METODE ANALISIS LIPID TOTAL TERPILIH DARI PENDEKATAN KONVENSIONAL HINGGA LANJUTAN

Selected Total Lipid Analysis Methods from Conventional to Advanced Approaches

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ABSTRAK

Lipid merupakan komponen penting dalam pangan yang berperan dalam kualitas gizi, sifat fisik, dan karakteristik sensori, sehingga analisis lipid total menjadi aspek krusial dalam evaluasi pangan. Namun, makanan memiliki matriks yang kompleks dan keberagaman fraksi lipid sehingga dibutuhkan pemilihan metode analisis yang tepat, akurat, dan efisien. Artikel ini menyajikan tinjauan naratif kualitatif terhadap perkembangan metode analisis lipid total, mencakup pendekatan konvensional, modern, dan non-destruktif. Literatur dikumpulkan dari artikel internasional *open access* periode 2016–2025 dan dianalisis berdasarkan prinsip kerja, keunggulan, keterbatasan, dan aplikasinya dalam bahan pangan. Metode konvensional berbasis pelarut, seperti Goldfisch, Soxhlet, Bligh dan Dyer, serta Mojonnier, masih banyak digunakan karena dinilai sebagai metode sederhana, meskipun memiliki keterbatasan waktu dan konsistensi. Metode modern seperti *Supercritical Fluid Extraction* (SFE), *Microwave Assisted Extraction* (MAE), dan *Pressurized Liquid Extraction* (PLE) memiliki efisiensi dan selektivitas yang lebih tinggi, sementara *Near-Infrared Spectroscopy* (NIRS) dimanfaatkan sebagai alternatif non-destruktif yang cepat dan efisien. Tinjauan ini menekankan perlunya kombinasi antara metode konvensional dan modern dalam analisis lipid total sesuai dengan tujuan pengujian dan karakteristik bahan pangan.

Kata kunci : analisis lipid; metode konvensional; metode modern; ekstraksi; non-destruktif

ABSTRACT

Lipids are essential components of food, contributing to nutritional quality, physical properties, and sensory characteristics. Therefore, total lipid analysis is crucial in food evaluation. However, the variety of lipid fractions and the intricacy of food matrices necessitate the use of suitable, precise, and effective analytical techniques. A qualitative narrative review of the evolution of total lipid analysis techniques, including traditional, contemporary, and non-destructive procedures, is presented in this article. International open-access research publications from 2016 to 2025 were used to create the literature, which was then compared according to its constraints, performance, efficiency, and guiding principles. Despite their time and consistency restrictions, traditional solvent-based techniques like Goldfisch, Soxhlet, Bligh and Dyer, and Mojonnier are still often employed because of their ease of use. Higher efficiency and selectivity are provided by contemporary techniques like Supercritical Fluid Extraction (SFE), Microwave-Assisted Extraction (MAE), and Pressurized Liquid Extraction (PLE), while Near-Infrared Spectroscopy (NIRS) has become a quick and effective non-destructive substitute. This review emphasises the importance of integrating conventional and modern methods in total lipid analysis according to the analysis objectives and characteristics of the food matrix.

***Keyword**: lipid analysis; conventional methods; modern methods; extraction; non-destructive*

INTRODUCTION

A class of molecules known as lipids is characterized by its strong solubility in organic solvents including ether, alcohol, chloroform, and benzene and poor solubility in water (Ramírez, 2022). They are hydrophobic in part because of their mostly nonpolar structure, which is made up of both polar and nonpolar functional groups. Nevertheless, not every compound categorised as a lipid necessarily displays nonpolar behaviour. The length of the carbon chain in the lipid molecules greatly influences how much of this trait is present (Nabede et al., 2022). Polar solvents like ethanol or methanol-chloroform mixtures are suitable for extracting polar lipids, whereas nonpolar lipids are more efficiently extracted with n-hexane (Esonye, Onukwuli, Anadebe, Ezeugo, & Ogbodo, 2021).

