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Review of NIR spectroscopy methods for nondestructive quality analysis of oilseeds and edible oils

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ABSTRACT

Background: Edible oils play a vital role in our daily life, which provide human beings with energy, essential fatty acids and nutrients. The quality of edible oils can be dependent on the quality of the oilseeds they originate from, and their adulteration during processing. In recent years, near infrared spectroscopy was widely used in the rapid assessment of quality of oilseeds and edible oils. However, to the best of our knowledge, a comprehensive review on near infrared spectroscopy for the quality of oilseeds remains to be published.

Scope and approach: The applications of near infrared spectroscopy in the quality of oilseeds and edible oils have been emphasized in this review. This article briefly summarizes the basic knowledge of near infrared spectroscopy. In addition, we highlight the application of this technique on the detection of physicochemical properties and quality, specific nutrient components, authentication, and geographical origin traceability of oilseeds and edible oils. Moreover, the application of near infrared hyperspectral imaging technology in oilseeds has been addressed.

Key findings and conclusions: Near infrared spectroscopy possesses the advantages of rapid, green and low-cost analysis. Meanwhile, it is also a nondestructive method and therefore suitable to quality analysis of oilseeds in agricultural sciences. It can be used to detect macro nutrients in oilseeds and edible oils by combining NIR and advanced chemometrics. In the future, NIR could be applied in the rapid detection and online detection of hazardous substances and nutrients in oilseeds by developing the new instrument and chemometric methods.

1. Introduction

Edible oils play a vital role in our daily life, which provide with energy, essential fatty acids and nutrients. The quality of edible oils can be dependent on the quality of the oilseeds. Recently, there is increasing interest in the consumer quality and safety of oilseeds (Wang et al., 2017). As a staple food, oilseeds provide many nutritious and functional components for human health, such as starch, crude protein content (CPC), oil content (OC), fatty acids, amino acids, vitamins, phytosterols, and polyphenols (Vithu & Moses, 2016; Yang et al., 2018). Oilseed production and consumption is significant worldwide, and the quality and safety of oilseeds are important to human health.

In addition, as an important and consumable raw material, the quality and safety of oilseeds are critical. Quality parameters of oilseeds are determined using techniques such as ultraviolet (UV) spectroscopy, near-infrared (NIR) spectroscopy, Raman spectroscopy, fluorescence spectroscopy, nuclear magnetic resonance (NMR), hyperspectral imaging (HSI), gas chromatography (GC), gas chromatography mass spectrometry (GC-MS), liquid chromatography (LC), liquid chromatography mass spectrometry (LC-MS) (Ogrinc, Košir, Spangenberg, & Kidrič, 2003; Wang et al., 2017). Generally, Soxhlet extraction is performed to determine the OC of oilseeds (García-Ayuso, Velasco, Dobarganes, & Castro, 2000). Kjeldahl and Dumas combustion methods are commonly used to analyze the CPC of oilseeds (Beljkas et al., 2010). The moisture content (MC) is often measured by low-resolution pulsed NMR (Gambhir, 1992) and Terahertz radiation (Parasoglou et al., 2009). The

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Table 1
Overview of the detection methods of quality parameters of oilseeds.

Quality parameter	Method	Reference
Oil content	Soxhlet extraction	García-Ayuso et al. (2000)
Protein	Kjeldahl method, Dumas combustion	Beljkas et al. (2010)
Moisture	Low-resolution pulsed NMR, Terahertz radiation	Gambhir (1992); Parasoglou et al. (2009)
Acid value	Titration	Hubik, (1965)
PV	Redox-potentiometric	Kardash-Strochkova et al. (2001)
Fatty acid composition	GC, GC-MS	Petrović et al. (2010)
Glucosinolates	HPLC	Lichter, Groot, Fiebig, Schweiger, and Gland (2006).
Total polyphenol content	Folin-Ciocalteus	Neveu et al. (2010)
Phenolic compounds	LC-MS	Wu et al., (2016); Lang et al. (2019)
Tocopherol	GC-MS, LC-MS	Melchert et al. (2002); Zhang et al. (2019)
Chlorophyll	Spectrophotometric	Daun, (2012); Li et al. (2019)

acid value of edible oils is determined by titration (Hubik, 1965). Redox-potentiometry, without titration, has been used to detect the peroxide value (PV) of edible oils (Kardash-Strochkova, Tur'yan, & Kuselman, 2001). The fatty acid (FA) composition of oilseeds and edible oils is analyzed by GC and GC-MS (Petrović, Kezić, & Bolanča, 2010; Zhang et al., 2014). High performance liquid chromatography (HPLC) is employed to analyze the concentration of the glucosinolates in rapeseed (Lichter, Groot, Fiebig, Schweiger, & Gland, 2006). The Folin-Ciocalteus method is often used to detect the total polyphenol content (TPC) (Neveu et al., 2010), while the concentrations of phenolic compounds in oilseeds and edible oils have been determined by LC-MS (Lang et al., 2019; Wu et al., 2016). The concentrations of tocopherols is determined by the GC-MS (Melchert, Pollok, Pabel, Rubach, & Stan, 2002) and LC-MS (Zhang et al., 2019). The chlorophyll content is measured with spectrophotometric techniques (Daun, 2012; Li et al., 2019). The detection methods used for quality parameters of oilseed are listed in Table 1. These methods are generally used as reference analysis methods for building the NIR prediction model.

