# Camellia Seed Oils

Subjects: Plant Sciences

Contributor: Efrén Pérez-Santín

Camellia genus (Theaceae) is comprised of world famous ornamental flowering plants. C. japonica L. and C. sasanqua Thunb are the most cultivated species due to their good adaptation. The commercial interest in this plant linked to its seed oil increased in the last few years due to its health attributes, which significantly depend on different aspects such as species and environmental conditions. Therefore, it is essential to develop fast and reliable methods to distinguish between different varieties and ensure the quality of Camellia seed oils. The present work explores the study of Camellia seed oils by species and location. Two standardized gas chromatography methods were applied and compared with that of data obtained from proton nuclear magnetic resonance spectroscopy (1H-NMR) for fatty acids profiling. The principal component analysis indicated that the proposed 1H-NMR methodology can be quickly and reliably applied to separate specific Camellia species, which could be extended to other species in future works.

Keywords: Camellia oil ; authentication ; quality ; chromatographic techniques ; nuclear magnetic resonance ; chemometrics

## 1. Introduction

*Camellia* is a genus of flowering plants in the family *Theaceae*, native to East Asia and widely distributed in China, India, Japan, and South-East Asian countries, whose seeds and leaves present high nutritional and medicinal values. This subtropical evergreen shrub or small tree arrived in Europe around the 16th century [1], and was introduced into the gardens of the highest social classes of Galicia (NW of Spain) at the beginning of the 19th.

Nowadays, cultivars of *Camellia* species are found worldwide in public and private gardens thanks to their excellent adaptation to climatic and edaphic conditions, easy spread, and resistance to pests and diseases. Particularly, *Camellia japonica* L. is the best known internationally as a cultivated species for ornamental value. In the last decade, commercial interest was remarkable, and consequently, production in Spain reached about 2.5 million *Camellia* plants per year, which are exported throughout Europe as ornamentals [2][3][4].

*Camellia* oil is obtained from the seeds, known as one of the most popular edible vegetable oils that was utilized for more than 1000 years in China, and also abundantly used in southeast Asian countries (Japan, Korea, India, Sri Lanka, Indonesia, and Vietnam), where *Camellias* are abundantly available [5].

*Camellia* oil is also known as “Eastern Olive Oil” because it shares a similar chemical composition with olive oil [6]. It contains several natural antioxidants, such as squalene, phytosterol, polyphenols, fat-soluble vitamins (vitamins A, B, E), sasanqua saponin, and other functional substances. It was recommended by the Food and Agriculture Organization of the United Nations as a high-quality, healthy vegetable oil because of its nutritional value and excellent storage qualities [7]. For these reasons, it is commonly used as cooking oil (edible oil) [8][9]. In China, the main species used for oil production is *Camellia oleifera* C. Abel [10], while in Japan this is *C. japonica* [11], and *C. sasanqua* in Vietnam [12].

*Camellia* oil is an expensive product with a particular and characteristic aroma and taste, good storage stability, and high nutritional and medicinal values, with high value interest for trade [13]. Thus, the economic interest in this crop increased exponentially in recent years for a variety of purposes [14]. Specifically, *Camellia* oil extracted from seeds of different species, including *C. reticulata Lindl.*, *C. sinensis* L., *C. oleifera*, and *C. japonica*, was long processed as an industrial oil used for oligosaccharide production [15], as a surfactant, in soaps, as a hair oil, and now it is generating interest as a biofuel source, lubricant, and biopolymer [16][17][18][19][20]. Although, in cosmetics *C. japonica* oil has a long history of traditional cosmetic usage in Japan as a protectant to maintain skin and hair health, where other species are nowadays commonly used for this purpose (e.g., *C. oleifera, C. grijsii* Hance, and *C. sasanqua*) [11][21]. *Camellia* oil has fat-soluble natural compounds with health benefits, reducing cholesterol and triglycerides in the blood, lowering blood pressure, and promoting effects such as antioxidation, antipermeability, anti-inflammation, as an analgesic, and anticancer properties [22]

[23][24], as well as antimicrobial and antiviral activities [25]. In addition to this, they are used in traditional treatments in China to prevent cardiovascular diseases, arteriosclerosis, and burn injuries [26][27][28].

Triacylglycerols are the principal components of *Camellia* oils, with a high proportion of oleic and linoleic acids and low saturated acids. This general lipidic profile is associated with well-known health properties. The oil yield of seeds from this plant is high, being on average 30% oil per seed. However, the seed oil content varies according to species, cultivar, and environmental conditions [29][30]. The profile of fatty acids (FAs) allows correlation to be made with their botanical origin, which is a very important aspect from a commercial point of view, since the traceability of these oils is mandatory to avoid fraud by adulteration. The properties of the oils are also dependent on the FAs' composition. The degree of unsaturation and chain length, and the presence of polyunsaturated FAs, appear to increase the potential beneficial properties of these oils [31]. The unsaturated FAs content in *Camellia* oil can reach as much as 90%, which is the highest amount so far reported for unsaturated FAs in edible oils [22][32][33]. In recent years, *Camellia* oil became one of the most popular and expensive edible vegetable oils on the market in China, being more susceptible to adulteration with other cheaper oils by unscrupulous traders for high profits. Another aspect of fraud, the mislabeling of oil extraction methods, and geographical or origin, also destabilize the local *Camellia* oil market economies [34]. The method for *Camellia* oil authentication currently used officially, employing gas chromatography (GC) techniques, includes the FAs' composition. The increased demand for *Camellia* oil made the development of rapid and reliable methods for the unequivocal chemical plant species oil characterization associated with the quality of the edible oil a priority objective to avoid commercialization of adulterated *Camellia* oils [35][36][37][38][39].

To determine the FA composition, a wide variety of analytical methods are available. In this context, traditional methods are gas chromatography with flame ionization detectors (GC-FID) [40] or gas chromatography-mass spectrometry (GC-MS) [41]. In these methods, a pretreatment of the sample is necessary to convert the FA into the corresponding methyl esters (FAMEs). So, these methodologies are tedious, time-consuming, require the use of FAs standards, and involve complicated pretreatment of the samples prior to analysis, such as the triacylglycerol hydrolysis and esterification that could face problems of oxidation during the derivatization process [42][43][44].

Currently, new, rapid, and nondestructive methods such as Near-InfraRed (NIR), Raman Spectroscopy, and Nuclear Magnetic Resonance (NMR) techniques were recognized as alternative analytical tools in combination with appropriate chemometrics in oil quality control [45]. Specifically, recent studies confirmed that NMR is a powerful tool for qualitative and quantitative analysis of FAs composition in edible vegetable oils [32][40][46][47][48][49][50].

## 2. Results and Discussion on Camellia Seed Oils

### 2.1. Oil Content

Seeds of all *Camellia* species contain oil. However, oil content and quality may vary with species [51]. High seed oil variability is likely the result of several factors, including environmental variables such as soil, altitude, light, rainfall, humidity, and temperature, all playing a key role, as previously demonstrated for a variety of plants [30]. Thus, seed oil content (SOC) of traditional *Camellia* varieties can range between 24% and 50%, with an average about 30% [29]. *C. oleifera,* which is the earliest species exploited for edible oil, accounting for 98% of the *Camellia* cultivated area in China, was previously reported to provide an SOC between 21% and 34% [52]. Moreover, some of the new *C. oleifera* cultivars can reach as much as 53% oil per dry seed [53].

In this study, seeds from different *Camellia* species (*C. japonica*, *C. sasanqua*, *C. reticulata*, and *C. hiemalis* Nakai) were harvested in various locations in the province of Pontevedra (Galicia, NW Spain, **Figure 1**) during the last four months of 2019. The percentage of seed oil extracted from *Camellias* varied from 16.1% to 31.9% for *C. japonica*, and from 22% to 30.1% for *C. sasanqua*, providing mean values of 23.1% and 25.8%, respectively (**Table 1**). Thus, both species are appropriate candidates for use in *Camellia* oil production. *C. reticulata* and *C. hiemalis* showed slightly lower values of 16.6% and 22.6%, respectively.

