Quantitative Analysis of the Fatty Acid Compositions of Different Oils and Associations with Antioxidant Capacity and Oxidative Stability

LIU Junchen[1], SUN Xiaoman[1], ZHANG Huirong[1], SHAO Haofan[1], LING Xiao[2], LI Li[1*]

(1.School of Light Industry Science and Engineering, Beijing Key Lab of Plant Resource Research and Development, Beijing Technology & Business University, Beijing 100048, China)

(2.Beijing Lan Divine Technology Co. Ltd., Beijing 100081, China)

Abstract: Fatty acids are the main constituents of vegetable oils. To determine the fatty acid compositions of small trade vegetable oils and some less well studied beneficial vegetable oils, and investigate their relationships with antioxidant activity and oxidative stability, gas chromatography-mass spectrometry was performed to characterize the associated fatty acid profiles. The antioxidant activity of vegetable oils, based on their DPPH-scavenging capacity (expressed as IC_{50} values), was used to assess their impact on human health, and their oxidative stability was characterized by performing lipid oxidation analysis to determine the oxidative induction time of fats and oils. In addition, correlation analyses were performed to examine associations between the fatty acid composition of the oils and DPPH-scavenging capacity and oxidative stability. The results revealed that among the assessed oils, coffee seed oil has the highest saturated fatty acid content (355.10 mg/g), whereas *Garddenia jaminoides* oil has the highest unsaturated fatty acid content (844.84 mg/g). Coffee seed oil was also found have the lowest DPPH IC_{50} value (2.30 mg/mL) and the longest oxidation induction time (17.09 h). Correlation analysis revealed a significant linear relationship ($P<0.05$) between oxidative stability and unsaturated fatty acid content, with lower contents tending to be associated with better oxidative stability. The findings of this study provide reference data for the screening of functional edible vegetable oils.

Key words: gas chromatography–mass spectrometry; vegetable oil; fatty acid composition; oxidative stability; antioxidant capacity

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定量分析不同油脂的脂肪酸组成及其与抗氧化能力和氧化稳定性之间的关系

刘峻辰[1]，孙晓曼[1]，张慧荣[1]，邵浩凡[1]，凌霄[2]，李丽[1*]

（1.北京工商大学轻工科学与工程学院，北京植物资源研究开发重点实验室，北京 100048）

（2.北京尚捷优蓝科技有限公司，北京 100081）

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作者简介：刘峻辰（2001-），男，硕士研究生，研究方向：化妆品配方创新及原料改性，E-mail：l15382166411@163.com

通讯作者：李丽（1980-），女，博士，教授，研究方向：中国特色植物原料研发与应用，E-mail：lili2212@163.com

摘要：植物油中主要组成为脂肪酸，为确定小宗植物油与一些研究较少的功效性植物油的脂肪酸组成并且研究其与抗氧化活性和氧化稳定之间的关系。该研究使用气相色谱－质谱法测定其脂肪酸组成，并通过植物油的 DPPH 清除能力来测试植物油的抗氧化活性以 IC_{50} 值表示，以此表征其对人体健康的影响，使用油脂氧化分析测试油脂氧化诱导时间表征其氧化稳定性，并通过将植物油的脂肪酸组成与 DPPH 自由基清除能力和氧化稳定性进行关联性分析。结果显示：咖啡籽油的饱和脂肪酸含量最高（355.10 mg/g）、青刺果油的不饱和脂肪酸含量最高（844.84 mg/g）；咖啡籽油的 DPPH IC_{50} 值最低（2.30 mg/mL），氧化诱导时间最长为 17.09 h。经相关性分析后植物油的氧化稳定性（P<0.05）与不饱和脂肪酸含量呈显著的线性相关，不饱和脂肪酸含量越低，氧化稳定性越好。该研究为功能性食用植物油的筛选提供了参考数据。

关键词：GC-MS；植物油；脂肪酸组成；抗氧化；氧化稳定性

Vegetable oils are indispensable necessities in people's daily lives and are widely used in food and cosmetics. However, due to the differences in the oil seeds of various plants, it leads to large differences in the fatty acids (FAs) composition and other aspects of different vegetable oils. At present, a lot of research has been done at home and abroad on the FAs composition and quality aspects of large trade vegetable oils, including soybean oil, but less research has been reported on small trade vegetable oils such as camellia seed oil and flaxseed oil, which have a small market share and production compared to the common vegetable oils[1].

In fact, the FAs composition, antioxidant properties and oxidative stability of vegetable oils are important factors in determining their quality and their impact on human health when consumed[2-4]. Therefore, the study of FAs composition of small trade vegetable oils as well as their antioxidant and oxidative stability can help to meet the nutritional and health needs of people for different fats and promote the development of small trade functional fats and oils.