With the development of science and technology, the demands of industrial manufacturing, government regulations, and consumer expectations have been directed towards quick and green oilseed quality analysis methods. Therefore, a fast and efficient detection technology has become an imperative scientific and technological demand in this field. NIR spectroscopy is an outstanding tool due to its simple operation, short analysis time, small sample requirement, low-cost and non-destructive measurement. Furthermore, it has proven to be an effective technique in the agriculture and food industries, particularly the qualitative and quantitative analysis of nutritional compounds, authenticity identification, and origin traceability (Haughey, Graham, Cancouët, Elliott & 2013; Yang et al., 2013).

Since NIR has been widely used in the quality and safety of agricultural products, there are several reviews on the assessment of aflatoxin and fungal contamination in various agricultural products (Tao et al., 2018), quality and safety of cereals (Hussain, Sun, & Pu, 2019), the identification of harmful insects species in grains (Johnson, 2020), quality assessment of fruit and vegetables (Nicolai et al., 2007; Pathmanabana, Gnanavelb, & Anandanc, 2019), quality assessment of potatoes (LopÀez, Arazuri, García, Mangado, & Jaren, 2013), the assessment of meat and fish (Weeranantanaphan, Downey, Allen, & Sun, 2011), as well as the evaluation of the chemical, microbiological and physical hazards in foods (Fu & Ying, 2016). However, to the best of our knowledge, no review has been published on NIR applications for the quality of oilseeds. This review summarizes the basic knowledge of NIR and builds on recent research to understand its applications for the quality of oilseeds and edible oils.

2. Principle of NIR

William Herschel discovered the NIR spectral region, outside the visible red light area, in the 19th century (Jr, 1996). NIR began to appear in 1960s and had a rapid development in the late 1980s (Chen, Zhang, Wu, & Shi, 2011). NIR light covers an electromagnetic spectrum from 780 to 2500 nm (wavenumbers 12500-4000 cm^{-1}), which lies between visible light and mid-infrared light (Arendse, Fawole, Magwaza, & Opara, 2018). The basic principle of NIR spectroscopy is to irradiate the sample using NIR light and to record reflected or transmitted radiation (Budic-Leto et al., 2011). NIR is a combination of overtone bands or basic absorption bands related to the transition of molecular rotation and vibration (Louw & Theron, 2010). NIR records the overtones and combination band information of the fundamental vibration of a single chemical bond in a molecule. The vibration signals are similar, and the spectrum is composed of many broad and overlapping bands (So et al., 2004). NIR spectra shows overtones and combination band information from hydrogen-containing groups, i.e. C–H, N–H, and O–H, which are the main chemical bonds of organic compounds. In addition, NIR detection conforms to Lambert-Beer's law; thus, the specific chemical bond determines the wavelength and quantity of absorbed light. Therefore, each substance possesses infrared absorption and has a unique NIR spectrum. The NIR spectrum can be characterized for qualitative and quantitative analysis (Chen, Xing, & Han, 2014; Guo & Baianu, 2011; Wang et al., 2006).

3. Characteristics of NIR spectrometry

Since 1908s, NIR technology has developed rapidly with the improvement of instrumentation and optical fibers, the advancements of computer technology and novel mathematical methods related to data processing (Corro-Herrera, Gomez-Rodriguez, Hayward-Jones, Barradas-Dermitz, & Aguilar-Uscanga, 2016; Roggo et al., 2007). NIR offers advantages such as rapid, accurate, and low cost analysis; simple operation; and no sample pretreatment. Moreover, it has probe flexibility and is suitable for online applications and multivariate data analysis to determine major components in samples. It is especially powerful for process monitoring and quality control (Bureau et al., 2009; Chen, Zhao, Chaitep, & Guo, 2009; Georgieva et al., 2013; Mainali, Li, Yehl, & Chetwyn, 2014; Nordey, Joas, Davrieux, Chillet, & Lechaudel, 2017; Yang et al., 2013). The NIR analysis includes the following steps: 1) collecting NIR spectra of known samples; 2) preprocessing the original spectra; 3) elimination of abnormal samples 4) establishing and validating the model using chemometric methods; and 5) predicting the target parameters of the unknown samples or characterizing the properties of the samples.

