

FATTY ACID COMPOSITION OF GRAIN OF EINKORN AND ITS RELATIVES

Liana RELINA, Oleh SUPRUN, Roman BOHUSLAVSKYI, Liudmyla VECHERSKA, Olha ANTSYFEROVA,
Nina ILCHENKO, Valeriia KOLOMATSKA, Liubov KOBYZEVA

Plant Production Institute named after V. Ya. Yuriev of the National Academy of Agrarian Sciences of Ukraine,
42 Moskovskiy Ave., 61060 Kharkiv, Ukraine

e-mail: lianaisaakovna@gmail.com

Abstract: Einkorn (*Triticum monococcum* L.) has a number of benefits attributed to the quality of its grain. Nevertheless, einkorn oil is little studied. Given a renewed interest in this crop, the purpose of the study was to investigate the lipid contents and fatty acid composition of oil from diploid wheat grain. Oil was extracted from dried whole wheat kernels by Soxhlet procedure. Fatty acid composition was determined by gas chromatography. The oil yield from the diploid wheat grain varied from $2.83 \pm 0.27\%$ dry basis in *Triticum monococcum* var. *sofianum* Stranski to $4.46 \pm 0.49\%$ in *Triticum sinskayae* A. Filat. et Kurk. Six major fatty acids were detected in all the wheat species under investigation. They are ranked in order of decreasing levels as follows: linoleic > oleic > palmitic > linolenic > stearic > palmitoleic. Ploidy doubling brought no significant alterations in fatty acid composition of *T. monococcum* grain. *T. monococcum* var. *sofianum* had the most beneficial unsaturated/saturated ratio (5.3) and the lowest ratio of omega-6/omega-3 (9:1). *Triticum boeoticum* Boiss. (wild progenitor of einkorn) was inferior to domestic diploid wheat in terms of unsaturated fatty acid amounts, despite the very high total oil content ($4.19 \pm 0.48\%$). As wheat oil is used in the cosmetics industry and given the surprisingly high oil yields from the diploid wheat grain, the collection accessions are worth considering through the lens of this trend in wheat products. However, none of the studied accessions can be recommended as breakthrough advantageous because of the ratios of omega-6/omega-3 of not lower than 9:1.

Keywords: diploid wheat, total lipids, oil quality, unsaturated/saturated ratio, omega-6/omega-3 ratio

Introduction

Wheat is the main cereal crop used for human food and animal feed consumption worldwide. Due to mass consumption, its products are among the major dietary sources of essential nutrients, including fatty acids. Common (hexaploid) wheat is widely used for bread making, whereas durum (tetraploid) wheat is mainly utilized in pasta production. Nowadays, einkorn, diploid ($2n=28$) wheat (*Triticum monococcum* L.), is neglected because of low yields and complicated threshing. It is an ancient wheat species and a potential crop for organic farming. Einkorn is generally more resistant to diseases and drought. Presently, *T. monococcum* is only grown in some locations of the Mediterranean area. However, some studies demonstrated that *T. monococcum* boasts other advantages such as low-immunogenic gluten [3, 8], low contents of amylase/trypsin-inhibitors [10], high contents of protein [12], lutein and tocopherols [4, 13, 26], carotenoids [2, 4], resistant starch [4], polyphenolic antioxidants [16], trace elements (selenium) [16]. Einkorn wholemeal flour is rich in lipids (mostly unsaturated fatty acids) [12, 17]. The lipid content in einkorn grain was 50% higher than that in bread wheat grain (4.2 vs. 2.8 g/100 g of dry weight) [19]. Linoleic acid was revealed to be one of the predominant acids among 14 identified fatty acids in *T. monococcum* grain [25]. Domestic einkorn oil has been characterized in several

studies [7, 15, 25]. At the same time, oil from related diploid species has been never investigated, though these can be valuable material for breeding. Taking into account a renewed interest in this crop due to the public concern about dietetic and nutritional aspects [2], the purpose of the study was to investigate the lipid contents and fatty acid composition of oil from grain of different diploid wheat species (including wild einkorn and artificially created tetraploid *T. monococcum*).

Materials and Methods

Test accessions

Accessions of *Triticum boeoticum* Boiss. (UA0300290, Azerbaijan), *Triticum monococcum* L. var. *monococcum* (UA0300116, Syria), *T. monococcum* var. *monococcum* (UA0300221, Azerbaijan), *T. monococcum* var. *monococcum* (UA0300537, Hungary), *Triticum monococcum* var. *sofianum* Stranski (UAUA0300440, Czech Republic), *Triticum sinskayae* A.Filat. et Kurk. (UA0300224, Russia), and *Triticum monococcum* var. *monococcum* tetraploid (UA0300010, Germany) were kindly provided by the National Center for Plant Genetic Resources of Ukraine.

