Journal of Food and Nutrition Research, 2018, Vol. 6, No. 7, 476-485
Available online at http://pubs.sciepub.com/jfnr/6/7/9

DOI:10.12691/jfnr-6-7-9

Phytochemical Content, Oxidative Stability, and Nutritional Properties of Unconventional Cold-pressed Edible Oils

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Received July 01, 2018; Revised August 02, 2018; Accepted August 15, 2018

Abstract Plant oils are a good source of compounds that decrease the risk of some diseases. Growing consumer awareness has led to more interest in natural cold-pressed plant oils, which are often considered functional foods. Many unconventional edible plant oils are available on the market, but their quality and composition are often unknown. The aim of this study was to compare the nutritional value and quality of sixteen unconventional cold-pressed edible oils. The acid value (AV), peroxide value (PV), oxidative stability, fatty acid composition, phytosterol content, and tocochromanol content were measured for both fresh and stored oils. The nutritional quality indexes were also calculated. Cluster analysis of all factors showed that the oils fell into two groups: the first contained argan oil, pine oil, apricot kernel oil, avocado fruit oil, and macadamia nut oil; these had high levels of saturated and monounsaturated fatty acids and low amounts of phytosterols and tocochromanols. The second group included oil from dill seeds, milk thistle seeds, parsley seeds, watermelon seeds, safflower, poppy seeds, black cumin seeds, hemp, blackcurrant seeds, borage, and wheat germ. The highest tocochromanol and phytosterol content were observed in wheat germ and blackcurrant seed oil, and the lowest in black cumin and dill seed oil.

Keywords: *cold-pressed plant oils, nutritional values, fatty acids, tocopherols, phytosterols, oxidative stability*

Cite This Article: Qian Ying, Paulina Wojciechowska, Aleksander Siger, Anna Kaczmarek, and Magdalena Rudzińska, "Phytochemical Content, Oxidative Stability, and Nutritional Properties of Unconventional Cold-pressed Edible Oils." *Journal of Food and Nutrition Research*, vol. 6, no. 7 (2018): 476-485. doi: 10.12691/jfnr-6-7-9.

1. Introduction

The role of dietary fat in human health has been intensely debated and subject to a great deal of research over the last few decades. For many years, a low-fat diet was recommended as a cure-all for many diseases of civilization, despite the fact that it is the quality of fat that has the greatest effect on human health [1]. The quality of dietary fat depends on its level of saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA), and especially on the ratio of omega-6 to omega-3 fatty acids. In 1991, Ulbricht and Southgate [2] recognized seven dietary factors that can be associated with coronary heart disease (CHD). Saturated fatty acids (SFA), which raise cholesterol levels, and thrombogenic SFA are promoters of CHD, whereas the omega-3 and omega-6 isomers of PUFA, MUFA, and antioxidants have been described as protecting against CHD [2]. Schwab et al. [3] summarized the effects of the quantity and quality of dietary fat on body weight, risk factors for type-2 diabetes, cardiovascular disease, and cancer in healthy subjects and in subjects at risk of these diseases. However, it is not only the composition of fatty acids that affects the nutritional quality of fat; phytosterols also possess a cholesterol-lowering property in humans [4]. Tucker and Townsend [5] have shown the efficacy of α-tocopherol in the prevention and treatment of heart disease, cancer, and Alzheimer's disease, but the properties of α-, β- and δ-tocopherols have also been described [6].

For this reason, vegetable plant oils are a good source of compounds that decrease the risk of some diseases. Growing consumer awareness has led to more interest in natural cold-pressed plant oils, which are often considered functional foods [7]. Various seeds, kernels, and nuts are used as sources in the production of edible cold-pressed oils. Alongside traditional oils from olives, rapeseed, linseed, and pumpkin, unconventional oils from melons, apricot and plum kernels, apples, pear and cherry seeds, and others are produced and are consumed by customers as "healthy" food [8,9,10]. In recent years, the range of cold-pressed vegetable oils available on the Polish market has increased significantly. The production of cold-pressed oils is simple and the cost of investment is low, but small operations typically produce oils without quality control. The most important factor in the quality of oil is the raw material, which is purchased from various domestic and imported sources. The maturity and cleanness of the seeds is very important, and directly affects the quality of

the cold-pressed oils. The quality and stability of the oils depends on many factors, including the composition of fatty acids, the production and storage conditions, and the presence of pro-oxidants and antioxidants. Different producers of cold-pressed plant oils suggest various shelf lives for the same type of oil; these values are often unjustified guesses, rather than conclusions based on experimental data.

Cold-pressed oils are often used by consumers as sources of PUFA, omega-3 fatty acids, antioxidants, and vitamins. Additionally, the use of cold pressing in the production of plant oils offers natural oils rich in bioactive compounds [7]. To obtain good quality oil, quality mature raw material is required, as is attention to the pressing and storage conditions including temperature, light exposure, and oxygen exposure. Cold-pressed oils are prone to oxidation, which can occur within a few days of storage if they are not properly processed [11,12]. Consumers increasingly seek original products from small manufacturers that employ traditional food production conditions. Guarantee of these oils' safety should be provided by quality and composition analysis. Many unconventional edible plant oils are available on the market, but their quality and composition are often unknown.

According to Codex Alimentarius [13], cold-pressed oils are obtained, without altering the oil, by mechanical procedures only, e.g. expelling or pressing, without the application of heat. They may have been purified by washing with water, settling, filtering and centrifuging only and no food additives are permitted in cold-pressed oils. Maximum level of acid value is 4.0 mg KOH/g oil and peroxide value is 15 meq O2/kg oil. Fatty acids composition, physical and chemical characteristics, levels of desmethylsterols and tocopherols of vegetable oils are presented in Codex Alimentarius [13] and could be used as standards. But these data concern the most popular plant oils like palm, rapeseed, soybean, olive and sunflower oils. When unconventional plant oils are produced from new sources, their quality is unknown and difficult for standardized. Comprehensive analysis of their quality, oxidative stability and bioactivity requires a long-term tests using precision instrumental methods, which are often too expensive for small manufacturers. Cold-pressed plant oils which are placed on the market need standardization and quality control.

Thus, our study aimed to evaluate the quality, nutritional properties, and storage stability of selected cold-pressed oils.

2. Material and Methods

2.1. Materials

2.1.1. Chemicals

All solvents of HPLC grade, sterol standards, 1 M methanolic KOH, and anhydrous pyridine were purchased from Sigma-Aldrich (St. Louis, MO, USA). Standards of α-, β-, γ- and δ-tocopherols (> 95% purity) were purchased from Merck (Darmstadt, Germany), and FAME standards and Sylon BTZ from Supelco (Bellefonte, PA, USA).

2.1.2. Materials

Sixteen cold-pressed plant oils (argan oil, apricot kernel oil, avocado fruit oil, blackcurrant seed oil, borage oil, dill seed oil, hemp oil, macadamia oil, milk thistle seed oil, black cumin seed oil, parsley seed oil, pine nut oil, poppy seed oil, safflower oil, watermelon seed oil, wheat germ oil) were purchased from retail outlets in Poland in three series, from January, March and June, 2017. All the oils were of good quality and fresh. The presented data are the averages from three replicates from three series (nine results).

2.1.3. Storage Conditions

All cold-pressed plant oils were subjected to analysis immediately after purchase, and then after six and twelve days of storage at 60°C, in line with AOCS Official Method Cg 5-97 [14].

2.2. Methods

2.2.1. Acid Value (AV)

The acid value was determined and calculated as mg of potassium hydroxide needed to neutralize the free fatty acids in 1 g of the sample, in line with AOCS Official Method Te 1a-64 [15].

2.2.2. Peroxide Value (PV)

The peroxide value was determined in line with AOCS Official Method Cd 8b-90 [16].