The drawback of NIR is that the NIR spectrum contains interference from the background, including noise and overlapping bands. This results in redundancy and colinearity of the variables. In addition, the absorption bands in NIR spectra are weak, which can be difficult to analyze compared with the bands of mid-infrared spectra. Different light scattering effects occur when recording the reflection spectrum because of the existence of many overlapping absorption bands; therefore, the spectral information becomes complicated and lacks the detailed structure required for analysis (Barbin, Souza Madureira Felicio, Sun, Nixdorf, & Hirooka, 2014; Daszykowski, Wrobel, Czarnik-

Matusewiczb, & Walczak, 2008; Guo, Ni, & Kokot, 2016). Moreover, the NIR technique relies on time-consuming and labor-intensive calibration procedures, which complicate data analysis (Pfaue, 2003). Another limitation is perhaps the weak sensitivity to minor constituents. Therefore, chemometrics is necessary to extract chemically relevant information from NIR spectra and construct calibration models to associate spectral features with the quality and safety parameters of samples. The combination of NIR and chemometrics is necessary for quality control and rapid detection (Qu et al., 2015; Daszykowski et al., 2008; Anjos, Campos, Ruiz, & Antunes, 2015). The International Society for Chemometrics defines chemometrics as the discipline that links the measured values of a chemical system to the state of a system by means of applied mathematical or statistical methods (Mark & Jr, 2007). Applied mathematics, statistics, and other methods are used to select the optimal test design and measurement method. Then, processing and analyzing the measurement data are carried out to maximize the composition, structure, and other related information of the relevant substances (Gendrin, Roggo, & Collet, 2008). Chemometrics is divided into two categories: supervised and unsupervised pattern recognition methods (Gad, El-Ahmady, Abou-Shoerb, & Al-Azizia, 2012). It includes spectral data preprocessing, calibration models for qualitative and quantitative analysis, and model transfer (Roggo et al., 2007; Qu et al., 2015). Spectral data preprocessing encompasses derivation, centralization, smoothing, and multivariate scatter correction. Smoothing improves the quality of the NIR spectrum via eliminating noise (Pfaue, 2003; Qu et al., 2015). Factors affecting the calibration model are sample state, representativeness of calibration set samples, and selection of chemometric methods (Wu & Shi, 2007; Hom, Becker, & Mollers, 2007). The model needs to be regularly reviewed and improved to achieve model stability. The chemometric methods used to calibrate models are partial least squares (PLS) (Zhang et al., 2020), principal components analysis linear discriminant analysis (PCA-LDA) (Dumalisile, Manley, Hoffman, & Williams, 2020), artificial neural networks (ANN) (Puertas & Vazquez, 2020), Random forest (Santana, Netob, & Poppia, 2019) and support vector machines (SVM) (Zareef et al., 2020). Recently, several reviews were published on chemometric methods for NIR, including data preprocessing, variable selection, modeling, and validation (Callao & Ruisanchez, 2018; Cheng and Sun, 2017; Cozzoline, 2014; Cui, Sun, Cai, & Shao, 2019; Gomez-Caravaca, Maggio, & Cerretani, 2016; Yang et al., 2019; Yun, Li, Deng, & Cao, 2019).

4. Quality evaluation

4.1. Physicochemical properties and quality of oilseeds

Protein, oilseed content, moisture, starch, and amino acid contents are quality parameters in oilseeds. NIR has been successfully applied to the detection of these quality parameters. An overview of NIR detection of quality parameters of oilseeds and edible oils is listed in Table 2.

The OC of rapeseed was studied via the ANN method. The result confirmed the variance of OC was 0.027, and the predicted residual error sum of squares (PRESS) value was 75.65 (Olivos-Trujillo, Gajardo, Salvo, González, & Muñoz, 2015). Protein content of sesame was determined with PLS analysis by means of NIR (Wang, Jin, Guo, & Yan, 2011). Likewise, rapeseed-mustard seeds were employed to estimate the oil, protein, and moisture content by NIR combined with PLS (Prem, Gupta, Sarkar, & Agnihotri, 2012). The CPC, MC, lipid, ash, and carbohydrate of soybean were investigated by Fourier transform NIR (FT-NIR) spectroscopy, with root mean square error of cross-validation (RMSECV) ranging from 0.40% to 2.30% and root mean square error of prediction (RMSEP) between 0.38% and 3.71% (Ferreira, Pallone, & Poppi, 2013). A feasibility study was conducted to rapidly test the OC and FA concentration of shelled peanuts using NIR (Sundaram, Kandala, Holser, Butts, & Windham, 2010). In addition, a study was conducted on the determination of the content of linoleic acid and erucic acid with single kernel of rapeseed (Sato, Uezonob, Morishitaa, & Tetsuka, 1998). Oleic acid content of single kernel of soybean was evaluated with the modified partial least squares (MPLS) chemometric tool (Han, Chae, Bilyeu, Shannon, & Lee, 2014). Meanwhile, NIR was able to estimate the protein and amino acid content of peanut (Wang, Wang, Liu, Liu, & Du, 2013). The amino acid content of single kernel of soybean was measured by NIR, and an R^2 higher than 0.8 was obtained (Lee et al., 2012).