The human body is unable to synthesise certain FAs due to the lack of certain unsaturating enzymes (Δ12- and Δ15-desaturases), and these nutrients must be provided through the diet[5]. Vegetable oils are a primary source of edible lipids that are rich in FAs[6]. Based on their chemical structures, FAs can be classified as saturated fatty acids (SFAs) and unsaturated fatty acids (UFAs). SFAs are stable and play a vital role in human metabolism. However, excessive intake of SFAs may cause cardiovascular and cerebrovascular diseases, which pose a threat to human health[7]. UFAs can be grouped into monounsaturated fatty acids (MUFAs) and polyunsaturated fatty acids (PUFAs), based on the degree of unsaturation. MUFAs significantly lower cholesterol, lower blood sugar, and regulate blood lipids. Oleic acid (C18:1n-9c) is a type of MFAs that has anti-atherosclerotic, anti-thrombotic properties, and can increase resistance to lipid peroxidation[8]. Of the PUFAs linoleic acid (LA) and α-linolenic acid (ALA) are considered essential fatty acids, and the synthesis of other FAs in the body is dependent on the dietary intake of these essential FAs[5].

The antioxidant capacity of vegetable oils plays an important physiological role in the prevention of many diseases, including cancer and cardiovascular disease. The ability of an oil to neutralize free radicals in the human body can be determined by measuring its 1,1-diphenyl-2-trinitrophenylhydrazine (DPPH) free-radical scavenging ability. Vegetable oils contain high concentrations of UFAs, which are easily oxidized under a variety of conditions, including exposure to light or high temperatures, resulting in vegetable oil deterioration, which is harmful to the human body if consumed. Oxidative stability testing is used to establish the shelf life of a vegetable oil, which can be used as reference for safe consumption[9,10].

Therefore, gas chromatography-mass spectrometry (GC-MS) was used to systematically examine the composition and content of FAs in *Linum usitatissimum* seed oil (*L. usitatissimum* seed oil), *Vitis vinifera* seed oil (*V. vinifera* seed oil), *Limnanthes alba* seed oil (*L. alba* seed oil), *Rosa rugosa* hip oil (*R. rugosa* hip oil), *Juglans regia* nut oil (*J. regia* nut oil), *Perilla frutescens* seed oil (*P. frutescens* seed oil), *Hippophae*

rhamnoides seed oil (*H. rhamnoides* seed oil), *Coffea arabica* seed oil (*C. arabica* seed oil), *Mauritia flexuosa* fruit oil (*M. flexuosa* fruit oil), *Plukenetia volubilis* oil (*P. volubilis* oil), *Garddenia jaminoides* oil (*G. jaminoides* oil), *Prinsepia utilits* rogle oil (*P. utilits* rogle oil). The antioxidant capacity of the plant oils was analysed and their oxidative stability was characterised using the oxidation induction time, and the data were used to analyse the relationship between the composition of FAs and the two. The results of this study will contribute to the development, production and further use of small trade vegetable oils, accelerate the formation of a new pattern of "soybean-based, multiple oils" in China, and promote the sustainable development of the vegetable oil industry.

1 Materials and Methods

1.1 Materials

Table 1 Types and sources of vegetable oils

No.	Oil sample	Source
1	*Linum usitatissimum* seed oil (S1)	Squeeze (Not refined)
2	*Vitis vinifera* seed oil (S2)	Baena Cold pressing
3	*Limnanthes alba* seed oil (S3)	Hai Lin Cold pressing
4	*Rosa rugosa* hip oil (S4)	Yun Li Squeeze
5	*Juglans regia* nut oil (S5)	Squeeze
6	*Perilla frutescens* seed oil (S6)	Squeeze (Not refined)
7	*Hippophae rhamnoides* seed oil (S7)	Squeeze
8	*Coffea arabica* seed oil (S8)	He An
9	*Mauritia flexuosa* fruit oil (S9)	Hai Lin Cold pressing
10	*Camellia japonica* oil (S10)	Squeeze
11	*Garddenia jaminoides* oil (S11)	Yun Li Squeeze
12	*Prinsepia utilis* rogle oil (S12)	Hai Lin Cold pressing

L. usitatissimum seed oil and *P. frutescens* seed oil for our own squeeze, and other vegetable oils (Table 1) were obtained from commercial suppliers. Standard for Analysis of Mixed Fatty Acid Methyl esters (FAME) with concentrations of 26.3~263 μg/mL (37 components), nonadecanoic acid (C19:0) at 100 μg/mL, KOH, CH_3OH, n-hexane (chromatographically pure), NaOH, 14% boron trifluoride methanol solution (BF_3-CH_3OH), and ethyl acetate were purchased from Shanghai Macklin Biochemical Co. Ltd.. 1,1-Diphenyl-2-trinitrophenylhydrazine (DPPH) was purchased from Tokyo Chemical Industry Co. Ltd..

