Heliyon 7 (2021) e06304

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

GC-MS and HPLC-DAD analysis of fatty acid profile and functional phytochemicals in fifty cold-pressed plant oils in Thailand

Jitkunya Yuenyong [a,b], Piramon Pokkanta [a], Nutthatida Phuangsaijai [c], Sila Kittiwachana [c,d], Sugunya Mahatheeranont [a,d,e], Phumon Sookwong [a,d,*]

[a] Rice and Cereal Chemistry Research Laboratory, Department of Chemistry, Faculty of Science, Chiang Mai University, Chiang Mai 50200, Thailand
[b] Master's Degree Program in Chemistry, Faculty of Science, Chiang Mai University, Chiang Mai 50200, Thailand
[c] Department of Chemistry, Faculty of Science, Chiang Mai University, Chiang Mai 50200, Thailand
[d] Research Center on Chemistry for Development of Health Promoting Products from Northern Resources, Chiang Mai University, Chiang Mai 50200, Thailand
[e] Center of Excellence for Innovation in Chemistry, Faculty of Science, Chiang Mai University, Chiang Mai 50200, Thailand

ARTICLE INFO

Keywords:
Oil
Fatty acid
Antioxidant
Phytosterols
Squalene
Cholecalciferol

ABSTRACT

Cold-pressed oil is one of the healthiest plant extracts, but its use is limited only in some kinds of plants. Therefore, we aimed to investigate some potential cold-pressed oils with attractive fatty acid profiles and high amounts of functional phytochemicals. Fifty cold-pressed plant oils were prepared from various plant materials in Thailand, in which some of them were from uncommon or unattended plant materials. The oils included were nut oils (n = 9), pseudo-cereal oils (n = 9), legume oils (n = 3), amaranth oils (n = 3), marrow seed oils (n = 8), cruciferous seed oils (n = 7), and leafy green seed oils (n = 11). Gas-chromatography mass-spectrometry (GC-MS) and high-performance liquid chromatography coupled with a diode array detector (HPLC-DAD) were employed to analyze fatty acid profile and five functional phytochemicals (e.g., phytosterols, cholecalciferol, and squalene). Saturated fatty acids were detected around 7.87–36.04%, monounsaturated fatty acids 10.17–80.25%, and polyunsaturated fatty acids nondetectable (ND)–78.25%, phytosterols 663–15123 μg g^{-1}, squalene 265–5979 μg g^{-1}, and cholecalciferol ND–1287.75 μg g^{-1}. The study showed chemical characteristic of the analyzed oils: some contained good fatty acid composition and some were rich in functional phytochemical content. Among the obtained oils, marrow seed oils are a good source of phytosterol, cholecalciferol, and linoleic acid. Pseudo-cereal oils are rich in squalene and linolenic acid. Legume oils are rich in phytosterols and oleic acid. Besides, principal component analysis (PCA) was applied to identify the significance of oils that share compositional similarity (e.g., the samples from pseudo-cereal oil were found on the lower side of the PCA space, which separated them from marrow and leafy green seed oils distributed on the upper part of the plot). In summary, the qualitative and quantitative data would provide a good foundation for further application or selection of those plant oils for health purposes.

1. Introduction

Cold-pressed oils are oils obtained by passing plant materials through a screw press or hydraulic press with zero chemicals and no heat treatment, resulting in plant lipophilic extract with high retention of their color, flavor, and nutritive properties and minimum degradation of the functional components [1, 2]. In general, cold-pressed oils contain better nutritional value than commercially refined oils because the chemical and thermal treatments in the refining process such as solvent extraction, degumming, neutralizing with NaOH, bleaching, dewaxing and deodorizing can cause degradation and reduction of some essential compounds as a consequence [3]. For instance, sunflower oil could lose up to 60% phytosterols, up to 55% tocols and up to 60% squalene due to the refining procedure as reported in a study by Gotor and Rhazi [4]. Refining process could increase the acid value, peroxide value and *p*-anisidine value in rapeseed oil, together with the diminished content of tocopherols, sterols, β-carotene and phenols as previously evidenced [5]. In addition, phytosterols are progressively lost during refining while continuously altering the ratio of free and esterified sterols [6].

* Corresponding author.
E-mail address: phumon.s@cmu.ac.th (P. Sookwong).

https://doi.org/10.1016/j.heliyon.2021.e06304
Received 7 December 2020; Received in revised form 13 January 2021; Accepted 12 February 2021

From the perspective of functional compounds, cold-pressed oils are considered as one of the healthiest chemicals-free products commercially available. Lipophilic phytochemicals present in cold-pressed oils such as phytosterols, squalene, and cholecalciferol have been demonstrated to improve physiological and biological activity in human health. Phytosterols have displayed their abilities to reduce the level of cholesterol in the blood, increase metabolic rates, enhance fat burning, and reduce the incidence of some types of cancers [7]. Squalene has some favourable health benefits such as cancer inhibitor, antitumor, antioxidant in the skin, and has been applied in pharmaceutical and cosmetic industries. Cholecalciferol helps regulate and control absorbability of phosphorus and calcium, and, furthermore, it is an effective compound for managing blood sugar levels, thereby controlling diabetic conditions [8, 9]. In addition, nutritional value of plant oils is also evaluated by the amount of monounsaturated fatty acids (MUFAs) and polyunsaturated fatty acids (PUFAs) [10]. Oils rich in MUFAs, such as oleic acid (C18:1), had the potential to lower blood cholesterol levels and reduce the aortic accumulation of oxidized LDL without adversely affecting HDL fraction [11, 12]. PUFAs are essential for the human health and can only be received from a proper diet. The benefits of linoleic acid (C18:2) have been evidenced for cholesterol and triglyceride lowering effects, anti-inflammation, cardioprotection, antidiabetes, and cancer prevention [13]. Meanwhile, linolenic acid (C18:3) has been known for its anti-inflammatory, anti-hypertensive, anti-thrombotic activities, and anticancer activities [14].

However, to date, the use of cold-pressed oils is restricted only in some kinds of plants. This is partly due to the difficulty in preparation of cold-press oil, including pre-treatment of plant oil material, shortage of material supply, and lack of knowledge about suitable plant material for oil extraction. In order to promote more use of cold-pressed plant oils, the study on nutritional information of other kinds of plant oils prepared from different plant materials is among one of the many possible solutions.

Therefore, this study is aimed at screening some potential cold-pressed oils with good nutritional properties by preparing a number of cold-pressed oils from various plant materials (total of 50 samples) and analyzing their chemical composition using chromatographic methods. Fatty acid compositions were quantitatively analyzed using gas-chromatography mass-spectrometry (GC-MS). Functional phytochemicals, including phytosterols (3 forms), squalene, and cholecalciferol were analyzed using high-performance liquid chromatography coupled with a diode array detector (HPLC-DAD). Principal component analysis (PCA) was applied to identify the significance of oil categories that share chemical similarity to the content of functional compounds and fatty acid composition. In some previous studies, PCA was successfully used to produce a clustering of variables and samples into distinct groups of oil samples such as the variation of fatty acid data on different soybean cultivars [15], and the variation of lipid composition of commercial olive oils [16]. The obtained quantitative data would be useful in the selection of plant materials for cold-press oil production or related applications for therapeutic and health purposes. The obtained quantitative data would be useful in the selection of plant materials for cold-press oil production or related applications for therapeutic and health purposes.

2. Materials and methods

2.1. Chemicals

Fatty acid standards (palmitic (C16:0, purity >97 %), palmitoleic (C16:1, purity >98 %), stearic (C18:0, purity >98 %), oleic (C18:1, purity >85 %), linoleic (C18:2, purity >85 %), linolenic (C18:3, purity >70 %), arachidic (C20:0, purity >98 %), and erucic (C22:1, purity >85 %) acids) were purchased from Tokyo Chemical Industry Co., Ltd. (Tokyo, Japan). Stigmasterol standard and mixed standards of β-sitosterol (60%) and campesterol (40%)), squalene (purity >98 %), and cholecalciferol (purity >98 %) were purchased from Tokyo Chemical Industry Co., Ltd. (Tokyo, Japan). Methanol and hexane were of HPLC grade, and other reagents were of analytical grade (RCI Labscan Co., Ltd, Bangkok, Thailand).

2.2. Samples and cold extraction

Plant oils were extracted by cold-pressing from different plant parts of the plant material, specifically those which could yield oil. All plant materials were purchased and collected from the agricultural areas in Chiang Mai province (the Northern Thailand, latitudinally and longitudinally extended by 18°47′ 22.5″ N to 99°00′ 04.2″ E and 19°29′ 06.6″ N to 99°01′ 13.2″ E) (Table 1). Oils derived from those plant samples were classifieds into 3 main categories, including nut oils, grain oils, and vegetable oils. In the category of nut oils, plant materials were mostly kernel parts (9 samples). In the category of grain oils, subcategories were pseudo-cereals (9 samples), legumes (3 samples) and amaranth (3 samples). The category of vegetable oils contained subcategories of marrow, cruciferous and leafy green seeds (8, 7, and 11 samples, respectively). Before oil extraction, the plant samples were kept in zip-lock bags and stored at or below 4 °C in a refrigerator. In the preparation of oil from plant raw materials, each plant material has different processes depending on the plant type such as peeling, sun-drying, roasting, grinding, extraction, and bottling as shown in Table 2 with the details are described below

I) Peeling: to remove the hard shell and obtain kernels.
II) Sun-drying: to reduce the amount of moisture and dry the seeds by pouring the seeds into a tray and then exposed to the sun during 9.00 A.M to 4.00 P.M for 3 days.
III) Roasting: to heat at 160 °C set of the using a heating pan for 5–10 min depends on the type of raw material. The roasting was done until the color changed but not burnt.
IV) Grinding: to down-sizing the sample by pounding with a pestle until the dimension of sample was less than 0.5 cm in size.
V) Extraction: to extract oil from raw materials with cold-press machine.
VI) Bottling: to store the compressed oil into a glass bottle and store it in the refrigerator at below 4 °C.

The cold-press process was operated with a home automatic oil press machine (1500 W, General Equipment Co., Ltd. (Guangzhou, China)). The small or ground plant materials were put into the feeding part, allowing the materials to be pressed with a spiral screw in an extraction cylinder. The screw pressing was continuously driven by a motor, yielding oil as a result of high-pressure pressing and dry solid cake which the oil was excluded. The cold extraction occurred at a temperature of 40–50 °C, and the sample mass of each extraction in this study was between 500-1000 g of each plant material.

2.3. GC-MS analysis for fatty acid composition

For GC-MS analysis of fatty acid composition, the fatty acids in oil samples were converted to fatty acid methyl esters (FAMEs) according to the method of Ichihara and Fukubayashi [17] before analysis. Briefly, oil samples (0.015 g) were mixed with 0.20 mL of toluene, 1.50 mL of methanol and 0.30 mL of 8.0% (w/v) concentrated hydrochloric acid. The mixture was incubated at 100°C for 5 min. Then, 1.00 mL of hexane and 1.00 mL of water was added and mixed with the mixture. The hexane layer (upper layer) was separated for analysis. Fatty acid composition in oil samples was analyzed using a 6890 GC/5973 MSD (Agilent, Polo Alto, CA). A HP-5MS capillary column (30 m × 0.25 mm, 0.25 μm) was used, and helium as carrier gas was flowed at 1 mL min^{-1}. The energy of electron impact was 70 eV. The inlet temperature was 280 °C, and injection volume was 1.0 μL with a split ratio of 15:1. The column temperature was set at 165 °C, followed by a 4 °C min^{-1} oven temperature ramped to 290 °C. The transfer line temperature was 290 °C, and the

Table 1. Common names and scientific names of the plants used in this study.