The PVs in corn and soybean oil were determined by PLS regression (PLSR), which had a higher correlation and minimal error (Yildiz, Wehling, & Cuppett, 2002). The regression model allowed for the determination of the oxidation level of corn and soybean oil. Portable NIR spectroscopy was used to quickly determine the acid value in peanut oil by combining NIR with the synergy interval-PLS-genetic algorithm (GA-Si-PLS) method (Yang et al., 2017). The acid value and PV of perilla seed oil was detected in different storage conditions and time periods by NIR (Hong et al., 2017). Olive oil samples were analyzed to construct the detection of free fatty acid (FFA), PV, and conjugated diene models based on chemometric analysis of the NIR spectral data (Sanchez, Moreda, & Garcia, 2013). PLSR was used to establish a model for the content of sterol and FA in 73 extra virgin olive oils from 21 varieties in four producing areas (Özdemira et al., 2018). The result indicated the total sterol content (TST) has a good predictive effect, and the FA content can also be predicted by the model, except for heptadecanoic acid and eicosenoic acid. It can be applied to determine the TST and major FA in extra virgin olive oil (EVOO). The NIR spectrum was collected to establish a model for the FFA concentration in 100 crude palm oil samples (Abdull Rani & Abdul Rahim, 2013). However, the accuracy was only 48.2%. Perhaps optimizing the chemometric method to predict the FFA concentration of crude palm oil is the next step. Similarly, the FA and chlorophyll content of 216 olive oil samples were discussed with standardization, first-order derivation pretreatment, and the PLS chemometric tool (Mailer, 2004). The author analyzed the reflectance spectral data and obtained R^2 values of oleic acid, linoleic acid, FFA, and chlorophyll greater than 0.97. However, the correlation between stearic acid and linolenic acid was poor and could not be used for the prediction of their contents. These studies have shown the applicability of NIR for the determination of oleic acid, linoleic acid, FFA, and chlorophyll contents in olive oil samples. NIR has been widely applied in the detection of regular quality parameters of oilseeds and has good prediction results. This brings great convenience to the breeding and detection of oilseeds. In the future, the study and utilization of intelligent, miniaturized, and portable NIR instruments will greatly benefit the oilseed industry.

4.2. Specific nutrient components in oilseeds

Development of high-quality agricultural products becomes an important direction of agricultural sciences, which could not only enhance efficiency, but also provide with high-nutrition products for consumers. Therefore, quantitative detection of specific nutrient components in these products draws more and more attentions. Therefore, it is essential to establish rapid detection technology of specific nutrient components in oilseeds and edible oils, such as tocopherol, chlorophyll, polyphenols, and glucosinolates. These compounds play significant roles in plants and humans. In recent years, NIR has made significant advances in the rapid detection of nutritional compounds in oilseeds and edible oils. Table 3 summarizes the application of NIR in the detection of nutritional compounds in oilseeds and edible oils.

Glucosinolate content of rapeseed was detected using PLSR method (Kumar, Chauhan, & Kumar, 2010). Meanwhile, NIR was used to determine total phenol content and glucosinolates in rapeseed, and R^2 values higher than 0.7 were obtained (Sen, Sharma, Kaur, & Banga, 2017). In addition, NIR was used to determine α-tocopherol in edible oil by the chemometric prediction model (Szlyk, Szydlowska-Czerniak, & Kowalczyk-Marzec, 2005). The authors observed reasonable accuracy

Table 2
Overview of application of NIR in the detection of regular nutrient components of oilseeds.