1.2 Preparation of analytical standard solutions

Internal standards were used to improve the accuracy of the quantitative results. C19:0 was used as the internal standard to correct for variations in the experimental process and was added 100 μL to the FAME standard[11]. 100 μL of the FAME standard solution was added to a 10 mL volumetric flask and diluted to volume with hexane. A series of standards was prepared and used to optimize the gas chromatographic conditions and characterize the FAs methyl esters.

1.3 GC-MS detection method

GC-MS analysis was performed using an Agilent 7890B-5977A. Gas chromatographic conditions: Agilent DB-FAt FAME column (60 m×0.250 mm, 0.25 μm); initial oven temperature 80 ℃ for 5 min, ramp 80 ℃ /min to 160 ℃ , hold 3 min, 5 ℃ /min to 185 ℃ , hold 5 min, 7 ℃ /min to 210 ℃ , hold 10 min, 1 ℃ /min to 220 ℃ , hold 3 min, and 5 ℃ /min to 230 ℃ , hold 5 min. carrier gas ultra-high purity helium, inlet temperature 280 ℃ ; split ratio 10:1, injection volume 1.0 μL; solvent delay 5 min. Mass spectrometer conditions: Electron ionization (EI) source; ion source temperature 230 ℃ ; mass scan range 40~500 u.

1.4 Comparison of methyl ester methods

FAs must be converted to their corresponding methyl esters before GC-MS analysis via derivatization using acid or base catalysts. There are advantages and disadvantages to each type of methyl esterification reaction; Therefore a common acid-catalyzed methyl esterification method (BF_3-CH_3OH) was compared to a base-catalyzed method (KOH-CH_3OH) to determine the most suitable FAs derivatization method for vegetable oils[12].

1.4.1 BF3 methylation method

10 μL of the oil sample was added to a test tube, 700 μL of 2% (wt.%) NaOH-CH_3OH solution was added, and the solution was reacted in a water bath at 60 ℃ for 30 min. 700 μL of 14% (wt.%) BF_3-CH_3OH

solution was added and the mixture was reacted in a water bath at 80 ℃ for 5 min. The mixture was allowed to cool to room temperature and 2 mL of hexane was added to extract the derivatized FAs. The mixture was left to stand to allow the layers to partition and the upper organic phase was reserved.

1.4.2 KOH-CH_3OH methylation method

10 μL of the oil sample was added to a test tube, 200 μL of 2 mol/L KOH-CH_3OH solution was added. The mixture was vortexed for 2 min to obtain a turbid solution, followed by sonication in a water bath at 60 ℃ for 45 min until the solution was clarified. The mixture was allowed to cool to room temperature and 2 mL of hexane was added to extract the derivatized FAs. The mixture was allowed to stand to allow the layers to partition and the upper organic phase was reserved.

1.5 Optimization of methyl esterification method

The oil samples were derivatized via the two methyl esterification methods and analyzed using GC-MS. The response of each peak in the total ion chromatogram (TIC) was compared and the most suitable methyl esterification method was selected for this experiment.

FAs determination of vegetable oils is affected not only by the methylation method but also by the time, temperature, and concentration of reagents added to the methylation reaction[13]. The reagent dosage for methyl esterification was optimized using repeated experiments with *H. rhamnoides* seed oil (S7) as the sample.

10 mg aliquots of the S7 were accurately weighed. 1 mL of a 1, 2, or 3% (wt.%) NaOH-CH_3OH solution was added and the mixture was heated in a water bath at 60 ℃ for 30 min. 0.2, 0.5, or 1 mL of 14% (wt.%) BF_3-CH_3OH solution was then added. The solution was heated in a water bath at 80 ℃ for 5 min. After cooling, 2 mL of hexane was added. The derivatized FAs were extracted and analyzed using GC-MS. The experiment was repeated five times under the same conditions.

1.6 Stability of GC-MS method and samples

Using the optimized GC-MS method, the FAs methyl esters and the internal standard were repeatedly injected six times and the relative standard deviation (RSD) of each peak area was calculated to verify the precision of the instrument. The stability of the derivatized oil sample was determined by injecting the same sample at 0, 3, 6, 12, and 24 h, and calculating the RSD of each peak area. Recovery experiments were conducted by adding a 1:1 ratio of the analytical standard solution to samples of known composition. The experiments were repeated three times and the recoveries of the components and their RSDs were calculated.

1.7 Analysis of FAs composition and content of vegetable oils

The 12 vegetable oils were derivatized using the optimized methyl ester method and analyzed using GC-MS to determine the FAs composition and content of each oil sample.

