The correlation between nutritional and health potential and antioxidant properties of raw edible oils from cultivated and wild plants

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Abstract

The nutritional properties and health potential of oils from 15 various cultivated and wild plants were investigated on the basis of the fatty acids profiles, total carotenoids and tocopherols content, antioxidant properties and health potential indexes such as atherogenicity index (AI). The oil contents of the plants varied between 0.9 g/100 g for lychee seeds and 29.7 g/100 g for borage seeds. The tocopherol content in oils ranged from 0.31 (lingonberry fruits) to 226.23 mg/100 g (hawthorn pulp), carotenoids ranged from 0.36 (borage seeds) to 14.22 mg/100 g (blackcurrant seeds). In four oils (raspberry seed, strawberry seed, lingonberry fruits, blackcurrant seeds) the PUFA contents contributed over 70% of the total fatty acids (FA), which was associated with the best values health potential indexes. It was found that TAC (Total Antioxidant Capacity) can be an indirect measure of the levels of carotenoids and tocopherols in oils. Additionally, a positive correlation between the level of carotenoids and the FA n-3 was demonstrated. Determining such relationships may facilitate research into new sources of valuable edible oils useful for the production of functional foods, dietary supplements and cosmetics.

Keywords: edible oil, antioxidant properties, fatty acids, carotenoids, tocopherols

Abbreviations: ABTS 2,2'-azino-bis (3-ethylbenzthiazoline-6-acid; AI atherogenicity index; ALA alfa-linolenic acid; DHA docosahexaenoic acid; DPPH 2,2-diphenyl-1-picrylhydrazyl; EPA eicosapentaenoic acid; FA fatty acids; FAME fatty acid methyl esters; GLA gamma-linolenic acid; HH hypocholesterolaemic/ hypercholesterolaemic ratio; LA linoleic acid; MUFA monounsaturated fatty acids; PA – palmitic acid; PUFA polyunsaturated fatty acids; SA stearic acid; SFA saturated fatty acids; SD standard deviation; SDA stearidonic acid; TAC Total Antioxidant Capacity; TCR total carotenoids; TE trolox; 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid; TEAC Trolox Equivalent Antioxidant Capacity; TI thrombogenicity index; TTP total tocopherols; ΔTC theoretical changes in plasma Total Cholesterol; ΔLDL theoretical changes in plasma Low-Density Lipoprotein Cholesterol

Introduction

Unhealthy eating habits, stress, lack of physical exercise and environmental pollution contribute to lifestyle diseases such as obesity, diabetes, hypertension, atherosclerosis and cancer [1,2]. Growing consumer awareness drives the demand for functional foods, rich in antioxidants and other health-promoting components (e.g. fruits of wild plants such as sea buckthorn and acai berries) and contribute to the prevention of lifestyle diseases [3–5].

In recent years, oils from certain plants, especially obtained by cold pressing, have been identified as a good source of functional compounds. Lipids, as one of the elementary nutrients, fulfill many functions in the human body [6–9]. The lipid fraction of many fruits and wild plants is rich in bioactive compounds and may become a desirable component of the human diet [5,10–12]. Plant oils contain polyunsaturated fatty acids (PUFAs) whose content varies across plant species. PUFAs play a host of important biological roles in the human body. They determine the structure of cell membranes, limit triglyceride synthesis, regulate insulin secretion and serve as substrates for the synthesis of eicosanoids [6,7,13]. Vegetable oils contain antioxidants such as tocochromanols, carotenoids, squalene and phenolic compounds which prevents the damage caused by free radical. The content of antioxidants is a species-specific feature, but it is also influenced by the quality, type and variety of plants, weather conditions and the applied agricultural treatments [14,15].

Consumers have growing interests in products with antioxidant properties, which motivates the search for new and unconventional sources of plant lipids that are rich in PUFAs and antioxidant compounds. Such new plant oil sources include sea buckthorn, evening primrose and pomegranate seed [10,16]. Likewise, agro-industrial wastes may be a potential bioactive oils and compounds sources [5,17].

The aim of this study was to determine the correlation between the nutritional and health potentials of cold-extracted oils from various parts of cultivated and wild plants, and their antioxidant properties. The nutritional potential of oils were detected on the basis of the fatty acids (FAs) profiles, total carotenoids and tocopherols content. The thrombogenicity index (TI), atherogenicity index (AI), polyunsaturated fatty acids/ saturated fatty acid ratio (P/S), plasma Total Cholesterol (ΔTC) and Low-Density Lipoprotein Cholesterol (ΔLDL cholesterol) were used as a measure of the health potential of oils. In order to assess the antioxidant capacities of the tested oils, the ABTS (TEAC value) and DPPH radical scavenging assays were applied.

Materials and Methods

Materials

Plant parts included seeds, pulp and whole fruits from conventional and unconventional plant oils sources characteristic of Central Europe and originating from Asia and grown in Europe. Plant products came from horticultural farms and markets in the Pomeranian region of Poland. The research material were borage (*Borago officinalis)* seeds, raspberry *(Rubus idaeus)* seeds, strawberry (*Fragaria ananassa)* seeds, apple (*Malus mill)* seeds, blackcurrant (*Ribes nigrum)* seeds, Japanese quince (*Chaenomeles japonica)* seeds, lychee (*Litchi chinensis)* seeds, oleaster (Russian olive, *Elaeagnus angustifolia)* seeds, common hawthorn (*Crataegus monogyna)* seeds and pulp (without seeds), cornelian cherry *(Cornus mas),* schisandra (*Schisandra chinensis)* berries, lingonberries *(Vaccinium vitis-idaea),* rowan *(Sorbus aucuparia)* and elderberries (*Sambucus nigra)* fruits.