Species	Spectrophotometer	Acquisition mode	Spectral range (nm)	Model	Attribute(s)	Performance/Accuracy	Reference
Rapeseed	Scanning	Reflectance	680–2500	ANN	OC	Variance-0.027, PRESS-75.65	Olivos-Trujillo et al. (2015)
Sesame	Scanning	Reflectance	570–1098	SNV	Protein	SEC-0.2313, SECV-0.9134, SEP-0.827	Wang et al. (2011)
Rapeseed-mustard seed	Scanning	Reflectance	1100–2500	PLS	OC, MC, protein	SECV-1.30-0.12-12.19, R^2-0.94-0.87-0.91 SEC-1.18-0.39-2.18	Prem et al. (2012)
Soybean	FT-NIR	Reflectance	1000–2500	PLS	CPC, MC, lipid, ash, carbohydrate	RMSECV-0.40%–2.30% RMSEP-0.38%–3.71%	Ferreira et al. (2013)
Peanut	FT-NIR	Reflectance	400–2500	PLS	OC, FA	Residual percent deviation > 5	Sundaram et al. (2010)
Rapeseed	Scanning	Reflectance	1100–2500	Second-derivative	Linoleic, erucic acid	-	Sato et al. (1998)
Soybean	Scanning	Reflectance	400–2500	MPLS	Oleic acid	R^2 > 0.91	Han et al. (2014)
Peanut	Scanning	Reflectance	950–1650	PCA, PLS	Protein, amino acid	R^2-0.99 R^2-0.83-0.90	Wang et al. (2013)
Soybean	Scanning	Reflectance	400–2500	PLS	Amino acid	R^2 > 0.8	Lee et al. (2012)
Corn oil, Soybean Oil	Scanning	Transmittance	400–2500	PLSR	PV	R-0.99	Yildiz, Randy, Wehling, and Cuppett (2002)
Peanut oil	Scanning	Transmittance	900–1700	GA-Si-PLS	Acid value	R_P-0.9426, RMSEP-0.2980.	Yang et al. (2017)
Perilla seed oil	Scanning	Transmittance	900–1700	ANN	PV, acid value	R^2tra-0.9210-0.9037, RMSEtra-1.1986-0.0694 R^2val-0.9341-0.8175, RMSEval-0.9806-0.0963, R^2test-0.8286-0.8555, RMSEtest-1.5876-0.1112	Hong et al. (2017)
Olive Oil	Scanning	Transmittance	350–2500	PLS	FFA, PV, conjugated diene	RPD-3.14-2.84-2.56	Sanchez, Moreda and Garcia (2013)
EVOO	FT-NIR	Reflectance	833–2500	PLSR	TST, FA	R_p^2 -0.839, RMSEP-192 mg/kg, RPD-2.64 R_p^2 -0.716-0.997 RPD-2.02-17.6	Özdemira et al. (2018)
Palm oil	Scanning	Reflectance	400–2500	PLSR	FFA	Accuracy-48.2%	Abdull Rani and Abdul Rahim (2013)
Olive Oil	Scanning	Reflectance	400–2500	PLS	Oleic, linoleic, FFA, chlorophyll	R^2-0.99-1.00-0.97-0.98	Mailer (2004)

Table 3
Overview of application of NIR in the detection of specific nutrient components of oilseeds.

Species	Spectrophotometer	Acquisition mode	Spectral range (nm)	Model	Attribute(s)	Performance/Accuracy	Reference
Rapeseed-mustard seeds	FT-NIR	Reflectance	800–2500	PLSR	Glucosinolates	R^2 -98.34%	Kumar et al. (2010)
Rapeseed	Scanning	Reflectance	400–2500	–	Phenols, glucosinolates	R^2 > 0.7	Sen et al. (2017)
Commercial edible oil	FT-NIR	Reflectance	1000–2500	PLSR	α-tocopherol	RSD-0.68–2.80%, recovery-97.2–102.4%	Szlyk et al. (2005)
Olive oil	Scanning	Transflectance	1100–2300	PLS	Total tocopherol content, α-tocopherol	RPD-2.37-2.01	Cayuela and Carcia (2017)
Crude oil	Scanning	Transflectance	1200–2400	PLSR	Total tocopherol content, Total carotenoid content	RMSEC-3.061-3.925, SEC- 3.068-3.935, R^2cal-0.149-0.591, RMSECV-3.061-3.188, SECV- 4.328-3.218 R^2val-0.011-0.704	Kahrıman, Onaç, Turk, Oner and Egesel (2019)
Sunflower seeds	Scanning	Reflectance	400–2500	PLS	Tocopherols, phytosterols	R^2-0.64-0.27	Gotor et al. (2007)
Rapeseed oil	Scanning	Reflectance	400–2498	Modified PLSR	Phytosterols	R^2cv-0.81, SECV-241 mg/kg	Amar et al. (2009)

and recoveries with NIR and HPLC methods. The relative standard deviations (RSD) were 0.68%–2.80% and 0.79%–3.06%, and the recoveries were 97.2%–102.4% and 96.8%–103.2%, which revealed the feasibility of NIR to predict the α-tocopherol content in unknown edible oil. Total content of tocopherol and α-tocopherol in olive oil was estimated by NIR. The great performance of the model revealed the residual predictive deviations (RPD) were 2.37 and 2.01 (Cayuela & Carcia, 2017). Moreover, NIR was employed as a rapid method to predict the carotenoid and tocopherol content in crude oil (Kahrıman, Onaç, Turk, Oner, & Egesel, 2019). The results showed the total contents of tocopherols and carotenoids have good predictive performances. The key wavelengths were selected to detect the tocopherol and phytosterol contents in sunflower seeds. The NIR model with PLSR treatment indicated the R^2 were 0.64 and 0.27 of tocopherol and phytosterol contents in sunflower seeds (Gotor et al., 2007). The work was successfully to determine the total phytosterol content of rapeseed oil by NIR reflectance spectrometer, with the explained variance of cross-validation (R^2cv) was 0.81, standard error of cross-validation (SECV) was 241 mg/kg (Amar, Becker, & Mollers, 2009). In future, more specific nutrient components in oilseeds will be discovered and used to develop high quality oilseeds and edible oils. Thus, it is necessary to continue developing NIR analysis methods for these specific nutrient components. However, since the concentrations of these nutrients are usually low, the signals from molecular rotation and vibration are weak and overlapped with other signals from other high-content compounds. Therefore, the development of new chemometric methods provides important possibilities for improving detection accuracy of prediction model.

