Analytical Methods to Evaluate the Quality of Edible Fats and Oils: The JOCS Standard Methods for Analysis of Fats, Oils and Related Materials (2013) and Advanced Methods

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Abstract: Edible fats and oils are among the basic components of the human diet, along with carbohydrates and proteins, and they are the source of high energy and essential fatty acids such as linoleic and linolenic acids. Edible fats and oils are used in for pan- and deep-frying, and in salad dressing, mayonnaise and processed foods such as chocolates and cream. The physical and chemical properties of edible fats and oils can affect the quality of oil foods and hence must be evaluated in detail. The physical characteristics of edible fats and oils include color, specific gravity, refractive index, melting point, congeal point, smoke point, flash point, fire point, and viscosity, while the chemical characteristics include acid value, saponification value, iodine value, fatty acid composition, trans isomers, triacylglycerol composition, unsaponifiable matters (sterols, tocopherols) and minor components (phospholipids, chlorophyll pigments, glycidyl fatty acid esters). Peroxide value, $p$-anisidine value, carbonyl value, polar compounds and polymerized triacylglycerols are indexes of the deterioration of edible fats and oils. This review describes the analytical methods to evaluate the quality of edible fats and oils, especially the Standard Methods for Analysis of Fats, Oils and Related Materials edited by Japan Oil Chemists’ Society (the JOCS standard methods) and advanced methods.

Key words: analytical methods, edible fats and oils, quality, standard method

1 Introduction

Edible fats and oils are among the basic components of the human diet, along with carbohydrates and proteins. Edible oils mainly include vegetable oils such as soybean, canola, palm, and corn oils, etc., while fish oils such as sardine and tuna oils are often supplemented to processed foods. Fats and oils are the source of high energy (9 kcal/g) and essential fatty acids such as linoleic (18:2), linolenic acid (18:3), EPA (20:5) and DHA (22:6) to human. Edible fats and oils are used in for pan- and deep-frying, and in salad dressing, mayonnaise and processed foods such as chocolates, cream and bakery products. The physical and chemical properties of fats and oils can affect the sensory attributes and nutritional quality of foods. Melting and congeal points, viscosity and consistency of edible fats and oils are responsible for the hardness and softness of food products, while the color and cloud point may affect the appearance of the food products. On the other hand, chemical characteristics such as saponification and iodine values based on the fatty acid composition can affect the stability of fats and oils during heat cooking and storage. Minor components such as sterols and tocopherols contained in vegetable oils can affect the nutritional value of products and their oxidative stability. Chlorophyll pigments and phospholipids may also affect the appearance and oxidative stability of edible fats and oils. Among the minor components, toxic metals and other harmful chemicals should not be present in edible fats and oils. Moreover, thermal deterioration of fats and oils due to oxidation, cyclization, polymerization and hydrolysis occurs during heat cooking, although pan- and deep-frying process impart the desirable flavor and taste to foods. Various low- and/or
high-molecular weight chemicals are formed during heat cooking. Particularly, by-products harmful to human health, such as hydroperoxides and polymers are formed during frying, which reduce the nutritional value of fats and oils. Moreover, some volatile low-molecular weight compounds with functional groups (aldehydes, ketones and alcohols) may impart undesirable flavor. Fats and oils in oil foods are also susceptible to auto- and photo-oxidation reactions during storage, and the products may lead to undesirable flavor and taste. Thus, it is very important to evaluate the degree of deterioration in fats and oils during heat cooking and storage to ensure and maintain the quality of the food products. Some internationally known standard methods are used to evaluate the quality of edible fats and oils such as the AOCS official methods\(^1\), IUPAC standard methods\(^2\) and Standard Methods for Analysis of Fats, Oils and Related Materials published by Japan Oil Chemists’ Society (named as the JOCS standard methods)\(^3\). This review describes the analytical methods to evaluate the quality of edible fats and oils, especially the JOCS standard methods and advanced methods.

2 Physical characteristics\(^1\)-\(^6\)

A list of physical characteristics of edible fats and oils described in the JOCS standard methods is shown in Table 1. The physical characteristics of edible fats and oils include color\((2.2.1)\), specific gravity\((2.2.2)\), refractive index\((2.2.3)\), melting point\((2.2.4)\), congeal point\((2.2.5)\), smoke point, flash point, fire point\((2.2.11)\), and viscosity\((2.2.10)\). Solid fat content\((2.2.9)\) and consistency\((2.2.15)\) are measured for processed oils such as margarine and shortening. Moreover, cold test\((2.2.8)\) is carried out for salad oil.