Lipid extraction

Lipids were extracted from freeze-dried and ground plant samples (seeds, pulp or all fruits) according to the procedure described by Bligh & Dyer[18]. Briefly, methanol, chloroform and aqueous sodium chloride solution were added to the sample in a two-step extraction. The chloroform lipid fraction were separated by centrifugation, and the solvent was removed under a stream of nitrogen (Table 1). Extracted oils were stored at 4 °C until analyzed.

ABTS assay

The total antioxidant capacity (TAC) of lipids was determined by the ABTS (2,2‘-azino-bis (3-ethylbenzthiazoline-6-acid)) radical cation assay[5]. The working solution was obtained by diluting the $ABTS^{\bullet+}$ stock solution (ABTS dissolved in sodium persulfate solution) with ethanol to obtain an absorbance of 0.7 ± 0.01 at 734 nm. An aliquot of 20 μL of the n-hexane solution of each oil (0.2 g/mL) was combined with 2 mL of the $ABTS^{\bullet+}$ solution. Absorbance was measured after 15 min by using UV-VIS spectrophotometer (Yenway 6305, Witko, Łódź, Poland) at 734 nm and TAC was calculated using a Trolox (Sigma-Aldrich, Merck, Poznań, Poland) standard curve. The antioxidant properties were expressed in milligrams of the Trolox Equivalent (TE) per 100 g of oil and presented as the Trolox Equivalent Antioxidant Capacity (TEAC).

DPPH assay

The DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging activity was determined as described by da Silva & Jorge[5]. The $DPPH^{\bullet}$ stock solution (0.1 mM) was prepared by dissolving a DPPH radical in ethanol. Next, 60μL of different solutions of the tested oils (concentration of

25, 50, 75 and 100 mg /1 mL of ethyl acetate) were combined with 2 mL of 0.1 mM DPPH•. The mixtures were shaken and left in dark for 30 min. Absorbance was measured by using UV-VIS spectrophotometer (Yenway 6305, Witko, Łódż, Poland) at 517 nm against ethanol. The inhibition of the DPPH• was calculated using the equation: IC(%) = 100 x ($A_0 - A_s$) / A_0, where A_0 is the absorbance of the control sample (60µL of ethyl acetate instead of an oil solution) and A_s is the absorbance of the tested samples. The effective concentration of oils required to inhibit of the free radical DPPH by 50 % (IC_{50}) was calculated based on the standard curve of IC(%) =f (oil concentration). Determinations were performed in triplicate.

Total tocopherols

Lipids extracted from plants was dissolve with n-hexane (40 mg/mL). Tocopherols were separated by normal-phase high-performance liquid chromatography (NP- HPLC) with UV detection (λ = 295 nm) on a Silica column (150 mm×4.6 mm, i.d. 5 µm, Phenomenex)[19]. Tocopherols were eluted isocratically using hexane:ethyl acetate, 85:15 (v:v) at a flow rate of 0.8 mL/min. Quantification was carried out using external standard curves of the individual tocopherols.

Total carotenoids

The total carotenoid content was determined spectrophotometrically. In this assay, 1.0 g of lipid was dissolved in 10 mL of n-hexane and the absorbance was measured in triplicate at 446 nm (Yenway 6305 UV-VIS, Witko, Łódż, Poland). The total carotenoid content was expressed as mg of β-carotene per 100 gram of oil (mg β-carotene/100g)[20].

Fatty acid composition

The FA composition of the oils was determined as fatty acid methyl esters (FAME). FAME was prepared using the boron trifluoride standard method [21]. The FAME were analyzed by high-resolution gas chromatography (HR-GC) on a Hewlett-Packard gas chromatograph with a flame-ionization detector (FID), with an Rtx 2330 capillary column (100m x 0.25 mm, Restek, USA). Helium carrier-gas column flow rate was 0.9 mL/min. A split-splitless injector (split mode ratio 1:100) at 250°C and flame-ionization detector (FID) at 250°C were used. The column temperature, after an initial isothermal period of 30 min at 150°C, was increased to 210°C at a rate of 1.5°C/min, and maintained for 40 min. Qualitative and quantitative analysis of FA were performed by internal standard method and correction factors using FAME standards (Supelco, USA) [22]. The FA composition was reported as the weight percentage of total FAs.

Determination of health potential of oils

Health- promoting potential of the analyzed oils we estimated on the basis of health potential indexes, which take into account the effects the dietary factors (saturated SFA, monounsatureted MFA and polyunsaturated PUFA fatty acids) on cardiovascular disease. The atherogenicity index (AI, thrombogenicity index (TI) and polyunsaturated FA/ saturated FA ratio (P/S) were calculated as described by Ulbricht & Southgate [23], while theoretical changes in plasma Total Cholesterol (ΔTC) and Low-Density Lipoprotein Cholesterol (ΔLDL) (mmol/L) were estimated as described by Muller et al. [24]

Statistical analysis

Determinations were done in triplicates, and results were reported as mean values with standard deviation (SD). The statistical analysis was conducted using Statistica 11.0 program (Systat Software, Inc., USA). The strength of the correlations between the composition of oils and their calculated health-promoting and antioxidant properties were expressed by the value of the Pearson correlation coefficient at $p = 0.05$ [25].