1.8 Antioxidant testing of vegetable oils

1.8.1 Determination of DPPH-scavenging capacity of vegetable oils

The method developed by Mukazayire[14] was used with slight modifications. The oil samples were diluted with ethyl acetate to various concentrations. The solutions were reacted with DPPH solution in a 96-well enzyme-labeled plate containing an enzyme marker for 30 min and the absorbance was measured at 517 nm by using an enzyme marker (Multiskan GO, Thermo Fisher).

Each experiment was conducted three times. The DPPH removal rate for each oil sample was calculated and the data were processed using GraphPad software. The results were expressed as half-maximal inhibitory concentration (IC_{50}) values.

1.8.2 Determination of oxidative stability of vegetable oils

According to the theory of free radical reaction and automatic oxidation[15], the oxidation rate of oil is related to the degree of unsaturation of fatty acids and is closely related to the trace components contained in the oil, such as the content of tocopherols and polyphenols. And the speed of oil oxidation has a great relationship with its shelf life, the faster the oxidation

speed of oil, the shorter the shelf life. At present, there are few researches on some functional oils. Therefore, we selects 7 kinds of edible functional oils that are not common in the market. Referring to the GB/T 21121-2007 standard method[16], the oxidation induction time of seven vegetable oils was measured using the Rancimat 892 (Metrohm) oil oxidation stability tester to reflect the storage shelf life and anti autooxidation ability of these seven functional oils, and combined with the fatty acid composition of the oils themselves for analysis.

Measurement parameters: temperature 120.0±0.1 ℃; sample injection volume 3.0±0.2 g; gas flow rate 20 L/h; deionized water (conductivity value <5 μS/cm) 60 mL.

1.9 Data analysis

Data was processed, plotted, and analyzed using Microsoft Excel 2021, SPSS software and GraphPad software. The results are expressed as mean±standard deviation.

2 Results and Discussion

2.1 GC-MS detection method

Using the established GC-MS method, 38 FAs, including the internal standard, were separated. The TIC is shown in Fig.1 and the results demonstrate that the GC-MS method could successfully detect all the FAs methyl esters.

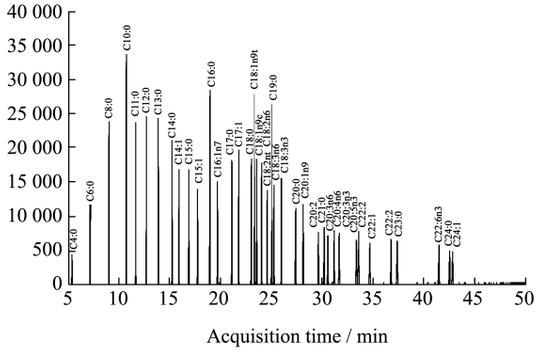

Fig.1 TIC diagram of 38 fatty acids mixed specimens including internal standard for separation

2.2 Selection and optimization of methylation method

The TICs of S7 samples derivatized using the two methyl esterification methods are shown in Fig.2.

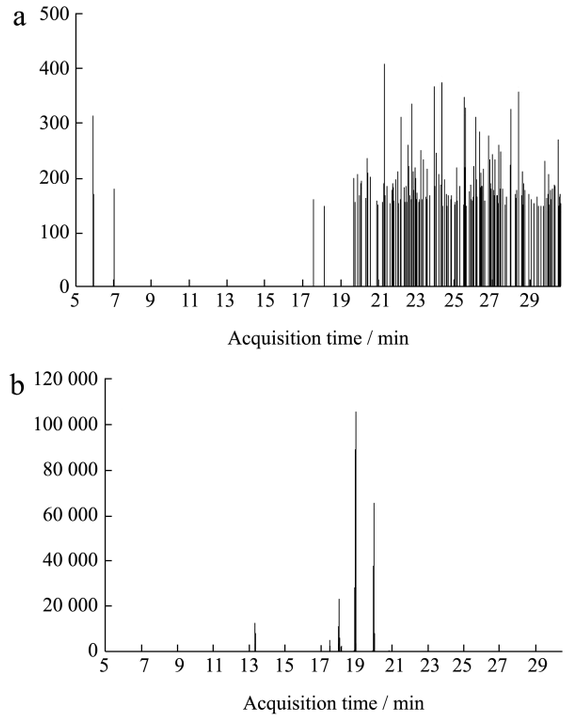

Fig.2 TIC diagram of fatty acid composition of S7 by GC-MS

Notes: (a) KOH-CH_3OH method; (b) BF_3 methyl esterification method.