**Figure 1.** *Camellia* locations.

**Table 1.** Origin and quality parameters of *Camellia* seed oils.

| Sample | Species | Origin-Code | Harvest | Extraction Yield (*w*/*w*, %) | Acid Value (mg KOH/g Oil) | Iodine Value (g $I_2$/100 g Oil) |
|---|---|---|---|---|---|---|
| 1 | *C. japonica* | Cuntis | Sep. | 26.0 | 5.61 ± 0.02 jk | 79.1 ± 0.5 de |
| 2 | *C. japonica* | EFA-826 | Sep. | 31.9 | 0.39 ± 0.00 b | 82.2 ± 0.0 g |
| 3 | *C. japonica* | EFA-942 | Sep. | 21.6 | 1.81 ± 0.02 e | 82.2 ± 0.2 g |
| 4 | *C. japonica* | Quiñones de León/O Castro-876 | Aug. | 24.0 | 5.55 ± 0.04 j | 83.2 ± 0.1 gh |
| 5 | *C. japonica* | Quiñones de León/O Castro-877 | Aug. | 24.0 | 5.66 ± 0.00 k | 85.6 ± 0.0 i |
| 6 | *C. japonica* | Pazo de Lourizán | Sep. | 28.4 | 5.60 ± 0.01 jk | 78.7 ± 0.4 cd |
| 7 | *C. japonica* | Pazo de Gandarón | Aug. | 23.2 | 4.52 ± 0.04 i | 76.5 ± 0.1 b |
| 8 | *C. japonica* | Castelo de Soutomaior | Sep. | 19.7 | 5.61 ± 0.00 jk | 80.9 ± 0.2 f |
| 9 | *C. japonica* | Pazo de Rubianes–Hob Hope | Nov. | 16.1 | 5.62 ± 0.00 jk | 79.4 ± 0.1 de |
| 10 | *C. japonica* | Pazo de Rubianes–Augusto Leal | Nov. | 17.5 | 5.63 ± 0.00 jk | 78.8 ± 0.5 cd |
| 11 | *C. japonica* | Pazo de Rubianes–Momoiro–Bokuhan | Nov. | 27.3 | 5.62 ± 0.00 jk | 80.1 ± 0.2 ef |
| 12 | *C. japonica* | Pazo de Rubianes–Bento de Amorim | Nov. | 16.1 | 5.62 ± 0.02 jk | 70.3 ± 0.4 a |
| 13 | *C. japonica* | Pazo de Rubianes–Royal Velvet | Nov. | 24.1 | 5.61 ± 0.00 jk | 83.1 ± 0.3 gh |
| 14 | *C. sasanqua* | EFA-826 | Sep. | 30.1 | 0.52 ± 0.00 c | 89.8 ± 0.1 j |
| 15 | *C. sasanqua* | EFA-942 | Sep. | 25.0 | 1.07 ± 0.00 d | 82.3 ± 0.0 g |
| 16 | *C. sasanqua* | Pazo de A Saleta | Oct. | 22.1 | 2.17 ± 0.01 f | 92.0 ± 0.5 k |
| 17 | *C. sasanqua* | Pazo de Rubianes | Nov. | 26.1 | 3.41 ± 0.06 g | 83.9 ± 0.4 h |
| 18 | *C. reticulata* | San Vicente do Mar | Oct. | 16.6 | 3.68 ± 0.01 h | 77.2 ± 0.3 b |
| 19 | *C. hiemalis* | Pazo de Rubianes | Nov. | 22.6 | 5.64 ± 0.00 jk | 83.0 ± 0.4 gh |

EFA: Estación Fitopatolóxica Areeiro; results are expressed as mean ± standard deviation ($n$ = 3). Different letters (a–k) in same column indicate statistically significant differences between samples ($p < 0.05$).

### 2.2. Quality Index Parameters

The quality of *Camellia* oil is greatly influenced by extraction technologies [54]. Cold-pressing is generally one of the most common traditional methods to produce healthy *Camellia* oil [51]. Acid value is an important index of the quality of edible oils, providing information about the free FAs content in lipids. Usually, the lowest acid value is related to the best oil quality and oxidation stability, while high values due to free FAs lead to decreased thermal and oxidative stability. Even though *Camellia* oil is not currently regulated at the European level as an edible oil, this parameter was determined for all *Camellia* oils in this study to compare with the standard values legislated by the official olive oil method, according to the Spanish and International regulation [55]. Thus, Extra Virgin Olive Oil must have an acid value lower than 6.0 mg KOH/g oil. **Table 1** shows mean acid values obtained for each of the camelia species studied, ranging from 0.39–5.66 mg KOH/g oil. Thus, *Camellia* oils showed low values, below the maximum authorized in olive oil for food/industrial purposes. Among species, *C. japonica*, with a greater number of samples analyzed, presented great variability in its composition (**Table 1**), with the oils from EFA being the ones that presented the lowest values (0.39 and 1.81 mg KOH/g oil). These results were also similar to the one (1.7 mg/g) found in the literature for the same species [56].

Iodine value is also an oil quality index representative of the number of unsaturated C-C bonds from FAs. Results obtained for the iodine index of *Camellia* oils were compared with those set by the official method for olive oil, ranging from 70.3 to 92.0 g $I_2$/100 g oil (**Table 1**). There is no regulation for *Camellia* oil in Spain, but values between 75 and 90 g $I_2$/100 g oil are set as healthy by Spanish legislation, and therefore they were used as a reference [55]. Thus, iodine values obtained for the different species of *Camellia* oils were, in general, similar to those referred to as healthy by Spanish legislation, with only two samples (S12 and S16) out of this range, since they showed iodine values slightly out of this range (Sample 12, Pazo de Rubiáns–Bento de Amorim, with 70.3 ± 0.4, and Sample 16, *C. sasanqua* from Pazo de A Saleta, with a value of 92.0 ± 0.5). Furthermore, the values obtained in *C. japonica* were really close to that of 79.9 g/100 g obtained by Zeng and Endo, (2019) [56] for the same species.

### 2.3. GC-FID Analysis

FAs composition is one of the most important indexes in edible oils, closely related to their price [57]. The proportion of saturated and unsaturated FAs varies in edible oils. This FAs profile of edible oils is closely related to lipid oxidation, product quality, and function of vegetable oils. Thus, highly unsaturated FAs' (UFAs) oil content is more expensive because consumers assume that they are healthier. Furthermore, the price of edible oils is different in any place depending on factors such as the local availability of the vegetable source needed to extract the oils, the mechanization of agriculture, and the economy of the oil production area, among others [51]. For example, the price of olive oil with a fairly mechanized production and cultivated in large areas of the south of Europe is relatively higher than that of soybean oil produced mainly in China, US, Argentina, and Brazil, with the latter more expensive than palm oil, which is the most widely consumed vegetable oil. Indonesia and Malaysia are the top palm oil producers, followed by Thailand, Nigeria, and Colombia.

*Camellia* oil has a very similar FAs profile and physicochemical properties to olive oil, being given with the designation of "oriental olive oil". It is rich in UFAs (>90%), especially oleic acid (74–87%), as well as in other type of compounds such as polyphenols, fat-soluble vitamins (Vitamins A, B, E), and minor unsaponifiable matters (2–5%), including squalene and phytosterol, etc., [51][58].

In this work, the FAs composition of *Camellia* oils from different species were analyzed by GC-FID as methylated derivatives (FAMEs) and the results expressed as mean values ± standard deviations as shown in **Table 2**. All tested samples contained similar FAs composition, showing nine common FAs compounds. Among them, oleic (C18:1), palmitic (C16:0), linoleic (C18:2), and stearic (C18:0) acids were the predominant FAs, which accounted for 98.5–99.5% of the total, similarly to the results found for total FAs composition of extra virgin olive oil (97.5%) used as a control. Oleic acid (C18:1) was the major component in *Camellia* samples, ranging from 77.9% to 83.6%, followed by palmitic acid (C16:0, 8.2% to 10.8%), linoleic acid (C18:2, 3.9% to 8.0%), stearic acid (C18:0, 1.7% to 3.9%), and linolenic acid (C18:3, 0.23% to 0.45%). Other fatty acids, such as myristic (C14:0), palmitoleic (C16:1), arachidic (20:0), and eicosenoic (C20:1) acids, were found in concentrations lower than 0.2%. Due to the *Camellia* oil characteristics based on a high oleic acid content and the presence of essential fatty acids (C18:2 and C18:3), which cannot be synthesized by the human body and need to be solely supplied through diet, *Camellia* oils may provide health functions, such as the lowering of blood pressure, cholesterol, and triglycerides, and thus prevent cardiovascular diseases, cancer, hypertension, and autoimmune disorders. It is also of value in protecting the liver against peroxidative damage, as was stated by the carbon tetrachloride-induced hepatotoxicity model [59].

