Chapter

Polyphenol Extraction for the Enhancement of Food Lipid Quality, with an Emphasis on the Roles of Extraction Technologies, Moisture and Drying Temperature

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Abstract

Polyphenols increase food lipid quality, the taste, stability, and health advantages of lipids in different dietary applications. Polyphenol content depends on the extraction process, moisture, and drying temperature. Polyphenol due to antioxidant and antibacterial capabilities, natural compounds, are used to improve dietary lipid quality. However, polyphenol extraction has been a very challenging task that has caused drawback in the fortification of food lipid. Extraction process of polyphenol and solvent, solid-phase, and supercritical fluid extraction techniques has been analysed. Moisture and drying temperature affect extraction efficiency quality. Optimised polyphenol extraction in the connections between polyphenols, extraction technique, moisture, and drying temperature needs to be more examined. Polyphenols role in dietary lipid quality is discussed, and food source polyphenol content needs to be well researched. Drying temperature impacts extraction efficiency as it was carried out in previous research, and moisture content affects polyphenol solubility. Polyphenol extraction improves lipid quality in olive oil enrichment, meat, poultry, dairy, nutritional supplements, and bread and confectionery goods. Stability, extraction efficiency, selectivity, standardisation, sustainability, and industrial adoption are still issues. Stability, preservation, green extraction, and industrial scalability are research priorities. Complicated interactions need to be understood for future research directions in polyphenol extraction for lipid quality enhancement.

Keywords: extraction, lipid, quality, storability, ultrasonic

1. Introduction

Food lipid quality plays an essential role in determining the sensory attributes, nutritional content, and shelf life of various food products. Lipids are a concentrated source of energy and vital fatty acids and enhance the flavour, texture, and fragrance of food. However, lipids can deteriorate due to oxidation, which can cause rancidity, bad flavours, and nutritional loss. Therefore, it is essential to maintain and improve the quality of food lipids in order to satisfy consumers and advance general health.

Recently, there has been a rise in interest in using natural substances to enhance the quality of dietary lipids. Among these substances, polyphenols have emerged as important bioactive elements known for strong antioxidant and antibacterial capabilities. Because of capacity to scavenge free radicals and suppress oxidative processes, polyphenols which are widely prevalent in fruits, vegetables, nuts, and other plant-based sources have been recognised for positive impacts on human health [1, 2].

To carefully examine the extraction methods used to extract polyphenols, such as solvent extraction, solid-phase extraction, and supercritical fluid extraction, in order to provide a thorough understanding [3, 4]. Examine at how moisture and drying temperature affect polyphenol extraction effectiveness and how that affects the quality of food lipids [5, 6]. will also look at how these variables interact and how it affects lipid quality improvement and the efficiency of polyphenol extraction [7, 8].

For the extraction process to be optimised and the full potential of polyphenols to improve the quality of food lipids to be realised, it is essential to comprehend the complex interactions between polyphenols, extraction technology, moisture, and drying temperature. This chapter intends to shed vital light on these linkages for researchers, food scientists, and industry experts interested in using polyphenols as natural additives to enhance lipid quality.

1.1 Definition of polyphenols and importance in food lipid quality improvement

Polyphenols are a broad class of bioactive compounds found abundantly throughout different plant-based sources of nutrition, including fruits, vegetables, whole grains, legumes, and herbs. These substances have drawn a lot of interest because of possible health advantages and contribution to improving food lipid quality. The definition of polyphenols, significance in enhancing the quality of dietary lipids, and the interaction between moisture, drying temperature, and extraction method in polyphenol extraction from food sources will all be covered in this book chapter.

2. Overview of the role of moisture, drying temperature, and extraction technology in polyphenol extraction from food sources

The presence of numerous phenolic groups distinguishes polyphenols, a general family of secondary metabolites found in plants. Flavonoids (flavones, flavonols, flavanones, etc.), phenolic acids (hydroxybenzoic acids, hydroxycinnamic acids), stilbenes, lignans, and tannins are some of the subclasses into which these chemicals are divided (**Figure 1**). According to Perino-Issartier et al. [10], each subclass has distinct biological and chemical characteristics. The Importance of Polyphenols in the Improvement of Food Lipid Quality Polyphenols have been thoroughly investigated for ability to improve food lipid quality. They have exceptional antioxidant qualities that can prevent lipid oxidation, which is the main factor in the rancidity and degeneration of lipid-based foods. Lipid oxidation causes sensory alterations, such as off flavours and colour deterioration,