The wheat was grown in experimental plots of the Plant Production Institute named after V.Ya. Yuriev of the National Academy of Agrarian Sciences of Ukraine in compliance with conventional farming techniques. Grain was harvested in 2017, 2018, 2019, 2020, and 2021. Freshly harvested grain was used for analyses.

Total lipid content

Three samples of each accession were analyzed for each year. Hulls were removed manually. Hulled whole wheat kernels were dried (to the constant weight). Then kernels were milled on a laboratory mill LZM (Olis, LLC, Ukraine). Nonpolar lipids were extracted from ground kernels (5 g, in two replications) by Soxhlet procedure [14]. Oil was repeatedly washed (percolated) with petroleum ether of boiling range between 40-60°C. The Soxhlet extractor (Cordial, China) was heated to 40°C (hot extraction). After 6-hour incubation at 40°C, the solvent was evaporated under vacuum using a rotary evaporator RV 10 digital (Ika, Germany). The percentage of oil in the initial sample was calculated using the following formula:

$$T = \frac{W_o \cdot 100}{W_k} ,$$

where T - total nonpolar lipids (hereinafter oil yield), %; W_o - weight of obtained oil; W_k - weight of absolutely dry milled kernels used in a run.

Gas chromatography

Three samples of each accession were analyzed for each year (see sample preparation in *Total lipid content*). Fatty acid methyl esters were prepared by the modified Peisker method [21]. Chloroform - methanol-96% sulfuric acid mixture in a ratio of 100:100:1 was used for methylation. 30 – 50 μ l of lipid extract was placed in a glass ampoule; 2.5 mL of methylation mixture was added, and the ampoule was sealed. Ampoules were incubated in a thermostat at 105°C for 3 hours. After methylation, ampoules were opened, the contents were transferred to test tubes, a pinch of powdered zinc sulfate was added, and then 2 mL of distilled water and 2 mL of hexane were poured to extract methyl esters. After thoroughly stirring and settling, the hexane extracts were filtered and analyzed by gas chromatography [22].

Fatty acid composition was determined using a gas chromatograph Selmikhrom 1 (OAO SELMI, Ukraine) equipped with a flame ionization detector (FID). The stainless steel column, 2.5 m length \times 4 mm i.d., was packed with a stationary phase, Inerton AW-DMCS (0.16-0.20 mm) processed with 10% diethylene glycol succinate. 2 μ l of hexane solution of fatty acid methyl esters was injected. Gas chromatography was operated under the following conditions: nitrogen flow 30 mL/min; hydrogen flow 30-35 mL/min; air flow 300 mL/min; column temperature 180°C; injector temperature 230°C and FID temperature 220°C. The fatty acids were identified by comparing the retention time of sample with those of reference fatty acid methyl esters (Sigma-Aldrich, US).

Data processing

The percentages of fatty acid methyl esters were calculated by internal normalization. The data were statistically processed in STATGRAPHICS PLUS, using ANOVA method. The results are presented as mean \pm standard deviation (SD) and reported to three significant figures. Principal component analysis (PCA) was conducted as described in [23].

Results and Discussion

Oil yield

The oil yield from the diploid wheat grain varied from 2.83 \pm 0.27% dry basis (d.b.) in *T. monococcum* var. *sofianum* to 4.46 \pm 0.49% d.b. in *T. sinskayae*. *T. boeoticum* also exhibited a very high oil yield – 4.19 \pm 0.48% d.b. These values are much higher than those published by other researchers. The total oil yield ranged within 1.45-1.74%, averaging 1.58% in Demir et al.'s study [7] of *T. monococcum* L. subsp. *monococcum*, though these authors used the same procedure as we did. In other cases, differences may be attributed not only to genotype features but also to various degrees of grain grinding or to different solvents used for lipid extraction. Suchowilska et al. [25] reported that the crude fat content in *T. monococcum* was 2.7%, exceeding the corresponding values for their spelt (2.4%) and emmer (2.3%) accessions, yet being significantly lower than in the diploid wheat accessions under investigation. According to the data of Kulatungha et al. [15], the crude fat content in einkorn accessions ranged from 2.1% to 2.5%, depending on the accession, and also exceeding the crude fat content in their emmer (2.0-2.3%), spelt (1.3-1.9%) and spring durum wheat (0.4-1.7%) accessions. In an older study, the crude fat content in *T. monococcum* grain was reported to be comparable with Suchowilska et al.'s [25] results – 2.48% [1]. As wheat oil is used in the health and cosmetics industries and given the surprisingly high oil yields from the diploid wheat grain, the collection accessions are worth considering in the context of this trend in wheat products.