Results and Discussion

Total lipid content

Among the tested samples, only *Borago officinalis* seeds can be considered a good source of edible oils. As expected, the seeds of this plant contained the highest total lipid followed by raspberry seeds (nearly 20 % of dry matter), then blackcurrant seeds (about 17%, Table 1), whiles lychee seeds recorded the lowest lipid content of 0.94 %, hence a poor source of lipids. The lipid content of plants is determined by species as well as the analyzed part of the plant. The pulp of common hawthorn was more abundant in lipids (3.6 % of dry matter) than its seeds (2.8 %). Comparing the fruits, Schisandra berries recorded the highest lipid content (9.4%) whiles Elderberry had the lowest lipid (1.34%). The obtained results of lipid content in the tested plants are consistent with the available literature data (Table 1). In the case of Lingonberry and Elderberry reference data (only one source) indicate a significantly lower lipid content in the fruit weight.

Composition and content of fatty acids

The analyzed oils contained 8 to 22 different FAs (at levels ≥0.05 % of total FAs), with a predominance of linoleic acid (LA, C18:2 n-6), oleic acid (OA, C18:1 n-9), alpha-linolenic acid (ALA, C18:3 n-3), gamma-linolenic acid (GLA, C18:3 n-6), palmitic acid (PA, C16:0) and stearic acid (SA, C18:0) (Table 2). In most cases, these FAs accounted for 90-99% of the total FAs. The oil extracted from rowan fruits had the highest content of saturated fatty acids (SFA),

about 30% of total FA with a predominance of PA making up 22% of oil's FA (Table 3). The apple seeds oil is composed of about 36 % of monounsaturated FA (MUFA), mainly OA (35% of total FA). Other rich sources of MUFA included the oils extracted from lychee and oleaster seeds (about 34%), where OA accounted for 94 and 75% of MUFA, respectively. Raspberry seed oil had the highest PUFA content (about 82%), whiles Hawthorn pulp oil had the lowest amount (about 48%). In five oils (raspberry seed, strawberry seed, lingonberry fruits, blackcurrant seed, elderberry fruits) the PUFA contents contributed over 70% of the total fatty acids (FA). For all oils, LA was the most abundant FA ranging from about 32 % in oleaster (Russian olive) seed to almost 70 % in schisandra fruits oil.

LA and ALA are essential FAs and the precursors of endogenous n-6 and n-3 FAs. LA is a precursor of arachidonic acid (20:4 n-6), the substrate for the biosynthesis of proinflammatory eicosanoids and the building block of membrane phospholipids in neurons and retinal receptors. ALA is a precursor of eicosapentaenoic acid (EPA, 20:5 n-3) and docosahexaenoic acid (DHA, 22:6 n-3) which are essential for the development of neurons, brain and retinal tissues [7,39]. The metabolites of n-6 and n-3 PUFA have mutually antagonistic effects. The metabolites of n-6 PUFA have proinflammatory and prothrombotic effects, whereas the metabolites of n-3 PUFA exert anti-inflammatory effects and inhibit platelet aggregation [12,23]

The richest sources of ALA and n-3 FAs are seafood and plant oils from linseed (around 60 % ALA), rapeseed (around 9 %) and soybean (around 8 %). In this study, most oils were also a very good source of ALA. The highest ALA content was observed in oils from strawberry seed, lingonberry, raspberry seed and elderberry seed (29-36 %). Only apple seed and schisandra seed oils contained less than 1% ALA.

The human diet should include foods abundant in FA precursors, but it should also be characterized by a healthy ratio of n-6 to n-3 PUFA. The n-6/n-3 ratio is considered to be the key factor for balanced synthesis of eicosanoids and also affects the metabolism of ALA to EPA and DHA because the same enzymes participate in metabolic processes of both FA groups. The optimal n-6/n-3 PUFA ratio in the human diet is 2-5 [40]. The Western diet is much more abundant in n-6 than n-3 FA, which can disrupt the synthesis of n-3 FA. Excessive levels of LA, which is derived mainly from vegetable oils, block the respective enzymes and prevent the synthesis of long-chain n-3 PUFA (EPA and DHA). Moreover, the bioconversion of ALA to EPA and DHA is poor, hence it is recommended to consume more natural sources of EPA and DHA. Therefore oils containing the metabolites of both FA groups, such as χ-linolenic acid (GLA, 18:3 n-6) or stearidonic acid (SDA, 18:4 n-3), have very high biological value. GLA and SDA are intermediate FA in the biosynthesis pathway from of LA to AA and ALA to EPA and

DHA. Their presence increases the efficiency of this process, providing substrates for the synthesis of eicosanoids even when FA metabolism is disrupted. There is a growing body of evidence that LC-PUFA deficiency and unbalanced n-6/n-3 PUFA ratio in early childhood can lead to developmental dysfunctions and neurological problems, including ADHD, dyslexia or even autism [7,8,13]. GLA has treatment of pharmaceutical production and being an important dietary and cosmetic.[41]

In this study, the best n-6/n-3 PUFA ratio was determined in the oils from strawberry seeds, lingonberries, elderberries seeds end raspberry seeds, which deliver significant health benefits (Table 3). Borage seed, blackcurrant seed and cornelian cherry fruit oils contain 20%, 15 % and 1% of GLA, respectively (Table 2). The presence of GLA was also noted in schisandra fruit and lingonberry oils, but in smaller quantities (<0.3%). Moreover blackcurrant oil contained SDA, a metabolite of ALA (about 3%) which makes this oil one of the most interesting vegetable oils.