**Table 2.** FAs composition by GC/FID, expressed as % total fatty acids.

| Sample | C14:0 | C16:0 | C16:1 | C18:0 | C18:1 | C18:2 | C18:3 | C20:0 | C20:1 | ∑SFA | MUFA | PUFA | ∑UFA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.06 ± 0.01 bc | 8.24 ± 0.26 a | 0.10 ± 0.02 a–c | 2.05 ± 0.05 b–d | 82.20 ± 0.66 f–h | 5.56 ± 0.12 c–e | 0.29 ± 0.02 a–c | 0.05 ± 0.01 ab | 0.29 ± 0.02 ab | 10.40 | 82.59 | 5.85 | 88.45 |
| 2 | 0.06 ± 0.01 bc | 9.17 ± 0.05 d–f | 0.10 ± 0.01 a–c | 2.43 ± 0.09 g–i | 81.59 ± 0.48 e–h | 5.12 ± 0.09 b–d | 0.23 ± 0.02 a | 0.05 ± 0.01 ab | 0.57 ± 0.07 f | 11.70 | 82.26 | 5.35 | 87.61 |
| 3 | 0.04 ± 0.01 a | 9.46 ± 0.23 e–g | 0.12 ± 0.01 a–c | 2.36 ± 0.08 f–h | 80.96 ± 0.47 c–g | 5.65 ± 0.06 e | 0.31 ± 0.03 a–d | 0.04 ± 0.01 a | 0.36 ± 0.03 b–d | 11.90 | 81.44 | 5.96 | 87.40 |
| 4 | 0.07 ± 0.01 c | 9.80 ± 0.11 gh | 0.09 ± 0.01 ab | 2.14 ± 0.09 c–f | 81.07 ± 0.56 d–g | 6.41 ± 0.07 f | 0.30 ± 0.04 a–d | 0.08 ± 0.01 bc | 0.37 ± 0.03 b–d | 12.09 | 81.53 | 6.71 | 88.24 |

| Sample | C14:0 | C16:0 | C16:1 | C18:0 | C18:1 | C18:2 | C18:3 | C20:0 | C20:1 | ∑SFA | MUFA | PUFA | ∑UFA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 0.07 ± 0.01 c | 9.53 ± 0.08 fg | 0.12 ± 0.01 a–c | 2.11 ± 0.06 c–e | 81.12 ± 0.47 d–g | 6.37 ± 0.07 f | 0.25 ± 0.03 ab | 0.07 ± 0.01 a–c | 0.24 ± 0.03 a | 11.78 | 81.48 | 6.62 | 88.10 |
| 6 | 0.06 ± 0.01 bc | 9.26 ± 0.05 d–f | 0.13 ± 0.01 bc | 2.29 ± 0.07 e–g | 81.06 ± 0.56 d–g | 5.61 ± 0.05 de | 0.32 ± 0.02 a–d | 0.07 ± 0.01 a–c | 0.33 ± 0.02 a–c | 11.67 | 81.51 | 5.93 | 87.44 |
| 7 | 0.05 ± 0.01 ab | 10.41 ± 0.22 ij | 0.18 ± 0.02 d | 2.28 ± 0.07 defg | 78.88 ± 0.33 b–d | 7.12 ± 0.09 gh | 0.26 ± 0.04 abc | 0.05 ± 0.01 ab | 0.28 ± 0.02 ab | 12.78 | 79.33 | 7.38 | 86.72 |
| 8 | 0.05 ± 0.01 ab | 9.05 ± 0.05 c–e | 0.10 ± 0.01 a–c | 2.46 ± 0.05 g–i | 79.18 ± 0.59 b–d | 7.43 ± 0.06 h | 0.32 ± 0.03 a–d | 0.09 ± 0.01 c | 0.53 ± 0.03 ef | 11.64 | 79.81 | 7.75 | 87.56 |
| 9 | 0.05 ± 0.01 ab | 8.21 ± 0.11 a | 0.12 ± 0.01 a–c | 1.85 ± 0.05 ab | 83.04 ± 0.54 gh | 5.08 ± 0.08 bc | 0.35 ± 0.03 b–e | 0.05 ± 0.01 ab | 0.44 ± 0.03 c–e | 10.15 | 83.59 | 5.43 | 89.02 |
| 10 | 0.05 ± 0.01 ab | 9.43 ± 0.11 e–g | 0.12 ± 0.01 a–c | 2.61 ± 0.04 ij | 81.65 ± 0.64 e–h | 5.83 ± 0.08 e | 0.33 ± 0.02 a–d | 0.06 ± 0.01 a–c | 0.44 ± 0.04 c–e | 12.14 | 82.20 | 6.16 | 88.36 |
| 11 | 0.07 ± 0.01 c | 9.13 ± 0.07 def | 0.14 ± 0.01 cd | 1.72 ± 0.06 a | 82.58 ± 0.80 f–h | 5.05 ± 0.14 b | 0.25 ± 0.04 ab | 0.06 ± 0.01 a–c | 0.53 ± 0.03 ef | 10.98 | 83.25 | 5.30 | 88.55 |
| 12 | 0.06 ± 0.01 bc | 8.67 ± 0.08 bc | 0.10 ± 0.01 a–c | 3.88 ± 0.09 m | 83.62 ± 1.26 h | 3.91 ± 0.06 a | 0.32 ± 0.03 a–d | 0.08 ± 0.01 c | 0.44 ± 0.04 c–e | 12.69 | 84.16 | 4.23 | 88.39 |
| 13 | 0.06 ± 0.01 bc | 8.99 ± 0.10 b–d | 0.12 ± 0.01 a–c | 2.73 ± 0.03 j | 82.86 ± 1.16 gh | 5.06 ± 0.07 bc | 0.28 ± 0.06 a–c | 0.06 ± 0.01 a–c | 0.44 ± 0.04 c–e | 11.83 | 83.41 | 5.34 | 88.76 |
| 14 | 0.05 ± 0.01 abc | 8.59 ± 0.16 ab | 0.07 ± 0.01 a | 2.12 ± 0.07 c–e | 80.54 ± 0.46 c–f | 6.82 ± 0.12 fg | 0.30 ± 0.01 a–d | 0.06 ± 0.01 a–c | 0.57 ± 0.05 f | 10.82 | 81.18 | 7.12 | 88.30 |
| 15 | 0.05 ± 0.01 abc | 8.86 ± 0.10 b–d | 0.10 ± 0.01 a–c | 2.57 ± 0.05 h–j | 79.00 ± 0.48 b–d | 7.44 ± 0.09 h | 0.45 ± 0.04 ef | 0.05 ± 0.01 ab | 0.82 ± 0.05 g | 11.53 | 79.93 | 7.89 | 87.81 |
| 16 | 0.06 ± 0.01 bc | 9.05 ± 0.08 c–e | 0.13 ± 0.02 bc | 2.48 ± 0.07 g–i | 78.68 ± 0.53 bc | 8.00 ± 0.09 i | 0.31 ± 0.03 a–d | 0.08 ± 0.01 bc | 0.52 ± 0.03 ef | 11.66 | 79.33 | 8.31 | 87.64 |
| 17 | 0.07 ± 0.01 c | 10.77 ± 0.09 j | 0.11 ± 0.02 a–c | 1.95 ± 0.12 bc | 79.36 ± 1.20 b–e | 6.95 ± 0.13 gh | 0.36 ± 0.05 c–e | 0.06 ± 0.01 abc | 0.43 ± 0.03 c–e | 12.84 | 79.90 | 7.31 | 87.22 |
| 18 | 0.05 ± 0.01 ab | 10.32 ± 0.11 i | 0.11 ± 0.01 a–c | 3.17 ± 0.07 k | 77.97 ± 0.76 b | 7.18 ± 0.07 gh | 0.41 ± 0.04 d–f | 0.04 ± 0.01 a | 0.35 ± 0.04 a–c | 13.58 | 78.43 | 7.59 | 86.01 |
| 19 | 0.06 ± 0.01 bc | 10.20 ± 0.11 hi | 0.13 ± 0.01 bc | 1.85 ± 0.06 ab | 79.23 ± 0.51 b–d | 7.12 ± 0.10 gh | 0.36 ± 0.01 c–e | 0.07 ± 0.01 abc | 0.44 ± 0.04 c–e | 12.17 | 79.79 | 7.49 | 87.28 |

∑SFA: total saturated fatty acids. MUFA: monounsaturated fatty acids. PUFA: polyunsaturated fatty acid. ∑UFA: total unsaturated fatty acids. (Results as sums of means); results are expressed as mean ± standard deviation ($n$ = 3). Different letters (a–m) in same column indicate statistically significant differences between samples ($p < 0.05$).

According to the species used in oil production in China, it was found that the composition of *C. japonica* was rich in oleic acid (C18:1) with values of 86.6%, followed by palmitic acid (C16:0; 7.5%), linoleic acid (C18:2; 3.0%), and stearic acid (C18:0, 2.1%), and showed low quantities of palmitoleic acid (C16:1), linolenic acid (C18:3), and arachidic acid (C20:0) in all of them with a proportion of 0.1%, and erucic acid (C22:1) (0.3%) [56]. In reference to our results, the *C. japonica* samples showed a slight decrease in the content of oleic acid and an increase in palmitic acid, as well as a higher concentration of essential fatty acids, namely linoleic acid (C18:2) and linolenic acid (C18:3). The oleic acid values found in *C. japonica* were higher than in that of other species of *Camellia,* such as *C. oleifera* and *C. sinensis,* with values of 80.5 and 58.4%, respectively, and even the oleic acid in olive oils, which showed values between 54.1 and 75.5% [60].

