškrouna)	9.52^{abcde}	0.13^{j}	2.05^{efgh}	13.18^{hij}	0.41^{de}	73.44^{abc}	1.04^{a}	11.57^{a}	13.72^{fghi}	74.52^{abc}
Bilý vanilkový	9.17^{cde}	0.16^{fgh}	2.13^{defg}	14.52^{cd}	0.53^{ab}	72.27^{cdef}	0.98^{b}	11.30^{a}	15.21^{b}	73.35^{bcdef}
Bilý mák I (Pardubicko)	9.43^{abcde}	0.15^{ghi}	2.03^{fghi}	15.37^{b}	0.43^{de}	71.41^{f}	1.10^{a}	11.46^{a}	15.95^{a}	72.50^{f}
Lenschow	9.94^{abcd}	0.15^{hij}	2.36^{bc}	12.95^{ijk}	0.35^{ef}	73.05^{abcde}	0.98^{b}	12.30^{a}	13.45^{hij}	74.23^{abcde}
Bilý mák III (Hejduk)	10.29^{a}	0.16^{efg}	2.10^{defgh}	12.76^{f}	0.45^{bcd}	73.31^{abcd}	0.92^{bc}	12.39^{a}	13.27^{ij}	74.45^{abcd}
Bilý mák od Púchova	9.55^{abcde}	0.14^{ij}	2.05^{efgh}	14.19^{jk}	0.44^{bcde}	72.48^{bcdef}	0.89^{bc}	11.60^{a}	14.77^{bcd}	73.68^{bcdef}
Major	9.65^{abcde}	0.16^{efgh}	2.00^{fghi}	14.59^{cd}	0.58^{a}	72.11^{def}	0.85^{bc}	11.66^{a}	15.26^{b}	72.96^{cdef}
Redy	9.23^{cde}	0.20^{a}	1.98^{ghi}	15.51^{a}	0.43^{cde}	71.43^{f}	0.90^{bc}	11.22^{a}	16.14^{a}	72.43^{ef}
Orel	9.70^{abcde}	0.17^{cde}	2.20^{cde}	13.26^{ghij}	0.51^{abc}	72.98^{abcde}	0.91^{bc}	11.90^{a}	13.94^{efgh}	73.87^{abcd}
$HSD_{0.05}$	0.88	0.01	0.16	0.64	0.1	1.32	0.17	3.06	0.67	1.35
2015	9.30^{b}	0.19^{a}	2.27^{c}	14.97^{a}	0.56^{a}	71.29^{c}	1.35^{a}	11.38^{b}	15.72^{a}	72.71^{c}
2016	9.23^{b}	0.13^{c}	2.15^{b}	14.08^{b}	0.43^{b}	72.63^{b}	1.31^{b}	11.02^{b}	14.52^{b}	73.91^{b}
2017	10.40^{a}	0.17^{b}	2.27^{a}	12.53^{c}	0.35^{c}	73.97^{a}	0.30^{c}	12.64^{a}	13.06^{c}	74.24^{a}
$HSD_{0.05}$	0.22	0.00	0.04	0.16	0.02	0.33	0.03	0.77	0.17	0.34

C16:0 – palmitic acid; C16:1 – palmitoleic acid; C18:0 – stearic acid; C18:1w9 – oleic acid; C18:1w7 – cis-vaccenic acid; C18:2 – linoleic acid; C18:3 – linolenic acid; SFA – saturated fatty acids; MUFA – monounsaturated fatty acids; PUFA – polyunsaturated fatty acids. Values in table are rounded, statistical significance corresponds with non-rounded values; *HSD* – honestly significant difference

https://doi.org/10.17221/316/2021-PSE

Table 6. Correlation matrix of the interactions of the studied fatty acids in poppy seeds