Health potential of oils

Among the currently recognized dietary factors that promote the development of cardiovascular diseases can be included cholesterol-raising atherogenic and thrombogenic SFAs, while the protective functions are assigned to n-6 and n-3 PUFA and antioxidants. In general, n-6 PUFA class have an anti-atheratogenic action and PUFA belonging to the n-3 class are appreciated for their anti-thrombogenetic effect [12,23,42,43]. The health-promoting potential of edible oils can be predicted from the FA composition[23,24,43].

Among the tested oils the best anti-atherogenic (low level of AI), anti-thrombogenic (low TI) and hypocholesteromic (ΔTC and ΔLDL values < -1.0 mM/L) predicted health potential properties shown the raspberry and strawberry seeds oils and oil from lingonberry fruits (Table 3). The lower the values of both parameters (ΔTC and ΔLDL) the higher the theoretical decrease in the level of undesirable fractions of cholesterol in the blood serum. All oils showed have a beneficial PUFA/SFA ratio, which ranged from 1.49 (Hawthorn pulp) up to a very high value of 15.96 for the oil Raspberry seed oil. WHO recommends the ratio of above 0.4, so all oils met this recommendation. [40] The health potential indexes in a purely theoretical way represent the health properties of oils, in based only on the FA profile. The nutritional and health value of oils is also influenced by other components, especially antioxidants. Due to the high content of SFA, rowan fruit oil showed the least desirable values of the studied factors (positive ΔTC and ΔLDL values and the highest AT and IT). However, this oil also showed the recommended P/S

ratio which, combined with the high level of antioxidants (TEAC 491 mg/ 100 g) and carotenoids (9.82 mg /100 g), does not disqualify this oil as a healthy dietary component.

Tocopherols and carotenoids contents

Hawthorn pulp recorded the highest tocopherols content (TTP) (226 mg/100g of lipid), followed by raspberry seeds (169 mg/100 g) and then borage seed (136 mg/100g) oils (Table 4). Hawthorn seed oil, however, contained only about 30 mg TTP /100 g. Higher tocopherols content in Hawthorn pulp oil than in seed oil may be related to the much higher level of ALA in the former (17 and 2% respectively). Although further reported studies did not show an overall correlation between FAs n-3 family and the tocopherols content. Anwar et al. [19] found a higher content of tocopherols (over 280 mg /100 oil) in the oil of hawthorn seed of the species *Crataegus mordenensis*. However, the level of bioactive ingredients can vary significantly within one plant depending on the species and cultivation methods. The content of tocopherols in borage oil can range from 105 to 514 mg per 100 g oil, depending on the borage species and the growing region[11]. While the hawthorn pulp contained the highest level of tocopherols, the level of these compounds in the oil from other fruits did not exceed 22 mg /100 g. Rowan and lingonberry fruit contained the least amounts of tocopherols, 1.3 and 0.3 mg/ 100 g, respectively. The commonly used in households rapeseed oil (crude) contains a high amount of tocopherols (43 –268 mg/100 g), sunflower crude oil – about 30 mg/100g.[44]

In the tested lipid samples total carotenoid content ranged from 0.39 mg/100 g in borage seed oil to 14.22 mg per 100 g in blackcurrant seed oil (Table 4). Rapeseed crude oil contain low amount of carotenoids, only 1.5 – 2.0 mg/ 100 mg, while sea buckthorn pulp oil may contain from 300 to 1000 mg/100 g.[44,45] Carotenoids are one of the most widely natural pigments occurring in nature. They were found throughout the all plant subgroups (fruit, vegetables, flowers) and in tissues of bacteria, fungi and animals (eggs, lobsters, some fish). Many carotenoids (β-carotene, lycopene, zeaxanthin and capsanthin in this) exhibit strong antioxidant activity.

Antioxidant capacity

Table 4 shows the ABTS and DPPH radical scavenging activities of the different oils. The TEAC of the oils ranged from 103.9 mg TE/ 100g (Elderberry) to 741 mg TE /100 g (Hawthorn pulp). More than half of the oils studied showed a TEAC values higher than 300 mg TE/100 g. The oils extracted from hawthorn pulp and seeds, schisandra berries and rowan fruits were characterized by the highest levels of antioxidant activity.

Likewise, the IC50 of DPPH radical scavenging of the oils varied. Cornelian and Rowan fruit oils showed the greatest potency to scavenge the DPPH free radicals with IC50 values of about

42 and 59 mg/mL, respectively. Borage, apple and lychee seed oils were least potent against DPPH•. Kraljić et al.[44] shown that the DPPH reduction of crude rapeseed oil is 70.9 - 83.4 % (for 10% (w/v) oil solution in ethyl acetate).

