Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Influence of fatty acid composition and aroma components on the flavor of green onion (Allium fistulosum L.) deep-fried oil

Bing Liu
Beijing Technology & Business University (BTBU)
Ruifang Wang
Beijing Technology & Business University (BTBU)
Yuan Chang
Beijing Technology & Business University (BTBU)
Zixuan Liu
Beijing Technology & Business University (BTBU)
Shuqi Wang
Beijing Technology & Business University (BTBU)
Jie Sun
Beijing Technology & Business University (BTBU)
Haitao Chen
Beijing Technology & Business University (BTBU)
Baoguo Sun
Beijing Technology & Business University (BTBU)
Ning Zhang (zh_ningts@btbu.edu.cn)
Beijing Technology & Business University (BTBU)

Research Article

Keywords: Green onion (Allium fistulosum L.), deep-fried oil, aroma component, fatty acid, flavor

Posted Date: April 27th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1583551/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License

Abstract

This paper aimed to explore the effects of different varieties of oils on the volatile flavor compounds and fatty acid composition of green onion deep-fried oils, and establish the flavor fingerprints of different green onion deep-fried oils. The volatile flavor compounds and fatty acids in 7 kinds of green onion deep-fried oils were identified and analyzed by electronic nose and gas chromatography-mass spectrometry (GC-MS). The results showed that sensory evaluations and electronic nose were accepted to detect the odor differences of different kinds of green onion deep-fried oils sensitively. 103 volatile flavor components were identified positively by GC-MS, and the key aroma compounds including aldehydes and sulfur-containing compounds that correlated highly with green, grease, pungent and shallot scent attributes. The fatty acid detection showed that there was not significant change in the types of fatty acids, but the relative content is different evidently after frying process. The unsaturated fatty acids (UFA, C18:1, C18:2, C18:3, and C20:1) had a significant influence on the flavor of frying oil, which were peculiarly prone to oxidation and heat-degradability reaction. These results had a positive impact on the development of deep-fried oil products and technology to differentiate between true and false deep-fried oil.

1. Introduction

Fried allium oil has been used extensively in traditional Chinese dishes and recently has enjoyed popularity in the food manufacturing industry(Zhang et al. 2019). When preparing Chinese dishes, small amounts of those seasonings are commonly fried in vegetable oil before adding other ingredients(WU et al. 1982a). Conventionally, this procedure can obtain unique flavor at a relatively high frying temperature, among these allium spices, green onion (*Allium fistulosum* L.) is most commonly used during cooking for Chinese cuisine(Gao et al. 2020).

During frying process, desirable sensory properties of foods correlated to color, flavor, texture, and palatability were developed(Tian et al. 2021). Complex physical and chemical interactions between food ingredients and the oil medium can usually promote the formation of special flavor in fried food (Saguy and Dana 2003; Bansal et al. 2010; Zhang et al. 2018). Additionally, a range of chemical reactions were happened complicatedly between fat itself and the other ingredients in the matrix during frying process (Sahin and Gülüm Sumnu 2008; Zhang et al. 2012). This flavor is mainly determined by the oxidative degradation of fat and the Maillard reaction(Hemmler et al. 2018), and the browning reaction and degradation of amino acids also contributed to the generation of flavor compounds at high temperature(Zhang et al. 2016). The volatile flavor compounds identified among the deep-fried oil include alkanes, alcohols, aldehydes, ketones, acids, esters, lactones and heterocyclic compounds(Zhang et al. 2012; Nieva-Echevarría et al. 2016; ben Hammouda et al. 2017).

Although, there were not comprehensive reports on the flavor formation mechanism of green onion deep-fried oil, volatiles of other alliums generated during heating processes have been studied, and major components included sulfides, disulfides, trisulfide, thiophene, etc(WU et al. 1982b). The headspace solid-phase microextraction (HS-SPME) was used to analyze the volatiles of four fried shallot-flavored oils, and indicated that 2-ethyl-3,5-dimethyl-pyrazine, 2,3-dihydro-benzofuran, and benzaldehyde contribute to grease flavor, and 2-ethyl-3,5- dimethyl-pyrazinemay contribute to shallot scent flavor(Tian et al. 2020). Besides, a Trace GC–MS system equipped with static headspace was adopted to compare the quality of fried shallots from microwave heat and gas heat treatment, and found that sulfur-containing compounds, including disulfides, trisulfides, and thiophenes, played an important role in contributing to the flavor of fried shallots(WU et al. 1982b; Chu and Hsu 2001). Garlic oil processed by heating process has also been researched(Yu et al. 1993; Kim et al. 1995). Although volatiles varied when treated by different heating treatments or extraction methods, most of them were belonged to sulfur-containing compounds. Moreover, nitrogen-containing volatile compounds were also found as major contributors in baked and oil-treated garlic samples.

Herein, the aims of this study were to systematically investigate the volatile flavor compounds and fatty acid present in green onion (*Allium fistulosum* L.) deep-fried oil. The differentiations in flavor profile from 7 kinds of vegetable oils were compared, and the aspects including sensory evaluation, GC-MS, electronic nose and fatty acid compositions were taking into consideration. Besides, the effects of free fatty acid composition and content on flavor fingerprint of green onion deep-fried oil were analyzed preliminarily.

2. Materials And Methods

2.1 Materials and Chemicals

Fresh native green onion samples (*Allium fistulosum* L.) were purchased from a local market in Beijing, China. And stored in vacuum-packed bags at 4°C. The vegetable oils including soybean oil (Yuanbao), palm oil (Jinhai), olive oil (Olivoila), corn oil (Fulinmen), sunflower oil (Fulinmen), camellia oil (Jinlongyu) and colza oil (Changkang) samples were purchased from local supermarkets, and the botanical origin and quality of all the samples were guaranteed by the manufacturers. All the samples were produced in 2021 and stored at room temperature away from light before analysis.

Chemicals (analytical reagent grade, ≥ 95% purity) used in this study were as follows: standards of n-alkanes (C6–C30, ≥ 99%) were purchased from Sigma-Aldrich Co. (Shanghai, China), 1,2-dichlorobenzene (99%) and dichloromethane (HPLC grade) was purchased from Thermo Fisher Scientific Inc. (Shanghai, China).

2.2 Oil preparation process

Fresh green onion stalks were chosen for the experiment. The stalks were cut into sections approximately 1 cm long. A 12 ~ 18 cm diameter basin and an induction cooker were used for frying and an oil thermometer was used to measure the temperature. Through pre-experiment, preparation process of the green onion deep-fried oil was determined to gain a favorable flavor. The process conditions were as follows: vegetable oil (300 g) was added into the basin and was heated to 140°C. Green onion stalks were then added to the hot oil and fried until the oil reached the desired final temperature 165°C. The minimum temperature in this process was slightly lower than 100°C. The fried stalks and oil were immediately separated once the oil temperature reached 165°C, and the oil was cooled to room temperature as soon as possible. During this procedure, the mixture was stirred continuously to prevent local overheating. The

above procedure was repeated twice, and the final deep-fried oil sample was obtained after mixing. The same procedure was used for those different kinds of vegetable oils. The different kinds of vegetable oils prepared by same procedure and named S1 to S7, respectively.

2.3 Isolation of the volatiles by solvent-assisted flavor evaporation (SAFE)

For the oil samples, 50 g of oil together with extraction solvent (dichloromethane, m : v = 1 : 4) were mixed together for the SAFE procedure. Besides, 1,2-dichlorobenzene (50 µL, 0.236 µg/µL) was added as internal standard. The extracts were subjected to SAFE to remove any nonvolatile materials(Kreissl and Schieberle 2017). The procedure was conducted by connecting a compact to a distillation vessel to rapidly achieve a high yield of the volatiles from the solvent extracts. A high vacuum was applied to the apparatus to separate the volatiles away from the organic phase(Engel et al. 1999). After removal of the non-volatile compounds, the SAFE distillate was dried over anhydrous Na_2SO_4 and concentrated to 0.5 mL using a Vigreux column (50 cm × 1 cm; Beijing Jingxing Glassware Co., Ltd., China). Samples were prepared in triplicate and stored in 2 mL glass vials at − 80°C for GC-MS analysis.