Generally vegetable oils are transparent and have a yellowish or greenish color due to the presence of carotenoids and chlorophyll pigments. Color is usually estimated by the Lovibond spectrophotometric colorimeter. The specific gravity, refractive index, melting point and fatty acid composition of major vegetable oils are shown in Table 2. The specific gravity of edible fats and oils such as corn, olive and soybean oils are in the range of 0.90-0.92 at 25°C, although palm oil and the related oil had slightly lower specific gravity\((0.89-0.90)\) at 25°C. The refractive index is in the range of 1.44-1.47, and it depends on the fats and oils variety. Palm oil has a refractive index of 1.44-1.45, while other vegetable oils have a refractive index of 1.47 at 25°C.

The melting point of vegetable oils depends on the fatty acid composition, as shown in Table 2. Olive and rapeseed oils rich in oleic acid\((18:1)\) have melting points \(\geq 0\)°C, while corn and soybean oils rich in linoleic acid\((18:2)\) have melting points \(\leq 0\)°C. Palm oil and coconut oil, which are rich in saturated fatty acids, especially palmitic acid\((16:0)\) have higher melting points. The viscosity of edible fats and oils is measured using the Brookfield method. The kine-

| Analysis                              | JOCS Standard Methods | Factor                           |
|---------------------------------------|-----------------------|----------------------------------|
| Color                                 | 2.2.1                 | Pigment                          |
| Specific gravity                      | 2.2.2                 |                                  |
| Refractive index                      | 2.2.3                 | Fatty acid (unsaturation)        |
| Melting point                         | 2.2.4                 | Fatty acid                       |
| Congeal point                         | 2.2.5                 | Fatty acid                       |
| Cold test                             | 2.2.8                 | Wax                              |
| Solid Fat content                     | 2.2.9                 | Saturated fatty acid             |
| Viscosity                             | 2.2.10                | Fatty acid, Polymer              |
| Smoke point, Flash point              | 2.2.11                | Fatty acid                       |
| Fire point                            |                       |                                  |
| Consistency                           | 2.2.15                | Saturated fatty acid             |

| Vegetable oil | Specific gravity (25°C) | Refractive index (25°C) | Melting point (°C) | Saponification value | Iodine value | Fatty acid composition (%) | 16:0 | 18:0 | 18:1 | 18:2 | 18:3 |
|---------------|-------------------------|-------------------------|--------------------|----------------------|-------------|-----------------------------|------|------|------|------|------|
| Corn          | 0.920-0.928             | 1.473-1.476             | -18 to -10         | 187-198              | 88-147      | 11                          | 2    | 33   | 52   | 1    |      |
| Olive         | 0.914-0.929             | 1.465-1.468             | 0 to -0            | 185-197              | 75-90       | 10                          | 3    | 73   | 11   | <1   |      |
| Palm          | 0.921-0.948             | 1.453-1.459             | 27 to 50           | 196-210              | 43-60       | 43                          | 5    | 41   | 10   |      |      |
| Soybean       | 0.922-0.934             | 1.472-1.475             | -7 to -8           | 188-196              | 114-138     | 10                          | 4    | 24   | 54   | 8    |      |

See Ref. 6
matic viscosity of edible fats and oils ranges from 6 to 10 mPa·s at 210°F (98.9°C). In addition, viscosity is an index used to determine the extent of oxidation and thermal deterioration of oils, because deteriorated oils have high viscosity due to polymers formation. Smoke point, flash point and fire point are often measured with a Cleveland open-cup tester. The flash point of vegetable oils is almost 320°C in regardless of the variety. However, the smoke point depends on the types of edible fats and oils.

The solid fat content in processed oil and cacao fat is measured by the nuclear magnetic resonance (NMR) spectroscopy⁷. Consistency is often measured to determine the rheological properties of processed oils such as margarine and shortening.

### 3 Chemical characteristics⁸⁻¹⁰

A list of chemical characteristics of edible fats and oils cited in the JOCS standard methods is given in Table 3. The chemical characteristics of edible fats and oils include acid value, saponification value, iodine value, fatty acid composition, trans isomers, triacylglycerol composition, unsaponifiable matter, sterols, tocopherols, phospholipids, chlorophyll pigments, and glycidyl fatty acid esters.