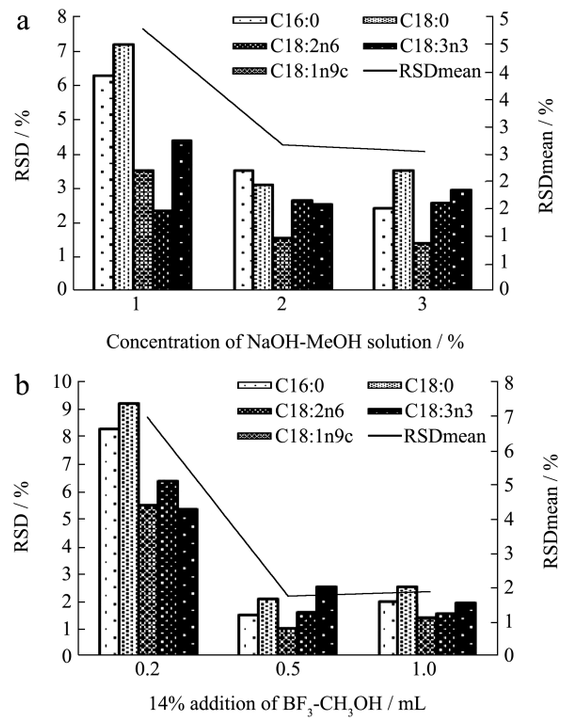

Fig.3 RSD of each peak area of S7 by GC-MS

Notes: (a) NaOH-CH_3OH methylation conditions; (b) 14% BF_3-CH_3OH methylation conditions.

Table 2 Peak detection time and standard curve of 38 fatty acids

Name	Peak time/h	Standard Curve	Linearity range/(μg/mL)	R^2	Limit of detection/(μg/mL)
C4:0	5.420	y=0.007 8x−0.113 1	26.3~263	0.998 0	0.003
C6:0	7.189	y=0.014 9x−0.185 7	26.3~263	0.996 6	0.002
C8:0	9.052	y=0.026 2x−0.574 4	26.3~263	0.996 6	0.002
C10:0	10.753	y=0.021 7x−0.115	26.3~263	0.996 1	0.003
C11:0	11.685	y=0.022 6x−0.273 7	26.3~263	0.993 1	0.001
C12:0	12.713	y=0.028 5x−0.433 9	26.3~263	0.996 2	0.004
C13:0	13.908	y=0.023 9x−0.249	26.3~263	0.997 3	0.003
C14:0	15.265	y=0.028 7x−0.480 4	26.3~263	0.994 9	0.003
C14:1	15.952	y=0.023 1x−0.491 1	26.3~263	0.996 7	0.003
C15:0	16.925	y=0.022 2x−0.216 8	26.3~263	0.996 2	0.002
C15:1	17.791	y=0.021 8x−0.478	26.3~263	0.999 1	0.004
C16:0	19.017	y=0.025 2x−0.618 5	52.6~526	0.999 2	0.002
C16:1n7	19.751	y=0.046 4x−0.292	26.3~263	0.996 6	0.001
C17:0	21.159	y=0.025 1x−0.381	26.3~263	0.996 9	0.004
C17:1	21.838	y=0.021 2x−0.226 8	26.3~263	0.998 7	0.002
C18:0	23.105	y=0.021 2x−0.048 6	26.3~263	0.999 1	0.002
C18:1n9t	23.399	y=0.021 7x−0.354 1	26.3~263	0.999 7	0.003
C18:1n9c	23.620	y=0.021 1x−0.253 8	26.3~263	0.996 8	0.001
C18:2n6t	24.102	y=0.020 7x−0.255 4	26.3~263	0.997 4	0.003
C18:2n6	24.650	y=0.022 4x−0.458 1	26.3~263	0.997 7	0.003
C18:3n6	25.304	y=0.021x−0.379 2	26.3~263	0.997 6	0.002
C18:3n3	26.047	y=0.021 7x−0.339 6	26.3~263	0.999 4	0.003
C20:0	27.503	y=0.021 4x−0.264 9	26.3~263	0.998 8	0.003
C20:1n9	28.246	y=0.020 2x−0.367	26.3~263	0.997 1	0.003
C20:2	29.718	y=0.02x−0.463 1	26.3~263	0.995 4	0.002
C21:0	30.339	y=0.023x−0.475 1	26.3~263	0.997 1	0.001
C20:3n6	30.658	y=0.019 1x−0.458 2	26.3~263	0.997 4	0.006
C20:4n6	31.279	y=0.02x−0.491 9	26.3~263	0.997 5	0.006
C20:3n3	31.786	y=0.021 2x−0.550 2	26.3~263	0.995 7	0.004
C20:5n3	33.535	y=0.021 4x−0.526 6	26.3~263	0.997 3	0.003
C22:0	33.715	y=0.02x−0.330 9	26.3~263	0.999 6	0.006
C22:1	34.794	y=0.018 6x−0.466 5	26.3~263	0.998 0	0.003
C22:2	36.895	y=0.018 2x−0.458 1	26.3~263	0.999 1	0.004
C23:0	37.508	y=0.020 8x−0.423 1	26.3~263	0.998 9	0.002
C24:0	41.636	y=0.017 8x−0.410 6	26.3~263	0.995 5	0.008
C22:6n3	42.646	y=0.017 9x−0.595 8	26.3~263	0.992 6	0.006
C24:1	42.977	y=0.016 7x−0.446 5	26.3~263	0.996 1	0.006
C19:0	25.001				

The peaks in the BF_3-CH_3OH sample TIC were more intense than those in the KOH-CH_3OH sample TIC, and the separation was better and more repeatable. Therefore, the BF_3 methyl esterification method was adopted for all further experiments.