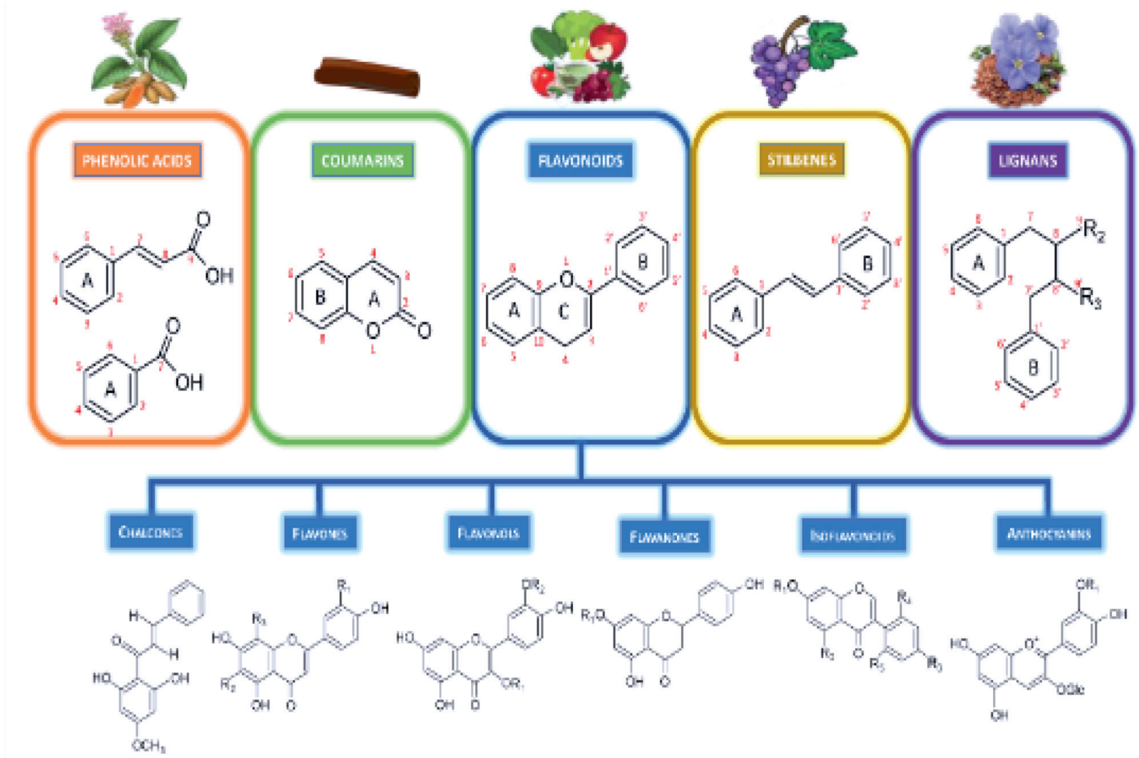

Figure 1.
Plant polyphenol classification (source: Golmakani et al. [9]).

as well as the loss of vitamins and important fatty acids, which lowers the food's nutritional value [11]. In order to successfully prevent oxidative damage and increase the shelf life of foods containing lipids, polyphenols work as free radical scavengers, chelators of pro-oxidant metal ions, and regulators of lipid peroxidation [12].

2.1 Moisture and polyphenol extraction

The amount of moisture in raw materials has a big influence on how well polyphenols are extracted. Water can make polyphenols more soluble, facilitating release from the food matrix during extraction. However, too much moisture can also cause enzymatic and non-enzymatic processes that cause polyphenols to degrade and disappear. In order to maximise the yield of polyphenol extraction and maintain the quality of the end product, moisture content must be well controlled [13].

Drying Temperature and Polyphenol Extraction: Another important factor that affects polyphenol extraction is drying temperature. By making polyphenols more solubilised and diffusible, higher temperatures can quicken the extraction process. However, too much heat can also result in bioactivity loss and thermal deterioration. In order to maximise polyphenol extraction efficiency while maintaining veracity, it is crucial to determine the ideal drying temperature [6, 7].