Common name	Scientific name	Families	Common name	Scientific name	Families
Nut/Kernel oil (9 samples)			**Marrow seed oil (8 samples)**		
Almond	*Prunus dulcis*	Rosaceae	Angled loofah	*Luffa acutangula* (L.) Roxb.	Cucurbitaceae
Cashew	*Anacardium occidentale* L.	Anacardiaceae	Cucumber	*Cucumis sativus* L.	Cucurbitaceae
Coconut	*Cocos nucifera* L.	Arecaceae	Long skinny eggplant	*Solanum melongena* Linn.	Solanaceae
Hazelnut	*Corylus avellana* L.	Betulaceae	Muskmelon	*Cucumis melo* L.	Cucurbitaceae
Macadamia	*Macadamia integrifolia*	Proteaceae	Pumpkin	*Cucurbita moschata* Decne.	Cucurbitaceae
Moringa	*Moringa oleifera* Lam.	Moringaceae	Wax gourd	*Benincasa hispida* Thunb. (1)	Cucurbitaceae
Sunflower	*Helianthus annuus* L.	Asteraceae	Winter melon	*Benincasa hispida* Thunb. (2)	Cucurbitaceae
Pistachio	*Pistacia vera* L.	Anacardiaceae	Watermelon	*Citrullus lanatus* Thunb.	Cucurbitaceae
Walnut	*Juglans regia* L.	Juglandaceae	**Cruciferous seed oil (7 samples)**		
Pseudo-cereal oil (9 samples)			Broccoli	*Brassica oleracea* var. *italica*	Cruciferae
Black chia seed	*Salvia Hispanica* L. (1)	Lamiaceae	Cauliflower	*Brassica oleracea* L. var. *botrytis* L.	Brassicaceae
Black sesame	*Sesamum indicum* L. (1)	Pedaliaceae	Chinese cabbage	*Brassica pekinensis* Lour.	Cruciferae
Brown flaxseed	*Linum usitatissimum* L. (1)	Linaceae	Chinese kale	*Brassica oleraceae* var. *alboglabra*	Cruciferae
Coriander	*Coriandrum sativum* L.	Apiaceae	Chinese radish	*Raphanus sativus* subsp. *longipinnatus* L.	Brassicaceae
Gold flaxseed	*Linum usitatissimum* L. (2)	Linaceae	Curly kale	*Brassica oleracea*	Cruciferae
Hairy Basil	*Ocimum citriodorum* Vis.	Lamiaceae	Hong Kong Chinese kale	*Brassica alboglabra* L.H. Bailey	Cruciferae
Perilla	*Perilla frutescens* (L.) Britton	Lamiaceae	**Leafy green seed oil (11 samples)**		
White chia seed	*Salvia Hispanica* L. (2)	Lamiaceae	Chinese flowering cabbage	*Brassica chinensis* L. var. *parachinensis*	Cruciferae
White sesame	*Sesamum indicum* L. (2)	Pedaliaceae	Chinese green mustard	*Brassica juncea* (L.) Czern. (1)	Brassicaceae
Legume oil (3 samples)			Chinese mustard	*Brassica juncea* (L.) Czern. (2)	Brassicaceae
Inca peanut	*Plukenetia volubilis* L.	Euphorbiaceae	False Pak Choi (Phukeaw)	*Brassica.camprestris* L. var. *chinensis* (Lour.)Rupr. (1)	Cruciferae
Soybean	*Glycine max* (L.) Merr.	Fabaceae	False Pak Choi (Inthanon)	*Brassica.camprestris* L. var. *chinensis* (Lour.)Rupr. (2)	Cruciferae
Peanut	*Arachis hypogaea* L.	Fabaceae	Flowering Pak Choi (1)	*Brassica chinensis* L. var. *parachinesis* Tsen & Lee (1)	Brassicaceae
Amaranth oil (3 samples)			Flowering Pak Choi (2)	*Brassica chinensis* L. var. *parachinesis* Tsen & Lee (2)	Brassicaceae
Green amaranth	*Amaranthus viridis* L.	Amaranthaceae	Green Pak Choi	*Brassica Chinensis* var. *Chinensis*	Brassicaceae
Love-lies-bleeding	*Amaranthus caudatus* L.	Amaranthaceae	Indian mustard	*Brassica juncea* (L.) Czern. (3)	Brassicaceae
Spiny amaranth	*Amaranthus spinosus* L.	Amaranthaceae	Lettuce	*Lactuca sativa*	Asteraceae
			Rat-tailed radish	*Raphanus sativus* Linn.	Cruciferae

ion-source temperatures were MS Quad 150 °C, and MS source 230 °C, respectively. The scanned mass range was 29–550 *m/z*, and the detector voltage was set at 1150 V. Identification of the detected components was performed by matching their mass spectra with the reference spectra in NIST 98 Mass Spectral Library and comparing retention times with their standards. The constructed calibration curves for FAMEs of the fatty acids as well as method validation parameters are shown in Table 3.

2.4. HPLC-DAD analysis for functional phytochemicals

For HPLC analysis, oil samples were pre-treated with non-saponification process since saponification can significantly degrade compounds due to high temperature, alkali condition, and its multi-step procedure as evidenced by many studies [1, 18]. A portion of oil (0.5 g) was diluted with dichloromethane to make a final volume of 1.00 mL. The resulting solution was filtered through a 0.45 μm syringe nylon filter before HPLC injection. Analysis of phytosterols, squalene and cholecalciferol in oil samples were separated and quantified using a modified method of Pokkanta et al. [1]. An HPLC system consisted of an Agilent HPLC 1100 connected to a diode array detector (Model G1315 A, Agilent Technologies, Palo Alto). A Kinetex PFP column (4.6 × 250 mm, 5 μm, Phenomenex, Inc., CA) was used as an analytical column. The mobile phases used were methanol (as component A) and water (as component B) operating in a gradient mode. The elution gradient was 90% A (0.0–13.0 min), 90–95% A (13.0–14.0 min), 95 to 85% A (14.0–17.0 min), 85–95% A (17.0–22.0 min), and 95% A (22.0–30.0 min). The column temperature was set at 30 °C, and the flow rate was 1.0 mL min^{-1}. Phytosterols and squalene were detected at 210 nm, and cholecalciferol at 265 nm. The concentrations of those compounds were calculated with calibration curves of their standards, and quantitative data were presented as μg g^{-1} sample. The constructed calibration curves for the targeted functional phytochemicals as well as method validation parameters are shown in Table 3.

2.5. Statistical analysis

All quantitative determinations were done in triplicates, and the data are presented as the mean ± standard deviation. Statistical analysis was done using one-way ANOVA. Differences at $P < 0.05$ were considered statistically significant. Principal component analysis (PCA) modeling was calculated based on the algorithm presented [19]. PCA is among the common exploratory data analysis methods in chemometrics. PCA establishes a set of new variables, called principal components (PCs), to represent the main and important variation in data. The mathematical transformation of an original data matrix ($\boldsymbol{X}$) by PCA can be expressed as the following equation as mentioned in a study of Brereton, R. G. [20].

$$\boldsymbol{X} = \boldsymbol{TP} + \boldsymbol{E} \quad (1)$$

According to equation (1), $\boldsymbol{T}$ is a score matrix, representing the relationship among the studied samples. On the other hand, $\boldsymbol{P}$ is a loading matrix, visualizing the behavior among the parameters. $\boldsymbol{E}$ is a residual matrix, containing the variation which is excluded from the analysis. Generally, the samples with relatively similar score values are located near each other on the PCA score plot implying that they have similarity property or share the same relationship in the dataset. Prior to the analysis, the intensity data was preprocessed by standardization scaling to ensure that all the intensity variables were adjusted to be on the same scale [20]. Therefore, the variables with low intensities had equal influence on the PCA model and were conducted using in-house scripts based on Matlab software, Matlab V7.10.0 (R2010a).

Table 2. Preparation process of sample oil.

Oils	I) Peeling	II) Sun-drying	III) Roasting	IV) Grinding	V) Extraction	VI) Bottling
Nut/Kernel oil (9 samples)						
Almond	-	✓	✓	✓	✓	✓
Cashew	-	✓	✓	✓	✓	✓
Coconut	✓	✓	-	✓	✓	✓
Hazelnut	-	✓	✓	✓	✓	✓
Macadamia	-	✓	✓	✓	✓	✓
Moringa seed	✓	✓	✓	✓	✓	✓
Sunflower seed	✓	✓	✓	✓	✓	✓
Pistachio	-	✓	✓	✓	✓	✓
Walnut	-	✓	✓	✓	✓	✓
Pseudo-cereal oil (9 samples)						
Black chia seed	-	✓	-	-	✓	✓
Black sesame	-	✓	-	-	✓	✓
Brown flaxseed	-	✓	-	-	✓	✓
Coriander	-	✓	-	-	✓	✓
Gold flaxseed	-	✓	-	-	✓	✓
Hairy basil	-	✓	-	-	✓	✓
Perilla	-	✓	-	-	✓	✓
White chia seed	-	✓	-	-	✓	✓
White sesame	-	✓	-	-	✓	✓
Legume oil (3 samples)						
Inca peanut	✓	✓	✓	✓	✓	✓
Soybean	-	✓	-	-	✓	✓
Peanut	✓	✓	-	✓	✓	✓
Amaranth oil (3 samples)						
Green amaranth	-	✓	-	-	✓	✓
Love-lies-bleeding	-	✓	-	-	✓	✓
Spiny amaranth	-	✓	-	-	✓	✓
Marrow seed oil (8 samples)						
Angled loofah	-	✓	-	-	✓	✓
Cucumber	-	✓	-	-	✓	✓
Long skinny eggplant	-	✓	-	-	✓	✓
Muskmelon	-	✓	-	-	✓	✓
Pumpkin	-	✓	-	-	✓	✓
Wax gourd	-	✓	-	-	✓	✓
Winter melon	-	✓	-	-	✓	✓
Watermelon	-	✓	-	-	✓	✓
Cruciferous seed oil (7 samples)						
Broccoli	-	✓	-	-	✓	✓
Cauliflower	-	✓	-	-	✓	✓
Chinese cabbage	-	✓	-	-	✓	✓
Chinese kale	-	✓	-	-	✓	✓
Chinese radish	-	✓	-	-	✓	✓
Curly kale	-	✓	-	-	✓	✓
Hong Kong Chinese kale	-	✓	-	-	✓	✓
Leafy green seed oil (11 samples)						
Chinese flowering cabbage	-	✓	-	-	✓	✓
Chinese green mustard	-	✓	-	-	✓	✓
Chinese mustard	-	✓	-	-	✓	✓
False Pak Choi (Phukeaw)	-	✓	-	-	✓	✓
False Pak Choi (Inthanon)	-	✓	-	-	✓	✓
Flowering Pak Choi (1)	-	✓	-	-	✓	✓
Flowering Pak Choi (2)	-	✓	-	-	✓	✓
Green Pak Choi	-	✓	-	-	✓	✓
Indian mustard	-	✓	-	-	✓	✓
Lettuce	-	✓	-	-	✓	✓
Rat-tailed radish	-	✓	-	-	✓	✓

Table 3. Method validation results for determination of fatty acids, phytosterols, squalene, and cholecalciferol.

Compound	Regression equation	R^2	Linearity[a]	LOD[b] (μg mL $^{-1}$)	LOQ[c] (μg mL $^{-1}$)	Recovery (%)	Precision (intra-day)[d]
Palmitic acid	y = 432.25 x - 222274	0.8217	valid	27.20	90.68	96.8	0.22
Steric acid	y = 435.70 x + 166531	0.9747	valid	7.39	24.62	90.4	0.76
Arachidic acid	y = 522.90 x + 254107	0.9469	valid	7.31	24.35	100.0	0.03
Palmitoleic acid	y = 530.92 x - 105282	0.9763	valid	35.44	118.13	98.7	0.03
Oleic acid	y = 435.15 x + 162147	0.9867	valid	8.04	26.80	83.8	0.51
Erucic acid	y = 435.15 x + 162147	0.9867	valid	3.90	13.01	88.7	1.16
Linoleic acid	y = 394.34 x + 258209	0.9662	valid	10.32	34.40	92.0	0.35
Linolenic acid	y = 401.67 x + 131010	0.9981	valid	21.88	72.92	92.6	0.63
Stigmasterol + Campesterol	y = 2.1737 x + 250.45	0.9901	valid	0.42	1.26	99.2	2.20
β-Sitosterol	y = 0.4587 x +123.60	0.9919	valid	0.36	1.04	98.6	2.02
Squalene	y = 1.780 x + 32.819	0.9906	valid	0.09	0.28	100.6	1.91
Cholecalciferol	y = 14.803 x + 11.001	0.9956	valid	0.31	0.95	99.0	0.17

[a] Linearity assessment was performed by Lack of fit, FIUPAC, and Mandel's fitting test.
[b] LOD was limit of detection (signal-to-noise ration of 3).
[c] LOQ was limit of quantification (signal-to-noise ratio of 10).
[d] Percentage of relative standard deviation (%).

3. Results and discussion

3.1. GC-MS analysis for fatty acid compositions in cold-pressed oils

3.1.1. Analysis of fatty acid composition using GC-MS

GC-MS chromatograms of FAMEs in some cold-pressed oils are shown in Figure 1. Using the method, good separation of FAMEs was obtained as methyl palmitoleate (FAME of palmitoleic acid) was eluted at 7.51 min, methyl palmitate (of palmitic acid) at 7.85 min, methyl linoleate (of linoleic acid) at 10.89 min, methyl oleate (of oleic acid) at 10.98 min, methyl linolenate (of linolenic acid) at 11.04 min, methyl stearate (of stearic acid) at 11.46 min, methyl arachidate (of arachidic acid) at 15.31 min, and methyl erucate (of erucic acid) at 18.75 min. Mass spectra of the detected FAMEs and information of their major fragmented ions were exhibited in Figure 2. According to Figure 1, composition of the fatty acids differed among samples. For example, black chia seed oil contained palmitic, linoleic, oleic, linolinic, stearic, and arachidic acids whilst false Pak Choi (Phukeaw) had palmitic, linoleic, oleic, stearic, erucic and arachidic acids. The result showed that a single run of FAME analysis required only 22 min, suggesting the present method suitable for FAME analysis of a large number of oil samples.