2.2.3. Tocochromanols Determination by NP-HPLC

Each oil (200 mg) was dissolved in *n*-hexane, made up to 10 ml, and transferred to vials for analysis. Tocopherols were qualitatively and quantitatively identified using a Waters HPLC system (Waters, Milford, MA) consisting of a fluorometric detector (Waters 474), a photodiode array detector (Waters 2998 PDA), an autosampler (Waters 2707), a column oven (Waters Jetstream 2 Plus), and a LiChrosorb Si 60 column (250 × 4.6 mm, 5 µm) from Merck (Darmstadt, Germany). To detect the fluorescence of the tocopherols and PC-8, the excitation wavelength was set to λ = 295 nm and the emission wavelength to λ = 330 nm [17].

2.2.4. Fatty Acid Composition

Methyl esters of fatty acids (FAMEs) were prepared according to AOCS Official Method Ce 1h-05 [18]. The diluted FAMEs were separated on a HP 5890 series II gas chromatograph (Hewlett Packard, Palo Alto, CA, USA) equipped with an Supelcowax 10 capillary column (30 m × 0.20 mm × 0.20 µm) and a flame ionization detector (FID). Fatty acids were identified by comparing retention times with authentic standards, and the results were reported as weight percentages following integration and calculation using ChemStation (Agilent Technologies).

2.2.5. Phytosterols

Sterol content and compositions were determined by GC following the procedure described by AOCS Official Method Ch 6-91 [19]. Briefly, 50 mg of lipids were saponified with 1 M methanolic KOH for 18 h at room

temperature; water was then added and the unsaponifiables were extracted three times with hexane/methyl *tert*-butyl ether (1:1, v/v). Silylated by Sylon BTZ derivatives of the sterols were separated on a HP 6890 series II Plus gas chromatograph (Hewlett Packard, Palo Alto, CA, USA) equipped with DB-35MS capillary column (25 m × 0.20 mm, 0.33 μm; J&W Scientific, Folsom, CA, USA). The sample was injected in splitless mode. An internal standard, 5α-cholestane, was used for sterol quantification. Phytosterols were identified by comparing the retention data with the standards. Samples of each oil were analyzed in triplicate.

2.2.6. Oxidative Stability Index

AOCS Official Method Cd 12b-92 [20] was applied to determine the oxidative stability of the oils. The test was performed on an automated Metrohm Rancimat model 743 (Herisau, Switzerland) at 110 ± 0.1°C and with an air flow of 20 L/h to determine the induction period (IP) of the oils.

2.2.7. Nutritional Quality Index

The atherogenic index (AI) (Eq. 1) and the thrombogenic index (TI) (Eq. 2) of the cold-pressed plant oils were evaluated following Ulbricht and Southgate [2]. The ratio of hypocholesterolemic to hypercholesterolemic FA (HH) (Eq. 3) was calculated based on Santos, Bessa, and Santos [21]. The ratio of omega-6 to omega-3 fatty acids was also calculated.

$$AI = \frac{C_{12:0} + 4 \times C_{14:0} + C_{16:0}}{\sum MUFA + \sum(\omega 6) + \sum(\omega 3)}.$$

Equation 1. Atherogenicity index (AI)

$$TI = \frac{C_{14:0} + C_{16:0} + C_{18:0}}{0.5 \times \sum MUFA + 0.5x\sum(\omega 6) + \sum(\omega 3)}.$$

Equation 2. Thrombogenicity index (TI)

$$HH = \frac{C_{18:1} + C_{18:2} + C_{18:3} + C_{18:4} + C_{20:4}}{C_{14:0} + C_{16:0}}.$$

Equation 3. Hypocholesterolemic:hypercholesterolemic FA ratio (HH).

2.2.8. Statistical Data Analysis

All statistical tests were performed using Statistica 13.0 software (Statsoft, Tulsa, OK) equipped with a multivariate statistics package. In the first stage, the raw data matrix (number of samples × number of variables) was standardized to correct significant differences in the variances obtained for the raw data. This transformation allowed easier comparison of the sample profiles. Cluster analysis (CA) and principal component analysis (PCA) were the methods of chemometric analysis used to compare the properties of various oils during storage. PCA is one of the oldest and most popular methods used for data analysis and involves compressing the size of the data by simplifying, extracting, and retaining only the important information. PCA creates linear combinations of the original variables called principal components, which describe the systematic patterns of variation between the samples. Cluster analysis (CA) is an unsupervised pattern recognition technique that can be used either instead of PCA or in combination with PCA. Cluster analysis may involve nonhierarchical or hierarchical algorithms. Hierarchical cluster analysis using Ward's linkage was used in this study, as the algorithm showed the best results for our data. It was thought that combining unsupervised clustering with supervised information might demonstrate the differences and similarities between the oils.

3. Results and Discussion

3.1. AV and PV of Fresh and Stored Oils

The acid value (AV) and peroxide value (PV) are commonly used parameters in the specification of fat and oil quality. Black cumin oil showed the highest AV (15 mg KOH/g) and PV (58 meq O_2/kg) (Table 1). When Kiralan et al. [22,23] determined the PV of fresh black cumin oil, the level of hydroperoxides was affected by the extraction method used and was lower (18–31 meq O_2/kg). A high level of hydroperoxides was also detected in blackcurrant and poppy seed oils, amounting to 30 meq O_2/kg for both. A high AV was also detected for borage oil, dill seed oil, and wheat germ oil, at 8, 7, and 6 mg KOH/g, respectively. The AV was lower than 3 mg KOH/g in the other oils.

The AV of all oils remained stable during storage for six and twelve days at 60 °C, but an increase in PV was seen, except in the case of black cumin oil, where the PV remained high and unchanged (Table 1). Kiralan et al. [22] showed that, during storage of cold-pressed black cumin oil at 60 °C for six days, the PV remained unchanged, but that when the storage time was extended to twelve days, the PV increased by about 20%. The highest increase in PV was detected for avocado fruit oil, safflower oil, and milk thistle seed oil (Table 1). PVs lower than 15 meq O_2/kg were detected after six days of storage in macadamia seed oil, argan oil, dill seed oil, apricot kernel oil, and avocado fruit oil. After twelve days of storage, only the macadamia seed oil showed a PV of less than 15 meq O_2/kg. According to the Codex Alimentarius, the AV of good quality cold-pressed plant oils should be below 4 mg KOH/kg, while their PV should be below 15 meq O_2/kg. In our analysis, 11 and 12 of the oils satisfied both of these recommendations.

3.2. Oxidative Stability

The oxidative stability of oil is an important quality and safety parameter for its potential commercial applications and its uses in food and other commercial products. Oxidative stability depends mostly on the FA composition, as well as on the potency and concentration of the antioxidants in the oil [24]. The oxidative stability of the oils was measured immediately after purchase using a Rancimat apparatus at 110 °C; the data are presented in Figure 1. The induction periods (IP) differed, ranging from 0.2 h for apricot kernel oil, hemp oil, and wheat germ oil to 14 h for black cumin oil, followed by argan (11 h), milk thistle (10 h), and macadamia nut (10 h) oils (Figure 1). The data obtained were much lower than those of Hassanien et al. [25], who reported IPs for cold-pressed

apricot kernel oil and black cumin oil of 36 h and 17 h, respectively, while the IP of grape seed oil, rapeseed oil, and linseed oil were 8 h, 7.0 h, and 1.5 h, respectively [24,25,26]. Kiralan et al. [22] showed that the IP of cold-pressed black cumin oil was 3.5 h but that, when this oil was extracted using the Soxlet method, the IP was much longer (19.6 h). The quality of commercial cold-pressed plant oils varied, with the production technology and storage time and conditions affecting their oxidative stabilities [27].