Total lipid analysis is essential for determining the fat content in food products. Conventional methods for total lipid analysis rely on solvent extraction, including Goldfisch, Soxhlet, Bligh and Dyer, and Mojonnier methods. These conventional approaches are relatively simple but exhibit low batch-to-batch stability and are time-consuming (Jaradat, Weaver, Meziane, & Lamprou, 2022). In contrast, modern methods such as Supercritical Fluid Extraction, Microwave Assisted Extraction, and Pressurized Liquid Extraction are instrument-based. These advanced methods offer shorter analysis time, high selectivity, and sensitivity for lipid analysis in foods. However, they are associated with high maintenance costs for quantitative analysis (Toribio, Bernal, Martín, & Ares, 2021).

With advances in technology, non-destructive methods have been developed to rapidly, efficiently, and accurately determine lipid content in various food products. Near-Infrared Spectroscopy is among the most commonly used non-destructive methods, functioning through the absorption of electromagnetic radiation by fundamental structural elements of lipids (da Silva Medeiros et al., 2022; Tsegay, Ammare, & Mesfin, 2023). The advantages of non-destructive approaches make them a compelling option for lipid analysis.

This review highlights the advancements in lipid analysis techniques, encompassing both conventional and modern approaches. Each method is compared based on its working principle, effectiveness, and efficiency. Readers can better grasp the benefits and drawbacks of each approach to figuring out the total lipid content of food products thanks to this comparison.

METHOD

This article was prepared as a qualitative–descriptive narrative review using the narrative review method, aiming to synthesise and evaluate developments in total lipid extraction and analysis methods applied to food matrices. The literature search was conducted using the Google Scholar database, with inclusion criteria consisting of articles published in international journals, available as open access, and published within the period 2016–2025. The search strategy employed combinations of the keywords "lipid extraction", "lipid extraction method", "conventional lipid extraction", "modern lipid extraction", and "non-destructive lipid extraction", connected using Boolean operators.

The literature selection process was carried out in several stages, including screening titles, abstracts, and full texts to ensure relevance to the objectives of the review. Articles were considered relevant if they discussed the working principles of the methods, their advantages and limitations, and their applications in lipid extraction or analysis of food materials. A total of 74 articles meeting the inclusion criteria were comparatively analysed and categorised according to the type of method discussed, namely conventional solvent-based methods, advanced extraction methods based on instrumental technologies, and non-destructive approaches. To enhance conceptual clarity, the methodological schemes from the selected literature were redrawn in Canva and presented as supporting illustrations in this review article.

RESULT AND DISCUSSION

Conventional Lipid Analysis

Conventional methods for total lipid analysis can be categorised into continuous, semi-continuous, and discontinuous methods based on how the solvent interacts with the sample. Each method has unique characteristics that affect the efficiency and accuracy of the analysis. This section will discuss the main conventional methods, including Goldfisch (continuous), Soxhlet (semi-continuous), and Bligh and Dyer and Mojonnier (discontinuous), covering their principles, advantages, and limitations.

Continuous Solvent Extraction Method

Goldfisch is a continuous lipid extraction technique that effectively removes lipids from a sample by using an organic solvent that flows continuously through it. This technique dissolves lipid components in the sample by constantly passing solvents like hexane, petroleum ether, or diethyl ether through it. This method's capacity to dissolve hydrophobic substances selectively makes it appropriate for analyzing non-polar lipids (Nielsen & Ismail, 2024).

A number of variables, such as sample moisture content, extraction temperature, particle size, and solvent type, can influence how well a solvent extraction works (Gatea, Alshamkhawy, & Abdul-Hassan, 2022; Pham et al., 2019). As a result, the extraction procedure usually requires a sample preparation step. To increase the surface area, the material is ground into smaller particles in this stage. The efficiency of the continuous extraction process is increased when the solvent has a greater surface area to make better contact with the sample (Ezeh, Gordon, & Niranjan, 2016).

Continuous extraction has advantages in terms of speed and time efficiency when compared to semi-continuous techniques like Soxhlet extraction. By continuously flowing through the sample, lipids can be extracted more quickly, making the method more practical and efficient. This technique is frequently applied in the examination of crude fat and is particularly well-suited for applications involving the analysis of dry food materials. However, this method also has disadvantages, one of which is the potential occurrence of channelling. Channelling refers to the formation of uneven flow paths within the sample, which can result in portions of the sample not being optimally extracted, thereby reducing the overall extraction efficiency (Nielsen & Ismail, 2024).