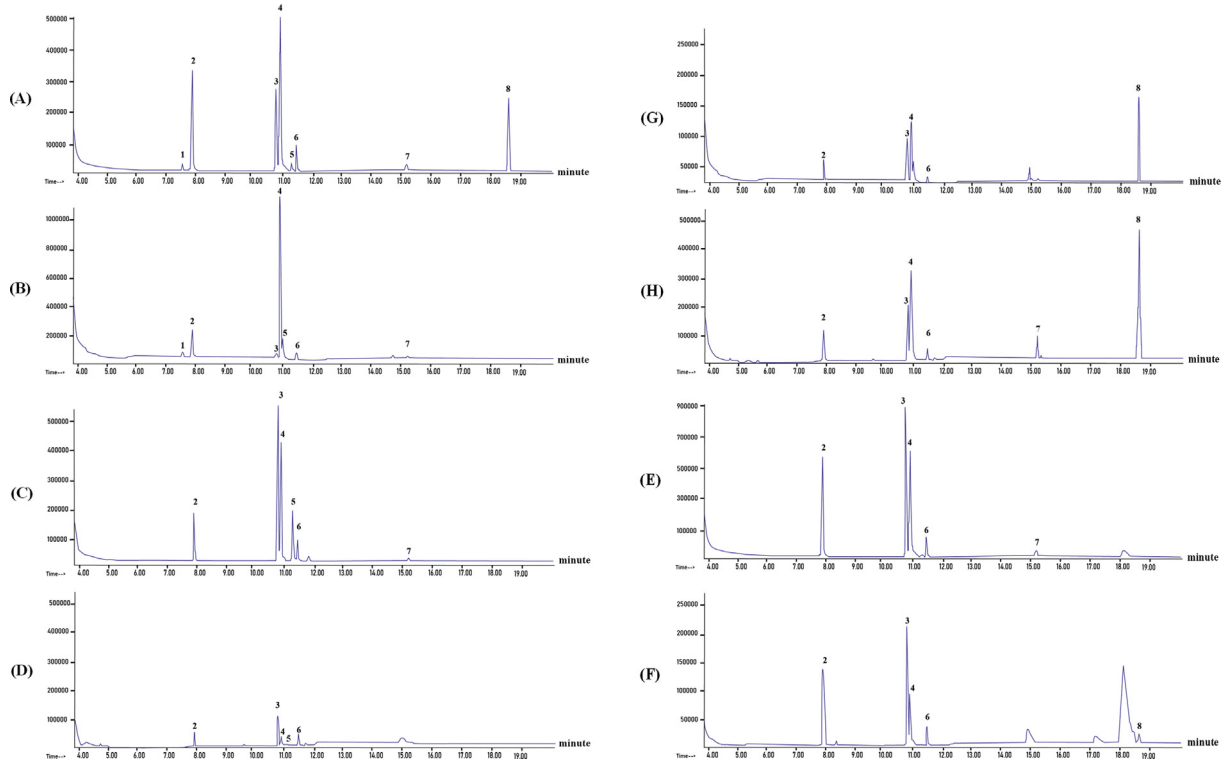

Figure 1. GC-MS chromatograms of fatty acid methyl esters (FAMEs). (A) Standard fatty acids, (B) moringa seeds oil (C) brown flaxseeds oil, (D) soybean oil, (E) green amaranth seed oil, (F) cucumber seed oil (G) Chinese cabbage seed oil, and (H) False Pak Choi (Phukeaw) seed oil. Peak identification: 1 = methyl palmitoleate, 2 = methyl palmitate, 3 = methyl linoleate, 4 = methyl oleate, 5 = methyl linolenate, 6 = methyl stearate, 7 = methyl arachidate, and 8 = methyl erucate.

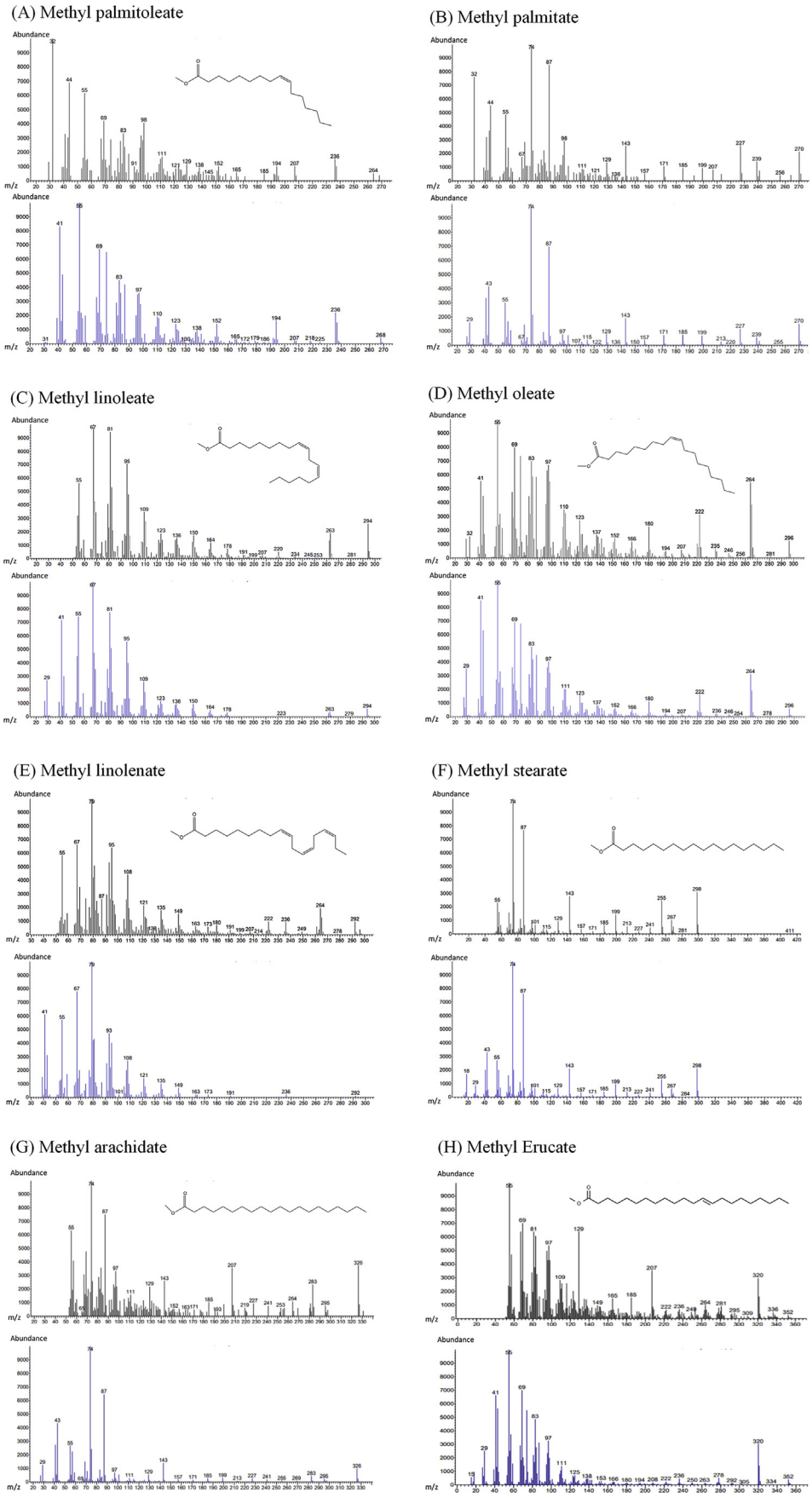

Figure 2. MS spectra of FAMEs of analyzed fatty acids found in cold-pressed oils. (A) Methyl palmitoleate, (B) methyl palmitate, (C) methyl linoleate, (D) methyl oleate, (E) methyl linolenate, (F) methyl stearate, (G) methyl arachidate, and (H) methyl erucate.

Table 4. Composition of individual fatty acid in each cold-pressed plant oil (%).

Oils	Saturated fatty acids (SFAs)			Monounsaturated fatty acids (MUFAs)			Polyunsaturated fatty acids (PUFAs)		Others
	Palmitic acid (C16:0)	Stearic acid (C18:0)	Arachidic acid (C20:0)	Palmitoleic acid (C16:1)	Oleic acid (C18:1)	Erucic acid (C22:1)	Linoleic acid (C18:2)	Linolenic acid (C18:3)	
Nut/Kernel oil (9 samples)									
Almond	19.21 ± 0.86	2.87 ± 0.56	ND	ND	49.08 ± 0.29	ND	21.43 ± 0.04	ND	7.41 ± 0.02
Cashew	14.61 ± 0.23	8.75 ± 2.74	0.43 ± 0.37	ND	62.73 ± 1.82	ND	13.27 ± 0.16	ND	0.21 ± 0.02
Coconut	21.47 ± 0.05	5.56 ± 0.27	ND	ND	37.52 ± 0.27	14.85 ± 0.03	10.73 ± 0.03	ND	9.87 ± 0.01
Hazelnut	7.95 ± 0.43	2.11 ± 1.52	ND	ND	73.19 ± 4.24	ND	16.63 ± 0.01	ND	0.12 ± 0.02
Macadamia	12.02 ± 0.08	2.78 ± 1.27	ND	13.38 ± 2.64	58.69 ± 0.56	8.18 ± 0.03	ND	ND	4.96 ± 0.02
Moringa seed	13.42 ± 0.32	2.83 ± 2.22	0.91 ± 0.81	1.55 ± 0.52	78.21 ± 1.32	ND	2.64 ± 0.01	ND	0.42 ± 0.03
Sunflower seed	11.30 ± 0.13	3.50 ± 0.63	ND	ND	24.02 ± 0.08	ND	59.32 ± 0.60	ND	1.85 ± 0.02
Pistachio	10.73 ± 0.05	0.30 ± 0.52	ND	1.52 ± 0.02	43.97 ± 0.60	ND	40.26 ± 0.24	ND	3.23 ± 0.03
Walnut	12.50 ± 0.48	1.57 ± 0.96	ND	ND	26.24 ± 1.20	ND	47.19 ± 0.25	10.73 ± 0.24	1.79 ± 0.03
Pseudo-cereal oil (9 samples)									
Black chia seed	9.85 ± 0.54	3.25 ± 1.92	0.16 ± 0.16	ND	11.88 ± 0.41	ND	27.87 ± 0.04	46.59 ± 0.52	0.39 ± 0.02
Black sesame	9.97 ± 0.35	4.48 ± 1.09	0.26 ± 0.10	2.12 ± 0.12	32.34 ± 0.45	ND	50.62 ± 0.10	ND	0.2 ± 0.03
Brown flaxseed	6.59 ± 0.33	4.65 ± 2.35	0.16 ± 0.11	ND	10.17 ± 0.37	ND	21.57 ± 0.13	56.68 ± 0.24	0.16 ± 0.02
Coriander	10.72 ± 0.07	2.78 ± 0.42	0.40 ± 0.11	ND	50.87 ± 0.52	8.05 ± 0.04	26.66 ± 0.18	ND	0.54 ± 0.02
Gold flaxseed	8.60 ± 0.18	2.68 ± 0.74	0.59 ± 0.61	ND	13.89 ± 0.13	ND	21.12 ± 0.07	51.22 ± 1.08	1.93 ± 0.03
Hairy basil	8.66 ± 0.48	3.16 ± 1.93	0.06 ± 0.01	ND	11.17 ± 0.07	ND	26.25 ± 0.18	50.25 ± 0.34	0.46 ± 0.02
Perilla	10.96 ± 0.17	2.64 ± 0.35	0.77 ± 0.46	ND	17.04 ± 0.15	ND	16.46 ± 0.32	51.43 ± 0.96	0.7 ± 0.01
White chia seed	12.27 ± 0.52	3.74 ± 1.29	0.39 ± 0.28	ND	12.46 ± 0.14	ND	21.06 ± 0.07	49.61 ± 1.37	0.48 ± 0.01
White sesame	12.57 ± 0.46	5.81 ± 2.95	0.22 ± 0.06	1.22 ± 0.06	30.06 ± 0.20	ND	49.43 ± 1.81	ND	0.67 ± 0.03
Legume oil (3 samples)									
Inca peanut	10.74 ± 0.64	2.72 ± 1.49	ND	ND	15.39 ± 0.19	ND	26.02 ± 0.74	43.42 ± 0.14	1.73 ± 0.03
Soybean	8.84 ± 0.33	2.68 ± 0.78	ND	ND	28.03 ± 0.08	ND	50.31 ± 0.14	6.02 ± 0.04	4.15 ± 0.03
Peanut	12.23 ± 0.03	5.00 ± 1.59	0.08 ± 0.03	1.31 ± 0.02	47.60 ± 0.33	ND	33.08 ± 1.26	ND	0.73 ± 0.04
Amaranth oil (3 samples)									
Green amaranth	25.10 ± 0.22	2.96 ± 2.23	0.53 ± 0.75	ND	25.49 ± 1.95	ND	45.04 ± 0.81	ND	0.85 ± 0.03
Love-lies-bleeding	11.21 ± 0.34	2.04 ± 0.45	0.32 ± 0.08	ND	27.07 ± 0.44	ND	59.24 ± 0.84	ND	0.15 ± 0.03
Spiny amaranth	27.39 ± 0.96	3.04 ± 0.87	0.99 ± 0.16	ND	24.14 ± 0.85	ND	44.12 ± 1.54	ND	0.34 ± 0.02
Marrow seed oil (8 samples)									
Angled loofah	23.71 ± 0.87	5.44 ± 2.43	ND	ND	17.98 ± 0.63	10.64 ± 0.59	39.17 ± 1.66	ND	3.06 ± 0.01
Cucumber	14.04 ± 0.01	7.46 ± 4.32	ND	ND	19.37 ± 0.18	12.69 ± 1.57	42.04 ± 2.00	ND	4.4 ± 0.02
Long skinny eggplant	16.29 ± 0.03	6.00 ± 0.89	ND	ND	9.87 ± 0.13	14.70 ± 0.76	49.72 ± 0.12	ND	3.43 ± 0.02
Muskmelon	20.10 ± 0.29	8.95 ± 0.29	ND	ND	8.91 ± 0.19	1.99 ± 0.02	58.79 ± 1.23	ND	1.28 ± 0.03
Pumpkin	21.40 ± 0.35	3.84 ± 0.82	ND	ND	25.39 ± 0.27	4.71 ± 0.06	41.53 ± 0.18	ND	3.15 ± 0.02
Wax gourd	20.60 ± 0.15	1.59 ± 0.62	ND	ND	13.01 ± 0.18	10.25 ± 0.51	48.50 ± 0.41	ND	6.06 ± 0.01
Winter melon	21.33 ± 0.77	3.05 ± 2.33	ND	ND	13.39 ± 0.09	10.42 ± 0.29	46.83 ± 0.24	ND	4.98 ± 0.01
Watermelon	16.20 ± 0.14	2.39 ± 1.79	ND	ND	14.69 ± 0.28	9.58 ± 0.33	51.23 ± 0.14	ND	5.93 ± 0.02
Cruciferous seed oil (7 samples)									
Broccoli	8.25 ± 0.01	ND	ND	ND	17.26 ± 0.01	51.11 ± 3.51	16.86 ± 0.16	ND	6.52 ± 0.01
Cauliflower	30.08 ± 0.83	ND	ND	ND	16.53 ± 0.48	45.92 ± 1.96	ND	ND	7.45 ± 0.02
Chinese cabbage	8.19 ± 0.20	0.34 ± 0.03	ND	ND	23.00 ± 1.08	51.54 ± 2.33	15.27 ± 0.17	ND	1.67 ± 0.01
Chinese kale	14.14 ± 0.49	0.56 ± 0.66	ND	ND	23.76 ± 0.26	40.40 ± 2.39	14.91 ± 0.29	ND	6.24 ± 0.02
Chinese radish	33.50 ± 0.32	ND	ND	ND	24.12 ± 0.32	31.78 ± 0.52	ND	ND	10.63 ± 0.03
Curly kale	22.31 ± 0.59	4.29 ± 0.72	ND	ND	31.31 ± 1.68	30.75 ± 2.28	8.87 ± 0.21	ND	2.47 ± 0.02
Hong Kong Chinese kale	9.75 ± 0.41	ND	0.94 ± 0.51	ND	31.95 ± 0.48	39.84 ± 1.92	15.09 ± 0.10	ND	2.43 ± 0.02
Leafy green seed oil (11 samples)									
Chinese flowering cabbage	19.37 ± 0.43	0.83 ± 0.75	ND	ND	26.21 ± 1.65	19.23 ± 1.41	30.35 ± 0.26	ND	4.03 ± 0.02
Chinese green mustard	19.98 ± 0.72	ND	ND	ND	29.95 ± 0.60	31.25 ± 1.98	14.45 ± 0.18	ND	4.4 ± 0.02
Chinese mustard	14.80 ± 0.30	ND	1.23 ± 0.49	ND	16.97 ± 0.25	54.72 ± 1.92	ND	ND	12.26 ± 0.02
False Pak Choi (Phukeaw)	6.08 ± 0.23	1.42 ± 0.82	0.37 ± 0.36	ND	28.57 ± 1.26	48.60 ± 1.85	14.19 ± 0.08	ND	0.75 ± 0.02
False Pak Choi (Inthanon)	6.49 ± 0.21	1.34 ± 0.16	0.09 ± 0.04	ND	25.54 ± 1.13	50.91 ± 2.41	14.51 ± 0.11	ND	1.12 ± 0.02
Flowering Pak Choi (1)	19.04 ± 0.34	5.23 ± 0.37	ND	ND	34.53 ± 0.25	40.09 ± 1.75	ND	ND	6.34 ± 0.01
Flowering Pak Choi (2)	20.37 ± 0.72	10.77 ± 0.47	4.90 ± 0.00	ND	27.47 ± 1.33	20.44 ± 0.18	13.89 ± 0.25	ND	2.18 ± 0.02