5. Authentication and geographical origin traceability of oilseeds and edible oils

Adulteration of oilseeds and edible oils is a major issue in the food and agricultural product markets. The addition of cheap substitutes could affect consumer health and reduce the commercial value of expensive oilseed and edible oils (Barbin et al., 2014). General chemical methods are ineffective at identifying adulterated oilseeds because of their similar appearance, taste, physical and chemical properties. Therefore, it is indispensable to use NIR to identify the authenticity of oilseeds and edible oils (Luo, Liu, & Liu, 2012). A summary of NIR applications in the identification of adulterated oilseeds and edible oils is listed in Table 4.

NIR can accurately distinguish cottonseed oil, peanut oil, soybean oil, and rapeseed oil, as well as precisely classify unknown vegetable oil samples with discriminant analysis (DA) (Bewig, Clarke, Roberts, & Unklesbay, 1994). The FA composition of 9 kinds of plant oils in the wavelength range of 1600–2200 nm was confirmed, which showed that PCA can be used for the classification of 9 kinds of plant oils (Sato, 1994). The PLS model was proposed by collecting NIR spectra of pure camellia oil and camellia oil samples mixed with 5%–25% adulterated soybean oil (Wang, Lee, Wang, & He, 2006). The correlation coefficient (R) value for the calibration model was 0.992. The root mean standard errors of calibration (RMSEC), RMSEP, RMSECV were 0.70, 1.78 and 1.79, respectively. PLS was successfully used to predict the adulteration of corn oil, hazelnut oil, soybean oil, and sunflower oil in olive oil (Kasemsumran, Kang, Alfred Christy, & Ozaki, 2007). Moreover, a model was designed for pure camellia oils with PCA, hierarchical cluster analysis (HCA), DA, and radical basis function neural network (RBFNN), which resulted in a total correct classification rate of 98.3% (Li et al., 2012). The spectral differences of key peaks of soybean oil, palm oil, sesame oil, and peanut oil were analyzed, and four vegetable oils were successfully differentiated with two-dimensional correlation analysis technology (Chen, Tian, Lu, Zhou, & Shao, 2012). A calibration model was successfully validated using transgenic and non-transgenic soybean oil. SVM-discriminant analysis (SVM-DA) and PLS-discriminant analysis (PLS-DA) were the best methods to distinguish

Table 4
Overview of application of NIR in the adulterated identification of oilseeds.

Species	Spectrophotometer	Acquisition mode	Spectral range (nm)	Model	Performance/Accuracy	Reference
Cottonseed oil, peanut,oil, soybean oil, canola oil	Scanning	Reflectance	1100–2500	DA	A chi square of 18.9	Bewig et al. (1994)
Soybean oil, corn oil, cottonseed oil, olive oil, ricebran oil, peanut oil, rapeseed oil, sesame oil and coconut oil	Scanning	Transmittance	1600–2200	PCA	-	Sato (1994)
Camellia oil	Scanning	Reflectance	1000–2500	PLS	R-0.992, RMSEC-0.70, RMSEP-1.78, RMSECV-1.79	Wang, Lee, Wang and He (2006)
Olive Oil	FT-NIR	Transmittance	833–2198	PLS	%CP-100%, error limits- ± 1.05% - ± 0.47% w/w	Kasemsumran et al. (2007)
Camellia Oil	Scanning	Transflectance	1000–2500	PCA, HCA, DA, RBFNN	Correct classification-98.3%	Li et al. (2012)
Soybean oil, palm oil, sesame oil,peanut oil	Scanning	Reflectance	1000–3333	-	-	Chen et al. (2012)
Soybean oil	Scanning	Transmittance	1100–2500	SVM-DA, PLS-DA	Correct classification > 80%	Luna, Silva, Pinho, Ferré, and Boqué (2013)
Virgin olive oil	FT-NIR	Transmittance	800–2500	PLS	-	Inarejos-García et al. (2013)
EVOO	FT-NIR	Reflectance	1250–2222	PLS1	-	Azizian et al. (2015)
EVOO	FT-NIR	Transmittance	833–2500	PLSR	RMSEP-1.76, $R^2 > 0.98$	Mendes et al. (2015)
Sesame oil	Scanning	Reflectance	1350–1800	SVM	R-99.0772%, MSE-0.082	Luo, Yu, Xu, Chen and Zheng (2018)
Copaiba Oil	Scanning	Transflectance	908–1676	PLSR	RMSEP-1.5%, R^2-0.991, REP < 2.0%	Oliveira Moreira et al. (2018)
EVOO	FT-NIR	Transmittance	1000–2500	BOSS-PLS	R^2-0.9922, RMSEP-1.4889% v/v	Jiang and Chen (2019)