The conditions of the cultivation year do not appear to influence the oil content of the accessions under investigation (the inter-year differences did not exceed 0.5%). Narducci et al. [20] obtained similar results in their study of durum wheat.

Fatty acid composition

Six major fatty acids were detected in all the wheat species under investigation. They are ranked in order of decreasing levels as follows: linoleic > oleic > palmitic > linolenic > stearic > palmitoleic. In some *T. boeoticum* samples a trace amount (0.08%) of myristoleic acid (omega-5) was found, although it was negligible and did not influence the unsaturated/saturated ratio. The only species, in which myristoleic acid was repeatedly detected, was *T. monococcum* var. *sofianum* (0.06 \pm 0.01%). Fig. 1 is a typical chromatogram of *T. monococcum* var. *sofianum*.

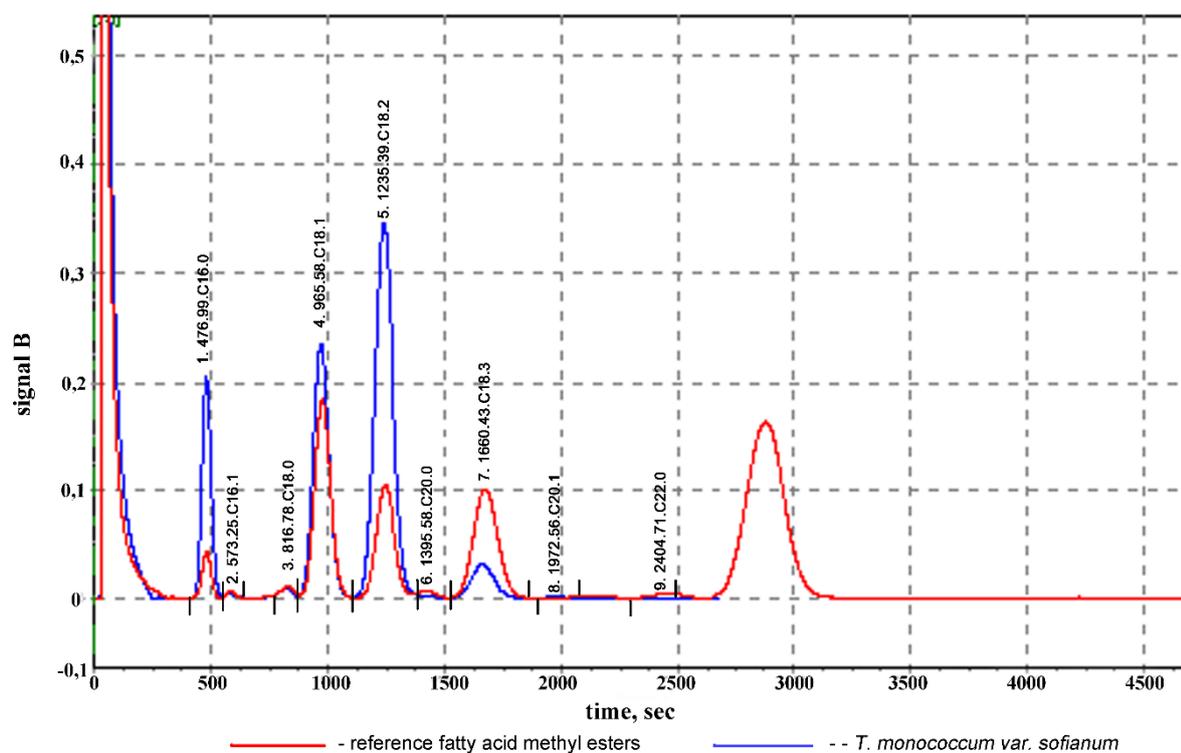


Fig. 1: Chromatogram of fatty acid methyl esters from *T. monococcum* var. *sofianum* grain. Elution time is at the x-axis

This distribution remains unchanged from year to year and is slightly different from the rankings reported by other authors. Demir et al. [7] determined the fatty acid contents in einkorn oil, and their ranking of fatty acids in order of decreasing levels was as follows: linoleic > oleic > palmitic > linolenic > eicosenoic (they did not detect stearic acid). Suchowilska et al. [25] determined the percentages of fatty acids in *T. monococcum* and arranged them in decreasing order as linoleic, oleic, palmitic, α -linolenic and stearic acids. Kulatungha et al. [15] also reported on small amounts of margaric, nervonic, eicosadienoic, and homo- α -linolenic acids. Fatty acids in their study are arranged in order of decreasing levels as follows: linoleic > oleic > palmitic > linolenic > gonodic > stearic and vaccenic > margaric > palmitoleic and nervonic > eicosadienoic and homo- α -linolenic. Trace amounts of three minor fatty acids were also detected in the wheat species under investigation: eicosanoic (arachidic) acid, eicosenoic acid and behenic acid. Their contents were 0.1% in most of the species under investigation (below 0.5% in all the species) and characterized by wide variability.