Also, slight differences between total saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA) were found. All *Camellia* oils showed low values of SFA (10.2–13.6%), mainly for palmitic acid (C16:0) (**Table 2**). The SFA in *C. Japonica* was in the range of 7.3% to 9.5%, while *C. Sasanqua* showed higher values between 10.8% and 12.8%. *C. reticulata* and *C. hiemalis* presented SFA values of 13.6% and 12.1%, respectively. The MUFA content is mainly due to the contribution of oleic acid, with a minor contribution from other monounsaturated acids, with *C. japonica* being the species with the highest percentage in reference to the other species studied, 79.3% to 84.2% and 78.4% to 81.2%, respectively. However, this trend is the opposite in the case of PUFA, showing values from 4.2% to 7.7% in *C. Japonica*, while the values were higher in the other species, ranging between 7.1% and 8.3%. In general, oleic acid (C18:1) is usually considered to be more stable than linoleic (C18:2) and linolenic acid (C18:3). The results showed that *Camellia* oils contained high levels of MUFA and low PUFA, favoring the nonappearance of unpleasant odors due to oxidation. Therefore, this may be a justification of the suitability of this oils for cosmetic applications and for cooking at high temperatures [56].

### 2.4. GC-MS Analysis

Gas chromatography-mass spectrometry is a practical and powerful analytical technique used for the quantification of fatty acids, and also commonly used as a separating criterion for *Camellia* oil authentication [61]. The results obtained using the method based on GC-MS (**Table 3**) were analogous to those using the GC-FID methodology previously described. However, some differences were found. Although the values for the main compounds, namely oleic (C18:1), palmitic (C16:0), linoleic (C18:2), and stearic (C18:0) acids showed similar ranges in both techniques, the minor fatty acids myristic (C14:0), palmitic (C16:1), linolenic (C18:3), and arachidic (C20:0) acids presented values lower than 0.2%, and therefore, they were not quantified. The limits of quantification from GC-MS are usually higher than those from GC-FID. For example, Dodds et al., (2005) [62] found for standard FAMES that the limit of quantification (LOQ) of myristic acid (C14:0) is five times higher for GC-MS than that of GC-FID, e.g., 2.52 pmol and 0.50 pmol, respectively. Also, higher LOQs were found by GC-MS for the compounds palmitic (C16:1), linolenic (C18:3), and arachidic (C20:0) acids, which, due to the low concentrations found in the samples, did not allow for their quantification.

**Table 3.** FAs composition by GC/MS, expressed as % total fatty acids.

| Scheme 16. | C16:0 | C18:0 | C18:1 ω-9 *cis* | C18:1 ω-9 *trans* | C18:2 ω-6,-9 | C20:1 ω-9 | ∑SFA | MUFA | PUFA | ∑UFA |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 6.69 ± 0.00 c | 1.66 ± 0.02 ef | 87.1 ± 0.1 gh | 0.72 ± 0.03 d–f | 3.59 ± 0.02 d | 0.25 ± 0.01 ab | 8.35 | 88.07 | 3.59 | 91.65 |
| 2 | 7.44 ± 0.07 fg | 1.94 ± 0.04 ij | 86.5 ± 0.1 fg | 0.76 ± 0.04 d–g | 3.08 ± 0.03 bc | 0.24 ± 0.02 bc | 9.38 | 87.53 | 3.08 | 90.62 |
| 3 | 6.84 ± 0.03 cd | 1.64 ± 0.02 d–f | 87.7 ± 0.1 hi | 0.66 ± 0.03 c–e | 3.12 ± 0.05 bc | ND | 8.48 | 88.43 | 3.12 | 91.52 |
| 4 | 7.80 ± 0.06 hi | 1.68 ± 0.01 e–g | 85.3 ± 0.2 c–e | 0.92 ± 0.06 h | 4.06 ± 0.09 ef | 0.22 ± 0.00 a | 9.48 | 86.43 | 4.06 | 90.52 |
| 5 | 7.51 ± 0.03 gh | 1.58 ± 0.01 de | 86.1 ± 0.1 ef | 0.90 ± 0.07 gh | 3.75 ± 0.04 de | 0.20 ± 0.01 a | 9.09 | 87.17 | 3.75 | 90.91 |
| 6 | 8.04 ± 0.17 i | 1.49 ± 0.02 cd | 85.5 ± 0.3 de | 0.74 ± 0.01 d–f | 4.27 ± 0.09 f–h | ND | 9.53 | 86.20 | 4.27 | 90.47 |
| 7 | 8.46 ± 0.01 j | 0.89 ± 0.02 a | 84.6 ± 0.1 c | 0.89 ± 0.02 gh | 4.35 ± 0.06 f–h | ND | 9.35 | 85.53 | 4.35 | 89.86 |
| 8 | 6.92 ± 0.19 c–e | 1.86 ± 0.03 g–i | 87.6 ± 0.4 hi | 0.66 ± 0.03 c–e | 3.01 ± 0.14 b | ND | 8.78 | 88.23 | 3.01 | 91.22 |
| 9 | 6.07 ± 0.02 a | 1.27 ± 0.01 b | 89.2 ± 0.1 j | 0.62 ± 0.04 c–e | 2.79 ± 0.06 b | ND | 7.34 | 89.87 | 2.79 | 92.66 |
| 10 | 7.45 ± 0.11 fg | 2.05 ± 0.08 j | 85.5 ± 0.6 de | 1.18 ± 0.06 i | 3.49 ± 0.39 cd | 0.29 ± 0.01 c | 9.50 | 87.03 | 3.49 | 90.50 |
| 11 | 7.17 ± 0.08 ef | 1.39 ± 0.05 bc | 87.4 ± 0.3 hi | 0.80 ± 0.06 f–h | 2.92 ± 0.11 b | 0.34 ± 0.01 c | 8.56 | 88.50 | 2.92 | 91.44 |
| 12 | 6.38 ± 0.05 b | 2.76 ± 0.05 l | 87.9 ± 0.2 i | 0.92 ± 0.01 gh | 2.08 ± 0.09 a | ND | 9.14 | 88.77 | 2.08 | 90.86 |
| 13 | 7.06 ± 0.11 de | 2.02 ± 0.03 j | 87.1 ± 0.3 g–i | 0.77 ± 0.02 e–h | 3.02 ± 0.14 b | ND | 9.08 | 87.90 | 3.02 | 90.92 |

| Scheme 16. | C16:0 | C18:0 | C18:1 ω-9 *cis* | C18:1 ω-9 *trans* | C18:2 ω-6,-9 | C20:1 ω-9 | ∑SFA | MUFA | PUFA | ∑UFA |
|---|---|---|---|---|---|---|---|---|---|---|
| 14 | 7.11 ± 0.10 de | 1.78 ± 0.03 f–h | 85.6 ± 0.2 de | 0.53 ± 0.01 a–c | 4.54 ± 0.05 gh | 0.41 ± 0.00 d | 8.89 | 86.57 | 4.54 | 91.11 |
| 15 | 7.17 ± 0.03 e | 1.97 ± 0.01 j | 85.2 ± 0.1 cd | 0.57 ± 0.00 b–d | 4.70 ± 0.03 h | 0.38 ± 0.00 d | 9.14 | 86.13 | 4.70 | 90.86 |
| 16 | 7.50 ± 0.11 gh | 1.84 ± 0.04 g–i | 83.4 ± 0.3 b | 0.42 ± 0.04 a | 6.53 ± 0.15 i | 0.33 ± 0.01 c | 9.34 | 84.13 | 6.53 | 90.66 |
| 17 | 8.39 ± 0.06 j | 1.46 ± 0.05 bc | 85.2 ± 0.3 cd | 0.75 ± 0.05 d–h | 4.21 ± 0.20 fg | ND | 9.85 | 85.93 | 4.21 | 90.15 |
| 18 | 9.32 ± 0.07 k | 2.64 ± 0.02 kl | 83.3 ± 0.2 b | 0.46 ± 0.02 ab | 4.03 ± 0.15 ef | 0.21 ± 0.01 a | 11.96 | 84.00 | 4.03 | 88.04 |
| 19 | 7.84 ± 0.07 i | 1.28 ± 0.03 b | 86.0 ± 0.1 ef | 0.65 ± 0.04 c–f | 4.23 ± 0.03 fg | ND | 9.12 | 86.67 | 4.23 | 90.88 |

∑SFA: total saturated fatty acids. MUFA: monounsaturated fatty acids. PUFA: polyunsaturated fatty acid. ∑UFA: total unsaturated fatty acids. Results as sums of means; results are expressed as mean ± standard deviation ($n$ = 3). ND: not detected. Different letters (a–k) in same column indicate statistically significant differences between samples ($p < 0.05$).