(*continued on next page*)

Table 4 (*continued*)

Oils	Saturated fatty acids (SFAs)			Monounsaturated fatty acids (MUFAs)			Polyunsaturated fatty acids (PUFAs)		Others
	Palmitic acid (C16:0)	Stearic acid (C18:0)	Arachidic acid (C20:0)	Palmitoleic acid (C16:1)	Oleic acid (C18:1)	Erucic acid (C22:1)	Linoleic acid (C18:2)	Linolenic acid (C18:3)	
Green Pak Choi	24.07 ± 0.55	ND	ND	ND	11.93 ± 0.97	49.28 ± 3.61	10.63 ± 0.13	ND	4.08 ± 0.01
Indian mustard	28.12 ± 0.85	ND	ND	ND	23.04 ± 0.24	38.46 ± 3.14	3.14 ± 0.05	ND	7.23 ± 0.02
Lettuce	15.36 ± 0.53	2.51 ± 0.15	0.01 ± 0.00	ND	11.39 ± 0.08	9.65 ± 0.57	60.33 ± 0.32	ND	0.72 ± 0.04
Rat-tailed radish	18.87 ± 4.50	ND	ND	ND	28.29 ± 0.10	22.91 ± 0.17	22.84 ± 0.15	ND	7.1 ± 0.01

ND = non-detectable.

3.1.2. Composition of fatty acid in fifty cold pressed oils

The fatty acid compositions of the various oil samples are presented in Table 4. The fatty acids were found in ranges from nondetectable to 13.38% for palmitoleic acid (average of 3.52%), 6.08–33.50% for palmitic acid (average of 15.63%), nondetectable to 60.33% for linoleic acid (average of 25.85%), 8.91–78.21% for oleic acid (average of 27.31%), nondetectable to 56.68% for linolenic acid (average of 40.66%), nondetectable to 10.77% for stearic acid (average of 2.96%), nondetectable to 4.90% for arachidic acid (average of 0.28%), and nondetectable to 54.72 % for erucic acid (average of 27.00%). Among the fatty acids observed, the major species were palmitic, oleic, linoleic, and linolenic acids. The minor fatty acids were palmitoleic, stearic, arachidic, and erucic acids that were found only in some plant oils. For instance, palmitoleic acid were detected only in 6 plant oils such as macadamia, moringa, pistachio, black sesame, white sesame, and peanut oils. Linolenic acid was mainly found in pseudo-cereal oils and legume oils such as brown flaxseed, perilla and inca peanut oils. Arachidic acid was mostly found in pseudo-cereal and amaranth oils but with relatively low amount of less than 1.00%.

3.1.2.1. Proportion of PUFAs:MUFAs:SFAs. In this study, all the oil samples had a large proportion of PUFAs (10.14–62.98%) and MUFAs (22.77–67.34%) but relatively small proportion of SFAs (14.25–26.62%). Table 5 shows compositional percentage of saturated fatty acids (SFAs, including palmitic, stearic, and arachidic acids), MUFAs (including palmitoleic, oleic, and erucic acids), and PUFAs (including linoleic and linolenic acids) in the oil samples. Oils from pseudo-cereals and legumes contained relatively low amount of SFAs as 14.25 and 15.64%, respectively. The oils from pseudo-cereals consisted of high amount of unsaturated fatty acids, especially PUFAs (62.98%), while the oils from kernel, cruciferous seeds, and leafy green seeds were rich in MUFAs (55.68–67.34 %). The oils from amaranth and marrow seeds were comparable in ratios of SFAs: MUFAs: PUFAs (Table 5). The oils from kernel, cruciferous seeds, and leafy green seeds tended to have MUFAs (55.68–67.34%) > PUFAs (10.14–24.69%), but the oils from pseudo-cereal, legumes, amaranths, and marrow seeds had PUFAs (47.23–62.98%) > MUFAs (22.77–31.41%). The UFAs and SFAs ratio of the oil can be used in selection of appropriate oil for the specific application. For instance, oils used for deep-frying should have high content of SFAs that is likely to be more stable when heated. Besides the degree of unsaturation, the types of predominant fatty acids were compared (Table 6). The major fatty acids observed in the sample oils were palmitic acid, oleic acid, linoleic acid and linolenic acid. Linolenic acid was abundant in pseudo-cereal oils (33.98%). Linoleic acid was found rich in amaranth and marrow seed oils (49.46% and 47.23%, respectively). The oils from kernels were great in oleic acid (C18:1) as 50.41%. The minor

Table 5. Percentage of saturated fatty acids, monounsaturated fatty acids, and polyunsaturated fatty acids in oil samples.

Oil	Saturated fatty acids (SFAs)	Monounsaturated fatty acids (MUFAs)	Polyunsaturated fatty acids (PUFAs)
Kernel oil	19.63	55.68	24.69
Pseudo-cereal oil	14.25	22.77	62.98
Legume oil	15.64	31.41	52.95
Amaranth oil	24.97	25.57	49.46
Marrow seed oil	26.62	26.16	47.23
Cruciferous seed oil	22.52	67.34	10.14
Leafy green seed oil	22.92	60.32	16.76

Table 6. Average content of fatty acids in each oil group.

Oil	Major fatty acid				Minor fatty acid			
	Palmitic acid	Oleic acid	Linoleic acid	Linolenic acid	Stearic acid	Arachidic acid	Palmitoleic acid	Erucic acid
Kernel oil	13.69	50.41	23.50	1.19	3.36	0.15	1.83	2.56
Pseudo-cereal oil	10.02	21.10	29.01	33.98	3.69	0.34	0.37	0.89
Legume oil	10.60	30.34	36.47	16.48	5.00	0.03	0.44	ND
Amaranth oil	21.23	25.57	49.47	ND	2.68	0.61	ND	ND
Marrow seed oil	19.21	15.33	47.23	ND	4.84	ND	ND	9.37
Cruciferous seed oil	18.03	23.99	10.14	ND	0.74	0.13	ND	41.62
Leafy green seed oil	17.50	23.99	16.76	ND	2.01	0.60	ND	35.05

ND = non-detectable.

fatty acids were stearic acid, arachidic acid, palmitoleic acid and erucic acid. Although some minor fatty acids were present in small amounts, it may bear some significant health effect. For instance, erucic acid that were greatly found in cruciferous and leafy green seed oils have been evidenced for it adverse health effects against human organs such as the heart (myocardial lipidosis) [21].

Furthermore, all cold-pressed oils were individually assessed for health benefits based on their major fatty acid composition (Table 4). Considering legume oils, linolenic acid was found highest in Inca peanut oil (43.42%), and linoleic acid in soybean oil (50.31%). Peanut oil was highest in oleic acid (47.60%). The group of pseudo-cereal oils were relatively high in PUFAs (26.66–78.25%), in which linolenic acid was found highest in brown flaxseed oil (56.68%), and highest linoleic acid in black sesame oil (50.62%). The highest oleic acid was observed in coriander oil (50.86%). In the group of kernel oils, PUFAs was rather low when compared with the two previous groups. The observed PUFA was only linolenic acid in walnut oil (10.73%), but MUFAs were quite abundant as oleic acid content for moringa seed oil and hazelnut oil was 78.21% and 73.19%, respectively. The oils from amaranth and marrow seeds had a comparable decent amount of linoleic acid (39.17–59.24%), but oleic acid was found higher in amaranth oils (24.14–27.07%) than marrow seed oils (8.91–25.39%). In contrast, oils from subcategories of cruciferous seeds and leafy green seeds tended to have mediocre profile of PUFAs (nondetectable-30.35%) except lettuce seed oil (linoleic acid as 60.33%). Erucic acid (C22:1) was observed as a predominat fatty acid in this groups, in which the oils from Chinese mustard seeds, Chinese cabbage seeds, broccoli seeds and false Pak Choi (Inthanon) seeds contained more than 50% of their fatty acid composition.