Azerbaijani *T. monococcum* var. *monococcum* differs ($P < 0.05$) from Hungarian *T. monococcum* var. *monococcum* in palmitic, stearic, oleic, linoleic and linolenic acid content and from Syrian *T. monococcum* var. *monococcum* in palmitic, oleic, linoleic, and linolenic acid content (Table 1).

T. monococcum var. *sofianum* differs ($P < 0.05$) from Azerbaijani *T. monococcum* var. *monococcum* in palmitic, palmitoleic, oleic and linolenic acid content; from Hungarian *T. monococcum* var. *monococcum* in palmitic, palmitoleic, stearic, oleic, linoleic and linolenic acid

content; and from Syrian *T. monococcum* var. *monococcum* in palmitic, palmitoleic, linoleic and linolenic acid content. In general, *T. monococcum* var. *monococcum* grain and *T. monococcum* var. *sofianum* grain are not similar in their amounts of fatty acids.

Azerbaijani *T. monococcum* var. *monococcum* and *T. sinskayae* (which is awnless naked diploid wheat) only differ ($P < 0.05$) in one fatty acid (oleic), though Hungarian *T. monococcum* var. *monococcum* and Syrian *T. monococcum* var. *monococcum* differ in 5 (palmitic, stearic, oleic, linoleic, and linolenic) and 4 (palmitic, stearic, oleic, and linoleic) fatty acids, respectively. As for *T. monococcum* var. *sofianum*, it differs from *T. sinskayae* ($P < 0.05$) in palmitic, palmitoleic, oleic and linolenic acid content.

T. boeoticum is a wild progenitor of einkorn [18]. It is extensively studied as a source of resistance to fungal diseases [6], but little is known about the quality of its grain. *T. boeoticum* differs ($P < 0.05$) from *T. monococcum* var. *sofianum* in palmitic, oleic, linoleic and linolenic acid contents and from *T. sinskayae* in oleic, linoleic, and eicosenoic acid content (it should be noted that it is the only pair of species differing in eicosenoic acid). As to differences between *T. boeoticum* and *T. monococcum* var. *monococcum*, there were differences ($P < 0.05$) in 5 fatty acids between *T. boeoticum* and Syrian *T. monococcum* var. *monococcum* (palmitic, stearic, oleic, linoleic, and linolenic) as well as between *T. boeoticum* and Hungarian *T. monococcum* var. *monococcum* (palmitic, palmitoleic, stearic, linoleic and linolenic), but only in 2 fatty acids ($P < 0.05$) between *T. boeoticum* and Azerbaijani *T. monococcum* var. *monococcum* (oleic and linoleic). Thus, with regard to fatty acid composition, *T. boeoticum* is closer to Azerbaijani *T. monococcum* var. *monococcum* than to Hungarian or Syrian *T. monococcum* var. *monococcum*.

Artificially created tetraploid *T. monococcum* var. *monococcum* and regular einkorn (Azerbaijani *T. monococcum* var. *monococcum* and Hungarian *T. monococcum* var. *monococcum*) showed significant differences ($P < 0.05$) in palmitic, stearic, oleic, linoleic and linolenic acid content. Similar differences were observed between tetraploid *T. monococcum* var. *monococcum* and Syrian *T. monococcum* var. *monococcum*: in palmitic, stearic, oleic and linoleic acid contents. Thus, increase in ploidy was associated with higher content of oleic and stearic acids, but with slightly lower content of palmitic and linoleic acids.