Acid value (AV) is a measure of the concentration of free fatty acids in fats and oils. AV is determined by the titration method based on the neutralization reaction with potassium hydroxide in ethanol solution. AV is an index for the purification of fats and oils, and a value ≤ 0.1 is desirable for refined edible fats and oils. Saponification value (SV) and iodine value (IV) are determined by the fatty acid composition of edible fats and oils, as shown in Table 2. Both SV and IV are measured by the titration methods. For measuring the SV, edible fats and oils are refluxed together with known quantity of potassium hydroxide in ethanol solution, and then the unreacted potassium hydroxide is titrated against standard hydrochloric acid. SV means the average molecular weight of triacylglycerols. A higher SV is a measure of low-molecular weight triacylglycerols of edible fats and oils. Most vegetable oils such as corn, olive, rapeseed and soybean oils have an SV of about 190, whereas the SV of palm oil and coconut oil, rich in palmitic acid (16:0), myristic acid (14:0) and lauric acid (12:0) is more than 200. IV is based on the extent of unsaturation of fatty acids located in triacylglycerol. When a constant amount of iodine solution is added to edible fats and oils, addition of the iodine molecule to the double bonds occurs on the acyl chain in triacylglycerols. The residual iodine is titrated with standard sodium thiosulfate to a starch endpoint. IV is an effective index for characterizing vegetable and fish oils. Olive oil, which is rich in monounsaturated fatty acids (18:1), has an IV ranging from 75 to 90, while soybean and corn oils rich in polyunsaturated fatty acids (18:2) have IV in the range of 120-140. Both SV and IV of vegetable oils can also be estimated from their fatty acid composition obtained by gas liquid chromatography (GLC)⁹,¹⁰.

Fatty acid composition is a useful parameter to distinguish between different edible fats and oils. The fatty acid composition of edible fats and oils is estimated by GLC with a flame ionization detector (FID) and a capillary column after derivatization from fatty acids in triacylglycerols to the corresponding methyl esters.

The trans isomers of unsaturated fatty acids in edible fats and oils are also quantified by GLC using a capillary column¹¹. Hardened oil and hydrogenated oil such as margarine and shortening may contain considerable amounts of trans fatty acids. The presence of trans fatty acids in edible fats and oils has raised concerns among consumers as they may increase the LDL-cholesterol levels in blood. The infrared (IR) spectrum of trans fatty acids shows in IR peak at 966 cm⁻¹¹².

![Table 3 Chemical characteristics of edible fats and oils.](image-url)
The triacylglycerol composition may affect the physical properties such as melting and freezing properties and the crystalline structure of edible fats and oils. Triacylglycerol moieties are determined by high-performance liquid chromatography (HPLC). They are separated using the C18 (ODS), C22 or C30 reversed phase column and detected with a refractive index detector (Fig. 1).

Most edible fats and oils contain minor components, especially unsaponifiable matters containing sterols and tocopherols, along with triacylglycerols. Sterols are quantified by GLC with FID after saponification of edible fats and oils. The major sterol in vegetable oils is β-sitosterol, whereas in animal fats such as lard and beef tallow is cholesterol. Tocopherols are determined by HPLC with a fluorescence detector. Tocopherols in vegetable oils include α-, β-, γ- and δ-isomers. The tocopherol composition depends on the types of vegetable oils. Palm oil and rice bran oil have tocotrienols in addition to tocopherols.

Crude oils sometimes contain phospholipids. The phospholipid values are reported as phosphorus contents, which are estimated colorimetrically by the reaction between phosphorus and ammonium molybdate.

Some of the vegetable oils are rich in chlorophyll pigments, mainly pheophytins a and b and pyropheophytins a and b. Olive oil and rapeseed oils often contain considerable amounts of chlorophyll pigments that may induce photosensitized oxidation of unsaturated fatty acids. Chlorophyll pigments are measured by HPLC with a UV or fluorescence detector.

Recently, glycidyl fatty acid esters have been found as undesirable minor components in palm oil and some processed oils rich in di- and mono-acylglycerols. Glycidol may be carcinogenic to humans, although there is no conclusive evidence as yet. Glycidyl fatty acid esters may be the by-products of mono- and di-acylglycerols under high-temperature refining conditions, such as the deodorization process of edible fats and oil. These esters are quantified by direct and indirect methods. In the JOCS standard methods, glycidyl fatty acid methyl esters are determined by HPLC coupled with mass spectrometry (MS).

Butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) are sometime added as synthetic antioxidants to enhance the stability of edible fats and oils. Both BHA and BHT are measured by GLC after reflux extraction. Undesirable and toxic metals such as lead, cadmium, and arsenic are detected by atomic absorption spectrometry.