The fatty acid profiles obtained in this study was compared with some of the same cold-pressed oils that had been reported in the literature [22]. In general, the content of fatty acid profiles from our results was comparable with those in the literature. The oils with both predominant polyunsaturated linoleic acid and monounsaturated oleic acid were sesame oils (our contents were 49.43–50.62% and 30.06–32.34 %, when the literature showed 46.20% and 38.80% of linoleic acid and oleic acid, respectively), amaranth oils (ours were 44.12–59.24% and 24.14–27.07%, while those of the literature were 40.10–47.30% and 24.50–31.30%), pistachio oil (ours were 40.26% and 43.97%, when those of the literature were 31.33% and 54.59%), and peanut oil (ours were 33.08% and 47.60%, when those of the literature were 20.40–39.10% and 35.70–55.30%). The oils rich in oleic acid were moringa seed oil (our oleic acid content as 78.21%, and that of the literature as 67.65–79.58%), hazelnut oil (ours as 73.19% and that of the literature as 79.30%), coriander seed oil (ours as 50.87% and that of the literature as 65.00–70.00%), and macadamia oil (ours as 58.69% and that of the literature as 54.60–63.40%). The oils with major linoleic acid were sunflower seed oil (our linoleic acid content as 59.32%, and that of the literature as 48.00–75.00%), muskmelon seed oil (our content as 59.79%, and that of the literature as 59.20%), soybean oil (our content as 50.31%, and that of the literature as 50.80–55.20%), walnut oil (our content as 47.19%, and that of the literature as 54.60–60.80%), and pumpkin seed oil (our result as 41.53%, and that of the literature as 16.01–37.10%). Finally, the oils especially rich in linolenic acid were

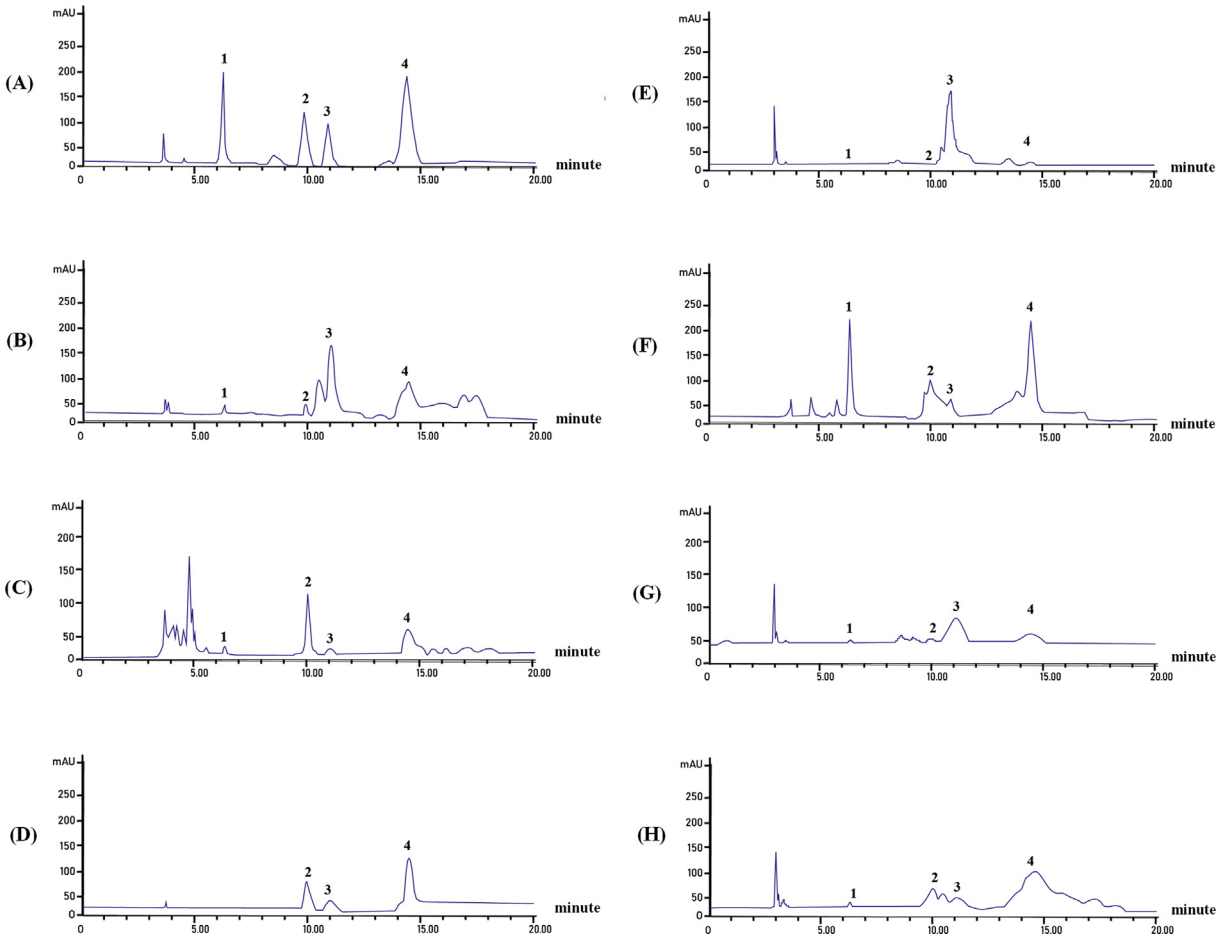

Figure 3. HPLC chromatograms of analyzed cold-pressed oils. (A) Standard solution, (B) pistachio oil, (C) coriander seed oil, and (D) soybean oil, (E) green amaranth seed oil, (F) long skinny eggplant seed oil, (G) cauliflower seed oil, and (H) lettuce seed oil. Peak identification: 1 = cholecalciferol, 2 = stigmasterol + campesterol, 3 = β-sitosterol, and 4 = squalene.

Table 7. Content of bioactive compounds (present as bioactive groups) in each cold-pressed plant oil (μg g^{-1}).

	Oils	Total Phytosterols	Squalene	Cholecalciferol (Vitamin D_3)	Total Bioactive compounds
	Nut/Kernel oil (9 samples)				
1	Almond	2135 ± 0.35	923 ± 0.13	29.44 ± 0.10	3087
2	Cashew	705 ± 1.22	265 ± 3.08	ND	970
3	Coconut	2431 ± 1.75	702 ± 0.14	106.14 ± 0.15	3239
4	Hazelnut	6062 ± 2.27	2356 ± 5.14	78.03 ± 0.29	8496
5	Macadamia	2400 ± 1.09	549 ± 0.18	76.58 ± 0.34	3026
6	Moringa seed	2650 ± 0.66	671 ± 0.19	84.56 ± 0.20	3406
7	Sunflower seed	2999 ± 1.74	1537 ± 0.41	73.71 ± 0.61	4610
8	Pistachio	1200 ± 0.76	2568 ± 0.20	11.93 ± 0.23	3780
9	Walnut	2479 ± 0.42	1185 ± 0.25	48.21 ± 0.46	3712
	Pseudo-cereal oil (9 samples)				
10	Black chia seed	3684 ± 1.88	5625 ± 1.70	90.33 ± 0.69	9399
11	Black sesame	2690 ± 1.73	1171 ± 0.47	650.30 ± 7.10	4511
12	Brown flaxseed	3548 ± 1.52	4464 ± 0.14	28.58 ± 0.20	8041
13	Coriander	3029 ± 0.92	1577 ± 0.14	520.83 ± 0.60	5127
14	Gold flaxseed	4328 ± 1.50	2485 ± 0.17	ND	6813
15	Hairy basil	3719 ± 1.61	5868 ± 0.28	66.37 ± 0.18	9653
16	Perilla	4129 ± 0.36	4974 ± 1.18	75.19 ± 0.06	9178
17	White chia seed	3903 ± 0.67	2278 ± 0.51	55.14 ± 0.08	6236
18	White sesame	2565 ± 1.66	2611 ± 0.29	59.11 ± 1.58	5235
	Legume oil (3 samples)				
19	Inca peanut	6258 ± 1.23	1341 ± 0.15	345.04 ± 1.35	7944
20	Soybean	5070 ± 0.75	2535 ± 0.45	ND	7605
21	Peanut	5368 ± 0.43	773 ± 1.42	124.98 ± 0.21	6266
	Amaranth oil (3 samples)				
22	Green amaranth	2326 ± 1.41	671 ± 0.15	0.63 ± 0.11	2998
23	Love-lies-bleeding	2336 ± 1.49	788 ± 0.44	48.28 ± 0.10	3172
24	Spiny amaranth	2213 ± 1.00	725 ± 5.00	22.44 ± 0.20	2960
	Marrow seed oil (8 samples)				
25	Angled loofah	1477 ± 1.41	803 ± 0.31	1287.75 ± 2.47	3568
26	Cucumber	9814 ± 0.34	891 ± 0.42	186.39 ± 1.00	10891
27	Long skinny eggplant	3397 ± 1.09	1801 ± 0.08	632.14 ± 4.81	5830
28	Muskmelon	8845 ± 2.57	1072 ± 0.44	25.18 ± 0.18	9942
29	Pumpkin	6738 ± 0.84	516 ± 0.32	107.75 ± 1.81	7362
30	Wax gourd	15123 ± 1.60	2162 ± 0.34	619.02 ± 0.55	17904
31	Winter melon	13138 ± 1.59	5979 ± 3.26	815.99 ± 0.20	19933
32	Watermelon	11012 ± 0.84	3183 ± 0.68	98.55 ± 0.09	14294
	Cruciferous seed oil (7 samples)				
33	Broccoli	1386 ± 0.66	419 ± 0.18	16.46 ± 0.10	1821
34	Cauliflower	1365 ± 0.62	1174 ± 4.25	30.74 ± 0.50	2570
35	Chinese cabbage	1711 ± 1.16	2027 ± 1.44	102.84 ± 0.42	3841
36	Chinese kale	992 ± 1.02	456 ± 0.41	41.21 ± 0.09	1489
37	Chinese radish	6666 ± 1.02	648 ± 0.43	50.67 ± 0.24	7365
38	Curly kale	7504 ± 1.96	971 ± 0.15	44.85 ± 0.52	8520
39	Hong Kong Chinese kale	1435 ± 0.56	397 ± 0.74	49.64 ± 2.22	1882
	Leafy green seed oil (11 samples)				
40	Chinese flowering cabbage	758 ± 2.03	268 ± 0.24	39.64 ± 0.10	1066
41	Chinese green mustard	818 ± 1.29	301 ± 1.28	3.88 ± 0.23	1123
42	Chinese mustard	749 ± 1.79	308 ± 0.70	17.39 ± 0.53	1074
43	False Pak Choi (Phukeaw)	698 ± 1.59	331 ± 0.75	32.42 ± 0.18	1061
44	False Pak Choi (Inthanon)	663 ± 0.91	297 ± 0.16	31.60 ± 0.39	992
45	Flowering Pak Choi (1)	1318 ± 0.95	364 ± 0.10	46.36 ± 0.27	1728
46	Flowering Pak Choi (2)	1972 ± 0.77	445 ± 2.00	55.74 ± 0.31	2473
47	Green Pak Choi	944 ± 0.88	329 ± 3.67	36.29 ± 0.11	1309
48	Indian mustard	909 ± 0.37	288 ± 1.71	15.07 ± 0.43	1212
49	Lettuce	2550 ± 0.97	754 ± 0.67	61.10 ± 0.19	3365
50	Rat-tailed radish	7189 ± 1.14	750 ± 0.32	84.49 ± 0.07	8023

ND = non-detectable.

Table 8. Content of individual phytosterol detected in each cold-pressed oil (μg g^{-1}).