Semi-Continuous Solvent Extraction Method

Based on the idea of cyclic solvent recirculation, Soxhlet is a semi-continuous lipid extraction technique that continues until the lipid fraction is completely recovered (Garcia-Mendoza et al., 2021). Lipids are gradually dissolved through repeated cycles of heating the solvent to vapor, condensing it, and letting it percolate through the sample (Nebolisa et al., 2023; Wicker et al., 2021). The selection of solvent is typically based on lipid polarity, with n-hexane commonly used for non-polar lipids, and methanol–chloroform mixtures applied for extracting polar lipids (Rajesh et al., 2023; Zhou et al., 2022).

The Soxhlet method typically entails sample pretreatment, such as acid hydrolysis, prior to analysis, to facilitate the release of lipids from the sample matrix, particularly those associated with carbohydrates or proteins (Lestari et al., 2022). The extraction procedure starts by heating the solvent using a heating mantle, which leads to its evaporation and subsequent condensation. The thimble holding the solid sample is subsequently filled with the condensed solvent. Until the lipid extraction is finished, this procedure is repeatedly carried out (Mkhize, Ngema, & Ramsuroop, 2023). Figure 1 shows a schematic illustration of this process.

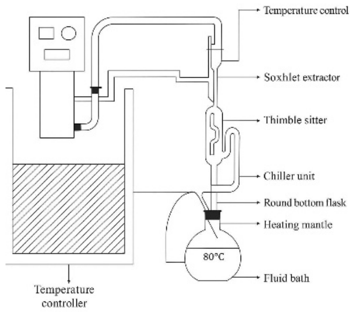

Figure 1. Soxhlet Scheme
Source: Redrawn from Mkhize et al., (2023)

The Soxhlet technique offers notable advantages, particularly its ability to achieve efficient extraction from solid samples and to reuse solvent throughout the extraction process (Trolles-Cavalcante, Dutta, Sofer, & Borenstein, 2021; Zaini et al., 2022). This method is suitable for total lipid analysis in food products, grains, and animal products (de Faria, de Queiroz, & Novaes, 2025). Moreover, Soxhlet extraction is commonly applied to determine crude fat content (Omeje et al., 2022).

However, Soxhlet has a number of drawbacks, such as the need for high temperatures (>70°C) and lengthy extraction times (up to several hours) depending on the solvent type. Furthermore, using solvents derived from organic compounds can pose environmental risks (Cazzaniga et al., 2022; Hou et al., 2024). Furthermore, this method is limited to samples with a solid matrix and a liquid solvent, which is why it is known as a solid-liquid extraction technique (Torres-Rodriguez et al., 2024).

Discontinuous Solvent Extraction Method

Mojonnier and Bligh and Dyer are lipid extraction methods that work according to the principle of the discontinuous solvent extraction method, which is a lipid extraction method carried out without continuous solvent circulation during the process. Both methods rely on the principle of gradually and manually separating lipids from the sample matrix using organic solvents. All stages, from solvent mixing and phase separation to evaporation, are carried out without repeated solvent flow to obtain pure fat, which is then calculated from the weight difference before and after the evaporation process (Nielsen & Ismail, 2024; Zhou et al., 2022). The crude fat content of the sample is usually the outcome of the extraction process (Samoo et al., 2022).

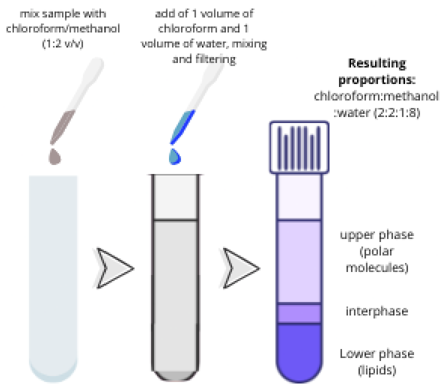

Figure 2. Bligh and Dyer Extraction
Source: Redrawn from Sündermann et al., (2016)