Different reagent volumes were used with the S8 sample to optimize the BF_3 methyl esterification method based on the RSD of the peak areas and the principle of reagent saving (that is adding the smallest amount of reagent to produce the desired effect). As shown in Fig.3, the optimal reagent volumes were 1 mL of 2% (wt.%) NaOH-CH_3OH solution and 0.5 mL of 14% (wt.%) BF_3-CH_3OH solution, which were used for subsequent derivatization of the 12 vegetable oils.

2.3 Stability of GC-MS method

The calibration curves were constructed by plotting the peak area ratios of the analytes to the internal standard versus the corresponding analyte concentrations (Table 2). The regression coefficients (R^2) were greater than 0.99 and the analyte responses were linear in the corresponding ranges.

The RSD of the analytical standard peak areas were below 3.0% for 6 replicate injections of the mixed standard, demonstrating the high precision of the GC-MS. The peak areas for the sample stability tests, in which the same sample was injected at different times, was ＜4.0%, which confirmed that the sample was stable. The recovery studies showed good recoveries of 96.3%~103.0% for three replicates of the 1:1 mixture of the known sample and corresponding standard.

The results showed that the GC-MS method is reliable, with high sensitivity, complete baseline separation, and good reproducibility, and meets the requirements for quantitative determination of 37 FAs.

2.4 FAs composition and content of vegetable oils

The oil samples were analyzed by GS-MS using the optimized experimental method. Significant variations in the FAs content of different varieties of vegetable oil were observed (Table 3).

As shown in Table 3, palmitic, stearic, oleic, and linoleic acids were detected in the 12 vegetable oils. ALA was detected in S1, S3, S5~S8, and S11. Low levels of arachidic acid were detected in S8.

The highest SFAs content was observed in *C. arabica* seed oil (355.10 mg/g), and the lowest was in *C. japonica* oil (55.56 mg/g).

The highest MUFAs content was observed in *M. flexuosa* fruit oil (738.76 mg/g), whereas *C. arabica* seed oil contained the lowest amount (65.07 mg/g). Among the 12 vegetable oil samples S9, S10 and S12 were predominantly composed of MUFAs, which have significant cholesterol-lowering and blood lipid-regulation effects. The primary MUFAs in the samples was oleic acid, which can prevent atherosclerosis and thrombosis, and increase the peroxidation activity in the body[17].

LA (n-6) was the major PUFAs detected. *R. rugosa* hip oil contained the highest levels of LA (517.72 mg/g), followed by *J. regia* nut oil (514.3 mg/g); the lowest levels were observed in *M. flexuosa* fruit oil (16.42 mg/g). ALA were the major n-3 FAs detected in the samples. The highest and lowest ALA contents were observed in *P. frutescens* seed oil (496.09 mg/g) and *C. arabic*a seed oil (10.55 mg/g), respectively. PUFAs were predominant in S1~S8 and S11, among the 12 vegetable oil samples. The n-3 and n-6 series of FAs form part of the PUFAs, among which LA and ALA are essential FAs. Increased consumption of PUFAs-rich edible oils can provide a good supplement of the essential FAs required by the human body. The ratio between LA and ALA in PUFAs can inhibit inflammation and prevent various chronic diseases. At present, the optimal intake range of this ratio is not uniform among countries and varies between 3:1 and 10:1[1]. Among the 12 vegetable oils, the LA:ALA ratios of *L. alba* seed oil, *J regia* nut oil and *C. arabic*a seed oil are within this range.

The FAs composition and content of various vegetable oils were determined in this study and can provide a scientific data reference for nutritional analysis.