However, the quantification of FAMEs by GC-MS offers two powerful advantages over GC-FID, namely the ability to confirm the identity of analytes based on spectral information, retention time, and the ability to separate peaks from a noisy background, or coeluting peaks if unique ions are available [62]. The results indicate that GC with a mass detector allowed for the identification and quantification of two positional isomers of oleic fatty acid (C18:1 ω-9 *cis* and *trans*) due to its different fragmentation profiles, while with GC-FID this was not possible.

The oils found in nature are in the form of triglycerides, fatty acids generally found with saturated and unsaturated bonds, and the FAs containing double bonds are usually stable as cis isomers. A small percentage of these acids can isomerize to their *trans* configuration during the extraction, refinement, or hydrogenation processes. The *cis* configuration is nutritionally important, while the conversion into *trans* from *cis* is reported to have adverse effects on human serum lipoproteins and contributes to increasing the risk of coronary heart disease [63]. Our results showed very low amounts of C18:1 ω-9 *trans* (from 0.42% to 1.18% depending on the species) in all samples. In contrast, the presence of C18:1 ω-9 *cis* was higher, with values ranging between 83.3% and 89.2%. This is of great importance due to the different healthy properties of this compound found in high quantities in *Camellia* oils.

MS-chromatographic techniques were widely employed in oil quality and safety assessments, with a high specificity and sensitivity to quantify those targeted analytes (FAs) to have a rigorous control (authentication and classification) of samples. However, as in the case of the GC-FID technique, it involves tedious, destructive, and extensive sample preparation. So, these conventional chromatographic techniques have a number of limitations for further quality control oil applications.

### 2.5. H-NMR Analysis

The NMR spectroscopy was extensively used for oil analysis, and it was established as a valuable tool for the assessment of the quality and authenticity of olive oil [64][65]. NMR was used to develop accurate analytical fingerprinting methods for the authentication or certification of the geographical origin of olive oils aided by suitable chemometric analysis [66][67]. Studies of time, thermal, and oxidative stability of olive oils by NMR analysis were also powered by multiway chemometric methodologies [68][69]. Also, $^{1}$H-NMR combined with chemometrics were employed for the prediction of fatty acid composition [50], to detect the adulteration of *Camellia* oil [49], and to determine oxidative stability in *Camellia* oils [70].

In previous work, Feás et al., (2013) [32] determined the FA profile of three species of Galician *Camellia* oils (*C. oleifera, C. reticulata* and *C. sasanqua*, see **Table 4** samples 21–23) collected at the *Estación Fitopatolóxica do Areeiro* in 2011, with values ranging between 82.3% and 84.5%, 5.69% and 7.78%, 0.26% and 0.41%, and 8.04% and 11.2%, for oleic, linoleic, linolenic, and saturated acids, respectively. These values demonstrate that the FAs composition remained fairly stable over time for these species in the region. In this methodology, Feás et al. used the tertiary hydrogen of the glyceryl group (δ 5.25 ppm) as the key indicator to estimate the FAs composition. The magnetic field for providing good results was established as 17.6 T (750 MHz) to avoid signal overlapping of protons of the acyl and glyceryl groups (5.32 and 5.25 ppm, respectively, see **Table 5**). However, the NMR equipment at 750 MHz is of high cost, which would make the technique not easily available and therefore not applicable. To improve the applicability of the $^{1}$H-NMR technique for the

determination of the FA composition in *Camellia* oils, an adaptation of the Barison method was carried out in the present work taking as reference a more common NMR instrument of 400 MHz [71] (**Table 6**).

**Table 4.** FAs composition by $^{1}$H-NMR, expressed as % total fatty acids.

| Sample | Species | C18:1 (MUFA) | C18:2 | C18:3 | ∑SFA | PUFA | ∑UFA |
|---|---|---|---|---|---|---|---|
| 1 | *C. japonica* | 89.9 ± 0.4 f | 5.78 ± 0.19 b–e | ND | 12.36 | 5.78 | 95.63 |
| 2 | *C. japonica* | 86.3 ± 0.4 e | 4.33 ± 0.00 a | ND | 12.92 | 4.33 | 90.63 |
| 3 | *C. japonica* | 86.0 ± 0.2 de | 5.33 ± 0.00 bc | ND | 12.64 | 5.33 | 91.35 |
| 4 | *C. japonica* | 94.3 ± 0.3 g | 7.33 ± 0.00 hi | ND | 15.25 | 7.33 | 101.63 |
| 5 | *C. japonica* | 96.4 ± 0.6 hi | 7.33 ± 0.00 hi | ND | 14.75 | 7.33 | 103.69 |
| 6 | *C. japonica* | 86.4 ± 0.2 e | 7.11 ± 0.19 g–i | ND | 13.75 | 7.11 | 93.46 |
| 7 | *C. japonica* | 85.6 ± 0.9 de | 6.67 ± 0.33 e–h | ND | 14.25 | 6.67 | 92.30 |
| 8 | *C. japonica* | 89.6 ± 0.3 f | 5.33 ± 0.00 bc | ND | 13.36 | 5.33 | 94.96 |
| 9 | *C. japonica* | 90.4 ± 0.7 f | 5.22 ± 0.19 b | ND | 11.64 | 5.22 | 95.58 |
| 10 | *C. japonica* | 98.1 ± 0.8 i | 6.33 ± 0.33 d–g | ND | 14.69 | 6.33 | 104.41 |
| 11 | *C. japonica* | 97.8 ± 0.3 i | 5.11 ± 0.19 ab | ND | 13.63 | 5.11 | 102.91 |
| 12 | *C. japonica* | 94.5 ± 1.0 gh | 5.11 ± 0.19 ab | ND | 16.02 | 5.11 | 99.63 |
| 13 | *C. japonica* | 93.3 ± 0.4 g | 5.56 ± 0.19 b–d | ND | 13.91 | 5.56 | 98.85 |
| 14 | *C. sasanqua* | 84.7 ± 0.1 c–e | 6.67 ± 0.00 f–h | ND | 12.25 | 6.67 | 91.41 |
| 15 | *C. sasanqua* | 83.6 ± 0.1 c | 7.67 ± 0.00 i | ND | 12.86 | 7.67 | 91.24 |
| 16 | *C. sasanqua* | 85.7 ± 0.2 de | 10.33 ± 0.00 j | ND | 13.80 | 10.3 | 96.08 |
| 17 | *C. sasanqua* | 84.1 ± 0.3 cd | 7.33 ± 0.00 hi | ND | 14.36 | 7.33 | 91.41 |
| 18 | *C. reticulata* | 81.0 ± 0.5 b | 7.11 ± 0.19 g–i | ND | 17.25 | 7.11 | 88.07 |
| 19 | *C. hiemalis* | 91.1 ± 1.7 f | 7.89 ± 0.77 i | ND | 14.58 | 7.89 | 98.96 |
| 20 * | *C. japonica* | 80.7 | 6.65 | 0.29 | 12.4 | 6.94 | 87.64 |
| 21 ** | *C. sasanqua* | 82.3 | 6.20 | 0.30 | 11.2 | 6.50 | 88.80 |
| 22 ** | *C. reticulata* | 84.5 | 5.69 | 0.26 | 9.58 | 5.95 | 90.42 |
| 23 ** | *C. oleifera* | 83.8 | 7.78 | 0.41 | 8.04 | 8.19 | 91.96 |

∑SFA: total saturated fatty acids. MUFA: monounsaturated fatty acids. PUFA: polyunsaturated fatty acid. ∑UFA: total unsaturated fatty acids. Results as sums of means; results are expressed as mean ± standard deviation ($n$ = 3). ND: not detected. Different letters (a–j) in same column indicate statistically significant differences between samples ($p < 0.05$). Values from bibliography. Reference: * [3]. ** [32].

**Table 5.** Chemical shift assignment of $^{1}$H-NMR for FAs.

| Peak | δ (ppm) | Multiplicity | Functional Group | Compound |
|---|---|---|---|---|
| 1 | 5.32 | m | –CH=CH– | acyl group |
| 2 | 5.25 | m | –CH–O–COR | glyceryl group |
| 3 | 4.27 | dd | $–CH_2–O–COR$ | glyceryl group |
| 4 | 2.74 | t | $=CH–CH_2–CH=$ | acyl group (linoleic and linolenic group) |
| 5 | 2.29 | dt | $–OCO–CH_2–$ | acyl group |
| 6 | 2.01 | m | $–CH_2–CH=CH–$ | acyl group |
| 7 | 1.61 | m | $–OCO–CH_2–CH_2–$ | acyl group |

| Peak | δ (ppm) | Multiplicity | Functional Group | Compound |
|---|---|---|---|---|
| 8 | 1.29 | m | –$(CH_2)$n– | acyl group |
| 9 | 0.98 | t | –CH=CH–$CH_2$–$CH_3$ | linoleic acyl group |
| 9 | 0.88 | t | –$CH_2$–$CH_2$–$CH_2$–$CH_3$ | saturated oleic except linoleic acyl group |

d: doublet; t: triplet; m: multiplet; dt: double of triplet; dd: doublet of doublet.