It is evident that *T. sinskayae* did not exceed *T. monococcum* in terms of unsaturated fatty acid contents, though it contained the maximum total oil amount of all the diploid wheat species under investigation. The unsaturated/saturated ratios in *T. monococcum* tetraploid was 5.0, while it ranged from 4.5 (Azerbaijani *T. monococcum*) to 5.3 (*T. monococcum* var. *sofianum*) in regular einkorn. Thus, ploidy doubling brought no significant alterations in fatty acid composition of *T. monococcum* grain. The palmitic acid content was higher in all the studied diploid species (except for *T. monococcum* var. *sofianum* - $14.8 \pm 0.16\%$) in comparison with the published data: $10.3 \pm 0.98\%$ [7] and 14.9% (no standard error of mean [SEM] or SD reported) [25]. Suchowilska et al. [25] detected no palmitoleic acid in einkorn. The stearic acid content was higher (0.96%) in oil from einkorn grain in Suchowilska et al.'s [25] study than in oil from the *T. monococcum* var. *monococcum* accessions under investigation (but not in *T. sinskayae* [$1.04 \pm 0.06\%$] and *T. monococcum* var. *sofianum* [$1.01 \pm 0.04\%$] grain). The oleic acid content in oil in Demir et al.'s [7] study was surprisingly high ($34.3 \pm 1.10\%$) in comparison with Suchowilska et al.'s [25] data (26.4%) and the values obtained in this study ($27.7 \pm 0.19\%$ - $29.5 \pm 0.04\%$). The linoleic acid content was the highest in Suchowilska et al.'s [25] study.

Table 1: Fatty acid composition of grain oil from einkorn and related species (relative content, %)

Source	Palmitic 16:0	Palmitoleic 16:1n-7	Margaric 17:0	Stearic 18:0	Oleic 18:1n-9	Vaccenic 18:1n-7	Linoleic 18:2n-6	Linolenic 18:3n-3	Eicosanoic 20:0	11- Eicosenoic (gonodic) 20:1n-9	Eicosadienoic 20:2n-6	Homo- alpha- linolenic 20:3n-3	Behenic 22:0	Nervonic 24:1n-9	Unsaturated / Saturated Ratio	Omega- 6/Omega- 3 Ratio
15	15.4 ± 0.4	0.2 ± 0.0	0.2 ± 0.1	1.1 ± 0.1	27.8 ± 0.2	1.1 ± 0.1	54.2 ± 0.4	3.3 ± 0.3	Not reported	1.5 ± 0.1	0.2 ± 0.0	0.1 ± 0.0	Not reported	0.2 ± 0.0	5.2	16:1
7	10.3±0.98	Not reported	Not reported	Not reported	34.3±1.10	Not reported	49.4±0.98	3.59±0.49	Not reported	2.38±0.46	Not reported	Not reported	Not reported	Not reported	8.7	14:1
25	14.9	Not reported	Not reported	0.96	26.4	Not reported	52.8	3.76	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported	5.2	14:1
Our species or cultivar																
<i>T.boeoticum</i>	17.0±0.01 ^{thi}	0.28±0.01 ⁱ	Not detected	1.05±0.01 ^{hi}	29.6±0.17 ^{fghj}	Not detected	47.2±0.09 ^{fghij}	4.31±0.02 ^{thi}	0.13±0.02	0.12±0.01 ^g	Not detected	Not detected	0.23±0.09	Not detected	4.4	11:1
<i>T. monococcum</i> var. <i>monococcum</i> (Syria)	15.9±0.05	0.08±0.04	Not detected	0.79±0.13	28.5±0.13	Not detected	50.3±0.16	3.83±0.11	0.08±0.01	0.13±0.01	Not detected	Not detected	0.35±0.05	Not detected	4.8	13:1
<i>T. monococcum</i> var. <i>monococcum</i> (Azerbaijan)	17.0±0.27 ^{ab}	0.14±0.05	Not detected	0.88±0.03 ^a	28.3±0.20 ^{ab}	Not detected	48.8±0.30 ^{ab}	4.35±0.07 ^{ab}	0.08±0.01	0.10±0.01	Not detected	Not detected	0.35±0.07	Not detected	4.5	11:1
<i>T. monococcum</i> var. <i>monococcum</i> (Hungary)	15.2±0.18	0.06±0.01	Not detected	0.57±0.09	29.5±0.04	Not detected	50.1±0.07	3.98±0.11	0.09±0.02	0.14±0.01	Not detected	Not detected	0.38±0.03	Not detected	5.1	13:1
<i>T. monococcum</i> var. <i>sofianum</i>	14.8±0.16 ^{cdk}	0.50±0.21 ^{cdk}	Not detected	1.01±0.04 ^d	28.7±0.07 ^{cdk}	Not detected	49.0±0.32 ^{de}	5.38±0.09 ^{cdk}	0.21±0.01	0.17±0.02	Not detected	Not detected	0.30±0.03	Not detected	5.3	9:1
<i>T. sinskayae</i>	17.2±0.18 ^{op}	0.08±0.01	Not detected	1.04±0.06 ^{op}	27.7±0.19 ^{opr}	Not detected	49.0±0.04 ^{op}	4.51±0.04 ^o	0.09±0.02	0.11±0.01	Not detected	Not detected	0.32±0.02	Not detected	4.4	11:1
<i>T. monococcum</i> var. <i>monococcum</i> tetraploid	15.0±0.07 ^{lmn}	0.06±0.01	Not detected	1.15±0.13 ^{lmn}	32.4±0.17 ^{lmn}	Not detected	47.3±0.43 ^{lmn}	3.60±0.08 ^{lm}	0.07±0.03	0.14±0.01	Not detected	Not detected	0.39±0.09	Not detected	5.0	13:1