Table 3 12 Fatty acid composition and content of vegetable oils (mg/g)

Oil sample	C16:0	C18:0	C18:1n9	C18:2n6	C18:3n3	C20:0	SFAs	MUFAs	PUFAs
S1	43.52 ± 2.94	26.83 ± 2.76	90.38 ± 18.46	99.52 ± 5.79	466.85 ± 43.38		70.35 ± 5.70	90.38 ± 18.64	566.37 ± 49.17
S2	79.67 ± 6.74	40.98 ± 4.33	308.30 ± 1.39	482.25 ± 54.31			120.65 ± 11.07	308.3 ± 1.39	482.25 ± 54.31
S3	52.98 ± 4.98	17.82 ± 1.22	157.9 ± 30.44	347.00 ± 24.98	37.60 ± 3.59		70.80 ± 6.20	144.60 ± 30.44	384.60 ± 28.57
S4	48.2 6 ± 3.90	21.99 ± 3.76	193.12 ± 32.47	517.72 ± 43.01			70.25 ± 7.66	193.12 ± 32.47	517.72 ± 43.01
S5	48.37 ± 1.25	16.35 ± 0.48	182.12 ± 4.44	514.3 ± 11.62	60.50 ± 1.35		64.72 ± 1.73	182.12 ± 4.44	574.80 ± 39.60
S6	55.40 ± 5.40	14.27 ± 1.99	146.74 ± 33.97	82.64 ± 17.65	496.09 ± 29.43		69.67 ± 7.39	146.74 ± 33.97	578.73 ± 47.08
S7	58.93 ± 8.43	20.33 ± 1.87	105.2 ± 6.28	403.86 ± 33.97	206.47 ± 45.53		79.26 ± 10.30	105.20 ± 6.26	610.33 ± 79.50
S8	270.61 ± 41.32	62.62 ± 5.43	65.07 ± 0.36	347.82 ± 26.05	10.55 ± 0.31	21.87 ± 2.05	355.10 ± 48.80	65.07 ± 0.36	358.37 ± 26.36
S9	166.09 ± 23.49	19.41 ± 0.22	738.76 ± 45.91	16.42 ± 2.35			185.5 ± 23.71	738.76 ± 45.91	16.42 ± 2.32
S10	43.41 ± 6.22	12.15 ± 0.44	517.20 ± 35.98	57.88 ± 3.90			55.56 ± 6.66	517.20 ± 35.98	57.88 ± 3.90
S11	55.02 ± 5.44	21.54 ± 3.00	137.05 ± 20.61	292.10 ± 11.36	25.28 ± 4.40		153.12 ± 8.44	137.05 ± 20.61	317.38 ± 15.76
S12	48.26 ± 6.30	12.38 ± 0.40	527.77 ± 55.51	317.05 ± 34.19			60.64 ± 6.70	527.79 ± 55.51	317.05 ± 34.19

Table 4 IC_{50} values for DPPH removal from vegetable oils

Types	Concentration/(mg/mL)	Rate of clearance/%	IC_{50}/(mg/mL)	Types	Concentration/(mg/mL)	Rate of clearance/%	IC_{50}/(mg/mL)
	0.5	39.67 ± 0.34			0.5	22.19 ± 2.81	
	5	90.57 ± 0.59			5	37.53 ± 0.61	
S8	10	92.59 ± 1.03	2.30	S3	10	49.77 ± 1.53	10.05
	20	95.18 ± 1.83			20	57.79 ± 3.33	
	40	96.58 ± 0.83			40	74.77 ± 1.65	
	0.5	9.64 ± 4.23			0.5	12.83 ± 2.82	
	5	50.99 ± 0.80			5	41.02 ± 2.12	
S4	10	57.91 ± 0.55	5.75	S6	10	48.89 ± 1.90	11.48
	20	77.19 ± 0.35			20	55.26 ± 0.71	
	40	93.02 ± 0.65			40	73.96 ± 1.75	
	0.5	8.28 ± 5.36			0.5	35.37 ± 5.21	
	5	47.78 ± 1.47			5	37.23 ± 4.04	
S11	10	51.67 ± 0.73	7.41	S9	10	46.25 ± 4.73	12.58
	20	61.31 ± 3.90			20	61.47 ± 4.39	
	40	76.14 ± 2.11			40	74.14 ± 1.90	
	0.5	23.21 ± 0.90			0.5	17.36 ± 2.91	
	5	48.13 ± 2.93			5	39.19 ± 1.37	
S1	10	49.49 ± 2.20	7.58	S12	10	42.96 ± 0.23	13.18
	20	59.27 ± 4.51			20	50.30 ± 0.63	
	40	76.14 ± 1.15			40	73.32 ± 1.39	
	0.5	12.26 ± 1.44			0.5	23.66 ± 2.22	
	5	46.82 ± 4.38			1	22.90 ± 1.51	
S2	10	51.02 ± 4.16	8.18	S7	5	24.91 ± 3.29	15.13
	20	65.27 ± 4.97			10	44.98 ± 4.04	
	40	76.36 ± 1.87			20	62.59 ± 3.03	
	0.5	29.67 ± 3.20			1	9.00 ± 0.65	
	5	34.08 ± 2.97			10	35.18 ± 2.08	
S5	10	52.69 ± 2.19	9.97	S10	20	50.01 ± 1.55	17.05
	20	67.45 ± 1.83			30	65.90 ± 2.71	
	40	79.96 ± 4.68			40	81.95 ± 0.59	

2.5 Analysis of antioxidant activity of vegetable oils

2.5.1 Analysis of DPPH-scavenging ability of vegetable oils

The DPPH radical scavenging ability of the various vegetable oils was tested and the IC_{50} values were calculated; the results are displayed in Table 4.