4 Methods to determine the extent of deterioration

The most common methods used to determine the extent of oxidation and thermal deterioration of edible fats and oils are cited in the JOCS Standard Methods, as described in Table 4. The detailed procedure to analyze the oxidation products of fats and oils are also discussed in other books and reviews.

Methods to determine the oxidative stability of edible fats and oils include the active oxygen method (AOM) and conductometric determination method (CDM). Fats and oils are exposed to accelerated oxidation in both stability tests. In the case of AOM, fats and oils are heated in a special glass test tube at 98.8 ± 0.2°C, and air is bubbled through the heated liquid at a rate of 2.3 mL/min. Samples are periodically collected.

| Analysis                        | JOCS Standard Methods | Method               | Index        |
|---------------------------------|-----------------------|----------------------|--------------|
| Fat stability (AOM)             | 2.5.1.1                | Titrations           | Stability    |
| Peroxide stability (CDM)        | 2.5.1.2                | Conductivity         | Stability    |
| Peroxide value (PV)             | 2.5.2                  | Titrations, Potentiometric | Hydroperoxide |
| p-Anisidine value (p-AnV)       | 2.5.3                  | Colorimetric         | Carboxyls (aldehyde, ketone) |
| Carbonyl value (CV)             | 2.4.4                  | Colorimetric         | Carboxyls (aldehyde, ketone) |
| Polar compounds                 | 2.5.5                  | Column chromatography | Non-triacylglycerol |
| Polymerized triacylglycerols    | 2.5.7                  | HPLC                 | Polymer      |

![Fig. 1](Triacylglycerol composition of rapeseed oil. P, 16:0; S, 18:0; O, 18:1; L, 18:2; Ln, 18:3.)
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and their peroxide value (PV) is measured. The induction period is described as the time required to attain 100 meq/kg of PV. The CDM\(^2\) also uses the special apparatus. In this experiment, 3 g of the fats and oils sample is heated in a glass container at 120 °C, and air is bubbled through the liquid at a rate of 20 L/h. This air eluate from the glass container is trapped in 50 mL deionized water and the conductivity is measured. The induction period in conductivity measurements is described as the time at which the inflection point occurs, as the conductivity is increased by the presence of volatile low-molecular weight compounds such as free fatty acids, alcohols and carboxyls.

The methods to determine the extent of oxidation and thermal deterioration of edible fats and oils include measurement of PV (2.5.2), \(p\)-anisidine value (2.5.3) and carbonyl value (2.5.4), as well as the amount of polar compounds (2.5.5) and polymerized triacylglycerols (2.5.7).

PV is the most popular index of the oxidation of oils. Titration\(^2\) and potentiometric\(^2\) methods are used to measure the PV. The principle underlying both methods is the oxidation-reduction reaction of hydroperoxides with potassium iodide. Accordingly, potassium iodide is added to the sample oils, and the liberated iodine is titrated with standard sodium thiosulfate. PV is useful in evaluating the initial step of oxidation of edible fats and oils in Japan, the permissible limit for PV is 30 meq/kg for fats and oils in instant noodles and confectionery. However, the determination of PV is not applicable for heated oils used for deep- and pan-frying, because hydroperoxides are rapidly decomposed at temperature ≥ 100°C.

\(p\)-Anisidine value (\(p\)-AnV)\(^2\) and carbonyl value (CV)\(^2\) describes the total amount of carbonyl compounds, which are the secondary oxidation products of edible fats and oils. When carbonyl compounds such as aldehydes and ketones produced from hydroperoxides by the oxidation of fats and oils are reacted with \(p\)-anisidine in isoctane solution, colored compounds formed: these are measured spectrophotometrically at 350 nm. \(p\)-AnV is defined as the absorbance of the resultant solution when the reaction is complete, and is given by the following equation.

\[
p-\text{AnV} = \frac{25(A-B)}{C}
\]

where \(A\) is the absorbance of the solution resulting after the reaction is complete, \(B\) is the absorbance of sample oil in isoctane solution, and \(C\) is the weight of sample oil in 25 mL isoctane solution.

However, \(p\)-AnV does not always show the accurate carbonyl compounds contents, because \(p\)-anisidine is sensitive only to alkenal and alkadienal compounds but not alkanal compounds in the aldehyde series.