2.4 Gas chromatography–mass spectrometry (GC–MS) analysis

GC-MS analysis was performed on an TRACE 1310 gas chromatograph (Thermo Fisher Scientific, Waltham, MA) equipped with an ISQ LT mass spectrometer (Thermo Fisher Scientific, Waltham, MA). Samples were analyzed with TG-Wax column (30 m × 0.25 mm i.d., 0.25 µm, Thermo Fisher Scientific, Waltham, MA). Helium was used as the carrier gas at a constant flow rate of 1.0 mL/min. The injector temperature was 250°C, and the injection volume was 1 µL. The sample was injected in a 1:5 split ratio. The oven temperature was programmed as follows: initial temperature 40°C and held for 1 min, then ramped at 2°C /min to 130°C and held for 1 min, and finally ramped at 10°C/min to 220°C and held for 8 min. MS conditions were set as follows: The electron ionization mode (EI) was used at 70 eV. The ion source temperature was kept at 250°C, and the mass range was operated in 35–350 with a solvent delay of 6 min for the samples.

2.5 Identification and quantification of the aroma compounds

Volatile compounds from the deep-fried vegetable oils were tentatively identified by GC-MS by comparing their mass spectra with spectra from the NIST 2014 data base. The homologous series standards of n-alkanes (C6 ~ C30) were analyzed under the same chromatographic conditions to calculate the retention index (RI) of the detected compounds, and compare them with the RI in the NIST 2014 database using the same capillary column(Mahattanatawee et al. 2018). Authentic compounds were used to confirm the identification of the volatile compounds(Liu et al. 2019). The results in the following Eq. (1) to calculate the RI of each compound:

$$RI = 100 \times \{n + [\lg t'(i) - \lg t'(n)] / [\lg t'(n+1) - \lg t'(n)]\} \quad (1)$$

where: (n) and (n + 1) represent the number of carbon atoms in the alkanes eluting before and after the compound, respectively, t'(n) and t'(n + 1) are the corresponding retention times of the alkanes, and t'(i) is the retention time of the compound to be identified (t'(n) < t'(i) < t'(n + 1)).

Relative concentrations of the aroma compounds were calculated by relating the peak areas of the volatiles to the peak area of the internal standard (1,2-dichlorobenzene). Content of each compound can be expressed in the Eq. (2).

$$w(i) = f'(i) \times [A(i)/A(s)] \times w(s) \quad (2)$$

where: w(i) represents the volatile compound to be detected; w(s) is the content of the internal standard; A(i) and A(s) are the peak areas of the volatile compound and the internal standard, respectively, on the GC system. The relative correction factor, f'(i), was considered to be 1.0 for each component here.

2.6 Electronic Nose Analysis

An electronic nose device PEN 3 E-Nose (Winmuster Airsense Analytic Inc., Schwerin, Germany) was used to identify the 7 kinds of green onion deep-fried oils. The sensor array system consisted 10 metal oxide semiconductors (MOS) of different chemical compositions and thicknesses to provide selectivity towards volatile compound classes, including W1C (aromatic compounds), W5S (broad-range compounds), W3C (ammonia, aromatic compounds), W6S (hydrogen), W5C (aromatic-aliphatic), W1S (methane, broad-range compounds), W1W (sulfur compounds), W2S (broad-alcohol compounds), W2W (sulfur-chlorine), and W3S (methane-aliphatic). The software Winmuster of the electronic nose was used for data storage and multivariate statistical processing.

7 g of deep-fried oil samples were put into 15 mL airtight vials (concentration chamber) respectively. The samples were prepared using an SCILOGEX BlueSpin LED digital hotplate magnetic stirrer (MS-H280-Pro, Berlin, CT, USA) (100 ± 2°C) for 30 min, and then, one Luer-lock needle (20 g) connected to a Teflon-tubing (3 mm) was used to perforate the seal (plastic) of the vial and absorb the volatile gases inside it. Clean air to replace the sampled air was furnished through a second needle connected to a charcoal filter. During the measurement time (60 s), the sampling unit inhaled the volatile gases present in the headspace at a constant rate causing changes in the sensor's conductance, which was long enough for the sensor signals to reach a steady value. When a measurement was completed, a standby of 500 s was initiated with the circuit, and the chamber was flushed by clean air until the sensor signals returned to baseline. The E-Nose analysis was performed at least three times for each oil sample.

2.7 Determination of the fatty acids contents

Fatty acid methyl esters (FAME) were prepared from total oils and the isolated fractions of deep-fried oils according to the standard method of GB/T 17376 − 2008 & GB/T 17377 − 2008. The contents of the fatty acid methyl ester in each sample were quantified by the heptadecanoic acid methyl ester served as internal standard. The temperature program and the parameters of GC-MS system was referred to the research(Morrison and Smith 1964; Feng et al. 2014).

2.8 Sensory Analysis

A descriptive sensory analysis was carried out in a sensory room with single cubicles at (20 ± 1) °C and relative humidity profile. And the aroma profile analysis was conducted by a panel consisting of ten panelists (6 females and 4 males, age: 23 to 30 years) from the Beijing Key Laboratory of Flavor Chemistry at Beijing Technology and Business University. They were trained for descriptive analysis and had a lot of experience in sensory profiling of diverse food samples. 10 g sample was put into a transparent PET bottle (30 mL), and the samples were randomly arranged. The panelists were requested to write down and discuss the odor attributes of deep-fried oil samples. They determined the final list of 7 descriptive terms by consensus. The odor attributes of salty, fried, oily, burnt, cooked vegetable, green grass and pungent were evaluated. A descriptive sensory analysis was performed along a scoring line ranging from 0 (not perceivable) to 9 (strongly perceivable) in duplicate for each sample. The final score for each odor attribute was the average from all panelists.

2.9 Statistical analysis

The statistical analyses were performed using XLSTAT v. 2018 (Addinsoft, New York, NY). And one-way analysis of variance (ANOVA) was made to determine the differences of each deep-fried oil samples. Principal component analysis (PCA) was used to study the possible grouping of the deep-fried oil and its corresponding properties. Besides, analysis of partial least squares regression (PLS) was used to show the relationship between aroma sensory variables and volatile compounds considered as aroma-contributing substance.

3. Results And Discussion

3.1 Sensory analysis of deep-fried oils

To obtain the idea of the overall flavor of the deep-fried vegetable oils, a descriptive aroma analysis was carried out. The consequence can be used to compare the accuracy of the instrumental analyses and sensory evaluations. The analysis provided the flavor profile of the analyzed products, and the strongest intensity was noted for fried note, followed by salty, oily, burnt, cooked vegetables, green grass and pungent. Besides, they exhibited approximately flavor characteristics after frying at a relatively higher temperature. In the light of the overall score, the deep-fried soybean oil (S1) presented a better flavor profile.