Correlation between FA composition, tocopherols and carotenoid content and antioxidant capacity of oils

TEAC values of oils were moderately positively correlated with the carotenoid content (correlation coefficient of Pearson r= 0.43) and weakly correlated with the tocopherols content (r= 0.34) (Table 5). The DPPH radical scavenging activity of the oils shows a weak negative correlation with carotenoids content (r= - 0.32) but not with tocopherols content (r = 0.03). The stronger correlation between carotenoids and TEAC than DPPH came as no surprise. It was due to the fact that the TEAC assay is able to recognize at least in part the antioxidant properties of all carotenoids because the functional groups of the carotenoids, such as carbonyl and hydroxyl groups as well as the conjugated double bonds show the relative strong abilities to scavenge the $ABTS^{\bullet+}$ [46]. Oils characterized by high TEAC values have lower IC_{50} values - smaller amounts of oil with high antioxidant capacity is required to scavenge the same amount of DPPH (r= - 0.56). However, the above relationship is not directly proportional because radicals have different properties. ABTS and DPPH assays involve single electron transfer (SET), but on the basis of the kinetic analysis of the reaction between polyphenols and DPPH, Jimenez et al. [47] suggested that the reaction involve hydrogen atom transfer (HAT) too. The ABTS assay was found to be more useful than DPPH for the assessment of the antioxidant potential of oils and the carotenoids level.

Interestingly, a fairly significant correlation was also found between the level of unsaturated FAs in oils, especially of the n-3 family, and the content of carotenoids (r = 0.31), but no correlation existed for the tocopherols content. The simultaneous high level of the FA n-3 family and carotenoids in the oils is highly desirable because the protective role of both types of nutrients in Alzheimer's disease have been shown [48].

In order to better illustrate the level of all measured nutrients and health-promoting and desirable properties of the tested oils, data were presented in the form of a cluster analysis. The color saturation is a measure of the concentration of the component (tocopherols, carotenoids, FA (n-3), FA (n-6), PUFA), the antioxidant activity (TEAC, DPPH radical scavenging) and better health-promoting potential.

Raspberry, Strawberry and Lingonberry seed oils showed the best values of health potential indexes (i.e. the composition of FA optimal for the cardiovascular system), but only with moderate antioxidant properties. Moreover, lingonberry oil contained a fairly high level of

carotenoids (10.5 mg /100g) and raspberry seed oil was characterized by a high content of tocopherols (about 170 mg / mL).

Hawthorn pulp and rowan fruit oil contains about 30% SFA, which had an adverse effect on the levels of the AI, TI, TC and LDL indexes. However, these oils also contained about 50% PUFA (P/S ratio 1.49 and 1.84, respectively) and a high concentration of carotenoids, which corresponded to a high antioxidant potentials. Hawthorn pulp oil was also the best source of tocopherols. Other oils were characterized by indirect but positive pro-health properties.

On the basis of the research, the least interest as the product with high health properties was aroused by lychee seed, Japanese quince seed, apple seed and hawthorn seed oils.

Conclusions

Oils from unconventional sources, such as edible parts of wild plants, can be a valuable addition to the human diet. The most valuable are those which, apart from the desired FA composition (presence of endogenous FA and their metabolites and the optimal n-6 / n-3 PUFA and P/S ratio), also contain components with a high level of biological activity, such as carotenoids and tocopherols.

The optimal fatty acid composition and high level of antioxidant components were found in raspberry seed, strawberry seed and lingonberry fruits oils. Hawthorn, black currant and rowan pulp oil contained high levels of carotenoids and showed high antioxidant potential. Taking into account the oil content in raspberry and strawberry seeds as well as the amount of seeds that can be processed, which are currently waste in the production of mousses and juices from these fruits, it seems realistic to obtaining these oils on a larger scale. The dependencies found in the study, especially the correlation between the level of carotenoids and the FA n-3 contents can be useful for a quick assessment of the quality of vegetable oils. However, more research and confirmation of the power of such relationships for more trials are needed.

Conflict of interest

The authors declare that they have no conflicts of interest

Ethical Guidelines

Ethics approval was not required for this research.

Data Availability

Research data are not shared. The data that support the findings of this study are available on request from the corresponding author.

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Table 1 Total lipid content of the analyzed plants (wt % dry matter ± SD)

Plant	Latin name	Part of plant	Total lipids	Total lipids references
Borage	*Borago officinalis*	seed	29.70 ± 2.80	30[26]
Raspberry	*Rubus idaeus*	seed	19.80 ± 0.65	10.7[27]
Blackcurrant	*Ribes nigrum*	seed	16.71 ± 0.72	16.5 – 25.7[28]
Apple	*Malus mill*	seed	8.53 ± 0.63	7.48 - 8.47[29]
Strawberry	*Fragaria ananassa*	seed	7.52 ± 0.52	6.2 [28]
Oleaster (Russian olive)	*Elaeagnus angustifolia*	seed	3.60 ± 0.32	3.1 – 6.9[30]
Japanese quince	*Chaenomeles japonica*	seed	3.46 ± 0.18	6.1–16.8[31]
Common hawthorn	*Crataegus monogyna*	seed	2.83 ± 0.09	3.40 ± 0.5[19]
Lychee	*Litchi chinensis*	seed	0.94 ± 0.15	3.20 ± 0.15[32]
Common hawthorn	*Crataegus monogyna*	pulp	3.55 ± 0.24	1.22± 0.09 (fruit)[33]
Schisandra	*Schisandra chinensis*	whole fruit	9.38 ± 0.38	10-50[34]
Lingonberry	*Vaccinium vitis-idaea*	whole fruit	3.77 ± 0.11	0.57 ± 0.03[35]
Rowan	*Sorbus aucuparia*	whole fruit	2.75 ± 0.19	2.0 – 6.2 [36]
Cornelian cherry	*Cornus mas*	whole fruit	1.40 ± 0.31	1.0[37]
Elderberry	*Sambucus nigra*	whole fruit	1.34 ± 0.78	0.35 ± 0.058[38]

Table 2 Composition of fatty acids (wt % of total fatty acids) † of lipids extracted from the analyzed plants.