**Table 6.** Signal identification and quantification according to Barison's method.

| Fatty Acid | Label | $^1$H NMR Signal | Reference Area (Signal) | Subtration |
|---|---|---|---|---|
| Linolenic | E | 0.98 ppm | 22.2 | -- |
| Linoleic | A | 2.74 ppm | 33.3 | 2 × linoleic |
| Oleic | C | 2.01 ppm | 16.7 | linolenic and linoleic |
| Saturated | B | 2.29 ppm | 33.3 | linolenic + linoleic + oleic |

Fatty acid compositions found in *Camellia* oils are shown in **Table 4**. *Camellia* oil samples showed values ranging from 81.0% to 98.1%, 4.33% to 10.4%, and 11.6% to 17.3% for oleic acid (C18:1), linoleic acid (C18:2), and saturated acids, respectively. In most cases, the fatty acid contents found were close to the levels showed in chromatographic analysis and comparable with data from the literature based on NMR analysis of Galician *Camellia* oils [3][32]. In general, the content of oleic acid (C18:1) in *C. Japonica* (91.4%) and *C. hiemalis* (91.1%) showed average values higher than in *C. sasanqua* (84.5%) and *C. reticulata* (81.0%), although *C. japonica* showed a wide variability, including that of linoleic acid in the range 4.3–7.3%. No significant amounts of linolenic acid (C18:3) were detected. The slight differences in the FA profile between chromatographic and NMR samples may be due to the approximations implied in Barison's method based on two approaches: (1) All fatty acid acyl chains were esterified on the glycerol moiety, and (2) there were no free fatty acids in the samples [71]. In relation to this, neither di- nor monoacylglycerols were detected, as confirmed by the absence of peaks in the spectrum at 4.12 and 2.27 ppm, respectively. Also, the acid value in all *Camellia* oil samples is lower than 6 mg KOH/g of oil, and therefore *Camellia* oils are optimal candidates for the application of this methodology.

The application of the $^1$H-NMR methodology developed to determine FA content in *Camellia* oils is simpler and faster than conventional methods due to the absence of sample pretreatment, low-reagent consumption, short analysis (approx. 3–4 min), excellent repeatability, and fully automatic routine protocol in the NMR software [20][50][70]. Although currently the costs per sample are affordable, however, professional operating personnel are necessary. Moreover, this technique avoids problems such as lipid oxidation present in the traditional GC analysis, it does not require the use of standards, it is a nondestructive technique, and it provides information about distribution of FAs (**Figure 2**) [72][73][74].

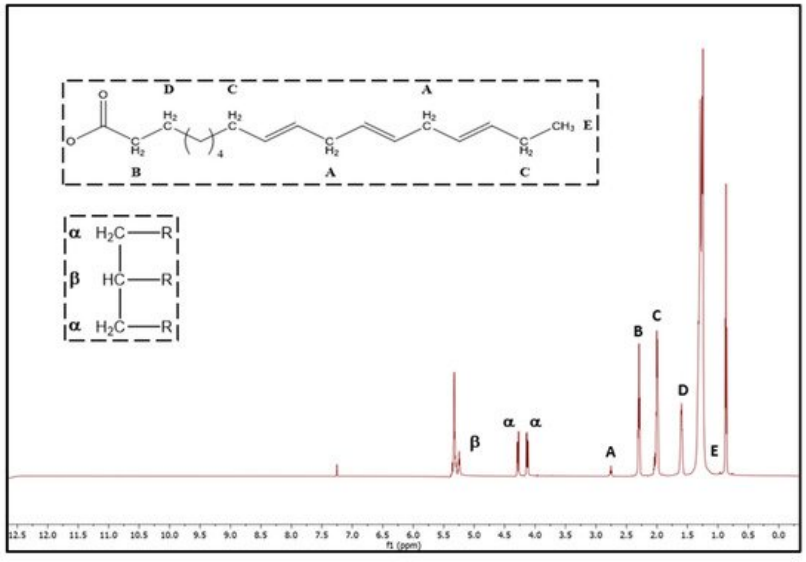


**Figure 2.** Structure of FAs and $^1$H-NMR spectrum at 400 MHz of camelia seed oil.

**2.6. Principal Component Analysis (PCA)**

Principal component analysis (PCA) was used to identify the parameters, mainly fatty acids, that better separate 19 seed oils from four species of *Camellia*, namely the most widespread *C. japonica* and *C. sasanqua*, and the less common species *C. reticulata* and *C. hiemalis*. **Figure 3**A–C show the biplot of the two main principal components (PC1 and PC2) characterized by the common parameters studied in samples including iodine and acid values, extraction efficiency, and the FAs profile studied with the gas chromatography techniques (GC-FID and GC-MS) and the proton nuclear magnetic resonance technique ($^{1}$H-NMR). This FA profile presented saturated FAs (C14:0, C16:0, C18:0 and C20:0), total saturated FA (∑SFA), total unsaturated FAs (C16:1, C18:1, C18:2, C18:3, and C20:1), total monounsaturated FA (MUFA), total polyunsaturated FA (PUFA), and total unsaturated FA (∑UFA). The cumulative explained total variance ranged from 54.31% (GC-FID) and 67.76% (GC-MS) for the chromatographic techniques to 67.84% for $^{1}$H-NMR technique.

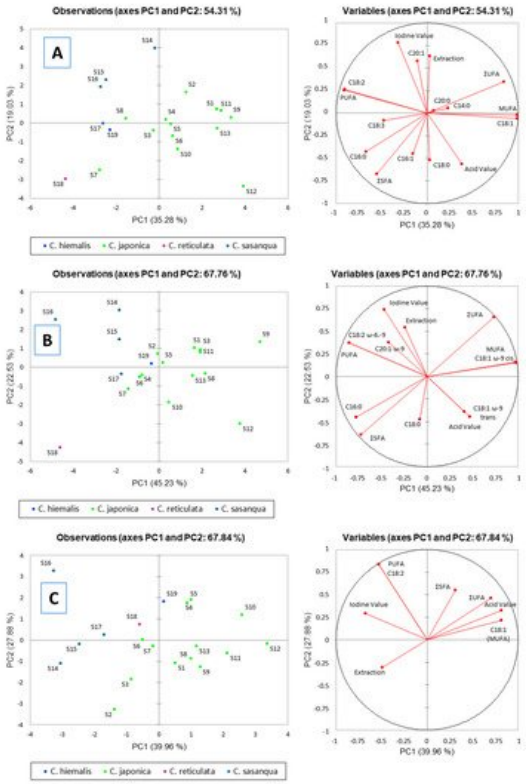


**Figure 3.** Principal component analysis plot of *Camellia* oils from different species. FAs were determined by (**A**) GC-FID, (**B**) GC-MS, (**C**) $^{1}$H-NMR.

## References


1. Cothran, J.R. Treasured Ornamentals of Southern Gardens—Michaux's Lasting Legacy. Castanea 2004, 69, 149–157.
2. Vela, P.; Salinero, C.; Sainz, M.J. Phenological growth stages of Camellia japonica. Ann. Appl. Biol. 2013, 162, 182–190.
3. Salinero, C.; Feás, X.; Mansilla, J.P.; Seijas, J.A.; Vázquez-Tato, M.P.; Vela, P.; Sainz, M.J. 1H-nuclear magnetic resonance analysis of the triacylglyceride composition of cold-pressed oil from Camellia japonica. Molecules 2012, 17, 6716–6727.
4. Salinero, C.; Vela, P.; Castiñeiras, J.R.; Sainz, M.J. Development of a touristic route of winter gardens in Galicia (NW Spain) based on the Camellias: The Camellia Route. Int. Camellia J. 2014, 46, 38–39.
5. Sahari, M.A.; Ataii, D.; Hamedi, M. Characteristics of tea seed oil in comparison with sunflower and olive oils and its effect as a natural antioxidant. J. Am. Oil Chem. Soc. 2004, 81, 4.
6. Wang, L.; Lee, F.S.C.; Wang, X.; He, Y. Feasibility study of quantifying and discriminating soybean oil adulteration in Camellia oils by attenuated total reflectance MIR and fiber optic diffuse reflectance NIR. Food Chem. 2006, 95, 529–536.
7. Zhu, X.Y.; Lin, H.M.; Chen, X.; Xie, J.; Wang, P. Mechanochemical-Assisted Extraction and Antioxidant Activities of Kaempferol Glycosides from Camellia oleifera Abel. Meal. J. Agric. Food Chem. 2011, 59, 3986–3993.
8. Yu, Y.; Ren, S.; Tan, K. Study on climatic regionalization and layer and belt distribution of oiltea Camellia quality in China. J. Nat. Resour. 1999, 14, 123–127.