In CV\(^2\), studies, the total carbonyl compounds can be determined by the reaction with 2,4-dinitrophenylhydrazine, and the colored hydrazone derivatives are measured spectrophotometrically at 420 nm. CV is estimated as the corresponding amount of 2-decenal per gram of oil (µmol/g). Both AnV and CV are effective tools to evaluate the quality of frying oil. In Japan, the permissible limit is CV 50 by the benzene method (corresponding to CV 75 by the butanol method) for frying oils.

When edible fats and oils are heated for deep- and pan-frying, several kinds of decomposition compounds are produced. Free fatty acids and \(d\)- and mono-acylglycerols produced by the hydrolysis of triacylglycerols, and hydroxy- and o xo-fatty acids and polymerized compounds produced by the thermal oxidation are all polar compounds. Polar compounds are measured by column chromatography using silicic acid\(^2\). When sample oils are loaded on the silicic acid column and developed with a mixture of \(n\)-hexane and diethyl ether (87:13, v/v) as the mobile phase, only unoxidized triacylglycerols are eluted and then weighed. The polar compounds content is defined as follows.

\[
Polar \, compounds(\%) = \frac{100 \times (A-B)}{A}
\]

where \(A\) is the weight of loaded sample oil (g) and \(B\) is the weight of unoxidized triacylglycerols (g).

The permissible limit of polar compounds is 24-27% for frying oil in Europe. Thin layer chromatography with FID is useful to quantify polar compounds in oils\(^2\). This method also uses a mixture of \(n\)-hexane and diethyl ether (87:13, v/v) as the mobile phase. It allows for the direct determination of polar compounds, because these compounds are observed at positions below triacylglycerol on the chromatogram. Recently, a portable digital edible oil-tester to estimate polar compounds by measuring the dielectric constant has been used for frying oil.

Polymerized triacylglycerols are often produced during deep frying with edible fats and oils. These triacylglycerols are measured by the gel permeation chromatography\(^2\). Sample oils are injected into gel permeation column, and then developed with tetrahydrofuran. Polymerized and unoxidized triacylglycerols are monitored with a refractive index detector. Polymerized triacylglycerols are eluted prior to unoxidized triacylglycerols. Polymerized triacylglycerols in oils are defined as follows.

\[
Polymerized \, triacylglycerols(\%) = \frac{100 \times C}{\Sigma B}
\]

where \(\Sigma B\) is the total areas on the chromatogram and \(C\) is the area of polymerized triacylglycerols on the chromatogram.

The permissible limit of polymerized triacylglycerols in frying oils is 10-16% in Europe.

5 Sensory characteristics

Sensory evaluation is often conducted to evaluate the quality of foods containing edible fats and oils. Humans are
very sensitive to taste and smell, and the sensory attributes not only depend on the panel reports but are also influenced by external factors, such as the room temperature, lightning in the room, and number of samples. In addition to the results from experienced panel members, standardization of score and expression are required to obtain accurate results. Hence, the instrumental analysis has been used instead of sensory evaluation.

GLC is often used to evaluate the sensory characteristics and extent of oxidation in edible fats and oils. GLC is capable of determining volatile compounds, which are responsible for imparting flavor in fats and oils. GLC methods for volatile compounds include the statistic headspace method, dynamic headspace method and direct injection method. The statistic method consists of 4 steps: 1) measuring and sealing a sample into a suitable container or vial, 2) heating to vaporize the components at a given temperature, 3) injecting an aliquot of the headspace gas directly into the gas chromatographic column, and 4) separating the volatile compounds on capillary column by temperature programming and FID or MS detection. This is such simple and rapid technique that it is suitable for routine analyses in succession, even though its sensitivity is low. Figure 2 shows the gas chromatogram of volatile compounds from oxidized and unoxidized rice bran oils. Recently, the solid phase microextraction (SPME) method using dimethylpolysiloxane as the solid phase is popular because of its high sensitivity.

Dynamic headspace method is also called “purge-and-trap” method, and it is more elaborate than the static headspace method. Volatile compounds are trapped in a short column containing porous polymer (Tenax or Porapaq) or charcoal and purged with nitrogen or helium gas and then desorbed from the trap at elevated temperature into the capillary inlet of the gas chromatograph.

However, the types and quantities of volatile compounds from sample oils depend on the trap variety.

Another method is the direct injection method where the sample oil is directly transferred into the gas chromatograph apparatus.

Recently, “electronic noses” using sensor arrays and pattern recognition systems that can detect and recognize odors and flavors have been developed, and used to classify different types of edible oils and evaluate the extent of deterioration of oils and oil foods.