Note: ^a significant differences between Azerbaijani *T. monococcum* var. *monococcum* and Hungarian *T. monococcum* var. *monococcum* (P<0.05); ^b significant differences between Azerbaijani *T. monococcum* var. *monococcum* and Syrian *T. monococcum* var. *monococcum* (P<0.05); ^c significant differences between *T. monococcum* var. *sofianum* and Azerbaijani *T. monococcum* var. *monococcum* (P<0.05); ^d significant differences between *T. monococcum* var. *sofianum* and Hungarian *T. monococcum* var. *monococcum* (P<0.05); ^e significant differences between *T. monococcum* var. *sofianum* and Syrian *T. monococcum* var. *monococcum* (P<0.05); ^f significant differences between *T. boeoticum* and *T. monococcum* var. *sofianum* (P<0.05); ^g significant differences between *T. boeoticum* and *T. sinskayae* (P<0.05); ^h significant differences between *T. boeoticum* and Syrian *T. monococcum* var. *monococcum* (P<0.05); ⁱ significant differences between *T. boeoticum* and Hungarian *T. monococcum* var. *monococcum* (P<0.05); ^j significant differences between *T. boeoticum* and Azerbaijani *T. monococcum* var. *monococcum* (P<0.05); ^k significant differences between *T. monococcum* var. *sofianum* and *T. sinskayae* (P<0.05); ^l significant differences between *T. monococcum* var. *monococcum* tetraploid and Azerbaijani *T. monococcum* var. *monococcum* (P<0.05); ^m significant differences between *T. monococcum* var. *monococcum* tetraploid and Hungarian *T. monococcum* var. *monococcum* (P<0.05); ⁿ significant differences between *T. monococcum* var. *monococcum* tetraploid and Syrian *T. monococcum* var. *monococcum* (P<0.05) ^o significant differences between *T. sinskayae* and Hungarian *T. monococcum* var. *monococcum* (P<0.05); ^p significant differences between *T. sinskayae* and Syrian *T. monococcum* var. *monococcum* (P<0.05); ^r significant differences between *T. sinskayae* and Azerbaijani *T. monococcum* var. *monococcum* (P<0.05).

The linolenic acid content in Suchowilska et al.'s [25] and Demir et al.'s [7] studies was slightly lower than in oil from the accessions under investigation. The eicosenoic acid content was also surprisingly high ($2.38 \pm 0.46\%$) in Demir et al.'s [7] study; (Suchowilska et al. [25] detected no eicosenoic acid in *T. monococcum*; $0.10 \pm 0.01\%$ - $0.14 \pm 0.01\%$ in this study). Therefore, due to oleic and eicosenoic acids, the unsaturated/saturated ratio calculated from Demir et al.'s data [7] was extremely high – 8.7 (5.2 in Suchowilska et al.'s [25] and Kulatungha et al.'s [15] studies; 4.4- 5.1 in this study). The discrepancies in fatty acid amounts between different studied may be caused by peculiarities of investigated genotypes or by even by minor differences in gas chromatography protocols. Of the diploid wheat accessions under investigation, *T. monococcum* var. *sofianum* had the most beneficial unsaturated/saturated ratio (5.3), primarily due to a relatively low content of palmitic acid ($14.8 \pm 0.16\%$) and an unexpectedly high content of linolenic acid ($5.38 \pm 0.09\%$). Demir et al. [7] only detected $3.59 \pm 0.49\%$ of linolenic acid, and Suchowilska et al. [25] – 3.76%. The highest unsaturated/saturated ratio of 5.3 in grain of *T. monococcum* var. *sofianum* is even more remarkable given that the total oil yield from grain of this species was the minimum across the accessions under investigation.

T. boeoticum accession was inferior to domestic diploid wheat in regard to unsaturated fatty acid quantities, despite the very high total oil content.