	10:0	12:0	14:0	14:1	15:1	16:0	16:1 9c	16:1	17:1	18:0	18:1 9c	18:1 11c	18:2 (n-6)	18:3 (n-6)	18:3 (n-3)	18:4 (n-3)	20:0	20:1 (n-9)	20:2 (n-6)	22:0	22:1	24:0
Borage seeds	-	-	0.08	-	-	11.96	0.28	-	-	4.56	18.81	0.23	37.88	20.38	1.22	0.26	0.22	0.98	-	-	1.46	-
Raspberry seeds	-	-	-	-	0.26	3.07	0.07	-	-	1.28	11.54	0.75	50.92	-	31.08	-	0.53	-	0.06	0.26	-	-
Blackcurrant seeds	-	-	-	-	0.21	7.74	-	-	-	1.72	11.81	0.86	43.93	15.22	14.6	2.83	0.20	-	0.27	-	-	-
Apple seeds	-	-	0.05	-	-	7.73	-	-	-	1.59	35.29	-	51.40	-	0.51	-	1.49	0.56	0.06	0.29	-	0.04
Strawberry seeds	-	-	-	-	-	4.41	0.17	-	-	1.56	18.44	0.83	36.95	-	36.26	-	1.14	-	-	-	-	-
Oleaster seeds	-	0.19	0.19	-	-	10.82	2.36	0.07	-	4.47	22.56	8.93	31.78	-	16.49	-	0.62	0.12	-	0.25	-	-
Japanese quince seeds	-	-	0.06	-	-	10.90	0.06	0.09	0.05	0.79	28.35	-	57.57	-	1.03	-	0.75	-	-	-	-	-
Lychee seeds	0.24	0.33	0.24	0.15	0.18	12.84	0.38	-	1.17	3.38	31.73	1.02	42.11	-	5.97	-	-	-	-	-	-	-
Common hawthorn seeds	-	-	0.12	-	-	7.99	0.10	-	-	2.11	27.94	0.52	56.96	-	2.27	-	1.19	0.69	-	-	-	-
Common hawthorn pulp	-	-	0.48	0.16	-	16.52	1.23	0.30	-	4.76	13.67	1.71	28.43	-	17.04	-	2.85	-	2.24	7.38	2.72	-
Schisandra fruits	1.09	0.61	0.22	0.14	-	8.02	0.80	-	0.10	3.62	14.36	0.23	68.16	0.26	0.92	0.08	0.36	-	0.12	-	0.34	-
Lingonberry fruits	-	0.12	0.34	-	-	6.52	0.53	0.13	-	1.46	11.24	0.76	39.41	0.18	35.73	-	0.35	0.25	0.31	0.42	0.17	0.78
Rowan fruits	-	0.58	0.99	0.27		22.31	0.81	0.28	-	3.47	9.62	1.93	38.81	-	13.26	-	1.23	.	3.05	0.69	0.19	0.67
Cornelian cherry fruits	-	0.41	1.43	-		6.59	0.44	0.42	-	2.81	17.11	1.25	52.37	1.13	11.43	-	0.53	.	0.96	0.51	-	0.92
Elderberry fruits	-	-	0.62	-	-	13.50	0.15	-	-	3.13	10.19	0.92	39.11	-	28.94	-	0.16	-	-	-	-	-

† Fatty acid composition was expressed as means (n=3)

Table 3 Fatty acid class composition (wt % of total FA) , n-6/n-3 ratio and health potential indexes of the lipids extracted from the analyzed plants.