PCA analysis (Figure. 1) was applied to the sensory scores, and the first two principal components (PC1 and PC2) explained 72.81% of the total variance, while PC1 (47.50%) got a much better explanation for the samples than PC2 (25.31%). The PCA results differentiated two groups. The first group was formed by soybean oil (S1), palm oil (S2) and corn oil (S4), and distributed in the positive side of PC1. These deep-fried oils were correlated to the sensory attributes of salty, fried, cooked vegetables, pungent and green grass. The second group was formed by olive oil (S3), sunflower oil (S5), camellia oil (S6) and colza oil (S7), and located in the negative side of PC1. They were related to the sensory attributes of oily and burnt. In general, the sensory evaluation of the deep-fried oil presented that a good flavor characteristic could be created by frying, and a significant role was played by the sensory evaluation in contrasting the differences of flavor.

3.2 Volatile compound analysis of deep-fried oils

A comparative analysis of volatile compounds was carried out among green onion deep-fried oils from the 7 kinds of vegetable oils by SAFE-GC-MS, and the corresponding results were showed in Table. 1. A total of 103 volatiles were identified by comparing the retention indices and mass spectrum information with previously reference, including the following 25 aldehydes, 20 alcohols, 4 nitrogen-containing compounds, 15 sulfur-containing compounds, 21 ketones, 3 furans, 5 acids, and 10 other compounds. This indicated that the frying process had a significant effect on the flavor characteristics of vegetable oils.

All the volatile flavor compounds of the 7 kinds of green onion deep-fried oils were quantitated in terms of the internal standards by a semi quantitative method, and presented in the heat map (Figure. 2). Clearly, the content of volatile flavor compounds in the colza deep-fried oil (S7) were higher than the others, and the flavor and fragrance was richer and better. The results showed that the most abundant aroma compounds in the deep-fried oils were (*E*)-2-heptenal (A30), dimethyl trisulfide (A34), furfural (A44), pyranone (A93), 5-hydroxymethylfurfural (A96), but the other specific compounds were different. Aldehydes and sulfur-containing compounds, such as (E)-2-hexenal (A18), (E,E)-2,4-heptadienal (A46), dimethyl disulfide (A1), and dimethyl trisulfide (A34) were the most prominent compounds in the extracts of the green onion soybean deep-fried oil (S1), and 5-methyl-2-furancarboxaldehyde (A61), nonanal (A35), methyl 1-propenyl disulfide (A26), (E)-1-methyl-3-(prop-1-en-1-yl) trisulfane (A63) were the most prominent compounds in the extracts of the green onion palm deep-fried oil (S2), and (E,E)-2,4-decadienal (A76), (E)-2-nonenal (A53), 2-undecenal (A71) were the most prominent compounds in the extracts of the green onion camellia deep-fried oil (S6). Besides, the major volatile compounds of the deep-fried soybean oil (S1) were 3,4-dimethyl-thiophene (A24), hexanal (A2), 2-pentyl-furan (A21), methyl propyl disulfide (A20), (*E*)-2-hexenal (A18), hexanoic acid (A81), limonene (A14), 1-allyl-2-isopropyldisulfane (A39), (E)-2-heptenal (A30), 2,4-dimethyl-cyclohexanol (A55), pentyl-oxirane (A7), *β*-myrcene (A9), 2-heptanone (A11), linalool (A56), linalyl acetate (A58), etc. In general, the volatile compounds of the 7 kinds of vegetable oils changed significantly after frying.

3.3 Electronic nose of green onion deep-fried oils

To screen the effective volatile compounds contributing to the aroma attributes of the 7 kinds of green onion deep-fried oils, the correlations between the chemical classes of volatile compounds and the intensities of the electronic nose were analyzed by PLS(Shiota et al. 2015; Xu et al. 2019). The data were standardized before the analysis and the PLS results showed in Figure. 3. The results indicate that most of the X variables (relative abundance of the chemical classes of volatile compounds) and Y variables (intensities of the electronic nose) are located within the ellipse (r^2 = 100%, r^2 represents the degree of interpretation)(Pu et al. 2019). A reliable model (Q^2 = 0.89 ≥ 0.50) was devised for the intensities of electronic nose and the species of deep-fried oil using all the volatile compounds data(Mimura et al. 2014). The plot (explaining 74.0% of the total variance) suggested a correlation between the chemical classes of volatile compounds and the intensities of the electronic nose, and their species of the deep-fried oils analyzed. And the results (Figure. 3) showed that palm oil

(S2), corn oil (S4) and sunflower oil (S5) were positioned in the first quadrant, camellia oil (S6) was placed in the second quadrant, olive oil (S3) and colza oil (S7) were distributed in the third quadrant while soybean oil (S1) was located in the fourth quadrant.

Additionally, chemical groups of volatile compounds and electronic nose sensors were highly correlated and associated to the deep-fried oils. In terms of the electronic nose sensors, Figure. 3 showed positive correlations between deep-fried oil samples and the sensors. In general, Sensor 1 (W1C, aromatic compounds), sensor 3 (W3C, ammonia compounds) and sensor 5 (W5C, aromatic-aliphatic) were related to palm oil (S2) and corn oil (S4), sensor 10 (W3S, methane-aliphatic), sensor 4 (W6S, hydrogen), sensor 8 (W2S, broad-alcohol compounds) and sensor 6 (W1S, methane compounds) were correlated to olive oil (S3) and colza oil (S7). Besides, sensor 2 (W5S, broad-range compounds), sensor 7 (W1W, sulfur compounds) and sensor 9 (W2W, sulfur-chlorine) were closely associated to soybean oil (S1), which agreed with the volatile compound analysis and sensory evaluation results.

In addition, the flavor fingerprints could be established to differentiate the different kinds of green onion deep-fried oils by the electronic nose and GC-MS analysis results. For example, the most important attributes to the flavor of soybean oil (S1) were the sulfur-containing components and aldehydes, included 3,4-dimethyl-thiophene (A24), dimethyl trisulfide (A34), methyl propyl disulfide (A20), and (E)-2-heptenal (A30), etc. The noteworthy components of the flavor of colza oil (S7) were aldehydes, furan and furanones, included (*E,E*)-2,4-heptadienal (A46), 5-hydroxymethylfurfural (A96), furyl hydroxymethyl ketone (A87), and 3,5-dihydroxy-2-methyl-4H-pyran-4-one (A94), etc. Generally, the electronic nose was effective for executant to differentiate the different kinds of deep-fried oil or the true and false deep-fried oil.

3.4 fatty acids of green onion deep-fried oils

To go a further insight into the constitutes of the deep-fried oils, variations of saturated fatty acids (SFA), unsaturated fatty acids (UFA), monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA) were tested and analyzed in the 7 kinds of green onion deep-fried oils (Figure. 4).

According to Figure. 4, the deep-fried oils whose contents of SFA increased after frying included soybean oil (S1), palm oil (S2), olive oil (S3), corn oil (S4), and camellia oil (S6). Among them, the deep-fried palm oil (S2) increased the most. On the contrary, the oils whose contents of SFA decreased after frying included sunflower oil (S5) and colza oil (S7). For the UFA, the contents of soybean oil (S1), olive oil (S3), corn oil (S4), and camellia oil (S6) were increased after frying and the palm oil (S2), sunflower oil (S5), and colza oil (S7) were decreased clearly. Specifically, the deep-fried oilve oil (S3) whose contents of UFA increased the most. For the MUFA and PUFA, the deep-fried oils whose contents of MUFA increased after frying, included soybean oil (S1), olive oil (S3), corn oil (S4), and camellia oil (S6), and the deep-fried olive oil (S3) increased the most. And the oils with incremental contents of PUFA slightly consisted of soybean oil (S1), palm oil (S2), olive oil (S3), corn oil (S4) and camellia oil (S6). Conversely, the oils with descending contents of MUFA and PUFA were sunflower oil (S5) and colza oil (S7). Significantly, the reason of the total amount of UFA of the deep-fried palm oil (S2) decreased was that the decrease of MUFA was significantly higher than the increase of PUFA after frying.