6 Non-destructive analytical methods

Spectrophotometric methods such as IR, near-infrared (NIR), and terahertz (THz) spectrophotometry as well as NMR are often used as non-destructive methods.

The titration method is generally used to determine the SV and IV of edible fats and oils; however, it is difficult to obtain reliable results, because skilled analysts are required and it takes more than 1 h to complete a sample evaluation. The SV and IV of vegetable oils can be calculated by the fatty acid composition estimated by GLC. However, the GLC method is time consuming and involves methylation pretreatment. Moreover, the GLC method cannot be used for fish oils because their fatty acid composition is highly complex.

NIR spectroscopy can scan the absorbance or reflectance of molecules at the region between 800 and 2500 nm. This has become a well-accepted method for evaluating the quality of food-related bio-organic materials because it does not require toxic organic solvent and involves rapid measurement. Some researchers have applied the NIR spectroscopy for the differentiation and determination of edible fats and oils. This technique is also useful to de-
determine the IV and SV of vegetable\textsuperscript{42} and fish\textsuperscript{43} oils (Figs. 3 and 4). NIR spectra of edible fats and oils are generally measured using a glass vial at a constant temperature (usually 40°C). SV and IV are calibrated using the spectral data over the region of 7560-9100 cm\textsuperscript{-1} and statistical method of partial least squares regression. NIR spectroscopy is also capable of determining free fatty acids, trans fatty acids and oxidation products such as hydroperoxides, carbonyl compounds and polar compounds in edible fats and oils, although their sensitivity is low. Free fatty acids\textsuperscript{44,45} are determined at 1882, 2010 and 2040 nm based on the C = O overtone, while hydroperoxides (PV)\textsuperscript{46} are determined at 1460-1480 nm and 2080 nm. Recently, the THz spectroscopy that can scan the region between 10 and 400 cm\textsuperscript{-1} has been developed and applied to food components such as sugars\textsuperscript{47}, amino acids\textsuperscript{48}, and drugs\textsuperscript{49}. Our group\textsuperscript{50} applied THz spectroscopy to evaluate the quality of edible fats and oils. Therefore, THz spectroscopy is capable of determining SV and polymerized compounds of vegetable and fish oils at 77 and 328 cm\textsuperscript{-1}(Figs. 5-8).

\textsuperscript{1}H and \textsuperscript{13}C NMR spectroscopy are also non-destructive quantitative methods useful to monitor the oxidation and thermal degradation of vegetable oils and to distinguish between different types of vegetable oils\textsuperscript{51,52}. High resolution \textsuperscript{1}H NMR is capable of providing information on the unsaturation of fatty acids located at glycerol and phytoster-ols\textsuperscript{53}. \textsuperscript{1}H NMR spectra of fats and oils are scanned in the range of -4 ppm and 8 ppm in a deuterated chloroform solution. It takes usually a few minutes to obtain an NMR spectrum. Thus, \textsuperscript{1}H NMR spectroscopy is a rapid and convenient method to distinguish between the various types of edible fats and oils. \textsuperscript{13}C NMR spectroscopy can also determine 2-acyl positional fatty acid distribution in vegetable oil\textsuperscript{54}, whereas \textsuperscript{1}H NMR spectroscopy can determine n-3 polyunsaturated fatty acids such as DHA in fish oils\textsuperscript{55}. Moreover, \textsuperscript{1}H NMR can detect oxidation products such as hydroperoxides and aldehydes (alkanal, alkenal, alkadai-
enal)\textsuperscript{56,57}. \textsuperscript{1}H NMR is also effective in investigating the oxidation mechanism of edible fats and oils during storage, although the quantification of oxidation products is difficult.

7 Conclusion

This review describes the analytical methods to evaluate the quality of edible fats and oils, especially the Standard Methods for Analysis of Fats, Oils and Related Materials edited by Japan Oil Chemists’ Society (the JOCS standard methods) and other advanced methods. Many physical and chemical characteristics are used to evaluate the quality of edible fats and oils. Although different types and quantities of solvents are used in the JOCS standard methods, non-destructive methods using no solvents and harmful chemicals such as NIR and THz spectroscopy and other portable sensors are expected to become more popular.

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Fig. 5 Terahertz absorption spectra of vegetable oils.

Fig. 6 Correlation curve between terahertz absorbance and saponification value of vegetable oils.

Fig. 7 Terahertz absorption spectra of heated high-oleic safflower oils.

Fig. 8 Correlation curve between terahertz absorbance and polymers in heated high-oleic safflower oils.
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