Lipids extracted from plants	Fatty acids [wt % of total FAs]			(n-6)/ (n-3)	AI	TI	P/S	ΔTC (mM/L)	ΔLDL (mM/L)
	SFA	MUFA	PUFA						
Borage seeds	16.82 ± 0.17	21.76 ± 0.47	59.76 ± 1.18	39.36	0.15	0.37	3.55	-0.40	-0.53
Raspberry seeds	5.14 ± 0.05	12.62 ± 0.27	82.06 ± 1.62	1.64	0.03	0.03	15.96	-1.27	-1.30
Blackcurrant seeds	9.66 ± 0.10	12.88 ± 0.28	76.85 ± 1.51	3.41	0.09	0.11	7.96	-0.87	-0.95
Apple seeds	11.19 ± 0.12	35.85 ± 0.78	51.97 ± 1.02	100.90	0.09	0.21	4.64	-0.59	-0.67
Strawberry seeds	7.11 ± 0.07	19.44 ± 0.42	73.21 ± 1.44	1.02	0.05	0.04	10.30	-1.08	-1.12
Oleaster seeds	16.54 ± 0.24	34.04 ± 0.74	48.27 ± 0.83	1.93	0.14	0.19	2.98	-0.33	-0.45
Japanese quince seeds	11.79 ± 0.12	28.54 ± 0.62	58.60 ± 1.15	55.89	0.13	0.25	4.69	-0.49	-0.60
Lychee seeds	17.03 ± 0.18	33.63 ± 0.73	48.08 ± 0.95	7.05	0.17	0.29	2.82	-0.20	-0.34
Common hawthorn seeds	11.41 ± 0.12	29.25 ± 0.63	59.23 ± 1.17	25.09	0.10	0.20	5.19	-0.66	-0.75
Common hawthorn pulp	31.99 ± 0.44	19.79 ± 0.43	47.71 ± 0.74	1.80	0.27	0.28	1.49	0.16	-0.03
Schisandra fruits	14.05 ± 0.15	15.44 ± 0.34	69.49 ± 1.37	68.54	0.11	0.26	5.00	-0.75	-0.84
Lingonberry fruits	9.99 ± 0.10	13.08 ± 0.28	75.63 ± 1.49	1.11	0.09	0.06	7.57	-0.92	-1.00
Rowan fruits	29.94 ± 0.31	13.10 ± 0.28	55.12 ± 1.09	3.16	0.39	0.40	1.84	0.46	0.19
Cornelian cherry fruits	13.20 ± 0.14	19.22 ± 0.42	65.89 ± 1.30	4.76	0.15	0.15	4.99	-0.63	-0.77
Elderberry fruits	17.41 ± 0.18	11.26 ± 0.24	70.54 ± 1.39	1.35	0.20	0.15	3.91	-0.36	-0.53

Fatty acid was expressed as means ± SD (n=3) , SFA – saturated fatty acid, MUFA – monounsaturated fatty acids, PUFA – polyunsaturated fatty acid

P/S polyunsaturated fatty acid/ saturated fatty acid ratio

AI atherogenicity index = C12:0 + 4 (C14:0) + C16:0/ ΣMUFA + Σ PUFA n-3 + Σ PUFA n-6

TI thrombogenicity index = C14:0 + C16:0 + C18:0/ 0.5 ΣMUFA + 0.5 Σ PUFA n-6 + 3 Σ PUFA n-3 + (Σ PUFA n-3 / Σ PUFA n-6)

ΔTC plasma Total Cholesterol (mM/L) = 0.01 (C12:0) + 0.12 (C14:0) + 0.057 (C16:0) + 0.031 (Trans FA)- 0.0044 (C18:1) - 0.017 (C18:2 + 18:3)

ΔLDL Low-Density Lipoprotein Cholesterol (mM/L) = 0.01 (C12:0) + 0.071 (C14:0) + 0.047 (C16:0) + 0.025 (Trans FA) - 0.0044 (C18:1) - 0.017 (C18:2 + C18:3)

Table 4 Total carotenoids and total tocopherols content, Trolox Equivalent Antioxidant Capacity (TEAC) and DPPH radical scavenging activity (IC_{50}) of total lipids extracted from the analyzed plants (mean ± SD).

Total lipids extracted from plants	Total Carotenoids	Total Tocopherols	TEAC	DPPH radical scavenging activity
	(mg/100g)	(mg/100g)	(TEmg /100g)	IC_{50} (mg /mL)
Borage seeds	0.39 ± 0.072	136.15 ± 5.20	135.95 ± 11.51	246.77 ± 14.80
Raspberry seeds	2.30 ± 0.52	169.40 ± 8.72	328.29 ± 43.11	81.09 ± 1.70
Blackcurrant seeds	14.22 ± 2.13	115.02 ± 3.69	279.09 ± 12.05	191.91 ± 10.40
Apple seeds	1.58 ± 0.12	53.45 ± 3.12	206.90 ± 22.55	243.96 ± 15.70
Strawberry seeds	1.33 ± 0.091	9.36 ± 0.321	168.96 ± 9.46	68.45 ± 0.42
Oleaster seeds	5.02 ± 0.55	39.47 ± 2.78	340.66 ± 13.61	201.72 ± 10.00
Japanese quince seeds	1.08 ± 0.013	72.62 ± 0.51	333.97 ± 1.09	214.24 ± 20.11
Lychee seeds	0.43 ± 0.07	43.98 ± 1.75	210.64 ± 10.62	232.93 ± 22.73
Common hawthorn seeds	6.13 ± 0.28	32.11 ±3.11	600.03 ± 9.06	71.05 ± 1.45
Common hawthorn pulp	12.03 ± 0.29	226.23 ±8.56	741.04 ± 16.89	70.00 ± 3.88
Schisandra fruits	4.26 ± 0.29	21.09 ±3.22	464.09 ± 18.27	143.46 ± 5.82
Lingonberry fruits	10.51 ± 1.06	0.31 ± 0.01	211.97 ± 56.61	121.07 ± 4.11
Rowan fruits	9.82 ± 0.79	1.30 ± 0.42	490.99 ± 30.05	59.09 ± 1.37
Cornelian cherry fruits	3.62 ± 0.44	16.31 ±1.16	331.71 ± 3.03	42.17 ± 0.98
Elderberry fruits	6.58 ± 0.33	3.12 ± 0.26	103.94 ± 1.78	199.66 ± 6.09

Table 5. The strength of the correlation between the oils fatty acid, total carotenoids and total tocopherols content and the antioxidant properties expressed by the value of the Pearson correlation coefficient.