Oils	Phytosterols		Total Phytosterols
	Stigmasterol & Campesterol	β-Sitosterol	
Nut/Kernel oil (9 samples)			
Almond	261 ± 014	1874 ± 0.40	2135 ± 0.35
Cashew	47 ± 0.68	658 ± 0.54	705 ± 1.22
Coconut	409 ± 0.17	2022 ± 1.58	2431 ± 1.75
Hazelnut	676 ± 0.70	5386 ± 1.91	6062 ± 2.27
Macadamia	290 ± 0.72	2110 ± 0.47	2400 ± 1.09
Moringa seed	285 ± 0.31	2365 ± 0.97	2650 ± 0.66
Sunflower seed	236 ± 0.25	2763 ± 1.49	2999 ± 1.74
Pistachio	137 ± 0.55	1063 ± 0.22	1200 ± 0.76
Walnut	106 ± 0.24	2373 ± 0.34	2479 ± 0.42
Pseudo-cereal oil (9 samples)	200 ± 0.47		
Black chia seed	922 ± 0.13	3484 ± 1.51	3684 ± 1.88
Black sesame	74 ± 0.12	1768 ± 1.60	2690 ± 1.73
Brown flaxseed	621 ± 0.08	3474 ± 1.42	3548 ± 1.52
Coriander	496 ± 0.47	2408 ± 0.89	3029 ± 0.92
Gold flaxseed	387 ± 0.09	3832 ± 1.19	4328 ± 1.50
Hairy basil	255 ± 0.13	3332 ± 1.64	3719 ± 1.61
Perilla	151 ± 0.08	3874 ± 0.39	4129 ± 0.36
White chia seed	373 ± 0.18	3752 ± 0.63	3903 ± 0.67
White sesame	200 ± 0.47	2192 ± 1.48	2565 ± 1.66
Legume oil (3 samples)			
Inca peanut	83 ± 0.05	6175 ± 1.18	6258 ± 1.23
Soybean	1870 ± 0.55	3200 ± 1.09	5070 ± 0.75
Peanut	494 ± 0.67	4874 ± 0.58	5368 ± 0.43
Amaranth oil (3 samples)			
Green amaranth	228 ± 0.41	2098 ± 1.16	2326 ± 1.41
Love-lies-bleeding	348 ± 0.48	1988 ± 1.17	2336 ± 1.49
Spiny amaranth	282 ± 0.25	1931 ± 1.04	2213 ± 1.00
Marrow seed oil (8 samples)			
Angled loofah	ND	1477 ± 1.41	1477 ± 1.41
Cucumber	480 ± 0.41	9334 ± 0.30	9814 ± 0.34
Long skinny eggplant	406 ± 0.22	2991 ± 0.91	3397 ± 1.09
Muskmelon	977 ± 1.39	7868 ± 2.21	8845 ± 2.57
Pumpkin	530 ± 0.38	6208 ± 0.46	6738 ± 0.84
Wax gourd	493 ± 0.10	14630 ± 1.70	15123 ± 1.60
Winter melon	1230 ± 0.24	11908 ± 1.48	13138 ± 1.59
Watermelon	604 ± 0.68	10408 ± 1.06	11012 ± 0.84
Cruciferous seed oil (7 samples)			
Broccoli	92 ± 0.21	1294 ± 0.47	1386 ± 0.66
Cauliflower	126 ± 0.08	1239 ± 0.69	1365 ± 0.62
Chinese cabbage	200 ± 0.19	1511 ± 0.97	1711 ± 1.16
Chinese kale	54 ± 0.07	938 ± 0.97	992 ± 1.02
Chinese radish	267 ± 0.23	6399 ± 1.22	6666 ± 1.02
Curly kale	226 ± 0.06	7278 ± 1.95	7504 ± 1.96
Hong Kong Chinese kale	122 ± 0.19	1313 ± 0.38	1435 ± 0.56
Leafy green seed oil (11 samples)			
Chinese flowering cabbage	46 ± 0.20	712 ± 1.97	758 ± 2.03
Chinese green mustard	30 ± 0.23	788 ± 1.12	818 ± 1.29
Chinese mustard	4 ± 0.05	745 ± 1.83	749 ± 1.79
False Pak Choi (Phukeaw)	48 ± 0.19	650 ± 1.52	698 ± 1.59
False Pak Choi (Inthanon)	18 ± 0.16	645 ± 1.07	663 ± 0.91
Flowering Pak Choi (1)	78 ± 0.13	1240 ± 0.90	1318 ± 0.95
Flowering Pak Choi (2)	172 ± 0.11	1800 ± 0.68	1972 ± 0.77
Green Pak Choi	54 ± 0.21	890 ± 0.78	944 ± 0.88
Indian mustard	49 ± 0.13	860 ± 0.47	909 ± 0.37
Lettuce	366 ± 0.09	2184 ± 0.90	2550 ± 0.97
Rat-tailed radish	218 ± 0.10	6971 ± 1.25	7189 ± 1.14

ND = non-detectable.

chia seed oil (our linolenic acid content as 46.59–49.61%, and that of the literature as 64.00%), and flaxseed oil (our content as 51.22–56.68%, and that of the literature as 54.77%).

Regarding applications of plant oils for health purposes, cold-pressing has demonstrated to yield oils with higher amount of unsaturated fatty acids compared with the oils derived from other preparation methods as reported previously [23]. A study by Ozcan et al. [24] presented that the moringa seed oil obtained from cold-pressing had greater amount of saturated fatty acids (75.49% oleic acid, 1.69% linoleic acid, and 1.87% linolenic acid) than that derived from soxhlet system (73.83, 1.27, and 1.73%, respectively). In a study of chia seed oil, cold-pressing could yield oil with higher content of linolenic acid (67.89%) and linoleic acid

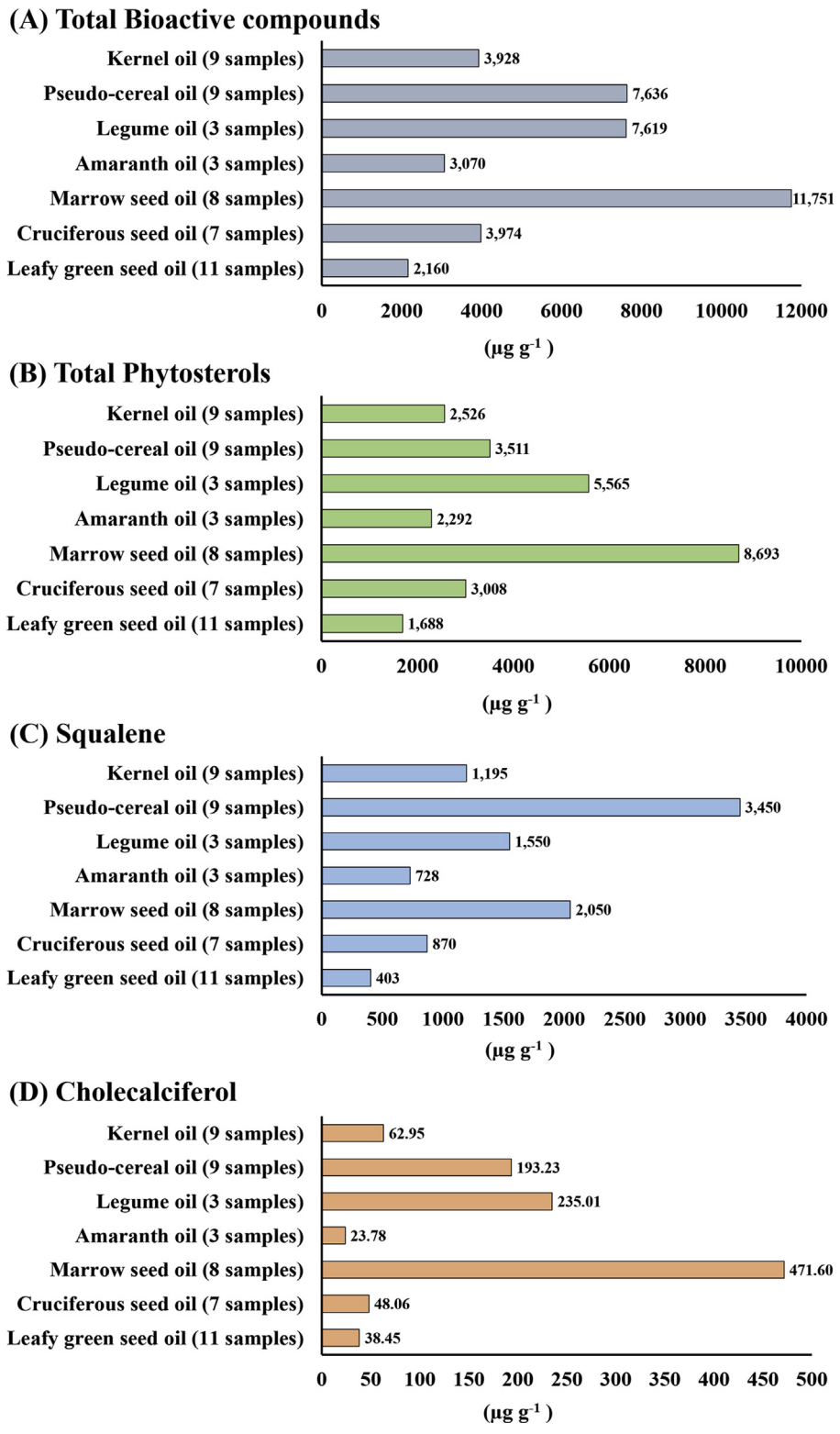

Figure 4. Content of bioactive compounds in cold-pressed oils (μg g^{-1}). (A) Total bioactive compounds, (B) total phytosterols, (C) squalene, and (D) cholecalciferol.

(19.07%) compared with the oil obtained from solvent extraction (67.87% and 17.63%, respectively) [25]. Walnut oil obtained by cold-pressing had higher oleic acid content (28.30%) than the oil from supercritical CO_2 extraction (23.50%) [26]. A number of studies reported that oils extracted by cold-pressing contained a composition of palmitic acid lower that those derived from other extraction methods [27, 28]. Those findings suggest that with the same plant material being used cold-pressing is an alternative method for oil extraction with higher unsaturated fatty acid and lower saturated fatty acid.

At present, oils with high ratio of MUFAs and PUFAs have been encouraged for the use of health promotion. Similarly, oils with high content of functional compounds have been gaining increasing interest for therapeutic uses. The continuous part of this study were focused on the chemical composition of beneficial lipid-soluble compounds in cold-pressed plant oils.

3.2. HPLC-DAD analysis for functional phytochemicals in cold-pressed oils

3.2.1. Analysis of functional phytochemicals using HPLC-DAD

In this study, HPLC-DAD was employed to separate and quantify some functional compounds in the fifty plant oils. Chromatographic results are shown in Figure 3. Functional phytochemicals were eluted as cholecalciferol (6.33 min), stigmasterol and campesterol (9.92 min), β-sitosterol (10.97 min), and squalene (14.42 min). All targeted compounds were successfully separated within 30 min. The chromatographic result has reconfirmed effectiveness and separatability of the reverse-phase column with pentafluorophenyl phase (PFP) for quantification of lipophilic compounds in cold-pressed vegetable oil samples as previously reported [1].

3.2.2. Content of the functional phytochemicals in the fifty cold pressed oils

Contents of cholecalciferol, phytosterols, and squalene present in each oil are individually reported in Tables 7 and 8. Presents the amount of each bioactive compound group and the sum value. The total amounts of the bioactive compounds were found in the range of 970–19933 μg g^{-1}, in which an average content was 5402 μg g^{-1}. As a result, oils from marrow seeds had the highest content of all the active compounds (19933 μg g^{-1}), and was 368.99% higher than the average value. Among the marrow seed oils analyzed, the oils that had the highest amount of bioactive compounds were winter melon (19933 μg g^{-1}), wax gourd (17904 μg g^{-1}), and watermelon (14294 μg g^{-1}). Oils from pseudo-cereals and legumes were also relatively high in the total content (comparable to 178.69 % and 147.06% of the average value, respectively) compared to those of the other categories. Since the functional phytochemicals are comprised of many chemical compounds that are diversified in structures and physiological roles, each group of compounds was then discussed for its content and availability among oil samples. Average contents of each specific compounds among categories of oils were compared and exhibited in Figure 4.

3.2.2.1. Content of phytosterols. Plant sterols, generally known as phytosterols, have gained much attention in reducing the serum cholesterol level in humans, as well as the risk of heart disease. In addition, phytosterols have anti-inflammatory, anti-bacterial, and anti-tumor properties [29]. Considering phytosterols content (Figure 4B), the oils from marrow seeds and legumes were of the highest values (8693 μg g^{-1} and 5565 μg g^{-1} respectively) with an average content of 3903 μg g^{-1}. The oils from leafy green seeds were lowest in phytosterols (1688 μg g^{-1}). Regarding individual oil, the oils rich in phytosterols were wax gourd seed oil (15123 μg g^{-1}), winter melon seed oil (13138 μg g^{-1}), and watermelon seed oil (11012 μg g^{-1}). In this study, β-sitosterol, campesterol, and stigmasterol were analyzed because they are the most abundant form in nature. In general, β-sitosterol is more abundant than stigmasterol and campesterol. Among the samples analyzed, the highest β-sitosterol content was detected in wax gourd seed oil (14630 μg g^{-1}), winter melon seed oil (11908 μg g^{-1}), and watermelon seed oil (10408 μg g^{-1}). All of them were subcategorized in marrow seed oils suggesting a close relationship between their chemical composition (phytosterols) and taxonomy. However, stigmasterol and campesterol were found relatively high in soybean oil (1870 μg g^{-1}) and winter melon seed oil

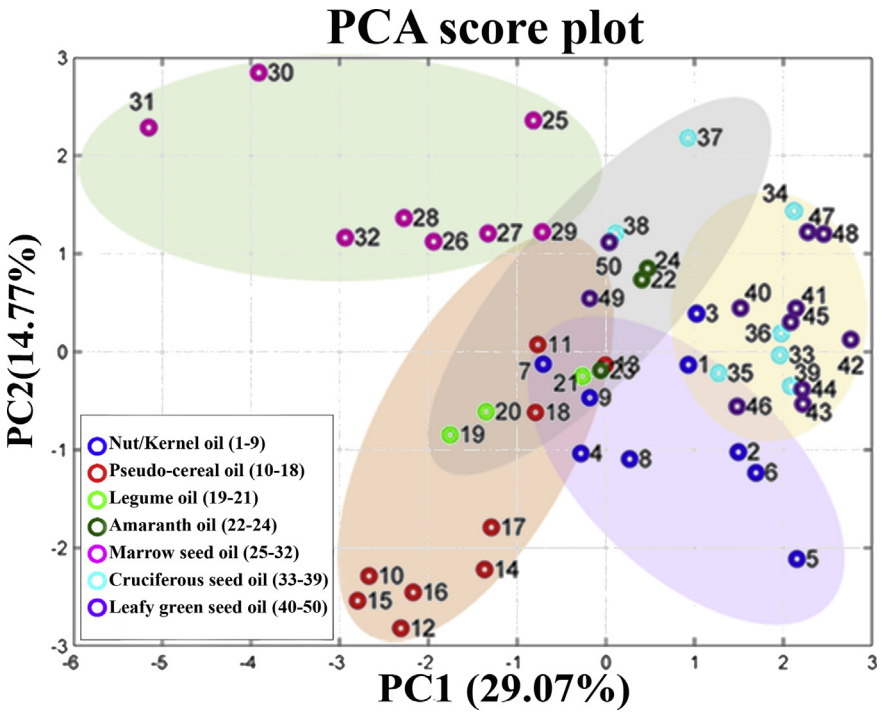

Figure 5. Principal component analysis of the cold-pressed oils for the content of fatty acids and bioactive compounds in the function of PC1 and PC21, score plot (n = 50) for oil samples in 7 groups of nut/kernel, pseudo-cereal, legume, amaranth, marrow seed, cruciferous seed, and leafy green seed. The code for the oils is a number that is counted from the order of the oils written in Table 7.