Table 1. Acid value (AV), peroxide value (PV), and fatty acid composition of cold-pressed plant oils before and after storage for six and twelve days at 60°C

Oils	Time of storage (days)	Acid value (mg KOH/g)	Peroxide value (meq O_2/kg)	SFA	MUFA	PUFA n-6	PUFA n-3
	0	0.40 ± 0.01	10.38 ± 0.52	5.2 ± 0.1	68.9 ± 3.4	25.8 ± 1.3	
Apricot kernel oil	6	0.43 ± 0.01	13.58 ± 0.58	5.1 ± 0.1	68.9 ± 3.6	25.6 ± 1.3	
	12	0.45 ± 0.01	21.75 ± 0.79	5.1 ± 0.1	69.1 ± 3.1	25.6 ± 1.3	
	0	0.95 ± 0.03	4.30 ± 0.15	18.2 ± 0.8	48.9 ± 2.1	32.9 ± 1.6	
Argan oil	6	0.96 ± 0.04	10.06 ± 0.32	18.2 ± 0.6	48.9 ± 1.8	32.6 ± 1.6	
	12	0.99 ± 0.04	19.98 ± 0.77	18.5 ± 0.9	48.9 ± 1.8	32.6 ± 1.6	
	0	0.68 ± 0.03	3.31 ± 0.10	28.9 ± 1.1	62.2 ± 2.5	8.6 ± 0.4	0.3 ± 0
Avocado fruit oil	6	0.65 ± 0.04	14.88 ± 0.52	28.9 ± 0.9	62.2 ± 2.8	8.4 ± 0.4	0.3 ± 0
	12	0.76 ± 0.04	27.98 ± 0.98	28.9 ± 1.1	62.4 ± 2.1	8.2 ± 0.4	0.3 ± 0
	0	14.72 ± 0.31	57.72 ± 1.12	17.6 ± 0.4	24.3 ± 0.9	57.1 ± 2.4	0.5 ± 0
Black cumin oil	6	14.68 ± 0,41	58.50 ± 1.34	17.6 ± 0.6	24.5 ± 0.9	56.6 ± 2.4	0.4 ± 0
	12	14.68 ± 0,43	56.93 ± 1.19	18.0 ± 0.8	24.7 ± 0.8	57.0 ± 2.4	0.3 ± 0
	0	2.01 ± 0.05	29.81 ± 1.10	7.7 ± 0.4	12.8 ± 0.6	48.2 ± 2.1	31.3 ± 1.6
Blackcurrant seed oil	6	2.02 ± 0.05	49.73 ± 2.05	7.8 ± 0.3	12.7 ± 0.6	48.3 ± 2.2	31.2 ± 1.6
	12	2.19 ± 0.05	63.78 ± 2.84	8.7 ± 0.4	12.9 ± 0.7	47.5 ± 1.9	29.8 ± 1.5
	0	8.27 ± 0.35	8.28 ± 0.37	19.3 ± 1.1	20.9 ± 1.2	35.4 ± 1.8	23.7 ± 1.2
Borage oil	6	8.19 ± 0.31	22.95 ± 0.98	19.2 ± 1.2	21.0 ± 1.0	35.5 ± 1.8	23.1 ± 1.2
	12	8.23 ± 0.30	33.50 ± 2.06	19.8 ± 0.9	21.5 ± 1.2	35.5 ± 1.8	23.0 ± 1.2
	0	6.67 ± 0.27	10.07 ± 0.55	9.6 ± 0.8	29.4 ± 1.1	56.4 ± 2.8	0.5 ± 0
Dill seed oil	6	6.60 ± 0.26	12.84 ± 0.59	9.6 ± 0.8	29.7 ± 1.4	56.7 ± 2.8	0.4 ± 0
	12	6.55 ± 0.26	25.45 ± 1.04	9.7 ± 0.7	29.1 ± 1.2	56.0 ± 2.8	0.1 ± 0
	0	0.68 ± 0.04	10.96 ± 0.71	8.6 ± 0.5	10.7 ± 0.4	53.2 ± 2.7	25.4 ± 1.3
Hemp oil	6	0.62 ± 0.03	27.59 ± 1.04	8.7 ± 0.5	10.7 ± 0.3	53.7 ± 2.7	24.7 ± 1.2
	12	0.58 ± 0.02	54.43 ± 1.96	8.9 ± 0.5	10.7 ± 0.3	53.6 ± 2.7	24.7 ± 1.2
	0	1.45 ± 0.07	6.18 ± 0.26	13.8 ± 1.0	83.4 ± 4.1	1.8 ± 0.1	
Macadamia nut oil	6	1.57 ± 0.07	7.98 ± 0.44	14.2 ± 0.9	82.1 ± 4.0	1.6 ± 0.1	
	12	1.62 ± 0.07	9.68 ± 0.32	15.2 ± 1.1	80.7 ± 3.3	1.6 ± 0.1	
	0	1.42 ± 0.06	10.95 ± 0.39	13.8 ± 0.9	27.7 ± 1.6	55.3 ± 2.8	0.5 ± 0
Milk thistle seed oil	6	1.27 ± 0.06	37.51 ± 2.31	14.1 ± 1.1	28.1 ± 1.1	56.4 ± 2.8	0.5 ± 0
	12	1.34 ± 0.07	72.29 ± 3.18	14.4 ± 1.1	28.6 ± 1.2	56.2 ± 2.8	0.4 ± 0
	0	2.62 ± 0.11	19.45 ± 0,87	8.7 ± 0.6	31.5 ± 0.9	56.8 ± 2.8	
Parsley seed oil	6	2.57 ± 0.12	41.14 ± 1.75	8.8 ± 0.5	30.5 ± 0.9	53.8 ± 2.7	
	12	2.24 ± 0.11	71.42 ± 2.69	9.1 ± 0.7	30.5 ± 0.8	53.8 ± 2.7	
	0	0.18 ± 0.01	10.19 ± 0.42	11.3 ± 0.9	45.1 ± 2.1	43.4 ± 2.2	
Pine nut oil	6	0.28 ± 0.02	24.68 ± 1.02	11.5 ± 0.7	45.5 ± 1.9	42.9 ± 2.1	
	12	0.31 ± 0.02	45.61 ± 2.63	11.5 ± 0.9	45.5 ± 1.9	41.4 ± 2.1	
	0	1.79 ± 0.06	30.14 ± 1.22	17.5 ± 0.9	18.2 ± 0.5	63.9 ± 3.2	0.4 ± 0
Poppy seed oil	6	1.85 ± 0.07	48.46 ± 1.78	18.1 ± 1.1	18.8 ± 0.5	62.7 ± 3.1	0.4 ± 0
	12	1.84 ± 0.07	63.06 ± 1.93	18.1 ± 1.0	19.9 ± 0.6	61.6 ± 3.2	0.3 ± 0
	0	1.08 ± 0.05	6.82 ± 0.21	14.0 ± 1.0	8.8 ± 0.4	76.1 ± 3.8	
Safflower oil	6	1.26 ± 0.06	25.77 ± 1.09	14.9 ± 0.7	9.5 ± 0.4	75.3 ± 3.8	
	12	1.22 ± 0.06	53.07 ± 2.36	15.0 ± 0.7	9.6 ± 0.4	73.8 ± 3.7	
	0	1.15 ± 0.06	9.46 ± 0.39	22.5 ± 1.5	14.1 ± 0.7	63.4 ± 3.2	
Watermelon seed oil	6	1.12 ± 0.06	27.94 ± 0.99	22.4 ± 1.1	14.3 ± 0.7	63.3 ± 3.2	
	12	1.09 ± 0.05	47.94 ± 1.15	22.2 ± 1.0	14.6 ± 0.7	63.1 ± 3.2	
	0	5.60 ± 0.21	18.65 ± 0.72	20.4 ± 1.3	12.7 ± 0.4	57.3 ± 2.9	9.4 ± 0.5
Wheat germ oil	6	5.32 ± 0.18	34.92 ± 1.17	20.4 ± 1.2	13.1 ± 0.6	57.3 ± 2.9	9.1 ± 0.5
	12	5.44 ± 0.16	50.53 ± 1.83	20.9 ± 1.0	13.2 ± 0.4	57.1 ± 2.9	8.8 ± 0.4