Contrast Analysis of the results of volatile flavor compounds and fatty acids, the noteworthy composition of fatty acids in frying oil impacted the flavor of deep-fried oil products. Among them, UFA (such as oleic acid, linoleic acid, arachidonic acid, etc.) were prone to oxidation due to their double bonds, which resulting in the formation of peroxides(Dobarganes and Márquez-Ruiz 2007). These peroxides are further decomposed to form volatile carbonyl compounds such as ketones, aldehydes, acids, and so on, and resulting in the characteristic flavor profile(Perkins 2007). Fatty acids containing hydroxyl groups are dehydrated and cycled to form lactones with pleasant aroma(Chen et al. 2004). Besides, products from thermal degradation continue to react with proteins and amino acids in the matrix to obtain heterocyclic compounds with special aroma(Mahanta et al. 2021). Above all, linoleic acid and oleic acid were the two unsaturated fatty acids with the highest contents in this research, and which had an important influence in forming note of fried and note of oily in the flavor profile of the deep-fried oils.

4. Conclusions

In summary, the volatile flavor compounds of 7 kinds of green onion deep-fried oils were successfully determined and differentiated using SAFE-GC-MS and electronic nose. Likewise, the correlation between the composition of fatty acid and specific flavor of the deep-fried oils was discussed. The frying craft substantially affected the flavor of vegetable oils, and the electronic nose could be sensitive to detect the subtle differences of 7 kinds of green onion deep-fried oils odor. A total of 103 volatile compounds were identified, including alkanes, aldehydes, alcohols, ketones, acids, esters, furan and furanones, sulfur-containing compounds, and nitrogen-containing compounds. Of these, aldehydes and sulfur-containing compounds were highly correlated with the flavor characteristic of the deep-fried oils, such as (E,E)-2,4-decadienal, (E)-2-heptenal, hexanal, dimethyl trisulfide, methyl propenyl disulfide, etc. There was an obvious correlation between the electronic nose sensor data and the key aroma compounds, and it was feasible to establish the flavor fingerprints of different kinds of green onion deep-fried oils. The fatty acid composition and relative content of deep-fried oils were closely related to the types of vegetable oil, and identified especially according to the changes in UFA content. The determination of fatty acid content results showed that the changes of vegetable oils mainly concentrated on MUFA and PUFA obviously, such as C18:1, C18:2, C18:3, and C20:1, and the oxidation and heat-degradability of UFA was promoted to produce a series of delightful flavor compounds at high temperature. It is crystal clear that the content changes of UFA had a significant effect on the flavor characteristics of green onion deep-fried oil. This study is an important basis for future research to probe into the influencing factors of flavor and the quality control of green onion deep-fried oil products during frying process.

Declarations

Acknowledgements We are greatly thankful to our preceptor N Zhang and H-T Chen for their contribution to this work. We also thank the staff of Beijing Key Laboratory of Flavor Chemistry for technical assistance during the course of this work.

Competing Interests: The authors declare no conflict of interest and competing interests.

Availability of data and material: The datasets used during the current study are available from the corresponding author on reasonable request.

Ethics approval: This article does not contain any studies with human participants or animals performed by any of the authors.

Author contributions: B Liu designed the experiments and collected the data with the help of R-F Wang, Y Chang, Z-X Liu, and S-Q Wang. All the authors participated in the analysis and interpretation of the data. B Liu wrote the manuscript draft and revised it according to the feedback of J Sun, H-T Chen, B-G Sun and N Zhang. All authors have read and agreed to the published version of the manuscript.

Funding: This work was financially supported by the National Natural Science Foundation of China (No. 31901620).

References

1. Bansal G, Zhou W, Barlow PJ, et al (2010) Review of rapid tests available for measuring the quality changes in frying oils and comparison with standard methods. Crit Rev Food Sci Nutr. https://doi.org/10.1080/10408390802544611
2. ben Hammouda I, Freitas F, Ammar S, et al (2017) Comparison and characterization of volatile compounds as markers of oils stability during frying by HS–SPME-GC/MS and Chemometric analysis. J Chromatogr B Anal Technol Biomed Life Sci. https://doi.org/10.1016/j.jchromb.2017.10.063
3. Chen S, Bobe G, Zimmerman S, et al (2004) Physical and sensory properties of dairy products from cows with various milk fatty acid compositions. J Agric Food Chem. https://doi.org/10.1021/jf035193z
4. Chu YH, Hsu HF (2001) Comparative studies of different heat treatments on quality of fried shallots and their frying oils. Food Chem. https://doi.org/10.1016/S0308-8146(01)00180-7
5. Dobarganes MC, Márquez-Ruiz G (2007) Formation and Analysis of Oxidized Monomeric, Dimeric, and Higher Oligomeric Triglycerides. In: Deep Frying: Chemistry, Nutrition, and Practical Applications: Second Edition
6. Engel W, Bahr W, Schieberle P (1999) Solvent assisted flavour evaporation - A new and versatile technique for the careful and direct isolation of aroma compounds from complex food matrices. Eur Food Res Technol. https://doi.org/10.1007/s002170050486
7. Feng Y, Chen Z, Liu N, et al (2014) Changes in fatty acid composition and lipid profile during koji fermentation and their relationships with soy sauce flavour. Food Chem. https://doi.org/10.1016/j.foodchem.2014.02.147
8. Gao S, Liu XN, Liu Y, et al (2020) Response characteristics of green onion (Allium fistulosum L.) to LED light quality under artificial climate chamber. Sci Agric Sin. https://doi.org/10.3864/j.issn.0578-1752.2020.14.015
9. Hemmler D, Roullier-Gall C, Marshall JW, et al (2018) Insights into the Chemistry of Non-Enzymatic Browning Reactions in Different Ribose-Amino Acid Model Systems. Sci Rep. https://doi.org/10.1038/s41598-018-34335-5
10. Kim SM, Wu CM, Kobayashi A, et al (1995) Volatile Compounds in Stir-Fried Garlic. J Agric Food Chem. https://doi.org/10.1021/jf00059a033
11. Kreissl J, Schieberle P (2017) Characterization of Aroma-Active Compounds in Italian Tomatoes with Emphasis on New Odorants. J Agric Food Chem. https://doi.org/10.1021/acs.jafc.7b01108
12. Liu H, Wang Z, Zhang D, et al (2019) Characterization of Key Aroma Compounds in Beijing Roasted Duck by Gas Chromatography-Olfactometry-Mass Spectrometry, Odor-Activity Values, and Aroma-Recombination Experiments. J Agric Food Chem. https://doi.org/10.1021/acs.jafc.9b01564
13. Mahanta BP, Bora PK, Kemprai P, et al (2021) Thermolabile essential oils, aromas and flavours: Degradation pathways, effect of thermal processing and alteration of sensory quality. Food Res. Int.
14. Mahattanatawee K, Luanphaisarnnont T, Rouseff R (2018) Comparison of Aroma Character Impact Volatiles of Thummong Leaves (Litsea petiolata Hook. f.), Mangdana Water Beetle (Lethocerus indicus), and a Commercial Product as Flavoring Agents in Thai Traditional Cooking. J Agric Food Chem. https://doi.org/10.1021/acs.jafc.7b01499
15. Mimura N, Isogai A, Iwashita K, et al (2014) Gas chromatography/mass spectrometry based component profiling and quality prediction for Japanese sake. J Biosci Bioeng. https://doi.org/10.1016/j.jbiosc.2014.04.006
16. Morrison WR, Smith LM (1964) Preparation of fatty acid methyl esters and dimethylacetals from lipids with boron fluoride–methanol. J Lipid Res. https://doi.org/10.1016/s0022-2275(20)40190-7
17. Nieva-Echevarría B, Goicoechea E, Manzanos MJ, Guillén MD (2016) The influence of frying technique, cooking oil and fish species on the changes occurring in fish lipids and oil during shallow-frying, studied by 1H NMR. Food Res Int. https://doi.org/10.1016/j.foodres.2016.03.033
18. Perkins EG (2007) Volatile Odor and Flavor Components Formed in Deep Frying. In: Deep Frying: Chemistry, Nutrition, and Practical Applications: Second Edition
19. Pu D, Zhang H, Zhang Y, et al (2019) Characterization of the oral breakdown, sensory properties, and volatile release during mastication of white bread. Food Chem. https://doi.org/10.1016/j.foodchem.2019.125003
20. Saguy IS, Dana D (2003) Integrated approach to deep fat frying: Engineering, nutrition, health and consumer aspects. In: Journal of Food Engineering
21. Sahin S, Gülüm Sumnu S (2008) Advances in deep-fat frying of foods
22. Shiota M, Iwasawa A, Suzuki-Iwashima A, Iida F (2015) Effects of flavor and texture on the sensory perception of gouda-type cheese varieties during ripening using multivariate analysis. J Food Sci. https://doi.org/10.1111/1750-3841.13135
23. Tian P, Zhan P, Tian H, et al (2021) Analysis of volatile compound changes in fried shallot (Allium cepa L. var. aggregatum) oil at different frying temperatures by GC–MS, OAV, and multivariate analysis. Food Chem. https://doi.org/10.1016/j.foodchem.2020.128748