(1230 μg g^{-1}) (Table 8). Our findings are in agreement with a study by Vlahakis et al. [30], who reported the phytosterol content of soybean oil ranging between 2350 and 4050 μg g^{-1} that were comprised of β-sitosterol for 1250–2360 μg g^{-1}, campesterol for 620–1310 μg g^{-1}, and stigmasterol for 470–770 μg g^{-1}.

3.2.2.2. Content of squalene. Squalene is a hydrocarbon intermediate in the biosynthesis of phytosterols in plants, and it is widely used for applications such as skin moisturizers, vaccines or carriers for active lipophilic molecules [31]. In this study, squalene was detected in the range of 265–5979 μg g^{-1}. The high amount of squalene was found in marrow seed and pseudo-cereals oils, in which the oils from winter melon seeds (5979 μg g^{-1}), hairy basil seeds (5868 μg g^{-1}), and black chia seeds (5625 μg g^{-1}) had the greatest amount of squalene (Figure 4C). On the other hand, squalene was least found in oils of leafy green seeds (403 μg g^{-1}). However, there is a report by Bozorov et al. [32] claiming that squalene content in oils obtained by extraction is greater than that obtained by cold-pressing. This implies that squalene content in the sample oils might be increased if extraction solvent were employed for extraction. However, it seems that many studies have emphasized that the quantitation of plant squalene is mostly done from materials rather than oils. For example, Ryan et al. [33] studied the content of squalene from some selected plant materials such as seeds, grains, and legumes, and found that pumpkin seed was the most abundant source of squalene (as high as 890 μg g^{-1}). The results contradict with ours because in our study oils obtained from grains and legume (such as sesame, soybean and peanut) contained higher amount of squalene than those of pumpkin. The difference would be partly due to difference in samples (grain versus oil) and in extraction efficiency of two different methods (solvent extraction versus cold pressing).

3.2.2.3. Content of cholecalciferol. Cholecalciferol, also known as vitamin D_3, is an important nutrient for calcium homeostasis and optimal bone health. It is found in some foods and can be taken to prevent vitamin D deficiency and related diseases, including altered phosphorus metabolism which could lead to renal osteodystrophy and increased mortality due to cardiovascular disease [34]. Recently, a number of investigations have focused on quantification of precursors and metabolites of vitamin D in plant lipids to be used for human nutrition [35]. Regarding Figure 4D, the oils from marrow seeds had remarkably high content of cholecalciferol as 471.60 μg g^{-1}, and an average value of 153.30 μg g^{-1}. The oils rich in cholecalciferol were angled loofha seed oil (1287.75 μg g^{-1}), winter melon seed oil (815.99 μg g^{-1}), and long skinny eggplant seed oil (632.14 μg g^{-1}). Cholecalciferol in the other groups were in range of non-detectable to 650.30 μg g^{-1}. Although there have been some reports evidencing vitamin D precursors and metabolites in plants [36], to our understanding this is the first study to report high contents of cholecalciferol in marrow seed oils, suggesting marrow seeds to be another good source of vitamin D from foods.

The content of functional phytochemicals derived from this study was compared with those reported in the literature of cold-pressed oil [22]. On the contrary to fatty acid composition, the obtained phytochemical content was rather different than that reported in the literature. Regarding phytosterol content, sesame oil had comparable amount of β-sitosterol (ours was 1768–2192 μg g^{-1} and that of the literature was 1900–2600 μg g^{-1}) and campesterol together with stigmasterol (ours was 74–200 μg g^{-1} and that of the literature was 310–420 μg g^{-1}). Total phytosterol content in amaranth oils (2213–2336 μg g^{-1}), chia seed oils (3684–3903 μg g^{-1}), pistachio oil (1200 μg g^{-1}), and coriander oil (3029 μg g^{-1}) were lower than those reported in the literature (19300, 6653–7765, 5586 and 9180 μg g^{-1}, respectively). However, the phytosterol content in sunflower seed oil (3000 μg g^{-1}), pumpkin seed oil (6738 μg g^{-1}), hazenut oil (6062 μg g^{-1}), peanut oil (5368 μg g^{-1}), moringa seed oil (2650 μg g^{-1}), walnut oil (2479 μg g^{-1}), soybean oil (5070 μg g^{-1}), macadamia oil (2400 μg g^{-1}) and muskmelon seed oil (8845 μg g^{-1}) were greater than those reported in the literature (2400–2600, 1806, 1096, 220–1200, 1344, 1236, 2970, 740 and 3250 μg g^{-1}, respectively). On the other hand, squalene content in the obtained cold-pressed oils were compared with those reported in the literature. Squalene content in sunflower seed oil (1537 μg g^{-1}), hazelnut oil (2356 μg g^{-1}) and macadamia oil (549 μg g^{-1}) was greater than those previously reported (150–200, 186 and 23 μg g^{-1}, respectively), while squalene content in pumpkin seed oil (516 μg g^{-1}) was lower than that in the literature (3520 μg g^{-1}). Since the analyzed functional phytochemicals are secondary metabolites in plants, they can be easily influenced by the type, variety, and environmental conditions, including fertilizers, farm management, harvesting conditions, and agroclimatic properties [37]. For instance, a study by Roche et al. [38] showed a large variability of phytosterol among sixteen sunflower inbred lines and hybrids (1780–3040 ppm). A delay of sowing and increased temperatures during seed formation could improve the sterol content by up to 35%. Therefore, in order to obtain high quality plant oils, breeding programs as well as cultivation conditions of the plant should be carefully considered and manipulated.

3.3. Statistical analysis of principal component analysis (PCA)

PCA was applied after the data was pretreated by standardization to exploratorily analyze the pattern in the oil samples. Figure 5 demonstrates the PCA score plots where the samples were labeled according to the categories of oils. It was observed that the plant oil samples from the same categories were located nearby each other. For example, most of the samples from pseudo-cereal oil were found on the lower side of the PCA space. The samples from the categories of marrow seed oil had higher PC2 scores, and tended to locate on the upper part of the score plots. A dense cluster on the middle right area of the PCA space were plots of samples from legume oils, amaranth oils, pseudo-cereal oils, and cruciferous and leafy green seed oils. The plots of the pseudo-cereal oils are quite distinct that some plots are distributed outside the main cluster, which is located around the middle low of the PCA plot. For instance, the plots of coriander seed oil (coded 13), black sesame oil (coded 11), and white sesame oil (coded 18) are scattered because these oils did not contain linolenic acid. Black sesame oil contained the highest content of linoleic acid and cholecalciferol in their group. White sesame oil was found high content of linoleic and oleic acids, and the coriander seed oil had very high cholecalciferol content and the highest content of oleic acid. Samples in a category of nut/kernel oil had a relatively high and wide range of oleic acid content as 24.02–78.21%, contributing to the dispersion of some plots from this group. Most of the plots from cruciferous seed oils and leafy green seed oils are found in the middle right area of the PCA space. This might be partly because the oils from these two groups contain rather a high composition of oleic and erucic acids. The latter was also found in some kernel oils including coconut and macadamia oils. The plots of amaranth oils are distributed in the same area of legume oils, which share the same range of oleic and linoleic acids content. For the cluster of samples from marrow seed oils, a group with relatively high contents of phytosterols and cholecalciferol, a lot of dispersion in PCA plot is observed because wax gourd seed oil (coded 30) and winter melon seed oil (coded 31) contained the highest amount of phytosterols. Their plots are scattered to the upper right area of the PCA plot. The PCA plot (Figure 5) suggests a similarity pattern for the analyzed samples that would be useful in performed to highlighting the dissimilarity of the oil profiles and PCA can clearly distinguish between different categories of plant material in cold-pressed oil.

Taken together, oil samples were evaluated in terms of both fatty acid composition and functional phytochemicals. In this work, superior oils refer to oils that contain larger fraction of unsaturated fatty acids and high amount of those functional compounds. Accordingly, characteristics of oils from different categories of plants are summarized. Marrow seed oils are a good source of total bioactive, phytosterol, cholecalciferol and linoleic acid, in which winter melon seed oil and wax gourd seed oil are

the most preferable ones. Pseudo-cereal oils are superior oils for high squalene and linolenic acid content, where perilla oil and hairy basil oil are the lead in this group. Legume oils are rich in phytosterols, where peanut oil, as well as soybean oil, are a good choice in this group. In contrast, oils from kernel, amaranth, cruciferous seeds, and leafy green seeds are rather moderate or inferior when considering the amounts of unsaturated fatty acids and the targets bioactive compounds present.

On the basis of the result from this study, some plant oil materials are suggested to be a good source for oil extraction with high nutritional value regarding fatty acid composition and functional phytochemicals. However, quality and stability of oil is another aspect to be concerned with, considering human consumption. If the oil is inappropriately prepared, handled and stored, its quality is diminished. For instance, triacylglycerol in oil can be hydrolyzed under improper circumstance, yielding free fatty acids and glycerol which can increase the rancidity of the oil. The oils with rancidity and off-flavor can be toxic and ultimately pose health risks. In general, quality and stability of oil can be accessed by mean of chemical properties including peroxide value (PV), acid value (AV), and oxidative stability index (OSI). The parameters are subjected to be studied together with optimization of oil extraction after plant oil materials are selected for further application.

Despite the content of beneficial phytochemicals being investigated and discussed in this study, some plants materials (such as oil seeds) contain natural anti-nutritional factors that can be toxic or reduce digestibility of oil nutrition on their consumption. For example, anti-nutrition substances in oil seeds include trypsin inhibitor, goitrogens, sponin, lectin, aflatoxin, allergens, and allergens [39]. Therefore, in order to safely consume those oils for health purpose, it is important to clarify the type and amount of those anti-nutrition substances in the targeted plant materials and remove these harmful substances by employing proper material control and related manufacturing processes.

On the basis of our results, the analyzed 50 cold-pressed oils were further classified according to their edibility, applicability and generalizability.

Regarding edibility, the analyzed oils can be categorized into three categories.

I) Oils containing large amounts of erucic acid. Erucic acid is a monounsaturated omega-9 fatty acid that has been evidenced for its long-term health risk such as myocardial lipidosis especially in children up to ten years [21]. The oils in this groups include Chinese mustard seed oil, Chinese cabbage seed oil, broccoli seed oil, false Pak Choi (Inthanon) seed oil, green Pak Choi seed oil, false Pak Choi (Phukeaw) seed oil, cauliflower seed oil, Chinese kale seed oil, flowering Pak Choi (1) seed oil, Hong Kong Chinese kale seed oil, Indian mustard seed oil, Chinese radish seed oil, Chinese green mustard seed oil, curly kale seed oil, rat-tailed radish seed oil, flowering Pak Choi (2) seed oil, and Chinese flowering cabbage seed oil.

II) Oils containing low amounts of erucic acid, or containing anti-nutrition substance that needs proper control on material handling and oil manufacturing process. The oils in this group include

black chia seed oil, white chia seed oil, moringa seed oil, hazelnut oil, pistachio oil, hairy basil oil, green amaranth oil, love-lies-bleeding oil, spiny amaranth oil, inca peanut oil, cashew oil, almond oil, muskmelon seed oil, pumpkin seed oil, coriander oil, macadamia oil, watermelon seed oil, lettuce seed oil, wax gourd seed oil, winter melon seed oil, angled loofah seed oil, cucumber seed oil, and long skinny eggplant seed oil.

III) Oils generally containing no harmful substances. The oils in this group include black sesame oil, white sesame oil, sunflower seed oil, soybean oil, peanut oil, walnut oil, brown flaxseed oil, gold flaxseed oil, coconut oil, and perilla oil.

On the other hand, the oils can be categorized into four groups based on their usability as follows.