2.2 Polyphenol extraction and extraction technology

To effectively recover polyphenols from dietary sources, a variety of extraction processes are used. Common techniques include solvent extraction, solid-phase extraction, and supercritical fluid extraction (**Figure 2**). Solid-phase extraction

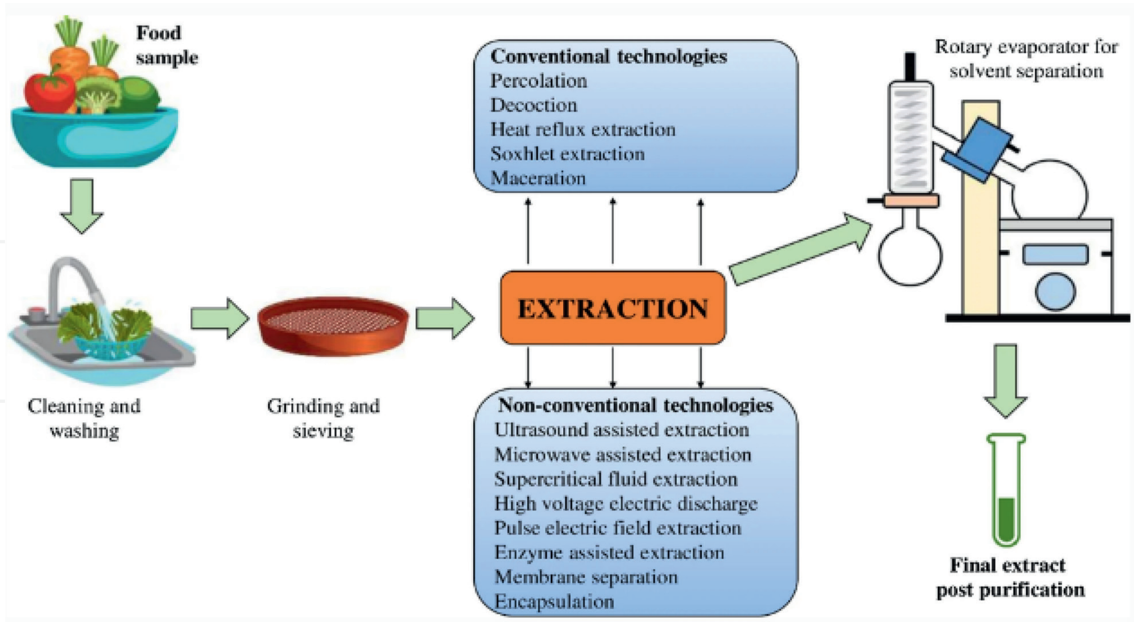

Figure 2.
Polyphenol extraction techniques and methods (source Sridhar et al. [14]).

makes use of solid adsorbents to selectively capture target chemicals, whereas solvent extraction uses organic solvents to extract polyphenols.

Polyphenols are extracted using supercritical fluids, such as carbon dioxide, under carefully regulated circumstances. The extraction yield, selectivity, and cost-effectiveness are all impacted by the benefits and limits of each approach [5, 15, 16]. The antioxidant abilities, how they affect sensory qualities, and how they can make lipid-based foods last longer on store shelves. How moisture content and drying temperature affect the effectiveness of polyphenol extraction and the preservation of bioactivity. For the [17] extraction process to be optimised and the full potential of polyphenols to enhance food lipid quality to be realised, it is essential to comprehend how moisture, drying temperature, and extraction technique interact. This chapter tries to clarify these interactions in order to offer helpful information to researchers, food scientists, and business experts who are considering using polyphenols as all-natural substances to improve lipid quality.

2.3 Factors affecting polyphenol content in food sources

Several factors, including genetic variation, agricultural practises, environmental conditions, and post-harvest processing, influence the polyphenol content of food sources. For optimising polyphenol extraction and ensuring the quality of polyphenol-rich products, it is essential to comprehend these factors.

2.3.1 Genetic variation

The polyphenol content of various plant varieties or cultivars varies. Genetic factors play an important role in determining the types and amounts of polyphenols present in different plant species [18].

2.3.2 Agricultural practises

Agricultural practises, such as fertilisation, irrigation, and pesticide application, can affect the polyphenol content of food sources. Montesano et al. [19] report that organic farming methods and sustainable agricultural practises increase polyphenol levels compared to conventional methods. The environment, including climate, exposure to sunlight, and soil composition, can have an effect on polyphenol synthesis in plants. As a defence mechanism against oxidative stress, increased ultraviolet (UV) radiation exposure can stimulate the synthesis of certain polyphenols [20].

3. Influence of moisture content on the extraction of polyphenols from food sources

Moisture content serves a crucial function in the extraction of polyphenols from food sources. It influences the extraction process's solubility, stability, and release of polyphenols. Understanding the effect of moisture content is crucial for optimising extraction efficacy and maintaining polyphenol integrity.