24. Tian P, Zhan P, Tian H, et al (2020) Effects of different vegetable oils on the aroma characteristics of deep-fried shallot flavoring evaluated by HS-SPME/GC-MS coupled with PLSR. J Food Process Preserv. https://doi.org/10.1111/jfpp.14698
25. WU JL, CHOU CC, CHEN MH, WU CM (1982a) Volatile Flavor Compounds from Shallots. J Food Sci 47:606–608. https://doi.org/10.1111/j.1365-2621.1982.tb10133.x
26. WU JL, CHOU CC, CHEN MH, WU CM (1982b) Volatile Flavor Compounds from Shallots. J Food Sci. https://doi.org/10.1111/j.1365-2621.1982.tb10133.x
27. Xu L, Li X, Huang J, et al (2019) Rapid Measuring Flavor Quality Changes of Frying Rapeseed Oils using a Flash Gas Chromatography Electronic Nose. Eur J Lipid Sci Technol. https://doi.org/10.1002/ejlt.201800260
28. Yu TH, Wu CM, Ho CT (1993) Volatile Compounds of Deep-Oil Fried, Microwave-Heated, and Oven-Baked Garlic Slices. J Agric Food Chem. https://doi.org/10.1021/jf00029a023
29. Zhang N, Sun B, Mao X, et al (2019) Flavor formation in frying process of green onion (Allium fistulosum L.) deep-fried oil. Food Res Int 121:296–306. https://doi.org/10.1016/j.foodres.2019.03.006
30. Zhang Q, Saleh ASM, Chen J, Shen Q (2012) Chemical alterations taken place during deep-fat frying based on certain reaction products: A review. Chem. Phys. Lipids
31. Zhang Q, Wan C, Wang C, et al (2018) Evaluation of the non-aldehyde volatile compounds formed during deep-fat frying process. Food Chem. https://doi.org/10.1016/j.foodchem.2017.09.121
32. Zhang WN, Zhang HL, Lu CQ, et al (2016) A new kinetic model of ultrasound-assisted extraction of polysaccharides from Chinese chive. Food Chem. https://doi.org/10.1016/j.foodchem.2016.05.144

Tables

Table 1. Comparative analysis of volatile compounds in the 7 kinds of green onion deep-fried oils.

No.	Compound name	Cas #	Concentration (μg/kg) [a]					
			soybean oil	palm oil	olive oil	corn oil	sunflower oil	camellia o
A1	Dimethyl disulfide	624-92-0	241.99±47.52	107.96±4.65	139.04±22.07	78.58±2.34	66.73±6.03	63.52±7.8
A2	Hexanal	66-25-1	697.71±96.14	97.87±0.95	436.75±80.36	115.33±6.94	265.05±24.58	173.89±22
A3	2-Methyl-2-butenal	1115-11-3	31.43±4.46	17.39±2.93	32.01±7.76	28.69±2.87	21.76±3.97	17.38±2.1
A4	4-Pentenal	2100-17-6	nd [c]	nd	nd	nd	nd	nd
A5	3-Methyl-thiophene	616-44-4	10.16±2.08	4.01±0.21	7.19±1.44	4.21±0.09	21.76±3.97	3.51±0.49
A6	(*E*)-2-Pentenal	1576-87-0	60.89±8.61	6.32±0.47	27.22±8.99	5.68±0.14	3.83±0.47	8.22±1.33
A7	Pentyl-oxirane	5063-65-0	12.64±1.31	nd	nd	nd	nd	nd
A8	1-Penten-3-ol	616-25-1	95.75±17.48	11.6±1.19	64.64±2.33	9.96±0.18	8.49±0.92	15.3±1.14
A9	*β*-Myrcene	123-35-3	9.31±0.9	nd	nd	nd	nd	nd
A10	3-Penten-2-ol	1569-50-2	803.38±149.17	576.45±41.85	923.16±169.27	708.55±49.59	687.3±92.12	540.74±48
A11	2-Heptanone	110-43-0	44.59±3.89	nd	nd	nd	nd	nd
A12	Heptanal	111-71-7	48.89±4.23	18.28±0.32	65.82±7.38	12.59±0.92	22.63±1.33	54.94±3.9
A13	2,4-Dimethyl-thiophene	638-00-6	18.63±3.28	10.6±0.68	18.71±3.29	12.44±0.57	14.78±2.86	9.75±0.88
A14	Limonene	138-86-3	69.36±5.8	14.7±0.19	23.37±3.26	7.7±0.51	6.91±0.21	9.01±0.56
A15	3-Methyl-2-butenal	107-86-8	62.24±11.58	50.03±17.49	67.03±11.17	42.62±3.91	36.78±2.9	38.95±8.4
A16	2,3-Dimethyl-2-butanol	594-60-5	45.49±9.29	38.41±5.6	66.95±15.6	36.48±3.53	37.36±5.89	35.06±8.0
No.	Compound name	Cas #	Concentration (μg/kg) [a]					
			soybean oil	palm oil	olive oil	corn oil	sunflower oil	camellia o
A17	3-Hexen-2-one	763-93-9	7.32±1.49	nd	nd	nd	nd	nd
A18	(*E*)-2-Hexenal	6728-26-3	94.49±12.99	18.49±0.65	48.75±9.92	29.48±0.36	41.3±4.21	30.18±3.2
A19	4-Octanone	589-63-9	nd	nd	nd	nd	nd	2.75±0.28
A20	Methyl propyl disulfide	2179-60-4	49.86±7.97	44.88±4.04	52.24±6.38	28.29±1.05	33.96±4.74	33.13±5.7
A21	2-Pentyl-furan	3777-69-3	108.33±6.03	25.31±1.22	82.88±10.17	33.87±1.25	65.28±6.65	40.22±4.8
A22	3-Hydroxy-3-methyl-2-butanone	115-22-0	29.58±3.17	19.49±1.7	34.49±7.09	19.68±0.55	22.52±2.16	18.93±1.7
A23	1-Pentanol	71-41-0	57.44±5.01	21.36±1.43	36.74±2.73	12.96±0.86	32.48±2.35	62.54±3.5
A24	3,4-Dimethyl-thiophene	632-15-5	246.79±28.99	153.56±10.09	241.91±29.62	172.47±10.74	187.96±13.1	155.25±11
A25	(*E*)-1-Methyl-2-(prop-1-en-1-yl)disulfane	23838-19-9	247.81±31.82	145.04±6.56	206.8±31.53	129.3±2.77	119.86±9.58	94.65±11.9
A26	Methyl 1-propenyl disulfide	5905-47-5	983.84±131.68	687.34±21.95	899.81±118.97	650.15±21.91	661.94±54.55	514.91±46
A27	Octanal	124-	37.25±1.49	18.31±5.41	68.17±2.66	9.09±3.51	8.31±2.86	79.72±1.6