9. Cheng, Y.T.; Wu, S.L.; Ho, C.Y.; Huang, S.M.; Cheng, C.L.; Yen, G.C. Beneficial Effects of Camellia Oil (Camellia oleifera Abel.) on Ketoprofen-Induced Gastrointestinal Mucosal Damage through Upregulation of HO-1 and VEGF. J. Agric. Food Chem. 2014, 62, 642–650.
10. Ruter, J.M. Nursery production of tea oil Camellia under different light levels. In Trends New Crop New Uses; Janick, J., Whipkey, A., Eds.; ASHS Press: Alexandria, VA, USA, 2002; pp. 222–224.
11. Jung, E.; Lee, J.J.; Baek, J.; Jung, K.; Lee, J.J.; Huh, S.; Kim, S.; Koh, J.; Park, D. Effect of Camellia japonica oil on human type I procollagen production and skin barrier function. J. Ethnopharmacol. 2007, 112, 127–131.
12. Van Thang, H.; Van Do, T.; Sato, T.; Khai, N.Q. Tea oil Camellia plantation, an enormous potentiality for poverty reduction. Asian J. Agric. Ext. Econ. Sociol. 2014, 3, 1–12.
13. Zhong, H.Y.; Wan, C.N.; Xie, B.X. The present status and development tendency of utilization and processing in Camellia oil in China. China For. Sci. Technol. 2001, 15, 6–9.
14. Berti, M.; Gesch, R.; Eynck, C.; Anderson, J.; Cermak, S. Camelina uses, genetics, genomics, production, and management. Ind. Crop. Prod. 2016, 94, 690–710.
15. Yan, C.; Liu, Y.; Cao, L.; Xia, M.; Zhang, Q.; Li, C.; Ruan, R. Oligosaccharide preparation from microwave-ethanol pretreated Camellia oleifera seed shell by enzymolysis of Agrocybe aegerita. Ind. Crops Prod. 2021, 161, 113155.
16. QingYun, L.; Le, Y.; YiMin, Q.; YanLin, L.; Min, C.; YouYan, L. The preparation of biodiesel from Camellia oil catalyzed by immobilized enzyme. Kezaisheng Nengyuan/Renew. Energy Resour. 2012, 30, 55–59.
17. Zheng, J.; Liu, H.; Zhou, L. Evaluation of Camellia oleifera as a source for biodiesel production. In Proceedings of the 2011 International Conference on Electrical and Control Engineering, ICECE 2011—Proceedings, Yichang, China, 16–18 September 2011; pp. 1551–1554.
18. Allen, C.B. Thermal degradation and biodiesel production using Camellia oleifera seed oil. Bachelor's Thesis, University of Georgia, Athens, Georgia, 2015.
19. Huang, Y.; Li, F.; Bao, G.; Wang, W.; Wang, H. Estimation of Kinematic Viscosity of Biodiesel Fuels from Fatty Acid Methyl Ester Composition and Temperature. J. Chem. Eng. Data 2020, 65, 2476–2485.
20. Yahaya, L.E.; Adebowale, K.O.; Olu-Owolabi, B.I.; Menon, A.R.R.; Arr, M. Compositional Analysis of Tea (Camellia sinensis) Seed Oil and Its Application. Int. J. Res. Chem. Environ. 2011, 1, 153–158.
21. Poojary, M.M.; Passamonti, P. Interesterification of mafura butter and Camellia oil for cosmeceutical formulations: Chemical composition and physicochemical properties of products. Ind. Crops Prod. 2020, 147, 112178.
22. He, L.; Guo-Ying, Z.; Zhang, H.-Y.; Jun-Ang, L. Research progress on the health function of tea oil. J. Med. Plants Res. 2011, 5, 485–489.
23. Lee, C.P.; Yen, G.C. Antioxidant Activity and Bioactive Compounds of Tea Seed (Camellia oleifera Abel.) Oil. J. Agric. Food Chem. 2006, 54, 779–784.
24. Meng, X.H.; Li, N.; Zhu, H.T.; Wang, D.; Yang, C.R.; Zhang, Y.J. Plant Resources, Chemical Constituents, and Bioactivities of Tea Plants from the Genus Camellia Section Thea. J. Agric. Food Chem. 2019, 67, 5318–5349.
25. Akihisa, T.; Tokuda, H.; Ukiya, M.; Suzuki, T.; Enjo, F.; Koike, K.; Nikaido, T.; Nishino, H. 3-Epicabraleahydroxylactone and other triterpenoids from Camellia oil and their inhibitory effects on epstein-barr virus activation. Chem. Pharm. Bull. 2004, 52, 153–156.
26. Yuan, J.; Wang, C.; Chen, H.; Zhou, H.; Ye, J. Prediction of fatty acid composition in Camellia oleifera oil by near infrared transmittance spectroscopy (NITS). Food Chem. 2013, 138, 1657–1662.
27. Kim, J.K.; Park, H.G.; Kim, C.R.; Lim, H.J.; Cho, K.M.; Choi, J.S.; Shin, D.H.; Shin, E.C. Quality evaluation on use of Camellia oil as an alternative method in dried seaweed preparation. Prev. Nutr. Food Sci. 2014, 19, 234.
28. Zhang, L.L.; Wang, Y.M.; Wu, D.M.; Xu, M.; Chen, J.H. Comparisons of antioxidant activity and total phenolics of Camellia oleifera Abel fruit hull from different regions of China. J. Med. Plants Res. 2013, 4, 1407–1413.
29. Huang, J.; Ahrends, A.; He, J.; Gui, H.; Xu, J.; Mortimer, P.E. An evaluation of the factors influencing seed oil production in Camellia reticulata L. plants. Ind. Crop. Prod. 2013, 50, 797–802.
30. Amiri-Darban, N.; Nourmohammadi, G.; Rad, A.H.S.; Mirhadi, S.M.J.; Heravan, I.M. Potassium sulfate and ammonium sulfate affect quality and quantity of camelina oil grown with different irrigation regimes. Ind. Crop. Prod. 2020, 148, 112308.
31. Kamal-Eldin, A.; Mäkinen, M.; Lampi, A.M. The Challenging Contribution of Hydroperoxides to the Lipid Oxidation Mechanism; Kamal-Eldin, A., Ed.; AOCS Press: Champaign, IL, USA, 2003; pp. 1–35.

32. Feás, X.; Estevinho, L.M.; Salinero, C.; Vela, P.; Sainz, M.J.; Vázquez-Tato, M.P.; Seijas, J.A. Triacylglyceride, Antioxidant and Antimicrobial Features of Virgin Camellia oleifera, C. reticulata and C. sasanqua Oils. Molecules 2013, 18, 4573–4587.

33. Su, M.H.; Shih, M.C.; Lin, K.H.H. Chemical composition of seed oils in native Taiwanese Camellia species. Food Chem. 2014, 156, 369–373.

34. Dais, P.; Hatzakis, E. Quality assessment and authentication of virgin olive oil by NMR spectroscopy: A critical review. Anal. Chim. Acta 2013, 765, 1–27.

35. Shi, T.; Wu, G.; Jin, Q.; Wang, X. Detection of Camellia oil adulteration using chemometrics based on fatty acids GC fingerprints and phytosterols GC–MS fingerprints. Food Chem. 2021, 352, 129422.

36. Shi, T.; Wu, G.; Jin, Q.; Wang, X. Camellia oil authentication: A comparative analysis and recent analytical techniques developed for its assessment. A review. Trends Food Sci. Technol. 2020, 97, 88–99.

37. Cheng, X.; Yang, T.; Wang, Y.; Zhou, B.; Yan, L.; Teng, L.; Wang, F.; Chen, L.; He, Y.; Guo, K. New method for effective identification of adulterated Camellia oil basing on Camellia oleifera-specific DNA. Arab. J. Chem. 2018, 11, 815–826.

38. Chu, X.; Wang, W.; Li, C.; Zhao, X.; Jiang, H. Identifying Camellia oil adulteration with selected vegetable oils by characteristic near-infrared spectral regions. J. Innov. Opt. Health Sci. 2018, 11, 1850006.