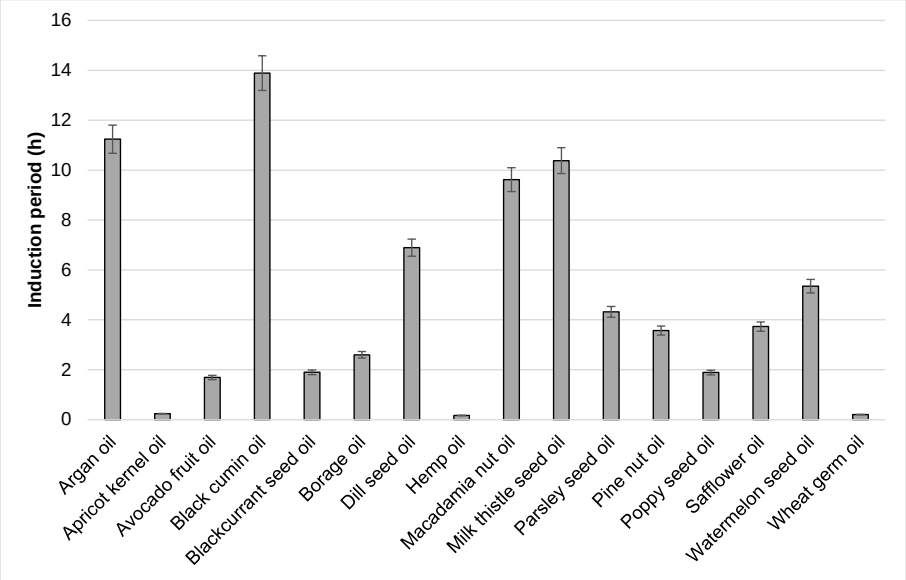

Figure 1. Oxidative stability of cold-pressed plant oils prior to storage, measured using a Rancimat at 110°C

3.3. Fatty Acid Composition

The fatty acid compositions of the sixteen tested cold-pressed plant oils are shown in Table 1. We found that the saturated fatty acid (SFA) concentration ranged from 5.2% in apricot kernel oil to 28.9% in avocado fruit oil. The highest level of monounsaturated fatty acids was found in macadamia nut oil (83.4%), and the lowest in safflower oil (8.8%). The oil richest in PUFA was hemp oil (80.7%), while macadamia nut oil was poorest (1.8%). Linoleic acid was detected in all the oils at levels ranging from 1.8% in macadamia nut oil to 76.1% in safflower oil. α-Linolenic acid was detected in nine oils, but made up less than 1% of five of them. Only hemp oil contained stearidonic acid (at 2.1%). No changes in fatty acid composition were found in any of the oils that had been stored for six or twelve days.

Fatty acid composition is not a good factor for determining the freshness of plant oils, but it does affect dietary factors [28,29]. It is well known that a human diet rich in SFA is associated with high levels of cholesterol in blood, and that this is associated with cardiovascular disease (CHD) [2]. Because cold-pressed plant oils are usually considered by consumers as a source of essential fatty acids, three nutritional quality indices: the atherogenicity index, the thrombogenicity index, and the hypocholesterolemic: hypercholesterolemic FA ratio were calculated on the basis of the fatty acid composition of the oils (Table 2). These indices are more useful than fatty acid composition in evaluating oils nutritionally. The lowest AI and TI, and the highest HH ratio, were calculated for apricot oil, amounting to 0.05, 0.11, and 21.49, respectively. The most atherogenic, thrombogenic, and hypercholesterolemic oil was avocado fruit oil, for which the values of AI, TI, and the HH ratio were 0.40, 0.81, and 2.06. Ulbricht and Southgate [2] showed that the AI of coconut oil, palm oil, olive oil, and sunflower oil are 13.63, 0.88, 0.14, and 0.07, respectively, whereas their TI values are 6.18, 2.07, 0.32, and 0.28, respectively. The HH for intramuscular fat of lamb ranged from 1.8 to 2.1, and was not affected by the feeding system [21]. Thus, if it were possible to make a diet less atherogenic without making it less thrombogenic, incidences of CHD might be expected to fall [2].

Table 2. Nutritional quality indices

Fresh oil samples	Atherogenicity Index	Thrombogenicity Index	Hypocholesterolemic: hypercholesterolemic FA ratio
Apricot kernel oil	0.05	0.11	21.49
Argan oil	0.18	0.45	5.69
Avocado fruit oil	0.40	0.81	2.06
Black cumin oil	0.15	0.34	6.41
Blackcurrant seed oil	0.10	0.23	13.82
Borage oil	0.18	0.45	6.77
Dill seed oil	0.08	0.22	12.56
Hemp oil	0.09	0.23	14.88
Macadamia seed oil	0.18	0.31	4.91
Milk thistle seed oil	0.23	0.53	4.15
Parsley seed oil	0.07	0.20	14.21
Pine nut oil	0.11	0.26	9.75
Poppy seed oil	0.18	0.41	5.46
Safflower oil	0.11	0.34	9.89
Watermelon seed oil	0.15	0.53	6.42
Wheat germ oil	0.26	0.53	4.24

3.4. Tocochromanols

Tocochromanols play an important role as antioxidants in the stability of cold-pressed oils, and as vitamin E in the human diet. Tocopherol (T) and tocotrienol (T3) levels were determined in the fresh and stored cold-pressed plant oils, and the results are presented in Table 3. The highest levels of these compounds were found in wheat germ oil and blackcurrant seed oil, at 155 mg/100 g and 112 mg/100 g, respectively. Wheat germ oil contained α-, β-, and γ-tocopherols, as well as δ-tocotrienols, whereas blackcurrant seed oil was found to contain α-, γ-, and δ-tocopherols and α-, β-, and γ-tocotrienols. Macadamia nut oil was characterized by the lowest level of tocochromanols, which contained only one isomer (α-T3) at 1.4 mg/100 g of oil. In avocado fruit oil, only δ-T was detected, and at a very low level (2.2 mg/100 g). The δ-T3 isomer was not detected in any of the examined oils. The total tocopherols in argan oil varied between 43 and 65 mg/100 g, with γ-tocopherol as the major fraction [30].

Individual tocopherol isomers differ in their antioxidant and biological activities. The greatest antioxidant properties are found in the case of δ-tocopherol, followed by γ-, β-, and α-tocopherol; the highest biological activity is that of α-tocopherol [31]. Magariño et al. [32] demonstrated that α-tocopherol degrades faster than β-tocopherol. In our study, borage oil was the richest in δ-T (85 mg/100 g), followed by blackcurrant oil (9 mg/100 g); the highest levels of α-T were found in wheat germ oil (84 mg/100 g), milk thistle oil (54 mg/100 g), safflower oil (54 mg/100 g), and parsley seed oil (48 mg/100 g).

The tocochromanol levels of the oils decreased during storage at 60 °C for six or twelve days, (Table 4). The smallest decrease in these compounds after six days of storage was observed in argan, black cumin, dill, milk thistle, parsley, safflower, and wheat germ oils, and ranged from 2% to 5% of total content. When the oils were stored for twelve days, the smallest degradation in tocochromanols was seen for argan oil (7%), and then for apricot kernel, black cumin, and dill oils (9%.) The highest tocochromanol degradation was seen in the oils that contained low amounts of these compounds. In avocado fruit oil stored for six days, 58% of the tocochromanols degraded, and 71% after twelve days. A large high decrease in tocochromanols was also observed for poppy seed oil, in which 38% of these important compounds had degraded after six days of storage and 64% after twelve days of storage.

The degradation of tocochromanols during storage has been widely investigated. In safflower oil stored at 10 °C for six months and at 37 °C for 3 months, 45% and 70% of tocopherols were found to degrade, respectively [33]. When canola oil was stored at 60 °C, the α-tocopherol was found to disappear within 7–11 days [34].