	TEAC TE mg/100g	DPPH mg lipids/ mg DPPH	FA n-6	FA n-3	PUFA	n-6/ n-3	TCR mg/100 g	TTP mg/100g
			% total FA					
TEAC (TE mg/100g)	-	- 0.56	- 0.02	- 0.26	- 0.32	- 0.05	0.43	0.34
	DPPH (mg/mL)	-	0.16	- 0.39	- 0.28	0.47	- 0.32	0.03
		FA n-6 % total FA	-	-0.58	0.33	0.57	-0.22	0.00
			FA n-3 % total FA	-	0.58	0.57	0.31	-0.06
				PUFA	-	-0.23	0.14	-0.07
					n-6/ n-3	-	-0.43	-0.04
						TCR mg/100g	-	0.14

TEAC - trolox equivalent antioxidant capacity (total antioxidant capacity measure by ABTS test). DPPH - radical scavenging activity against DPPH (IC50), FA n-6 – fatty acids n-6 family, FA n-3 - fatty acids n-6 family, PUFA – polyunsaturated fatty acids, TCR – total carotenoids, TTP – total tocopherols

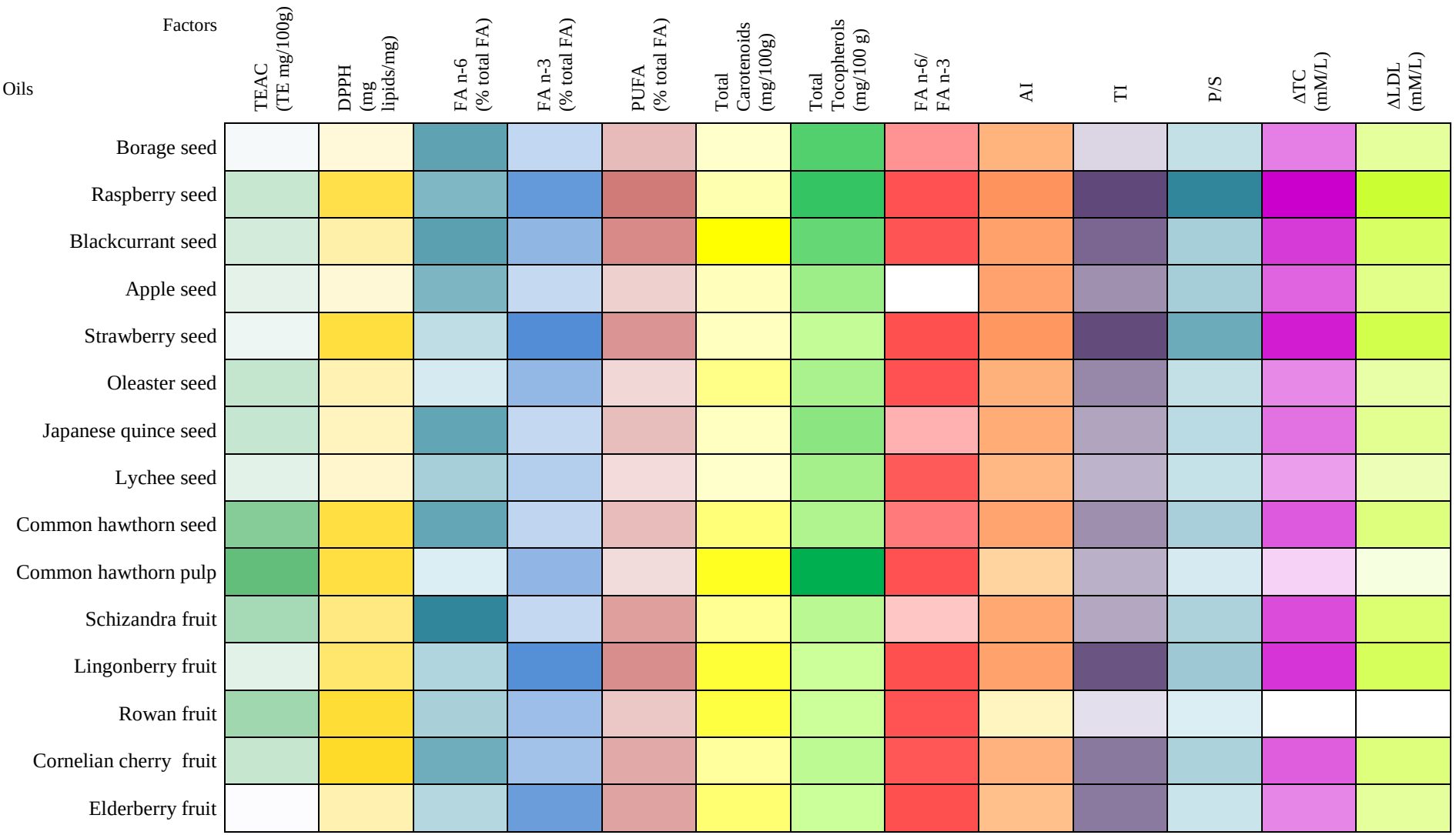

Figure 1 Cluster analysis. The color intensity determines higher levels of FA (n-3), FA (n-6), PUFA, carotenes and tocopherols, and in the case of other factors, better health-promoting and desirable properties of the tested oils from the analyzed plant sources.