39. Aparicio, R.; Aparicio-Ruıíz, R. Authentication of vegetable oils by chromatographic techniques. J. Chromatogr. A 2000, 881, 93–104.

40. Wang, X.; Zeng, Q.; Verardo, V.; Contreras, M.D.M. Fatty acid and sterol composition of tea seed oils: Their comparison by the “FancyTiles” approach. Food Chem. 2017, 233, 302–310.

41. Li, X.; Kong, W.; Shi, W.; Shen, Q. A combination of chemometrics methods and GC-MS for the classification of edible vegetable oils. Chemom. Intell. Lab. Syst. 2016, 155, 145–150.

42. Craske, J.D.; Bannon, C.D. Gas liquid chromatography analysis of the fatty acid composition of fats and oils: A total system for high accuracy. J. Am. Oil Chem. Soc. 1987, 64, 1413–1417.

43. Christie, W.W. Methylation of fatty acids. Lipid Technol. 1990, 2, 48–49.

44. Igarashi, T.; Aursand, M.; Hirata, Y.; Gribbestad, I.S.; Wada, S.; Nonaka, M. Nondestructive quantitative determination of docosahexaenoic acid and n-3 fatty acids in fish oils by high-resolution 1H nuclear magnetic resonance spectroscopy. J. Am. Oil Chem. Soc. 2000, 77, 737–748.

45. McKenzie, J.S.; Donarski, J.A.; Wilson, J.C.; Charlton, A.J. Analysis of complex mixtures using high-resolution nuclear magnetic resonance spectroscopy and chemometrics. Prog. Nucl. Magn. Reson. Spectrosc. 2011, 59, 336–359.

46. Kritioti, A.; Menexes, G.; Drouza, C. Chemometric characterization of virgin olive oils of the two major Cypriot cultivars based on their fatty acid composition. Food Res. Int. 2018, 103, 426–437.

47. Popescu, R.; Costinel, D.; Dinca, O.R.; Marinescu, A.; Stefanescu, I.; Ionete, R.E. Discrimination of vegetable oils using NMR spectroscopy and chemometrics. Food Control. 2015, 48, 84–90.

48. Zhang, L.; Wang, Y.; Wu, D.; Xu, M.; Chen, J. Microwave-assisted extraction of polyphenols from Camellia oleifera fruit hull. Molecules 2011, 16, 4428–4437.

49. Shi, T.; Zhu, M.; Chen, Y.; Yan, X.; Chen, Q.; Wu, X.; Lin, J.; Xie, M. 1H NMR combined with chemometrics for the rapid detection of adulteration in Camellia oils. Food Chem. 2018, 242, 308–315.

50. Zhu, M.T.; Shi, T.; Chen, Y.; Luo, S.H.; Leng, T.; Wang, Y.L.; Guo, C.; Xie, M.Y. Prediction of fatty acid composition in Camellia oil by 1H NMR combined with PLS regression. Food Chem. 2019, 279, 339–346.

51. Robards, K.; Prenzler, P.; Ryan, D.; Zhong, H. Camellia oil and tea oil. In Gourmet and Health-Promoting Specialty Oils; Moreau, R.A., Kamal-Eldin, A., Eds.; AOCS Press: Urbana, IL, USA, 2009; pp. 313–343. ISBN 978-1-893997-97-4.

52. Liang, H.; Hao, B.-Q.; Chen, G.-C.; Ye, H.; Ma, J. Camellia as an Oilseed Crop. HortScience 2017, 52, 488–497.

53. Yang, C.; Liu, X.; Chen, Z.; Lin, Y.; Wang, S. Comparison of Oil Content and Fatty Acid Profile of Ten New Camellia oleifera Cultivars. J. Lipids 2016, 2016, 3982486.

54. Yang, J.; Li, J.; Wang, M.; Zou, X.; Peng, B.; Yin, Y.; Deng, Z. A novel aqueous extraction for Camellia oil by emulsified oil: A frozen/thawed method. Eur. J. Lipid Sci. Technol. 2019, 121, 1800431.

55. World Health Organization. Codex Alimentarius Commission Standard for Olive Oils, and Olive Pomace Oils, Codex Stan 33-1981 rev. 2015; Codex Alimentarius International Food Standards; World Health Organization: Geneva, Switzerland, 2015.

56. Zeng, W.; Endo, Y. Lipid characteristics of Camellia seed oil. J. Oleo Sci. 2019, 68, 649–658.

57. Ma, J.; Ye, H.; Rui, Y.; Chen, G.; Zhang, N. Fatty acid composition of Camellia oleifera oil. J. Für Verbrauch. Leb. 2011, 6, 9–12.
58. Li, S.; Zhu, X.; Zhang, J.; Li, G.; Su, D.; Shan, Y. Authentication of Pure Camellia Oil by Using Near Infrared Spectroscopy and Pattern Recognition Techniques. J. Food Sci. 2012, 77, 7.
59. Lee, C.-P.; Shih, P.-H.; Hsu, C.-L.; Yen, G.-C. Hepatoprotection of tea seed oil (Camellia oleifera Abel.) against CCl4-induced oxidative damage in rats. Food Chem. Toxicol. 2007, 45, 888–895.
60. Oğraş, Ş.Ş.; Kaban, G.; Kaya, M. The effects of geographic region, cultivar and harvest year on fatty acid composition of olive oil. J. Oleo Sci. 2016, 65, 889–895.
61. Xie, J.; Liu, T.; Yu, Y.; Song, G.; Hu, Y. Rapid Detection and Quantification by GC–MS of Camellia Seed Oil Adulterated with Soybean Oil. J. Am. Oil Chem. Soc. 2013, 90, 641–646.
62. Dodds, E.D.; McCoy, M.R.; Rea, L.D.; Kennish, J.M. Gas chromatographic quantification of fatty acid methyl esters: Flame ionization detection vs. electron impact mass spectrometry. Lipids 2005, 40, 419–428.
63. Aro, A.; Becker, W.; Pederssen, J.I. Trans fatty acids in the Nordic countries. Food Nutr. Res. 2006, 50, 151–154.
64. Mannina, L.; D'Imperio, M.; Capitani, D.; Rezzi, S.; Guillou, C.; Mavromoustakos, T.; Vilchez, M.D.M.; Fernández, A.H.; Thomas, F.; Aparicio, R. 1H NMR-based protocol for the detection of adulterations of refined olive oil with refined hazelnut oil. J. Agric. Food Chem. 2009, 57, 11550–11556.
65. Šmejkalová, D.; Piccolo, A. High-power gradient diffusion NMR spectroscopy for the rapid assessment of extra-virgin olive oil adulteration. Food Chem. 2010, 118, 153–158.
66. Mannina, L.; Marini, F.; Gobbino, M.; Sobolev, A.P.; Capitani, D. NMR and chemometrics in tracing European olive oils: The case study of Ligurian samples. Talanta 2010, 80, 2141–2148.
67. Agiomyrgianaki, A.; Petrakis, P.V.; Dais, P. Influence of harvest year, cultivar and geographical origin on Greek extra virgin olive oils composition: A study by NMR spectroscopy and biometric analysis. Food Chem. 2012, 135, 2561–2568.
68. Cordella, C.B.Y.; Tekye, T.; Rutledge, D.N.; Leardi, R. A multiway chemometric and kinetic study for evaluating the thermal stability of edible oils by 1H NMR analysis: Comparison of methods. Talanta 2012, 88, 358–368.
69. Alonso-Salces, R.M.; Holland, M.V.; Guillou, C. 1H-NMR fingerprinting to evaluate the stability of olive oil. Food Control. 2011, 22, 2041–2046.
70. Zhu, M.T.; Shi, T.; Luo, X.; Tang, L.J.; Liao, H.X.; Chen, Y. Determination of the Oxidative Stability of Camellia Oils Using a Chemometrics Tool Based on 1H NMR Spectra and α-Tocopherol Content. Anal. Chem. 2020, 92, 932–939.
71. Barison, A.; Da Silva, C.W.P.; Campos, F.R.; Simonelli, F.; Lenz, C.A.; Ferreira, A.G. A simplemethodology for the determination of fatty acid composition in edible oils through 1H-NMR spectroscopy. Magn. Reson. Chem. 2010, 48, 642–650.
72. Sopelana, P.; Ibargoitia, M.L.; 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. 2016, 197, 1256–1263.
73. Guillén, M.D.; Ruiz, A. High resolution 1H nuclear magnetic resonance in the study of edible oils and fats. Trends Food Sci. Technol. 2001, 12, 328–338.
74. Ruiz-Aracama, A.; Goicoechea, E.; Guillén, M.D. Direct study of minor extra-virgin olive oil components without any sample modification. 1H NMR multisupression experiment: A powerful tool. Food Chem. 2017, 228, 301–314.