3.5. Phytosterols

Phytosterols are of a great interest to consumers, due to their health effects, particularly their cholesterol-lowering properties. Phytosterols are the main components of the unsaponifiable matter of plant oils and fats. The quantity and varieties of phytosterols detected in the sixteen tested cold-pressed plan oils were different (Table 4). The highest total level of phytosterols was found in wheat germ oil (858 mg/100g), followed by blackcurrant seed oil (254 mg/100g). The lowest level of total phytosterol content was detected in black cumin oil (44 mg/100g). The plant oils richest in phytosterols, which had more than 1 g of these compounds per 100 g of oil, are sea buckthorn seed oil, and rice bran oil [35,36], whereas the total amount of phytosterols in traditional plant oils such as rapeseed, sunflower, and soybean ranges from 300 mg/100g to 800 mg/100g [37]. The contribution of the most prevalent sterol, β-sitosterol, to the total sterol content in each oil was highest in apricot kernel oil (86%), followed by macadamia nut oil (84%), avocado fruit oil (79%), pine nut oil (77%), blackcurrant seed oil (67%), hemp oil (67%), safflower oil (65%), wheat germ oil (64%), dill seed oil (63%), poppy seed oil (61%), parsley seed oil (60%), black cumin oil, and milk thistle oil (45%–46%). Campesterol was the dominant sterol in borage oil (45%), stigmasterol in watermelon seed oil (32%), and other sterols in argan oil (79%).

The phytosterol content of oils and fats decreases with heating and storage [38,39]. When the oils were stored for six days at 60°C, the phytosterol content decreased by 4%–6% in avocado fruit, macadamia nut, and dill seed oils, and by 49%–50% in pine nut and blackcurrant seed oils. After twelve days of storage, the lowest level of phytosterol degradation was seen in avocado fruit and macadamia nut oils, which ranged from 5% to 6%; in blackcurrant seed oil and milk thistle oil, 72% and 68% of phytosterols decreased, respectively.

3.6. Comparison of Cold-pressed Plant Oils Using Euclidean Distances Analysis

Euclidean distances are the most often used way of comparing profiles across variables, and are usually the appropriate measure for comparing cases. This statistical method was used here to estimate the distances between different kinds of fresh cold-pressed plant oils and the effect of storage on their quality, taking AV, PV, fatty acid composition, tocopherols, and sterols as variables. In determining the quality of the oils, correlations between PV, AV, SFA, MUFA and oxidative stability were demonstrated, and also between PUFA, sterols, and tocopherols (Figure 2A). The data shows that the fresh oils can be divided into three groups (Figure 2B): one group contains apricot kernel oil, argan oil, avocado oil, and macadamia nut oil, which were characterized by high levels of MUFA. Blackcurrant seed oil, hemp oil, borage oil, and wheat germ oil fell into the second group, which contained high levels of sterols, tocopherols, and PUFA.

The final group of oils showed low PV and AV and better oxidative stability, with the exception of black cumin oil, which was characterized by high PV, AV, and oxidative stability (Figure 2B).

After storage, the oils could again be divided into these three groups; however, pine nut oil was added to the first group (Figure 2C and Figure 2D). The most similar changes during storage were observed for milk thistle oil, safflower oil, and parsley seed oil, where PV, AV, PUFA, and n-6 fatty acids showed changes on the same level.

Different cultivars of oilseed crops are often associated with significantly different concentrations of bioactive

compounds in the oils pressed from their seeds [8,9,40,41]. The impact of varietal factors, which are not studied here, should be also taken into account, since the yield and composition of oil made from the same cultivar, even if grown in the same location, may vary from year to year [42].

Table 3. Content of tocochromanols (mg/100 g) in the cold-pressed plant oils before and after storage for six and twelve days at 60°C

Oils	Time of storage (days)	α-T*	β-T	γ-T	δ-T	α-T3	β-T3	γ-T3	Total
	0	0.7±0		58.3±1.2	0.9±0				59.9±1.2
Apricot kernel oil	6	0.5±0		54.3±1.2	0.7±0				55.4±1.1
	12	0.4±0		53.4±1.2	0.5±0				54.3±1.1
	0	3.9±0.1		37.1±0.7	2.2±0	43.1±0.9			43.1±0.9
Argan oil	6	3.1±0.1		37.0±0.7	2.0±0	42.1±0.8			42.1±0.8
	12	2.9±0.1		35.4±0.7	1.8±0	40.1±0.8			40.1±0.8
	0				2.2±0				2.2±0
Avocado fruit oil	6				0.9±0				0.9±0
	12				0.6±0				0.6±0
	0	1.7±0		1.92±0.04		3.2±0.1	18.1±0.4		25.0±0.5
Black cumin oil	6	1.6±0		1.86±0.04		3.0±0.1	17.7±0.3		24.1±0.5
	12	1.2±0		1.73±0.03		2.8±0.1	17.1±0.3		22.8±0.5
	0	22.2±0.4		79.7±1.6	9.3±0.2	0.5±0	0.8±0	0.4± 0	112.9±2.3
Blackcurrant seed oil	6	15.3±0.3		77.1±1.5	9.0±0.2	0.4±0	0.7±0	0.4±0	102.9±2.1
	12	11.5±0.2		71.2±1.4	8.6±0.2	0.3±0	0.3±0	0.3±0	92.2±1.8
	0			9.5±0.2	84.5±1.7				93.9±1.9
Borage oil	6			2.8±0.1	71.6±1.4				74.4±1.5
	12			0.3±0	56.3±1.1				56.6±1.1
	0	39.4±0.8	2.2±0	0.6±0					42.1±0.8
Dill seed oil	6	38.1±0.8	2.0±0	0.5±0					40.6±0.8
	12	36.1±0.7	1.8±0	0.4±0					38.3±0.8
	0	2.4± 0.1		74.5±1.5	1.5±0				78.4±1.6
Hemp oil	6	1.2±0		67.2±1.3	1.5±0				69.9±1.4
	12	0.6±0		55.4±1.1	1.3±0				57.4±1.2
	0					1.4±0			1.4±0
Macadamia seed oil	6					1.0±0			1.0±0
	12					0.6±0			0.6±0
	0	54.4±1.1	2.1±0	5.1±0.1	1.7±0				63.3±1.3
Milk thistle seed oil	6	52.7±1.0	1.6±0	4.9±0.1	1.6±0				60.8±1.2
	12	49.0±1.0	0.9±0	4.3±0.1	1.4±0				55.6±1.1
	0	48.1±1.0	1.2±0	0.1±0					49.5±1.0
Parsley seed oil	6	46.3±0.9	1.2±0	0.1±0					47.5±1.0
	12	36.5±0.7	1.0±0	0.1±0					37.6±0.8
	0	7.4±0.2	0.1±0	10.3±0.2	0.7±0				18.5±0.4
Pine nut oil	6	3.2±0.1	0	8.4±0.2	0.4±0				12.1±0.2
	12	0.9±0		7.8±0.2	0.2±0				8.9± 0.2
	0	0.3±0		17.8±0.4					18.1±0.4
Poppy seed oil	6			11.1±0.2					11.1±0.2
	12			6.5±0.1					6.5±0.1
	0	53.5±1.1	1.0±0	5.5±0.1	1.5±0				64.5±1.3
Safflower oil	6	52.3±1.1	0.8±0	5.0±0.1	1.1±0				59.2±1.2
	12	28.4±0.6	0.2±0	3.0±0.1	0.5±0				32.2±0.6
	0	2.2±0		68.7±1.4	1.1±0				71.9±1.4
Watermelon seed oil	6	1.4±0		61.3±1.2	1.0±0				63.7±1.3
	12	1.0±0		53.5±1.1	1.0±0				55.5±1.1
	0	83.5±1.7	60.9±1.2	0.7±0		0.5±0	1.8±0	7.8±0.2	155.10±3.1
Wheat germ oil	6	79.1±1.6	58.7±1.2	0.7±0		0.5±0	1.6±0	6.7±0.1	147.1±2.9
	12	70.7±1.4	58.2±1.2	0.5±0		0.4±0	1.4±0	6.1±0.1	137.3±2.8

*α-T: α-tocopherol; β-T: β-tocopherol; γ-T: γ-tocopherol; δ-T: δ-tocopherol; α-T3: α-tocotrienol; β-T3: β-tocotrienol; γ-T3: γ-tocotrienol.