The Mojonnier method uses various types of organic solvents, namely ammonium hydroxide, ethanol, diethyl ether, and petroleum ether. Ammonium hydroxide is used first to release complexes of other components that are still bound to the sample at the start of extraction. Ethanol is added to prevent the formation of gels that could interfere with the extraction process. Diethyl ether acts as the primary solvent to extract the majority of fats, including semi-polar lipids. In order to extract the remaining non-polar lipids and eliminate any remaining water, petroleum ether is added last (Nielsen & Ismail, 2024; Tyasna, Agustin, Maharani, Utami, & Nurfadhilah, 2022). The Bligh and Dyer method uses a mixed solvent system consisting of both polar and non-polar (methanol and chloroform), to enhance the efficiency of extracting all lipid fractions through the formation of two phases, as shown in Figure 2 (Breil, Abert Vian, Zemb, Kunz, & Chemat, 2017; Nielsen & Ismail, 2024; Vasconcelos, Teixeira, Dragone, & Teixeira, 2018).

There are several advantages of the Mojonnier and Bligh and Dyer methods, including that the process does not require high temperature or pressure, making these methods widely used for analysing various types of samples (B. Chen & Ellefson, 2024). In addition, this method can extract lipids from multiple samples simultaneously in separate tubes, thereby increasing efficiency. The Bligh and Dyer method is efficient in terms of solvent use, as it requires low solvent consumption. The Bligh and Dyer method will effectively work on samples that have been homogenised in chloroform and methanol solvents, allowing for efficient extraction of total fat content (Nielsen & Ismail, 2024).

However, both methods also have the disadvantage of a risk of lipid loss during separation, as some lipids may be carried away, affecting the final calculation of total lipids. The Bligh and Dyer method tends to yield lower extraction results in products estimated to contain more than 2% fat due to differences in physical and chemical properties. In addition, chloroform solvents are toxic and costly (Moneeb, Hammam, Ahmed, Ahmed, & Alsaleem, 2021; Zhou et al., 2022).

Modern Lipid Analysis

Modern methods for analysing total lipid content are generally grouped into three main types according to the operational principles of the instruments used: chromatographic methods, spectroscopic techniques, and pressurized extraction systems. Every technique has unique features that affect the analysis's speed, precision, and effectiveness. This section discusses destructive modern methods such as Supercritical Fluid Extraction (SFE), Microwave-Assisted Extraction (MAE), and Pressurized Liquid Extraction (PLE), as well as non-destructive approaches like Near-Infrared Spectroscopy (NIRS), including their principles, advantages, and limitations.

Supercritical Fluid Extraction Method

Utilizing supercritical carbon dioxide ($ScCO_2$), Supercritical Fluid Extraction (SFE) is a sophisticated technique used to separate substances with different polarities, including both polar and non-polar molecules. A supercritical fluid, as seen in Figure 3, combines the characteristics of gases and liquids. Its gas-like viscosity and diffusivity enhance mass transfer efficiency, while its liquid-like density promotes exceptional solubility. A substance enters the supercritical phase when subjected to temperatures and pressures above its critical point, leading to significant changes in its physical and thermodynamic properties (Dimić et al., 2021).

Supercritical Fluid Extraction (SFE) operates optimally under high temperature and pressure conditions when using solvents such as supercritical CO_2 ($ScCO_2$). At its critical point, CO_2 exhibits increased density, enhancing lipid solubility and allowing it to penetrate complex sample matrices more effectively. After completing the extraction, the CO_2 undergoes depressurisation and cooling, allowing it to revert to its gaseous state. The configuration of the SFE system is illustrated in Figure 3 (Pinto et al., 2024).