between transgenic and non-transgenic soybean oil (Luna, Silva, Pinho, Ferre, & Boque, 2013). A study based on NIR spectral information was carried out for the rapid screening of virgin olive oil products and assessment of their quality levels by measuring their minor components and sensory characteristics (Inarejos-Garcí;a, Gómez-Alonso, Fregapane, & Salvador, 2013). A PLS1 model was built to identify adultergenic species and quantities of EVOO mixed with 9 different vegetable oils using FT-NIR (Azizian et al., 2015). NIR spectra were collected to study the adulteration of olive oil (Mendes et al., 2015). The blending ratio of olive oil and soybean oil ranged from 0% to 100%, resulting in an R^2 value of the constructed model greater than 0.98 and RMSEP of 1.76. Recently, an analytical method based on NIR for the distinction of soybean oil and rapeseed oil in sesame oil was developed (Luo, Yu, Xu, Chen, & Zheng, 2018). The R value was 99.0772%; the mean square error (MSE) was 0.082. Thus, this method can identify adulterated sesame oil. The amount of 53 Brazilian palm oil with 50%–100% other edible oil was evaluated using the NIR spectrum analysis technique (Oliveira Moreira, Lira Machado, Almeida, & Braga, 2018). The R^2 of the established model reached 0.991; the RMSEP was 1.5%; and the relative error of prediction (REP) was less than 2%. The identification of Brazilian palm oil adulteration can be successfully determined with this method. Besides, the adulteration content of EVOO can be determined using the novel bootstrapping soft shrinkage (BOSS)-PLS (Jiang & Chen, 2019). Generally, the two key points of NIR technology are the establishment of a NIR spectral library of representative samples and the chemometric methods. The current method is mainly used for detecting adulterated oil with one or two kinds of cheap oils. However, adulteration with more than 2 kinds of cheaper oils was applied to mask the above detection methods without incremental cost (Yuan et al., 2020). Therefore, it is necessary to develop NIR detection methods for multiple adulteration.

In addition, geographical origin traceability technology for oilseeds is a powerful means to monitor the quality of oilseeds (Hu & Cui, 2010). An overview of NIR applications in geographical origin traceability of oilseeds is listed in Table 5. NIR was employed to discriminate sesame seeds from Korean, Chinese, and Indian varieties (Choi et al., 2016). Meanwhile, NIR reflectance spectroscopy was employed to determine the African or Asian origin of the sesame seeds (Dossa et al., 2018). French virgin olive oils were clearly identified with satisfactory results using NIR combined with chemometrics (Galtier et al., 2007). NIR transflectance spectroscopy was suggested to determine the origin of European olive oil, which provided a new method for the identification of other oils (Woodcock, Downey, & O'Donnell, 2008). Similarly, NIR with potential functions techniques (POTFUN), soft independent modeling of class analogy (SIMCA), unequal-quadratic discriminant analysis (UNEQ-QDA), and multivariate range modeling (MRM) techniques was used to distinguish the EVOO from Ligurian (Casaler, Casolino, Ferrari, & Forina, 2008). A model for EVOO produced in Italy's protected region, with a stepwise-LDA (STEP-LDA), was established (Forina et al., 2015). From the above applications, we can find that NIR could effectively classify oilseeds or edible oils from different producing areas. However, it is difficult to detect adulterated oil or quality oilseeds from those of cheaper oils or oilseeds, or those produced in different geographical regions. Therefore, NIR hyperspectral imaging technology might be a better choice for tracing the geographical origins of oilseeds, which can determine the area of production for a single kernel.

6. Near infrared hyperspectral imaging technology in oilseeds

Near-infrared hyperspectral imaging (NIR-HSI) is a combination of spectroscopy and imaging technology, which provides both spectral and spatial backgrounds in a single system. It has become a viable alternative to traditional imaging and spectroscopy (ElMasry, Sun, &Paul Allen, 2012). The application of NIR-HSI technology is widely popular for oilseed analysis. An overview of NIR-HSI technology applications in oilseeds is listed in Table 6.

Table 5
Overview of application of NIR in geographical origin traceability of oilseeds.