Table 4. Content of phytosterols (mg/100g) in cold-pressed plant oils before and after storage for six and twelve days at 60°C

Oils	Time of storage	Campesterol	Stigmasterol	β-Sitosterol	Avenasterol	Cycloartenol	24Methylene cycloartenol	Others
Apricot kernel oil	0 d	5.3±0.1		56.8±3.1	3.8±0.1			
	6 d	2.7±0.1		43.4±2.0	2.7±0.1			
	12 d	2.4±0.1		30.2±1.8	2.2±0.1			
Argan oil	0 d				11.8±0.2	16.8±0.8	5.2±0.1	128.9±7.1
	6 d				9.2±0.2	14.6±0.8	2.8±0.1	120.5±5.8
	12 d				8.6±0.2	13.9±0.6	2.3±0.1	115.9±5.5
Avocado fruit oil	0 d	11.6±1.0	1.1±0.2	107.1±4.6	3.6±0.2	8.3±0.3	2.3±0.1	2.1±0.2
	6 d	11.0±0.9	0.9±0.1	104.3±4.5	3.0±0.2	7.6±0.3	2.1±0.1	1.7±0.2
	12 d	10.9±0.9	0.9±0.1	102.5±4.2	3.2±0.2	7.1±0.1	2.1±0.1	1.0±0.1
Black cumin oil	0 d	6.7±0.1	6.1±0.3	19.7±1.0	2.7±0.2	5.7±0.1	2.7±0.1	
	6 d	5.7±0.1	5.7±0.3	17.9±0.9	2.2±0.1	4.2±0.1	2.1±0.1	
	12 d	4.2±0.1	4.4±0.2	12.5±0.6	1.4±0.1	3.5±0.1	2.1±0.1	
Blackcurrant seed oil	0 d	21.7±1.1	1.6±0.1	170.5±2.1	6.6±0.2	16.3±0.6	18.8±0.9	18.2±0.9
	6 d	11.3±1.0	1.0±0.1	84.1±2.5	2,8±0.1	8.3±0.4	10.3±0.5	8.4± 0.4
	12 d	7.4±0.5	0.3±0.1	48.7±1.9	1.5±0.1	3.9±0.3	5.3±0.2	2.7±0.1
Borage oil	0 d	42.1±1.9		24.4±1.5	14.0±0.7	11.7±0.5	1.7±0.1	
	6 d	34.9±1.5		19.3±1.0	11.0±0.5	10.5±0.4	1.2±0.1	
	12 d	26.6±0.8		14.5±0.4	7.6±0.3	7.1±0.3	Nd	
Dill seed oil	0 d	8.5±0.6	5.8±0.2	39.1±1.8		3.2±0.1		5.2±0.2
	6 d	7.5±0.5	5.5±0.2	37.8±1.7		3.1±0.1		4.4±0.2
	12 d	6.0±0.3	5.0±0.2	32.5±1.1		2.7±0.1		4.0±0.2
Hemp oil	0 d	17.4±0.8	1.7±0.1	63.0±2.5	8.5±0.3	3.1±0.1		
	6 d	16.8±0.7	1.7±0.2	53.6±2.4	6.5±0.3	3.1±0.1		
	12 d	14.9±0.5	1.7±0.1	34.0±1.8	3.4±0.1	2.2±0.1		
Macadamia seed oil	0 d	7.0±0.3	1.4±0.1	65.6±2.5	4.2±0.2			
	6 d	6.2±0.2	1.4±0.1	63.7±2.6	4.2±0.2			
	12 d	6.1±0.3	1.2±0.1	63.2±2.2	4.2±0.2			
Milk thistle seed oil	0 d	10.3±0.3	11.9± 0.3	51.0±2.6		32.8±1.2	5.3±0.2	
	6 d	6.3±0.3	7.5±0.3	33.2±1.9		18.9±0.9	2.7±0.1	
	12 d	3.4±0.2	3.9±0.2	17.3±0.8		9.8±0.5	1.6±0.1	
Parsley seed oil	0 d	6.3±0.3	7.8±0.4	41.1±1.9	1.9±0.2	6.4±0.3		5.2±0.2
	6 d	6.0±0.3	6.0±0.3	32.1±1.6	1.3±0.2	5.9±0.3		4.9±0.2
	12 d	5.6±0.3	6.0±0.2	31.5±1.5	1.2±0.1	4.4±0.2		4.8±0.2
Pine nut oil	0 d	17.7±1.1	3.4±0.1	120.5±4.3	3.1±0.2	3.1±0.5	3.5±0.1	2.0±0.1
	6 d	15.1±0.8	3.2±0.1	53.5±2.2	2.4±0.1	2.4±0.2	1.2±0.1	1.6±0.1
	12 d	12.3±0.6	2.9±0.1	50.5±1.9	1.9±0.1	1.9±0.1	1.0±0.1	1.3±0.1
Poppy seed oil	0 d	16.5±1.0	10.3±0.8	110.0±4.6	11.9± 0.4	22.2±1.0	6.5±0.3	4.4±0.3
	6 d	15.3±0.8	5.7±0.3	58.5±2.7	3.2±0.1	12.2±0.6	3.5±0.2	1.9±0.2
	12 d	15.3±0.7	2.7±0.2	53.2±1.9	3.1±0.2	4.9±0.2	1.0±0.1	1.4±0.2
Safflower oil	0 d	26.1±1.2	4.4±0.2	122.9±5.3	11.6±0.6	18.7±0.4	4.9±0.2	
	6 d	16.3±0.8	3.9±0.2	88.8±4.2	11.1± 0.5	16.5±0.2	4.6±0.2	
	12 d	12.9±0.6	2.8±0.2	59.1±2.7	8.8±0.4	6.3±0.2	4.2±0.2	
Watermelon seed oil	0 d		27.5±0.8	13.8±0.8	21.7±1.8	21.7±1.1	2.5±0.1	
	6 d		21.4±0.6	11.8±0.8	20.0±1.5	19.7±0.8	2.5±0.1	
	12 d		19.8±0.8	7.9±0.1	13.0±0.8	12.9±0.6	2.0±0.1	
Wheat germ oil	0 d	225.3±9.8	17.5±0.8	545.2±21.7	31.6±1.6	8.5±0.2		29.8±1.2
	6 d	222.3±9.3	10.4±0.5	454.8±20.3	25.4±1.1	7.4±0.3		22.2±1.1
	12 d	196.1±8.4	7.8±0.4	383.2±18.4	19.7±0.9	6.5±0.3		21.2±1.0

Nd – not detected.