I) Oils with limited sources of raw materials but high nutritional value. The strategic application of oils in this group is mainly as an ingredient of cosmetic or high value products. The oils in this group are black chia seed oil, white chia seed oil, moringa seed oil, hazelnut oil, pistachio oil, hairy basil oil, green amaranth oil, love-lies-bleeding oil, spiny amaranth oil, inca peanut oil, cashew oil, almond oil, coriander oil, macadamia oil, angled loofah seed oil, cucumber seed oil, long skinny eggplant seed oil, watermelon seed oil, lettuce seed oil, curly kale seed oil, Chinese kale seed oil, Hong Kong Chinese kale seed oil, broccoli seed oil, and cauliflower seed oil.

II) Oils with raw material being treated as agricultural by-product or waste but containing good nutritional value. Raw materials from this group can be processed into cold-pressed oils or other value-added products as it could increase their economic value and reduce unnecessary waste. The oils in this groups are wax gourd seed oil, winter melon seed oil, muskmelon seed oil, and pumpkin seed oil.

III) Oils generally suitable for consumption or health purpose. There is no shortage supply of plant oil materials in this group, and the oils are black sesame oil, white sesame oil, sunflower seed oil, soybean oil, peanut oil, walnut oil, brown flaxseed oil, gold flaxseed oil, coconut oil, and perilla oil.

IV) Oil not suitable for consumption or health purpose. The oils that contain large amount of hazardous substance such as erucic acid. The oils in this group are include Chinese mustard seed oil, Chinese cabbage seed oil, false Pak Choi (Inthanon) seed oil, green Pak Choi seed oil, false Pak Choi (Phukeaw) seed oil, flowering Pak Choi (1) seed oil, Indian mustard seed oil, Chinese radish seed oil, Chinese green mustard seed oil, rat-tailed radish seed oil, flowering Pak Choi (2) seed oil, and Chinese flowering cabbage seed oil.

4. Conclusion

In summary, total fifty different cold-pressed oils were prepared in this study. The oils were analyzed for their fatty acid composition and the functional compounds using GC-MS and HPLC-DAD, respectively. The two chromatographic techniques allowed a good separation and quantification of the targeted compounds. A great diversification of fatty acid composition and bioactive compounds was demonstrated. Most oils had the greatest proportion of PUFAs, followed by SFAs and MUFAs, respectively. Considering the bioactive compounds, phytosterols were found in the highest amount, followed by squalene, and cholecalciferol, respectively. PCA was also performed to analyze the variation in identified cold-pressed oil profiles and it can be used to group oil with similar composition. Oils from marrow seeds, pseudo-cereals, and legumes tended to have superior chemical properties compared to oils from kernel, amaranth, cruciferous seeds, and leafy green seeds. In conclusion, the qualitative and quantitative data would be useful for application or selection of those plant oils in food and pharmaceutical industries.

Declarations

Author contribution statement

Jitkunya Yuenyong: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Piramon Pokkanta: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data.

Nutthatida Phuangsaijai, Sila Kittiwachana, Sugunya Mahatheeranont: Analyzed and interpreted the data.

Phumon Sookwong: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Funding statement

This work was supported by Dr. Bruno Werdelmann Foundation, the Functional Food Research Center for Well-being (Chiang Mai University), the Higher Education Research Promotion and National Research University Project of Thailand, the Center of Excellence for Innovation in Chemistry (PERCH-CIC), Office of the Higher Education Commission, Ministry of Education, Thailand, and Science Achievement Scholarship of Thailand (SAST).

Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

References

[1] P. Pokkanta, P. Sookwong, M. Tanang, S. Setchaiyan, P. Boontakham, S. Mahatheeranont, Simultaneous determination of tocols, γ-oryzanols, phytosterols, squalene, cholecalciferol and phylloquinone in rice bran and vegetable oil samples, Food Chem. 271 (2019) 630–638.

[2] M. Wroniak, K. Krygier, M. Kaczmarczyk, Comparison of the quality of cold pressed and virgin rapeseed oils with industrially obtained oils, Pol. J. Food Nutr. Sci. 58 (1) (2008) 85–89.

[3] M. Tasan, U. Gecgel, M. Demirci, Comparison of geometrical isomerization of unsaturated fatty acids in selected commercially refined oils, Grasas Aceites 62 (3) (2011) 284–289.

[4] A.A. Gotor, L. Rhazi, Effects of refining process on sunflower oil minor components: a review, Object Constraint Lang. 23 (2) (2016) D207.

[5] Y. Wu, R. Zhou, Z. Wang, B. Wang, Y. Yang, X. Ju, R. He, The effect of refining process on the physicochemical properties and micronutrients of rapeseed oils, PloS One 14 (3) (2019), e0212879.

[6] R. Verhe, T. Verleyen, V. Van Hoed, W. De Greyt, Influence of refining of vegetable oils on minor components, J. Oil Palm Res. 4 (2006) 168–179.

[7] R.A. Moreau, L. Nystrom, B.D. Whitaker, J.K. Winkler-Moser, D.J. Baer, S.K. Gebauer, K.B. Hicks, Phytosterols and their derivatives: structural diversity, distribution, metabolism, analysis, and health-promoting uses, Prog. Lipid Res. 70 (2018) 35–61.

[8] M.A. Lozano-Grande, S. Gorinstein, E. Espitia-Rangel, G. Dávila-Ortiz, A.L. Martínez-Ayala, Plant sources, extraction methods, and uses of squalene, Int. J. Agron. (2018) 1–13.

[9] R. de Souza Santos, L.M. Vianna, Effect of cholecalciferol supplementation on blood glucose in an experimental model of type 2 diabetes mellitus in spontaneously hypertensive rats and Wistar rats, Clin. Chim. Acta 358 (1-2) (2005) 146–150.

[10] B. Zhao, H. Gong, H. Li, Y. Zhang, T. Lan, Z. Chen, Characterization of Chinese grape seed oil by physicochemical properties, fatty acid composition, triacylglycrol profiles, and sterols and squalene composition, Int. J. Food Eng. 15 (9) (2019).

[11] E. Tortosa-Caparros, D. Navas-Carrillo, F. Marin, E. Orenes-Pinero, Anti-inflammatory effects of omega 3 and omega 6 polyunsaturated fatty acids in cardiovascular disease and metabolic syndrome, Crit. Rev. Food Sci. Nutr. 57 (16) (2017) 3421–3429.

[12] Graciela E. Delgado, B.K. Kramer, S. Lorkowski, W. Marz, C.V. Schacky, M.E. Kleber, Individual omega-9 monounsaturated fatty acids and mortality—the Ludwigshafen risk and cardiovascular health study, J. Clin. Lipidol. 11 (1) (2017) 126–135.

[13] L. Das, E. Bhaumik, U. Raychaudhuri, R. Chakraborty, Role of nutraceuticals in human health, J. Food Sci. Technol. 49 (2) (2012) 173–183.

[14] N. Kaur, V. Chugh, A.K. Gupta, Essential fatty acids as functional components of foods-a review, J. Food Sci. Technol. 51 (10) (2014) 2289–2303.

[15] E.C. Shin, C.E. Hwang, B.W. Lee, H.T. Kim, J.M. Ko, I.Y. Baek, K.M. Cho, Chemometric approach to fatty acid profiles in soybean cultivars by principal component analysis (PCA), Prev. Nutr. Food Sci. 17 (3) (2012) 184.

[16] A. López, A. Montaño, P. García, A. Garrido, Fatty acid profile of table olives and its multivariate characterization using unsupervised (PCA) and supervised (DA) chemometrics, J. Agric. Food Chem. 54 (18) (2006) 6747–6753.

[17] K. Ichihara, Y. Fukubayashi, Preparation of fatty acid methyl esters for gas-liquid chromatography, J. Lipid Res. 51 (3) (2010) 635–640.

[18] L.S. Afinisha Deepam, C. Arumughan, Effect of saponification on composition of unsaponifiable matter in rice bran oil, J. Oleo Sci. 61 (2012) 241–247.

[19] R.G. Brereton, Chemometrics: Data Analysis for the Laboratory and Chemical Plant, Wiley & Sons, England, Chichester, 2003, p. 489.

[20] R.G. Brereton, Chemometrics for Pattern Recognition, Wiley & Sons, England, Chichester, 2009, pp. 49–56.

[21] K.R. Chien, A. Bellary, M. Nicar, A. Mukherjee, L.M. Buja, Induction of a reversible cardiac lipidosis by a dietary long-chain fatty acid (erucic acid). Relationship to lipid accumulation in border zones of myocardial infarcts, Am. J. Pathol. 112 (1) (1983) 68–77.

[22] M.F. Ramadan (Ed.), Cold Pressed Oils: green Technology, Bioactive Compounds, Functionality, and Applications, Academic Press, 2020, pp. 105–623.

[23] S. Chandra, M. Kumar, P. Dwivedi, L.P. Shinde, Functional and nutritional health benefit of cold-pressed oils, Int. Res. J. Food Nutr. 2 (1) (2020) 1–5.

[24] M.M. Ozcan, K. Ghafoor, F. Al Juhaimi, I.A.M. Ahmed, E.E. Babiker, Effect of cold-press and soxhlet extraction on fatty acids, tocopherols and sterol contents of the Moringa seed oils, South Afr. J. Bot. 124 (2019) 333–337.

[25] S.S. Fernandes, D. Tonato, M.A. Mazutti, B.R. de Abreu, D. da Costa Cabrera, C.D.R.M. D'Oca, M. de las Mercedes Salas-Mellado, Yield and quality of chia oil extracted via different methods, J. Food Eng. 262 (2019) 200–208.

[26] M.L. Martinez, M.A. Mattea, D.M. Maestri, Pressing and supercritical carbon dioxide extraction of walnut oil, J. Food Eng. 88 (3) (2008) 399–404.

[27] P. Gao, R. Liu, Q. Jin, X. Wang, Comparison of solvents for extraction of walnut oils: lipid yield, lipid compositions, minor-component content, and antioxidant capacity, LWT Food Sci. Technol. 110 (2019) 346–352.

[28] E. Yilmaz, B.A. Güneşer, Cold pressed versus solvent extracted *lemon (Citrus Limon L.)* seed oils: yield and properties, J. Food Sci. Technol. 54 (7) (2017) 1891–1900.

[29] U. MS, S. Ferdosh, M.J. Haque Akanda, K. Ghafoor, A.H. Rukshana, M.E. Ali, B.Y. Kamaruzzaman, M.B. Fauzi, S. Hadijah, S. Shaarani, M.Z. Islam Sarker, Techniques for the extraction of phytosterols and their benefits in human health: a review, Separ. Sci. Technol. 53 (14) (2018) 2206–2223.

[30] C. Vlahakis, J. Hazebroek, Phytosterol accumulation in canola, sunflower, and soybean oils: effects of genetics, planting location, and temperature, J. Am. Oil Chem. Soc. 77 (1) (2000) 49–53.

[31] N.I. Ibrahim, S. Fairus, M.S. Zulfarina, I. Naina Mohamed, The efficacy of squalene in ardiovascular disease risk- a systematic review, Nutrients 12 (2) (2010) 414.

[32] S.S. Bozorov, N.S. Berdiev, U.J. Ishimov, S.S. Olimjonov, J.F. Ziyavitdinov, A.M. Asrorov, S.I. Salikhov, Chemical composition and biological activity of seed oil of amaranth varieties, Nova Biotechnologica et Chimica 17 (1) (2018) 66–73.

[33] E. Ryan, K. Galvin, T.P. O'Connor, A.R. Maguire, N.M. O'Brien, Phytosterol, squalene, tocopherol content and fatty acid profile of selected seeds, grains, and legumes, Qual. Plant. Mater. Veg. 62 (3) (2007) 85–91.

[34] P. Chandra, J.N.G. Binongo, T.R. Ziegler, L.E. Schlanger, W. Wang, J.T. Someren, V. Tangpricha, Cholecalciferol (vitamin D_3) therapy and vitamin D insufficiency in patients with chronic kidney disease: a randomized controlled pilot study, Endocr. Pract. 14 (1) (2008) 10–17.

[35] Z. Temova, R. Roskar, Stability-indicating HPLC–UV method for vitamin D_3 determination in solutions, nutritional supplements and pharmaceuticals, J. Chromatogr. Sci. 54 (7) (2016) 1180–1186.

[36] A.C. Baur, C. Brandsch, B. Konig, F. Hirche, G.I. Stangl, Plant oils as potential sources of vitamin D, Front. Nutr. 3 (2016) 29.

[37] B. Sampaio, R. Edrada-Ebel, F. Da Costa, Effect of the environment on the secondary metabolic profile of *Tithonia diversifolia*: a model for environmental metabolomics of plants, Sci. Rep. 6 (2016) 29265.

[38] J. Roche, M. Alignan, A. Bouniols, M. Cerny, Z. Mouloungui, F. Vear, O. Merah, Sterol content in sunflower seeds (*Helianthus annuus* L.) as affected by genotypes and environmental conditions, Food Chem. 121 (2010) 990–995.

[39] B. Jithender, N.C. Konga Upendar, P.J. Rathod, Nutritional and anti-nutritional factors present in oil seeds: an overview, Int. J. Conserv. Sci. 7 (6) (2019) 1159–1165.