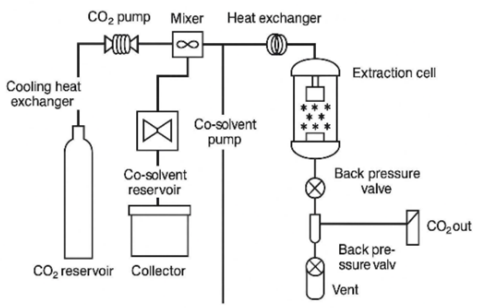

Figure 3. Supercritical Fluid Extraction System
Source: Redrawn from Khalil et al., (2021)

$ScCO_2$ is widely recognised as the preferred supercritical fluid owing to its non-toxic nature, safety profile, environmental compatibility, high purity availability, affordability, and relatively mild critical conditions (31.4 °C and 74.8 bar). Supercritical fluid extraction (SFE) is predominantly utilised to isolate compounds that are soluble in $ScCO_2$, particularly lipophilic substances. Given that the polarity of $ScCO_2$ closely resembles that of toluene, it supports an efficient extraction mechanism (Dimić et al., 2021). SFE offers targeted selectivity for separating lipid fractions from complicated matrices by utilizing the unique solvating properties of supercritical fluids. Consequently, this technique is regarded as a green and effective approach for extracting total lipids, cholesterol, essential oils, and other non-polar lipid components (Sprick, Linghu, Amamcharla, Metzger, & Smith, 2019).

Lipid content has been extracted using the SFE method from sources such *Schizochytrium* sp., *Chlorella vulgaris*, and *Pouteria lucuma* seeds (Chauca-Cerrutti, Inga, Pasquel-Reátegui, Betalleluz-Pallardel, & Puma-Isuiza, 2024; Khorramdashti, Samipoor Giri, & Majidian, 2021; Rodríguez-España et al., 2022). Sample preparation, such as for *Labisia pumila* leaves, involves drying the sample to constant weight, followed by size reduction to particles ranging from 0.5–0.8 mm (Radzali, Markom, & Md Saleh, 2022). The SFE method yields crude fat as the main extract (Chauca-Cerrutti et al., 2024).

SFE presents several limitations, as it is less suitable for extracting lipids from wet samples or matrices rich in polar lipids (Alwazeer et al., 2023). In addition, the technique requires substantial investment in specialised equipment and involves relatively high energy consumption. Despite these drawbacks, SFE offers notable advantages, including its environmentally friendly profile, flexibility in optimising extraction conditions through pressure and temperature adjustments, and enhanced extraction efficiency when CO_2 is combined with auxiliary solvents. These characteristics enable SFE to perform effectively in isolating a wide range of bioactive compounds (Armenta, Esteve-Turrillas, Garrigues, & de la Guardia, 2022; Perez-Vazquez et al., 2023). As a result, among both traditional and contemporary lipid extraction procedures, SFE is regarded as one of the most sophisticated and successful approaches. A comparative overview of the best-performing conventional and modern methods, namely Soxhlet and SFE, is presented in Table 1.

Table 1. Comparison of the Best Conventional and Modern Methods

Parameter	Soxhlet	Supercritical Fluid Extraction
Principle	Soxhlet extraction uses a solvent that is repeatedly heated and condensed, allowing its vapor to cycle through the sample and gradually extract lipids until fully recovered	Supercritical Fluid Extraction (SFE) uses supercritical carbon dioxide ($ScCO_2$) to extract both polar and non-polar compounds efficiently
Advantage	High extraction efficiency, particularly for solid samples, and solvent recycling during the extraction process	Mix CO_2 with co-solvents to potentially increase extraction yields, and modify temperature and pressure to customize extraction results
Disadvantage	Time-consuming, high-temperature (>70°C), solvent-related environmental concerns, and limited to solid-liquid systems	High equipment costs, high energy use, and limited suitability for wet or polar lipid-containing samples

Microwave Assisted Extraction

The extraction technique known as Microwave Assisted Extraction (MAE) measures the total lipid content by using microwave radiation (Khalfi, Garrigós, Ramos, & Jiménez, 2024). During the extraction process, the energy from microwaves can raise the temperature and pressure, which aids in the breakdown of the sample's intricate structure. As a result, the release of lipids from food products becomes easier and more efficient (de la Fuente et al., 2022). The schematic illustration of the MAE system used in this method is shown in Figure 4.