	C16:0	C16:1	C18:0	C18:1w9	C18:1w7	C18:2	C18:3
C16:0	1	0.3379**	0.2720*	–0.4849**	–0.0843	0.2836*	–0.3784**
C16:1	0.3379**	1	–0.0378	0.1062	0.2698*	–0.2520*	–0.0968
C18:0	0.2720*	–0.0378	1	–0.2974*	–0.3875**	0.3001*	–0.1653
C18:1w9	–0.4849**	–0.1062	–0.2974*	1	0.1262	–0.7574**	0.2089
C18:1w7	–0.0843	0.2698*	–0.3875**	0.1262	1	–0.2746*	–0.2821*
C18:2	0.2836*	–0.2520*	0.3001*	–0.7574**	–0.2746*	1	0.2364
C18:3	–0.3784**	–0.0968	–0.1653	0.2089	–0.2821*	0.2364	1

*$P < 0.05$; **$P < 0.01$; C16:0 – palmitic acid; C16:1 – palmitoleic acid; C18:0 – stearic acid; C18:1w9 – oleic acid; C18:1w7 – cis-vaccenic acid; C18:2 – linoleic acid; C18:3 – linolenic acid

(2012) found on the basis of their experiments that the effect of year was statistically significant only for oleic acid and palmitoleic acid contents, while in the linoleic acid content effect of year was insignificant. Our results showed, that in the very dry year of 2015 a significantly lower content of linoleic acid and a higher content of oleic acid were recorded. These results are in line with the findings of Lančarovičová et al. (2016), who determined a higher oleic acid content and lower linoleic acid content in a location that was characterised by drier and warmer weather conditions during the time of seed formation.

Nutritionally valuable polyunsaturated fatty acids ranged from 72.43–74.91% (Table 5). Similar contents of PUFA (71.01–74.57%) was detected by Özbek and Ergönül (2020) in five Turkish poppy cultivars. The range of PUFA (67.70–74.80%) showed by Lančaričová et al. (2016), was wider compared to our results. The average contents of PUFA – 67.9% reported by Senila et al. (2019) and 68% reported by Fotschki et al. (2020) were lower compared to our findings.

Monounsaturated fatty acids varied between 12.90% and 16.14% (Table 5). Slightly higher content of MUFA (14.18–16.98%) was obtained by Özbek and Ergönül (2020). The results presented by Lančaričová et al. (2016) showed that the range of MUFA was wider (13.60–21.00%), and Fotschki et al. (2020) reported that the content of MUFA represents on average 17% of all poppy fatty acids.

Saturated fatty acids occurred in substantially lesser amounts (10.99–12.46%) (Table 5). The results of Lančaričová et al. (2016) showed that the content of SFA (10.90–12.00%) was similar to our findings and also to results obtained by Özbek and Ergönül (2020), according to them the content of SFA represent 10.91–12.00% of all fatty acids. Bozan and Temelli (2008) stated that poppy seed oil contains on average 11.7% of SFA, and Fotschki et al. (2020) found the average content of SFA at 10%.

The results (Table 6) showed that there was a strong significant negative correlation between the linoleic and oleic acids content (–0.7574**). Highly significant negative correlation (–0.97**) between the linoleic and oleic acids content in poppy seed oil was also found by Lančaričová et al. (2016). The negative relationship between the above mentioned fatty acids seems to be valid also for other oil-containing seeds. For example, Miller et al. (1987) described the negative correlation between the linoleic and oleic acids content in sunflower (–0.84**) and Martinez et al. (2010) in oat (–0.72**).

In conclusion, the evaluated poppy genotypes could be a good source of nutritionally valuable oil owing to their favourable fatty acid composition. Nutritionally valuable polyunsaturated and monounsaturated fatty acids represented in total 85.33–91.50% of fatty acids, while saturated fatty acids occurred in substantially lesser amounts. Both contents of evaluated fatty acids and the total oil content were affected mostly by the crop year, but significant effects of genotype and interaction yield × genotype on the evaluated traits were also found. A comparison of evaluated modern cultivars and landraces showed that modern cultivars, both in the total oil content and fatty acid composition, generally did not deviate from landraces.

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Received: July 4, 2021
Accepted: September 28, 2021
Published online: October 14, 2021