		13-0						
A28	2-Heptanol	543-49-7	60.79±6.61	62.03±6.14	77.07±13.76	52.23±2.48	61.4±2.73	47.86±2.4
A29	Prenol	556-82-1	23.94±2.7	19.14±0.88	32.7±5.37	21.42±0.32	20.99±2.34	20.15±3.6
A30	(*E*)-2-Heptenal	18829-55-5	1275.27±112.83	148.22±10.43	388.62±31.43	295.99±8.47	570.6±23.15	360.89±18
A31	2,3-Octanedione	585-25-1	209.26±6	nd	nd	nd	nd	17.46±1.8
A32	1,4-Pentadien-3-ol	922-65-6	15.1±0.88	20.03±0.74	25.12±1.99	17.55±1.45	17.23±1.98	19.18±1.8
A33	2-Cyclopenten-1-one	930-30-3	29.88±2.53	19±2.05	32.08±1.67	21.9±1.6	23.72±0.97	23.2±1.04
A34	Dimethyl trisulfide	3658-80-8	983.34±86.74	790.9±7.05	855.51±93.78	640.16±15.39	628.49±31.57	569.62±37
A35	Nonanal	124-19-6	159.07±13.95	294.15±27.81	634.53±25.84	101.19±10.28	124.88±3.31	833±36.99
A36	Isoxazole	288-14-2	58.39±6.19	28.21±2.97	39.73±4.15	27.95±2.48	29.72±1.55	13.89±1.9
A37	Propyl sulfide	111-47-7	174.8±24.33	185.82±2.09	252.26±30.53	156.88±7.22	121.84±12.52	48.58±15.3
A38	(*E*)-2-Octenal	2548-87-0	205.92±6.35	66.32±2.37	179.61±5.98	66.63±5.32	110.59±3.39	192.08±9.4
A39	1-Allyl-2-isopropyldisulfane	67421-85-6	75.01±0.67	65.68±1.54	76.56±8.64	51.45±3.21	58.96±2.23	71.14±1.9
A40	1-Octen-3-ol	3391-86-4	238.57±1.02	43.34±1.57	80.36±0.95	84.81±6.38	166.37±4.79	103.28±6.4
A41	Methional	3268-49-3	25.65±6.12	nd	40.43±12.6	11.82±3.97	13.82±2.43	nd
A42	1-Heptanol	111-70-6	nd	nd	nd	nd	nd	38.75±7.5
A43	Acetic acid	64-19-7	101.22±16.23	70.35±7.87	nd	50.46±24.39	41.52±19.6	88.57±12.0
A44	Furfural	98-01-1	1897.96±249.09	1103.1±28.87	1685.38±314.83	1029.43±42.3	1197.84±112.87	1099.88±7
A45	2-Ethyl-1-hexanol	104-76-7	13.83±0.19	14.5±4.67	14.64±2.44	12.24±0.47	15.09±0.65	13.89±2.2
A46	(*E,E*)-2,4-Heptadienal	4313-03-5	578.21±10.94	54.57±1.28	191.56±4.32	46.94±4.1	8.83±0.33	151.51±7.4
A47	1-(Ethylthio)-2-methyl-1-propene	27482-14-0	31.43±4.05	36.1±0.97	34.12±7.31	35.13±2.26	24.26±2.86	12.37±6.8
A48	1-(2-Furanyl)-ethanone	1192-62-7	203.08±17.33	196.44±2.58	245.85±22.63	147.46±8.5	183.15±6.2	203.22±8.8
A49	3-Nonen-2-one	14309-57-0	32.16±4.99	26.27±3.16	30.12±4.86	17.33±3.59	28.88±3.02	45.56±4.1
A50	3-Methoxy-1-butanol	2517-43-3	39.71±1.55	38.98±0.99	35.98±13.39	39.78±1.91	36.63±6.25	42.34±4.9
A51	3,5-Octadien-2-one	38284-27-4	nd	nd	nd	nd	nd	nd
A52	Methyl propyl trisulfide	17619-36-2	77.71±4.3	92.75±3.08	94.03±5.56	68.61±5.64	13.08±1.98	71.21±5.9
A53	(*E*)-2-Nonenal	18829-56-6	19.56±2.16	15.18±0.42	39.35±5.84	12.94±1.47	22.81±3.11	127.67±10
A54	4-Ethylcyclohexanol	4534-74-1	74.89±17.22	nd	nd	35.27±6.09	75.22±10.22	42.24±3.7
A55	2,4-Dimethyl-cyclohexanol	69542-91-2	82.07±3.02	10.76±0.68	47.42±4.5	25.98±2.39	48.35±3.7	26.63±4.2
A56	Linalool	78-70-6	18.63±2.61	nd	nd	nd	nd	nd