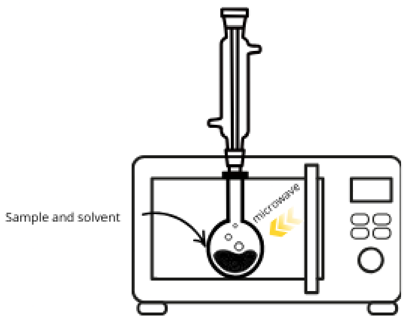

Figure 4. Microwave Assisted Extraction System
Source: Redrawn from dari Saifullah et al., (2021)

In the MAE method, n-hexane is used as an effective non polar solvent for lipid extraction. Meanwhile, the water in the sample absorbs microwave energy, increasing temperature and pressure. This rise facilitates the release of lipids into the hexane solvent by dissolving complicated linkages and cell walls (de la Fuente et al., 2022; Lourenço, Ettlin, Cardoso, & Rodilla, 2021).

The MAE method can be used for various sample types, but solid samples require pretreatment. Before the extraction process, solid samples can first be divided into smaller pieces to facilitate extraction. Then, the samples can be crushed so that the solvent can easily reach all parts of the sample. In order to improve contact between the sample and the solvent and enable more efficient extraction, this sample preparation is crucial (Akondi, Trexler, Pfiffner, Mouser, & Sharma, 2017; Lourenço et al., 2021).

MAE offers several advantages over conventional methods. Using a little amount of solvent is one of its primary benefits. Additionally, MAE can operate efficiently because the extraction process is rapid and requires less energy (Khalfi et al., 2024; Solaberrieta, Mellinas, Jiménez, & Garrigós, 2022).

Although MAE has several advantages, this method is also has several disadvantages. The weakness of the MAE method is that it uses toxic solvents (Kapoore, Butler, Pandhal, & Vaidyanathan, 2018). Also, there are limitations on the use of solvent because not all are compatible with microwaves (Lourenço et al., 2021).

Pressurized Liquid Extraction Method

In order to increase the effectiveness of lipid extraction from a variety of samples, Pressurized Liquid Extraction (PLE) uses liquid solvents at high temperatures and pressures (de Souza Mesquita et al., 2023). This technique enhances solvent penetration into the sample matrix, thereby significantly accelerating lipid release. Temperature is one of the most important variables in PLE since it influences the solvent's viscosity as well as the molecules' diffusivity (Dobroslavić et al., 2022). In practice, PLE applies high temperature and pressure to solid or semi-solid matrices and their solvents, aiming to boost lipid solubility, facilitate mass transfer, and ultimately increase extraction performance, making the process faster and more efficient as shown in Figure 5. (Blanco-Llamero & Señoráns, 2021; Chatzimitakos et al., 2024).

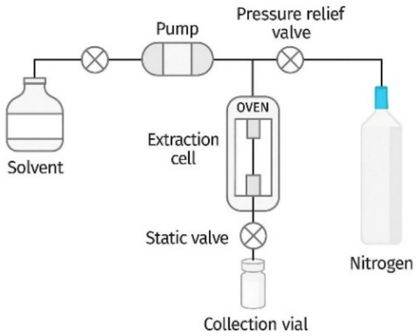

Figure 5. PLE Scheme
Source: Redrawn from Soriano et al., (2024)

Various factors, including solvent type, extraction temperature, applied pressure, and duration, can be modified to improve extraction efficiency depending on the sample matrix (Dobroslavić et al., 2022). Typically, PLE operates at 50–200 °C and 35–200 bar, allowing the solvent to stay liquid close to the supercritical zone (Agarwalla, Komandur, & Mohanty, 2023). These operational conditions substantially lower the solvent's surface tension and viscosity, which helps to shorten extraction times and use less solvent (Picot-Allain, Mahomoodally, Ak, & Zengin, 2021).

Before lipid extraction using PLE, the sample must undergo a preparation stage. In the case of spirulina, the preparation begins with drying using a freeze-dryer to reduce moisture content, followed by particle size reduction using a grinder (Zhou et al., 2021). Meanwhile, for *Perilla frutescens* L. leaves, lipid extraction preparation involves cutting the leaves into small pieces, drying them in an oven, and then grinding them until the particle size is less than 710 µg (Thy, Diep, Dung, & Dat, 2022).