To demonstrate similarities and distinctions more comprehensively, we applied PCA. Table 2 shows the most significant principal components (PCs) generated from the diploid wheat fatty acid data. The first principal component (i.e., PC1) had the highest eigenvalue of 3.74 and accounted for 41.51% of the variability in the data set. The second and third PCs (PC2 and PC3) had eigenvalues of 2.45 and 2.22 and accounted for 27.26% and 24.64% of the variance in the data, respectively. The remaining three generated PCs (PC4 to PC6) yielded progressively smaller eigenvalues and did not explain significant variability in the data. These numbers represent significant contributions of individual fatty acid variables to the total variability explained by the generated PCs. PC1 had high contributions from palmitoleic (0.98), linolenic (0.89), eicosanoic (0.98), eicosenoic (0.55) and behenic (-0.67) acid variables. PC2 showed significant loadings for palmitic (0.98), oleic (-0.53), eicosenoic (-0.82) and behenic (-0.59) acids. PC3 was most described by stearic (0.78), oleic (0.80) and linoleic (-0.92) acids.

Table 2: Eigen analysis of the correlation matrix loadings of the significant

Fatty acid	PC 1	PC 2	PC 3
Palmitic 16:0	-0.18	0.98	-0.06
Palmitoleic 16:1n-7	0.98	-0.04	-0.01
Stearic 18:0	0.37	0.28	0.78
Oleic 18:1n-9	-0.21	-0.53	0.80
Linoleic 18:2n-6	-0.22	-0.26	-0.92
Linolenic 18:3n-3	0.89	0.15	-0.31
Eicosanoic 20:0	0.98	-0.14	-0.11
11-Eicosenoic (gonodic) 20:1n-9	0.55	-0.82	0.01
Behenic 22:0	-0.67	-0.59	-0.10
Eigenvalue	3.74	2.45	2.22
Variance (%)	41.51	27.26	24.64

Fig. 2 depicts the score plot of fatty acids in the diploid wheat accessions (n=7) generated from comparing PC1, PC2, and PC3 and revealed that Azerbaijani *T. monococcum* var. *monococcum* and *T. sinskayae* formed the closest grouping. Syrian *T. monococcum* var. *monococcum* and Hungarian *T. monococcum* var. *monococcum* were not so close, but were still located in the same plane constructed by PC1 and PC2. *T. monococcum* var. *sofianum* and the Syrian *T. monococcum* var. *monococcum* and Hungarian *T. monococcum* var. *monococcum* grouping lay relatively close to the PC1-PC2 plane. The wild species, *T. boeoticum*, was located quite far from the domestic diploid wheat accessions (*T. monococcum*). The artificially created form, tetraploid *T. monococcum* var. *monococcum*, was closer to the Syrian *T. monococcum* var. *monococcum* and Hungarian *T. monococcum* var. *monococcum* grouping than to the other accessions under investigation.

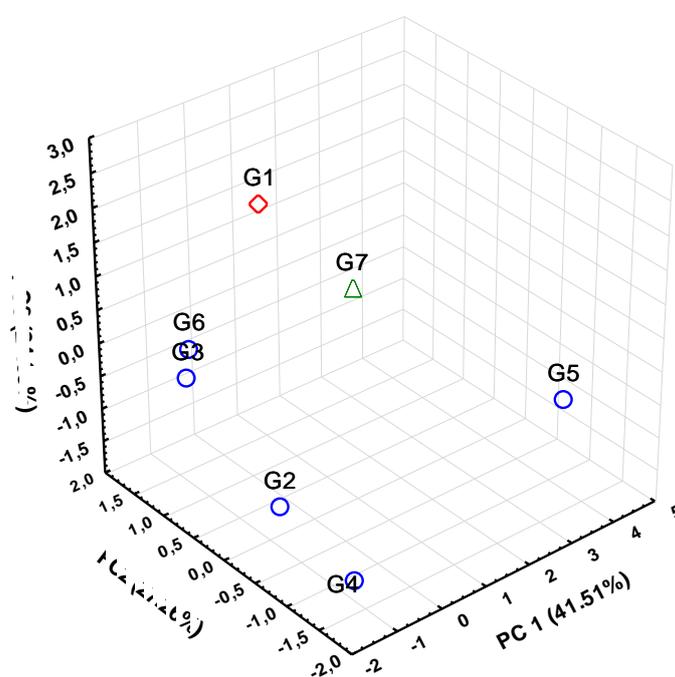


Fig. 2: Score plot of PC1-PC2-PC3 for fatty acid profiles in diploid wheat (G1 -*T. boeoticum*; G2 - *T. monococcum* var. *monococcum* (Syria); G3 - *T. monococcum* var. *monococcum* (Azerbaijan); G4 - *T. monococcum* var. *monococcum* (Hungary); G5 - *T. monococcum* var. *sofianum*; G6 - *T. sinskayae*; G7 - *T. monococcum* var. *monococcum* tetraploid)