A57	2-Pyridinecarboxaldehyde	1121-60-4	nd	11.88±3.59	16.3±3.63	6.68±2.94	nd	nd
A58	Linalyl acetate	115-95-7	51.95±13.89	nd	nd	nd	nd	nd
A59	1-Octanol	111-87-5	nd	nd	63.64±4.5	nd	nd	79.52±8.7
A60	Dimethyl sulfoxide	67-68-5	79.37±2.23	61.53±0.94	63.77±19.7	62.15±10.12	56.56±3.97	68.65±4.8
A61	5-Methyl-2-furancarboxaldehyde	620-02-0	433.16±16.5	601.08±17.05	587.71±41.34	370.12±29.01	473.5±5.92	644.35±22
A62	4-Cyclopentene-1,3-dione	930-60-9	73.67±0.83	70.67±14.38	63.34±16.59	56.02±3.61	62.54±3.91	56.2±13.2
A63	Butyrolactone	96-48-0	15.58±2.23	30.38±1.78	28.42±2.15	21.24±3.08	25.15±1.61	18.58±0.3
No.	Compound name	Cas #	Concentration (μg/kg) [a]					
			soybean oil	palm oil	olive oil	corn oil	sunflower oil	camellia o
A64	(*E*)-1-Methyl-3-(prop-1-en-1-yl)trisulfane	23838-25-7	621.9±72.03	634.74±40.89	462.56±46.64	529.91±74.19	532.18±25.16	497.15±28
A65	Benzeneacetaldehyde	122-78-1	642.02±34.9	892.03±56.84	920.11±45.81	948.68±62.97	624.12±15.97	1030.56±7
A66	2-Furanmethanol	98-00-0	415.36±40.24	376.09±15.64	423.39±51.9	311.61±17.46	370.04±26.66	416.17±31
A67	3-Methyl-1H-pyrazole	1453-58-3	nd	nd	nd	nd	nd	17.73±2.1
A68	5-Ethyldihydro-2(3H)-furanone	695-06-7	71.39±16.12	nd	nd	nd	nd	nd
A69	(*E*,*E*)-2,4-Nonadienal	5910-87-2	14.83±3.23	5.48±0.36	23.6±2.6	10.94±3.25	17.28±0.92	39.01±6.4
A70	5-Methyl-2-furanmethanol	3857-25-8	121.24±20.22	95.5±9.32	123.03±44.15	91.08±8.19	110.71±22.4	74.5±14.3
A71	2-Undecenal	2463-77-6	57.82±3.37	79.14±1.81	131.86±8.07	53.12±10.62	53.82±3.83	277.22±37
A72	2,4-Decadienal	2363-88-4	414.19±50.89	320.12±16.75	324.24±40.1	203.17±24.76	567.46±25.52	770±94.11
A73	2-Hydroxy-2-cyclopenten-1-one	10493-98-8	46.56±2.16	55.86±5.63	51.15±3.22	47.9±4.3	37.54±0.2	58.74±2.2
A74	1-(2-Butoxyethoxy)-ethanol	54446-78-5	108.94±15.84	95.49±28.26	192.47±62.22	95.28±9.24	73.22±9.9	76.97±14.5
A75	1,3-Butadiene-1-carboxylic acid	626-99-3	nd	nd	nd	nd	35.44±1.46	nd
A76	(*E*,*E*)-2,4-Decadienal	25152-84-5	750.94±79.66	589.93±34.1	600.26±73.53	433.43±46.73	1002.09±25.2	1414.77±1
A77	3-Methyl-1,2-cyclopentanedione	765-70-8	18.03±0.91	29±2.4	21.01±2.96	20.2±1.24	17.98±0.6	29.73±3.1
A78	2-(Ethylthio)-ethanol	110-77-0	89.1±2.83	79.25±3.51	83.02±5.22	70.57±10.08	63.59±0.74	65.88±5.0
A79	5,6-Dihydro-2H-pyran-2-one	3393-45-1	12.78±2.77	14.71±1.22	19.83±4.88	11.44±2.92	11.78±3	25.38±6.9
A80	3-(2-Furanyl)-2-propenal	623-30-3	nd	nd	nd	nd	nd	7.71±2.44
A81	Hexanoic acid	142-62-1	293.68±40.49	71.91±11.63	143.26±14.63	41.85±9.57	33.22±2.58	59.55±2.4
A82	Dihydro-5-pentyl-2(3H)-furanone	104-61-0	nd	nd	nd	nd	nd	11±1.23
A83	2-Propenamide	79-06-1	15.44±2.74	18.09±1.47	nd	11.82±0.12	10.55±0.91	13.49±0.5
A84	1-(1H-Pyrrol-2-yl)-ethanone	1072-83-9	274±39.15	366.65±11.97	338.54±23.55	299.06±43.52	409.82±119.15	421.81±59

A85	S-Methyl methanethiosulphonate	2949-92-0	111.4±36.92	89.18±15.52	69.05±13.06	52.5±14.43	63±6.01	88.45±16.
A86	2,5-Furandicarboxaldehyde	823-82-5	33.42±7.46	40.55±3.95	42.24±4.32	32.8±7.22	32.68±4.5	92.04±16.
No.	Compound name	Cas #	Concentration (μg/kg) [a]					
			soybean oil	palm oil	olive oil	corn oil	sunflower oil	camellia o
A87	Furyl hydroxymethyl ketone	17678-19-2	270.79±36.17	408.53±23	346.17±35.71	289.25±48.46	316.33±19.01	542.79±82
A88	1H-Pyrrole-2-carboxaldehyde	1003-29-8	16.16±3.16	23.96±2.1	20.87±3.19	20.6±4.18	21.47±6.31	24.49±3.5
A89	Furaneol	3658-77-3	21.49±5.95	21.23±2.85	13.01±4.27	24.92±3.63	26.83±4.07	23.7±5.95
A90	5-Methyl-1H-pyrrole-2-carboxaldehyde	1192-79-6	28.01±4.03	43.89±3.56	37.79±3.12	29.84±2.42	36.15±2.35	43.47±15.
A91	Nonanoic acid	112-05-0	nd	nd	nd	nd	36.44±13.5	107.34±23
A92	5-Acetoxymethyl-2-furaldehyde	10551-58-3	11.84±5.34	15.48±5.61	24.15±8.84	13.6±3.83	13.52±2.54	30.41±7.8
A93	Pyranone	28564-83-2	1353.16±353.41	1175.05±144.23	830±167.92	1334.23±86.09	1006.09±517.03	1066.88±2
A94	3,5-Dihydroxy-2-methyl-4H-pyran-4-one	1073-96-7	211.34±87.82	310.31±48.35	92.78±88.34	1684.56±258.29	751.88±267.35	1461.29±3
A95	(S)-(+)-2',3'-Dideoxyribonolactone	32780-06-6	33.7±7.05	50.23±5.99	30.74±14.35	43.73±5.9	42.96±5.2	74.15±11.
A96	5-Hydroxymethylfurfural	67-47-0	2824.54±118.56	2782.52±170.58	2823.73±236.2	3296.32±420.13	2972.4±185.56	3305.51±2
A97	1,2-Benzenedicarboxylic acid, bis(2-methylpropyl) ester	84-69-5	39.38±22.62	22.29±2.66	30.85±8.08	26.32±2.31	27.73±3.57	19.35±0.9
A98	3-Thiopheneethanol	13781-67-4	43.84±9.17	44.94±3.54	25.56±9.65	55.29±6.34	49.18±4.31	42.76±10.
A99	Dihydro-4-hydroxy-2(3H)-furanone	5469-16-9	nd	25.8±5.27	nd	20.95±0.93	17.11±1.28	38.16±1.7
A100	Benzyl benzoate	120-51-4	21.51±3.88	20.29±0.59	23.25±6.42	25.03±5.15	24.65±7.1	16.98±2.6
A101	Dibutyl phthalate	84-74-2	36.17±8.49	33.72±3.04	45.04±7.54	40.68±3.76	41.91±10.97	32.92±1.9
A102	Ethyl N-(o-anisyl)formimidate	15296-48-7	72.77±16.75	134.66±19.75	119.68±34.37	97.33±13.96	92.36±9.33	156.85±24
A103	n-Hexadecanoic acid	57-10-3	56.63±14.17	100.85±35.67	81.9±19.06	61.39±12.02	103.79±33.98	63.33±6.6

[a] The content of compounds was calculated by the internal standard quantitatively, and the data were the “mean standard deviation”.

[b] The retention indices of compounds on the TG-Wax column calculated against the GC-MS retention time of n-alkanes (C_6 - C_{30}). “Exp”: experimentally-measured on the TG-Wax. “Lit”: published retention index.
[c] Nd: non detected.

Figures

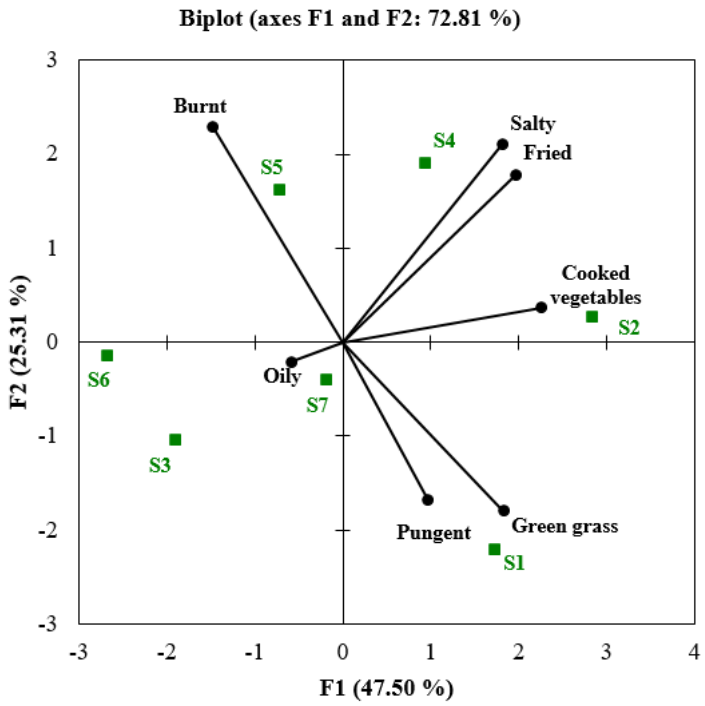

Figure 1

PCA of the deep-fried oils on the sensory evaluations of deep-fried oils. (S1: soybean oil; S2: palm oil; S3: olive oil; S4: corn oil; S5: sunflower oil; S6: camellia oil; S7: colza oil.).