A key benefit of Pressurized Liquid Extraction (PLE) lies in its potential for scale-up in large-scale production, alongside its efficiency in minimising solvent consumption, extraction duration, energy usage, and making it more environmentally friendly (Dobroslavić et al., 2022). This method also enables concurrent purification inside the extraction cell and delivers high extraction efficiency by utilising liquid solvents at temperatures exceeding their boiling points. However, PLE has several disadvantages (Soriano et al., 2024).

It requires high energy input due to heating and pressurization, and relies on costly consumables such as stainless steel cells, filters, and other single-use components made from inert materials. Moreover, the process demands a significant amount of nitrogen gas, further increasing operational costs (Soriano et al., 2024).

Near-Infrared Spectroscopy Method

The technique known as near-infrared spectroscopy (NIRS) is based on the absorption of electromagnetic waves in the near-infrared region, more precisely in the wavelength range of 780–2500 nm (da Silva Medeiros et al., 2022). As NIR light interacts with the sample, lipid molecules exhibit vibrational transitions within specific bond types—namely C–H, C=O, and O–H—which generate a distinct spectral pattern. This spectrum includes overtone and combination modes (Thilakarathna, Madhusankha, & Navaratne, 2022). Unlike traditional chemical procedures, NIRS works well for quantitative lipid analysis without requiring huge amounts of extraction solvents (Lim et al., 2022; Marcheafave et al., 2025). In Figure 6, the NIRS scheme is displayed.

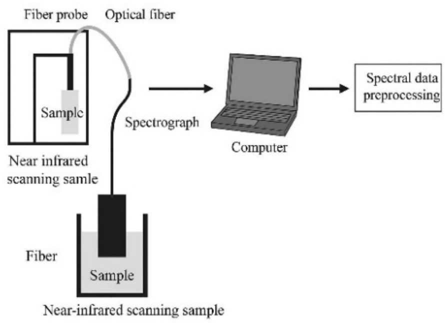

Figure 6. NIRS Scheme
Source: Redrawn from Chen et al., (2021)

Before to analysis, a calibration model must be established using reference samples to ensure the accuracy of NIRS measurements. Typically, standard samples with known lipid content are used for this purpose (Mishra et al., 2021). In addition, an initial sample preparation step is often necessary—for example, pine seeds are ground using a grinder to reduce particle size prior to testing (Khouja et al., 2022). The calibration model is typically built using Partial Least Squares Regression (PLSR), which correlates spectral data with lipid concentration (Cazzaniga et al., 2022). Once calibration is complete, the model can be applied to analyse lipid content in various samples by comparing their absorbance capability to the regression model (Heise, Delbeck, & Marbach, 2021).

The main benefits offered by NIRS are its ability to perform fast and non-destructive analyses, and its applicability to solid, liquid, and semi-solid samples (Kröncke, Wittke, Steinmann, & Benning, 2023). NIR radiation can penetrate deeper into the sample (several millimetres to centimetres), permitting greater sample amounts to be analysed (Beć, Grabska, & Huck, 2021). Furthermore, NIRS makes it possible to analyze particular lipid fractions, such as phospholipids, free fatty acids, and triglycerides (Afseth et al., 2022; Cebi, Bekiroglu, & Erarslan, 2023; Ripoll et al., 2021). Furthermore, this method provides faster results and does not require the small sample sizes typically needed in Fourier Transform Infrared (FTIR) spectroscopy (Ahmad et al., 2024; Circelli et al., 2024).

NIRS has been widely applied in various fields. It is used to determine total lipid content in pine seeds, measure triglycerides in olive oil, and analyse EPA and DHA fatty acids in salmon (Folli et al., 2022; Khouja et al., 2022; Lintvedt et al., 2023). Despite its effectiveness, NIRS has limitations, particularly the need for specific calibration for each sample type and a strong reliance on accurate predictive models (Mishra et al., 2021).

CONCLUSION

There are various methods for determining total lipids, ranging from conventional to advanced techniques. Conventional techniques including continuous, semi-continuous, and discontinuous extraction are straightforward, economical, and frequently time-consuming. However, although they require more expensive equipment, modern techniques like SFE, MAE, PLE, and NIRS yield better results more quickly. Among these, SFE stands out as the most due to its precision, selectivity, and strong environmental performance. It uses non-toxic CO_2 as the solvent, making it the most environmentally friendly option overall.

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