The smaller IC_{50} value indicates better DPPH scavenging ability. The DPPH scavenging ability of 12 vegetable oils was ranked by IC_{50} value as: S8＜S4＜S11＜S1＜S2＜S5＜S3＜S6＜S9＜S12＜S7＜S10. S8 had the best DPPH scavenging ability with a minimum IC_{50} value of 2.30 mg/mL, S10 had the worst DPPH scavenging effect with a maximum IC_{50} value of 17.05 mg/mL.

From the experimental results, it can be seen that the DPPH radical scavenging ability of vegetable oils has a relationship with unsaturated fatty acids, but there is no significant linear correlation. Combined

with the results of Liu et al[14], its antioxidant activity has a significant correlation with trace elements such as polyphenols, which may be one of the reasons why the content of S8 unsaturated fatty acids is not high but its antioxidant activity is the best among the 12 oils, and in-depth studies on the active composition and antioxidant activity of these vegetable oils will be carried out in the follow-up as well.

2.5.2 Analysis of oxidative stability of vegetable oils

The oxidation induction time of the 7 vegetable oils was measured under high temperature conditions and the results are shown in Fig.4. The longest oxidation induction time of 17.09 h was observed for S8, which has good oxidative stability and longer shelf-life, and is promising for applications such as food and cosmetics. The shorter oxidation induction times of S4, S6, S7, and S10 indicate that these four oils have poor oxidative stability and are susceptible to oxidative deterioration.

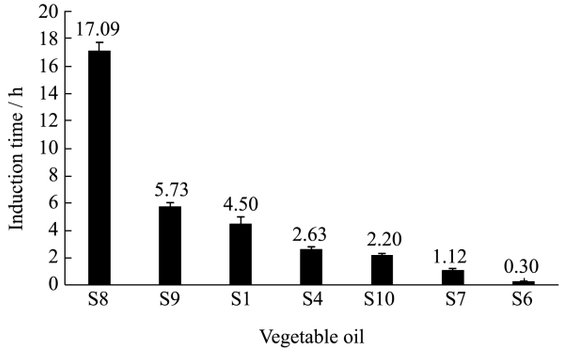

Fig.4 Oxidation induction time of 7 vegetable oils

Table 5 Correlation analysis between oxidation stability and UFAs content of 7 kinds of oils

	UFAs	Oxidative stability IC_{50}
Pearson correlation coefficient	1.00	−0.79*
Sig(Twin tails)		0.04
N	7	7

Notes: *$P < 0.05$.

SPSS data analysis showed that there was a significant linear correlation between the oxidation stability of vegetable oil and the content of UFAs (Table 5), and the higher the content of UFAs, the worse the oxidation stability, which is consistent with the results of Ma et al[18]. This result can show that the oxidative stability of fats and oils can be preliminarily judged according to their fatty acid content. Of course, the oxidative stability of vegetable oils is not only affected by their unsaturated fatty acids, but also by some trace components that have antioxidant effects.

3 Conclusions

A sensitive and reproducible GC-MS method was developed for the determination of the composition and content of FAs in 12 vegetable oils, and by comparing two vegetable oil methyl esterification methods, it was found that the BF_3 -CH_3OH methyl esterification method was more suitable as a derivatisation method for vegetable oil FAs.

Most of the small trade vegetable oils have their unique advantages in terms of fatty acid composition and antioxidant capacity, with high content of essential unsaturated fatty acids, which are of great value for consumption and health care.The ratio of LA and ALA in polyunsaturated fatty acids of *L. alba* seed oil, *J.* regia nut oil and *C. arabica* seed oil ranges from 3:1~10:1, which is good for inhibiting inflammation and preventing various chronic diseases. The content of UFAs in vegetable oil is directly related to its oxidation stability and antioxidant capacity. The lower the content of UFAs, the better the antioxidant capacity and oxidation stability. Among the 12 vegetable oils tested *C. arabica* seed oil showed the best antioxidant activity and oxidative stability, which has an important research value in the field of food and cosmetics for further in-depth study.

In conclusion, this study provides a good data basis and experimental scheme for further research on the nutritional function of vegetable oils, quality evaluation of functional vegetable oils, antioxidant capacity and shelf life of oils. Paving the way for the development of functional vegetable oils for commercial applications.

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