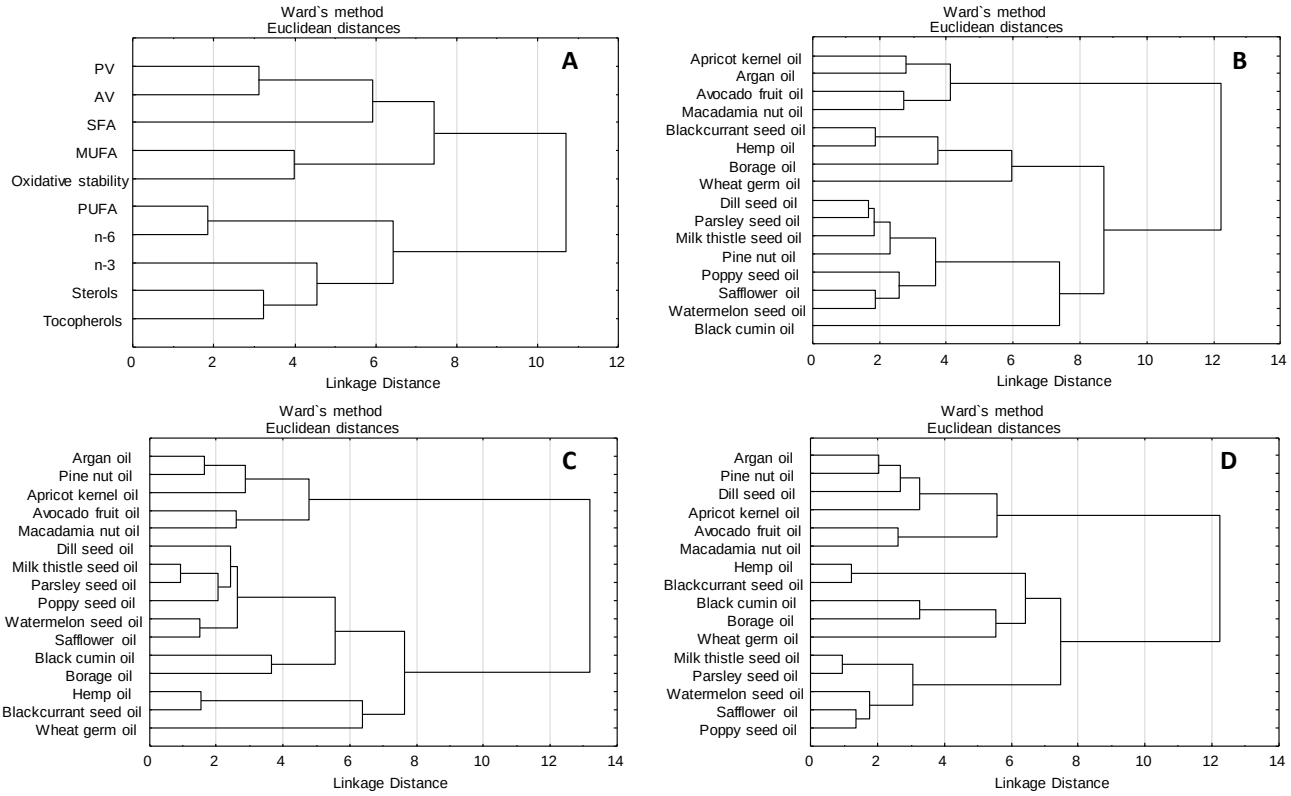

Figure 2. A: Euclidean distances for the variables used to determine relationships between the fresh cold-pressed plant oils; B: Dendrogram of relationships of fresh cold-pressed plant oils, based on chemical variables; C:Relationship of cold-pressed plant oils stored for six days, based on chemical variables; D: Relationship of cold-pressed plant oils stored for twelve days, based on chemical variables.

4. Conclusions

The quality and health properties of the sixteen cold-pressed plant oils differed. The wheat germ oil contained high levels of tocopherols (155 mg/100g), sterols (86 mg/100g), and n-3 PUFA (9.4%), but its AI (0.26) and TI (0.53) were rather high and its HH was low (4.24) compared to all the other tested oils. Apricot kernel oil showed the lowest AI (0.05) and TI (0.11) and the highest HH (21.49) of all the samples; it also did not contain any n-3 fatty acids, had low levels of phytosterols (66 mg/100g), and a rather middling quantity of tocopherols (60 mg/100g). Avocado oil, which nutritionally lay in the middle of all the oils, was characterized by a very low proportion of PUFA (n-6/n-3 = 29) and tocopherols (2.2 mg/100g), but had higher levels of phytosterols (135 mg/100g) than apricot oil. The conclusion which emerges from this analysis is that the incidence of CHD cannot be related to any single attribute of the dietary plant oils. The obtained data may contribute to further work on standardization of cold-pressed plant oils approved for consumption.

Conflict of Interest

The authors declare that they have no conflict of interest.

References

[1] FAO. 2010. Fats and fatty acids in human nutrition. Report of an expert consultation. 10_14 November 2008, Geneva. FAO Food and Nutrition Paper 91. Rome: Food and Agricultural Organization of the United Nations.

[2] Ulbricht, T.L.V. and Southgate, D.A.T., "Coronary heart disease: Seven dietary factors", *Lancet*, 338, 985-992, 1991.

[3] Schwab, U., Lauritzen, L., Tholstrup, T., Haldorsson, T.I., Riserus, U. and Becker, W., "Effect of the amount and type of dietary fat on cardiometabolic risk factors and risk of developing type 2 diabetes, cardiovascular diseases, and cancer: A systematic review", *Food Nutr. Res.*, 58, 25145, 2014.

[4] Ferguson, J.J.A., Stojanovski, E., MacDonald-Wicks, L. and Garg, M.L., "Fat type in phytosterol products influence their cholesterol-lowering potential: A systematic review and meta-analysis of RCTs", *Prog. Lipid Res.*, 64, 16-29, 2016.

[5] Tucker, J.M. and Townsend, D.M., "Alpha-tocopherol: Roles in prevention and therapy of human disease", *Biomed Pharmacother.*, 59, 380-387, 2005.

[6] Grimm, M.O.W., Stahlmann, C.P., Mett, J., Haupenthal, V.J., Zimmer, V.C., Lehmann, J., Hundsdorfer, B., Endres, K., Grimm, H.S., Hartmann, T., Marcus, O., Grimm, W., Stahlmann, C. P., Mett, J., Haupenthal, V. J., Zimmer, V. C. and Hartmann, T., "Vitamin E: Curse or benefit in Alzheimer's disease? A systematic investigation of the impact of α-, γ- and δ-tocopherol on Aβ generation and degradation in neuroblastoma cells", *J. Nutr. Health Aging.*, 19, 646-654, 2015.

[7] Obiedzińska, A. and Waszkiewicz-Robak, B., "Cold pressed oils as functional food.", *Żywn. Nauka Technol. Jakość.*, 80, 27-44, 2012.

[8] Górnaś, P., Rudzińska, M., Raczyk, M., Mišina, I. and Segliņa, D., "Impact of cultivar on profile and concentration of lipophilic bioactive compounds in kernel oils recovered from sweet cherry (*Prunus avium* L.) by-products", *Plant Foods Hum. Nutr.*, 71, 158-164, 2016.

[9] Górnaś, P., Rudzińska, M., Raczyk, M., Mišina, I., Soliven, A., Lācis, G. and Segliņa, D., "Impact of species and variety on concentrations of minor lipophilic bioactive compounds in oils recovered from plum kernels", *J. Agric. Food Chem.*, 64, 898-905, 2016.

[10] Górnaś, P., Rudzińska, M., Raczyk, M., Mišina, I., Soliven, A. and Segliņa, D., "Chemical composition of seed oils recovered from

different pear (*Pyrus communis* L.) cultivars", *J. Am. Oil Chem. Soc.*, 93, 267-274, 2016.

[11] Kiralan, M.and Ramadan, M.F., "Volatile oxidation compounds and stability of safflower, sesame and canola cold-pressed oils as affected by thermal and microwave treatments", *J. Oleo. Sci.*, 65, 825-833, 2016.

[12] Li, Q., Wang, J. and Shahidi, F., "Chemical characteristics of cold-pressed blackberry, black raspberry, and blueberry seed oils and the role of the minor components in their oxidative stability", *J. Agric. Food Chem.*, 64, 5410-5416, 2016.

[13] Codex Alimentarius. International Food Standards. Standard for named vegetable oils. Codex stan 210-1999, revision 2001, 2003, 2009. Amendment 2005, 2011, 2013 and 2015. Food and Agriculture Organization of the United Nations. World Health Organization.

[14] AOCS Official Method Cg 5–97, 1997. Oven storage test for accelerated aging of oils. Sampling and analysis of commercial fats and oils. *Methods and Recommended Practices of the AOCS*, Sixth edition. Firestone, D. (ed.); AOCS Press, Champaign, IL, USA, pp. 1-2.