Species	Spectrophotometer	Acquisition mode	Spectral range (nm)	Model	Reference
Sesame seed	FT-NIR	Reflectance	1000–2500	DA	Choi et al. (2016)
Sesame	Scanning	Reflectance	1100–2500	PCA, agglomerative hierarchical clustering	Dossa et al. (2018)
Olive oil	FT-NIR	Reflectance	1000–2222	PLS1-DA	Galtier et al. (2007)
Olive oil	Scanning	Transflectance	1100–2498	PCA	Woodcock, Downey, and O'Donnell (2008)
EVOO	FT-NIR	Transmittance	1000–2500	POTFUN, SIMCA, UNEQ-QDA, MRM	Casaler et al. (2008)
EVOO	FT-NIR	Transmittance	1000–2500	STEP-LDA	Forina et al. (2015)

Table 6
Overview of application of NIR-HSI Technology in oilseeds.

Species	Spectral range (nm)	Model	Attribute(s)	Performance/Accuracy	Reference
Peanut kernels	400–1000 1000–2500	PLSR	MC	R_P^2-0.908-0.906, RMSEP-0.603%–0.603%	Jin et al. (2015)
Peanut	400–1000 1000–2500	PLSR	OC	R_P^2-0.696-0.923, RMSEP-0.416%–0.208%	Jin et al. (2016)
Peanut	1000–2500	PLSR	OC, protein	R_P^2-0.945, RMSEP-0.196 R_P^2-0.901, RMSEP-0.441	Cheng et al. (2017)
Peanut kernels	1000–2500	PLSR	Protein	R_P^2-0.885, RMSEP-0.465%.	Wang and Cheng (2018)
Sesame oil	874–1734	CARS-LS-SVM, CARS-LDA	–	Correct classification > 80%	Xie et al. (2014)

Two spectral ranges of 400–1000 nm and 1000–2500 nm were tested to determine the MC of peanut kernels, which proved NIR-HSI was a potential method to predict the MC of peanut kernels (Jin, Li, & Cheng, 2015). Moreover, images were taken with PLSR to determine the OC in peanuts (Jin, Ma, Li, & Cheng, 2016). NIR-HSI was performed to find out the CPC and OC of peanut kernels. PLSR with multiplication scattering correction pretreatment was developed to predict the model (Cheng, Jin, Xu, & Zheng, 2017). The determination coefficients for prediction (R_P^2) of CPC and OC in peanut kernels were 0.901 and 0.945, respectively, and the RMSEP values were 0.441 and 0.196, respectively. In another study, NIR-HSI combined with PLSR can establish a model of CPC in peanut kernels (Wang & Cheng, 2018). The R_P^2 was 0.885, and the RMSEP was 0.465%, which proved NIR-HSI can be used to determine the CPC of peanut kernels. Competitive adaptive reweighted sampling (CARS)-LS-SVM and CARS-LDA models, combined with NIR-HSI, was capable of detecting sesame oil (Xie, Wang, & He, 2014). In summary, NIR-HSI is extensively used in oilseed analysis and quality control. NIR-HSI methods will be advantageous to the study of the distribution of components in samples and single kernel analysis in the future.

7. Conclusion and prospects

Oilseeds and edible oils are an important nutrient source in the human diet, and the quality of oilseeds and edible oils has drawn increasing attentions from industry and consumers. Therefore, it is crucial to evaluate the quality of oilseeds. Since NIR technology is fast, non-destructive, and low cost, it is a promising option for the detection of quality parameters of oilseeds, as well as for authenticity identification and origin traceability of oilseeds and edible oils. Moreover, the combination of NIR and chemometrics significantly broadens its application prospects. Recently, NIR was applied to detect pesticide residues in cucumber (Jamshidi, Mohajerani, & Jamshidi, 2016) and total heavy metals in soil (Angelopoulou et al., 2017). In fact, pesticide residues and heavy metals are also hazardous substances for oilseeds, and methods should be developed for these contaminants in the future. Owing to its advantages, NIR is generally used for on-line analysis in the food industry (Porep, Kammerer, & Carle, 2015). Therefore, the on-line analysis of oilseeds is also an important direction in the future. More importantly, nutritional compounds such as phytosterols, vitamins, and phenolic compounds are becoming important markers of high-quality oilseeds and edible oils. The ability to quantify nutritional compounds in oilseeds and edible oils by NIR will greatly benefit the quality control process and subsequently promote the development of a high-quality food industry.

CRediT authorship contribution statement

Xue Li: Formal analysis, Investigation, Writing - original draft, Writing - review & editing. **Liangxiao Zhang:** Conceptualization, Investigation, Project administration, Writing - original draft, Writing - review & editing. **Yong Zhang:** Formal analysis, Investigation. **Du Wang:** Formal analysis, Investigation. **Xuefang Wang:** Formal analysis, Investigation. **Li Yu:** Formal analysis, Investigation. **Wen Zhang:** Formal analysis, Investigation. **Peiwu Li:** Funding acquisition, Project administration, Supervision.

Declaration of competing interest

All of authors declare that they have no conflict of interest.

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