Another important characteristic of any oil is the ratio of omega-6/omega-3 essential fatty acids. Some medical studies suggest that excessive levels of omega-6 fatty acids relative to omega-3 fatty acids may increase the risk of certain diseases [5, 11]. Modern Western diets typically have ratios of omega-6/omega-3 of 20:1 or even 30:1, with the average of 15–17, mainly from vegetable oils, whereas the optimal ratio is thought to be 4:1 or lower [9, 25]. Through the lens of this indicator, none of the studied accessions can be recommended as breakthrough advantageous

because of the ratios of omega-6/omega-3 of not lower than 9:1 (Table 1), though the ratios of omega-6/omega-3 in the diploid wheat species under investigation were somewhat better than those calculated from the published data (14:1) [7, 25] or even 16:1 [15]. In wild diploid wheat *T. boeoticum*, the ratio of omega-6/omega-3 is 11:1; in most of the domestic diploid wheat accessions under investigation this ratio is 11:1 or 13:1. Thus, *T. boeoticum* did not best einkorn by this indicator. On the other hand, *T. monococcum* var. *sofianum* had the lowest the ratio of omega-6/omega-3 – 9:1, due to a surprisingly high content of linolenic acid, as it has been mentioned above.

Conclusions

The oil yield from grain of the collection accessions of diploid wheat turned out to be surprisingly high. As wheat oil is used in the cosmetics industry, the collection accessions are worth considering in the context of this trend in the use of wheat products. Six major fatty acids were detected in all the wheat species studied. They are ranked in order of decreasing levels as follows: linoleic > oleic > palmitic > linolenic > stearic > palmitoleic. Ploidy doubling brought no significant alterations in fatty acid composition of *T. monococcum* grain. In terms of fatty acid composition, *T. boeoticum* is closer to Azerbaijani *T. monococcum* var. *monococcum* than to Hungarian or Syrian *T. monococcum* var. *monococcum*. In addition, *T. boeoticum* was inferior to domestic diploid wheat in terms of unsaturated fatty acid amounts, despite the very high total oil content. *T. sinskayae* did not best other diploid wheat species in terms of unsaturated fatty acid contents, though it contained the maximum total oil amount. *T. monococcum* var. *sofianum* had the most beneficial unsaturated/saturated ratio and the lowest ratio of omega-6/omega-3, though the total oil yield from grain of this species was the minimum across the accessions under investigation. PCA revealed that Azerbaijani *T. monococcum* var. *monococcum* and *T. sinskayae* formed the closest grouping.

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COMPOZIȚIA ÎN ACIZI GRAȘI A BOABELOR DE ALAC ȘI A SPECIILOR ÎNRUDITE

(Rezumat)

Alacul (*Triticum monococcum* L.) prezintă o serie de beneficii atribuite calității boabelor sale. Cu toate acestea, uleiul de alac este puțin studiat. Având în vedere interesul crescut pentru această cultură, scopul acestui studiu a fost de a investiga conținutul de lipide și compoziția în acizi grași a uleiului obținut din boabele de grâu diploid. Uleiul a fost extras, prin procedura Soxhlet, din boabe integrale de grâu uscate. Compoziția în acizi grași a fost determinată prin cromatografie de gaz. Conținutul de ulei din boabele de grâu a variat de la $2,83 \pm 0,27\%$ bază uscată pentru *Triticum monococcum* var. *sofianum* Stranski la $4,46 \pm 0,49\%$ pentru *Triticum sinskayae* A.Filat. et Kurk. Pentru toate speciile de grâu investigate au fost identificate șase tipuri de acizi grași. Aceștia sunt prezentați în ordine descrescătoare: linoleic > oleic > palmitic > linolenic > stearic > palmitoleic. Diploidia nu a cauzat modificări semnificative în compoziția acizilor grași din boabele de *T. monococcum*. *T. monococcum* var. *sofianum* a avut cel mai benefic raport nesaturat/saturat (5,3) și cel mai mic raportul omega-6/omega-3 (9:1). *Triticum boeoticum* Boiss. (progenitor spontan al alacului) a fost inferior grâului diploid cultivat, în ceea ce privește cantitățile de acizi grași nesaturați, în ciuda conținutului foarte mare de ulei total ($4,19 \pm 0,48\%$). Întrucât uleiul de grâu este folosit în industria cosmetică și având în vedere cantitatea mare de ulei din boabele de grâu diploid, considerăm că aceste informații merită luate în considerare în ceea ce privește produsele obținute din grâu. Cu toate acestea, însă, nu se poate face o recomandare unică standard, ca fiind foarte avantajoasă, din cauza raporturilor omega-6/omega-3, care nu au valori mai mici de 9:1.