[15] AOCS Official Method Te 1a-64, 2009. Acid value. *Official Methods and Recommended Practices of the AOCS*, Sixth edition. Firestone, D. (ed.); AOCS Press, Champaign, IL, p 1.

[16] AOCS Official Method Cd 8b-90, 2009. Peroxide value Acetic Acid-Isooctane Method. *Official Methods and Recommended Practices of the AOCS*, Sixth edition. Firestone, D. (ed.); AOCS Press, Champaign, IL, USA, pp. 1-3.

[17] Siger, A., Kachlicki, P., Czubiński, J., Polcyn, D., Dwiecki, K. and Nogala-Kałucka, M., "Isolation and purification of plastochromanol-8 for HPLC quantitative determinations", *Eur. J. Lipid Sci. Technol.*, 116, 413-422, 2014.

[18] AOCS Official Method Ce 1h-05, 2005. Determination of *cis-*, *trans-*, saturated, monounsaturated and polyunsaturated fatty acids in vegetable or non-ruminant animal oils and fats by capillary GLC. *Official Methods and Recommended Practices of the AOCS*, Sixth edition. Firestone, D. (ed.); AOCS Press, Champaign, IL, USA, pp. 1-29.

[19] AOCS Official Method Ch 6–91, 1997. Determination of the composition of the sterol fraction of animal and vegetable oils and fats by TLC and capillary GLC. *Methods and Recommended Practices of the AOCS*, Sixth edition. Firestone, D. (ed.); AOCS Press, Champaign, IL, USA, pp. 1-5.

[20] AOCS Official Method Cd 12b-92, 1997. Oil stability index. Sampling and analysis of commercial fats and oils. *Methods and Recommended Practices of the AOCS*, Sixth edition. Firestone, D. (ed.); AOCS Press, Champaign, IL, USA, pp. 1-2.

[21] Santos, J.S., Bessa, R.J.B. and Santos, F.S., "Effect of genotype: Feeding system and slaughter weight on the quality of light lambs. II. Fatty acid composition of meat", *Livest. Prod. Sci.*, 77, 187-194, 2002.

[22] Kiralan, M., Özkan, G., Bayrak, A. and Ramadan, M.F., "Physicochemical properties and stability of black cumin (*Nigella sativa*) seed oil as affected by different extraction methods", *Ind. Crops Prod.*, 57, 52-58, 2014.

[23] Kiralan, M., Ulaş, M., Özaydin, A., Özdemir, N., Özkan, G., Bayrak, A. and Ramadan, M.F., "Blends of cold pressed black cumin oil and sunflower oil with improved stability: A study based on changes in the levels of volatiles, tocopherols and thymoquinone during accelerated oxidation conditions", *J. Food Biochem.*, 41, e12272, 2017.

[24] Parker, T.D., Adams, D.A., Zhou, K., Harris, M. and Yu, L., "Fatty acid composition and oxidative stability of cold-pressed edible seed oils", *J. Food Sci.*, 68, 1240-1243, 2003.

[25] Hassanien, M.M.M., Abdel-Razek, A.G., Rudzińska, M., Siger, A., Ratusz, K. and Przybylski, R., "Phytochemical contents and oxidative stability of oils from non-traditional sources", *Eur. J. Lipid Sci. Technol.*, 116, 1563-1571, 2014.

[26] Symoniuk, E., Ratusz, K. and Krygier, K., "Comparison of the oxidative stability of linseed (*Linum usitatissimum* L.) oil by pressure differential scanning calorimetry and Rancimat measurements.", *J. Food Sci. Technol.*, 53, 3986-3995, 2016.

[27] Symoniuk, E., Ratusz, K., Krygier, K., "Comparison of the oxidative stability of cold-pressed rapeseed oil using pressure differential scanning calorimetry and Rancimat methods", *Eur. J. Lipid Sci. Technol.*, 119, 1600182, 2017.

[28] Kalua, C.M., Bedgood, D.R. Jr., Bishop, A.G. and Prenzler, P.D., "Discrimination of storage conditions and freshness in virgin olive oil", *J. Agric. Food Chem.*, 54, 7144-7155, 2006.

[29] Virtanen, J.K., Mursu, J., Tuomainen, T.P. and Voutilainen, S., "Dietary fatty acids and risk of coronary heart disease in men: The Kuopio Ischemic Heart Disease Risk Factor Study", *Arterioscler. Thromb. Vasc. Biol.*, 34, 2679-2687, 2014.

[30] Marfil, R., Giménez, M.O., Bouzas, P.R., Rufián-Henares, J.A., Mesias, M. and Cabrera-Vique, C., "Determination of polyphenols, tocopherols, and antioxidant capacity in virgin argan oil (*Argania spinose*, Skeels)", *Eur. J. Lipid Sci. Technol.*, 11, 886-893, 2011.

[31] Eitenmiller, R. and Lee, J., "Nutritional and health implications of vitamin E", in *Vitamin E: Food Chemistry, Composition and Analysis*, Marcel Dekker, New York, 39-89.

[32] Magariño, M., Mateo, C.M. and Nolasco, S.M., "Kinetics of tocopherol degradation during the storage of wheat germ oil", *Can. J. Chem. Eng.*, 93, 1999-2004, 2015.

[33] Bauernfeind, JC, Desai ID. 1977. The tocopherol content of food and influencing factors. *Crit. Rev. Food Sci. Nutr.* 8: 337-382.

[34] Koski A, Psomiadou E, Tsimodou M, Hopia A, Kefalas P, Walala K, Heinonen M. 2002. Oxidative stability and minor constituents of virgin olive oil and cold-pressed rapeseed oil. *Eur. Food Res. Technol.* 214: 294-298.

[35] Teleszko, M., Wojdyło, A., Rudzińska, M., Oszmiański, J. and Golis, T., "Analysis of lipophilic and hydrophilic bioactive compounds content in sea buckthorn (*Hippophaë rhamnoides* L.) berries", *J. Agric. Food Chem.*, 63, 4120-4129, 2015.

[36] Sawadikiat, P. and Hongsprabhas, P., "Phytosterols and γ-oryzanol in rice bran oils and distillates from physical refining process", *Int J. Food Sci. Technol.*, 49, 2030-2036, 2014.

[37] Vlahakis, C. and Hazebroek, J., "Phytosterol accumulation in canola, sunflower, and soybean oils: Effect of genetics, planting location, and temperature", *J. Am. Oil Chem. Soc.*, 77, 49-53, 2000.

[38] Rudzińska, M., Górnaś, P., Raczyk, M. and Soliven, A., "Sterols and squalene in apricot (*Prunus armeniaca* L.) kernels oils: The variety as a key factor", *Nat. Prod. Res.*, 31, 84-88, 2016.

[39] Sopelana, P., Ibargoitia, M.L. and Guillén, M.D., "Influence of fat and phytosterols concentration in margarines on their degradation at high temperature: A study by 1H nuclear magnetic resonance", *Food Chem.*, 197, 1256-1263, 2016.

[40] Galvão, M.S., Narain, N. and Nigam, N., "Influence of different cultivars on oil quality and chemical characeristics of avocado fruit", *Food Sci. Technol.*, 34, 539-546, 2014.

[41] Górnaś, P., Mišina, I., Olšteine, A., Krasnova, I., Pugajeva, I., Lācis, G., Siger, A., Michalak, M., Soliven, A. and Segliņa, D., "Phenolic compounds in different fruit parts of crab apple: Dihydrochalcones as promising quality markers of industrial apple pomace by-products", *Ind. Crop Prod.*, 74, 607-612, 2015.

[42] Król, B. and Paszko, T., "Harvest date as factor affecting crop yield, oil content and fatty acid composition of the seeds of calendula (*Calendula officinalis* L.) cultivars", *Ind. Crop Prod.*, 97, 242-251, 2017.