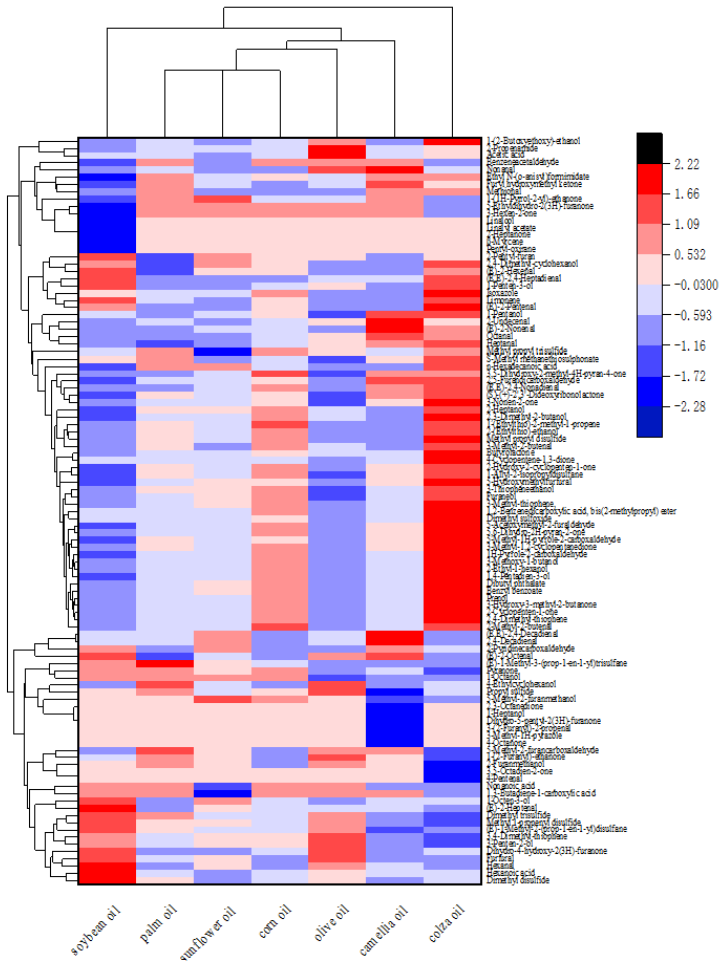

Figure 2

Heat map analysis of volatile flavor compounds in the 7 kinds of green onion deep-fried oils.

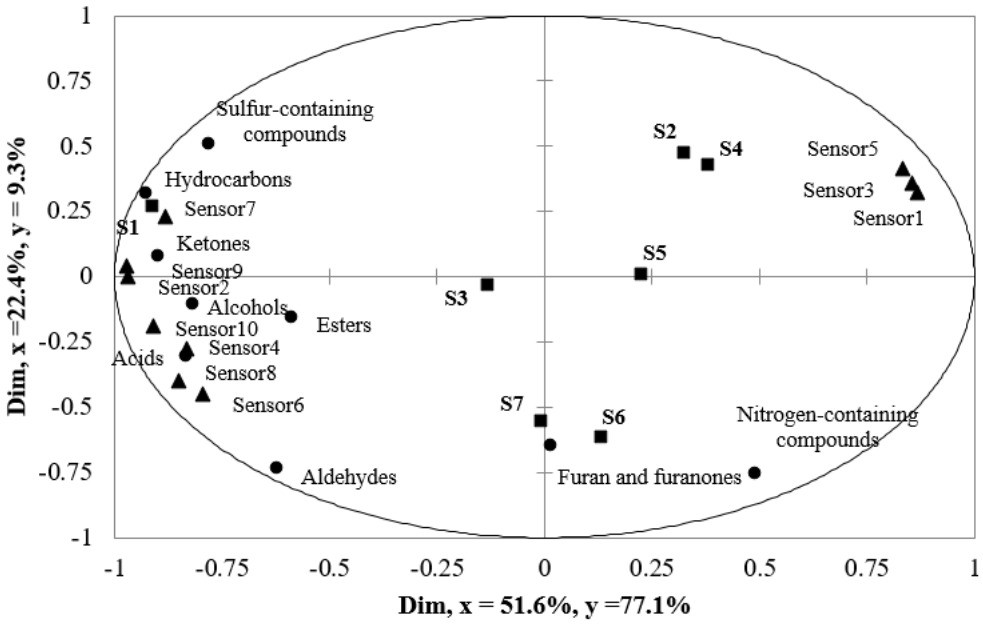

Figure 3

PLS for explaining the relationship between chemical groups of volatile compounds and electronic nose sensors in the green onion deep-fried oils. (S1: soybean oil, S2: palm oil, S3: olive oil, S4: corn oil, S5: sunflower oil, S6: camellia oil, S7: colza oil; Sensor 1–10 pointed to sensors of W1C, W5S, W3C, W6S, W5C, W1S, W1W, W2S, W2W and W3S consequently)

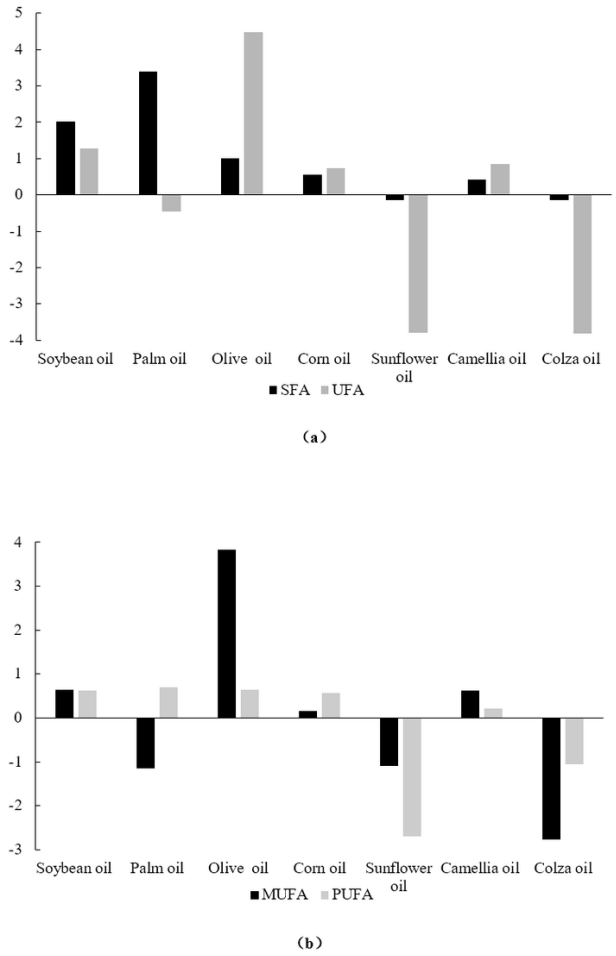

Figure 4

Changes of fatty acids in deep-fried oils after frying. (a: variations of saturated fatty acid (SFA) and unsaturated fatty acid (UFA); b: variations of monounsaturated fatty acid (MUFA) and polyunsaturated fatty acid (PUFA))