3.1 Solubility and diffusion

According to Kahraman et al. [21], moisture can increase the solubility and diffusion of polyphenols from the food matrix into the extraction solvent, resulting in a higher extraction efficiency.

3.2 Enzymatic reactions

Excessive moisture content can cause enzymatic reactions, such as polyphenol oxidase activity, which result in the degradation and loss of polyphenols during extraction [21].

4. Mechanisms of polyphenol degradation and oxidation under various conditions of humidity

Polyphenols are susceptible to degradation and oxidation under certain conditions of moisture. The presence of water can initiate chemical reactions that compromise polyphenols' stability and bioactivity. Moisture can catalyse hydrolysis reactions, resulting in the dissolution of glycosidic bonds and the release of aglycones. This procedure can alter polyphenols' composition and bioactivity.

Moisture can stimulate oxidative reactions, leading to the oxidation of polyphenols and the production of reactive oxygen species. These reactions can reduce polyphenols' antioxidant capacity [12, 21].

4.1 Moisture control strategies for polyphenol extraction

Drying and Pre-treatment Methods: Controlling the moisture content is crucial for optimising the extraction of polyphenols. Various techniques, such as dehydrating and pretreatment procedures, can be used to control moisture levels and improve extraction efficacy.

Drying is frequently employed to minimise the moisture content of dietary sources prior to extraction. Freeze-drying, air drying, and microwave drying are all effective techniques for removing moisture while maintaining polyphenol integrity [22].

Pre-treatment Methods: Pre-treatment methods, such as blanching, steaming, and marinating, can be used to modify the moisture content and structure of food sources, thereby facilitating the release of polyphenols during extraction [13].

5. Examples of food applications utilising polyphenol extraction for lipid quality enhancement

Various food applications have effectively utilised polyphenol extraction to improve lipid quality. These applications demonstrate the ability of polyphenols to enhance the sensory qualities, stability, and health-promoting properties of lipids. The following instances illustrate the efficacy of polyphenol extraction in various food contexts:

Olive Oil Enrichment Olive oil has been enriched with polyphenol-rich compounds derived from olive pomace or leaves. The incorporation of these extracts increases the lipid content of the oil by enhancing its oxidative stability and antioxidant capacity [19, 23].

Incorporating polyphenol extracts into meat and poultry formulations can improve lipid stability and prevent lipid oxidation [24, 25]. These extracts function as natural antioxidants, preventing the formation of rancid flavours and preserving the overall quality of the products.

To enhance the lipid quality of dairy products, polyphenol extracts from sources such as grape seeds and berry pomace have been added [26, 27]. These extracts can improve the oxidative stability and inhibit the development of off-flavours in dairy products such as yoghurt, cheese, and butter.

Polyphenol-rich extracts have been incorporated into the formulation of nutritional supplements, particularly those that target lipid metabolism and cardiovascular health. These extracts, derived from green tea, cocoa, or citrus fruits, contribute to the positive effects of supplements on lipid profiles and oxidative stress markers [28, 29].

Bakery and Confectionery Products: Polyphenol compounds have been added to bakery and confectionery products to improve lipid quality and extend storage life [30, 31]. These extracts can inhibit lipid oxidation and enhance overall oxidative stability, thereby preserving the sensory attributes and freshness of the products.

The impact of dietary polyphenols on gut microbiota compositions and how gut microbiota affect polyphenol metabolism are the main possible mechanisms of the gut microbiome. In combination, dietary polyphenols could be a helpful nutritional strategy for modifying lipid metabolism or treating obesity [32]. According to studies by [33], dietary TP appears to have had a major role in activating lipolysis and enhancing lipid metabolism in grouper given high-fat diets. For enhancing lipid metabolism in juvenile grouper high-lipid diets, 0.045–0.067% was advised based on the broken-line regressions analysis of the serous LDL and hepatic VLDL contents. [34] The effects of TP concentration (0, 100, and 400 mg/L), solution pH (3 and 7), and the addition of ethylenediaminetetraacetic acid (0 or 20 mol/L EDTA) were investigated on the antioxidant/prooxidant activities of TP in walnut oil-in-water

(O/W) emulsions under accelerated storage conditions (50°C for 0, 48, and 96 h). At pH 3, TP concentrations of 100 mg/L and 400 mg/L both showed better antioxidant activity for lipids and proteins, respectively.

6. Challenges and future perspectives polyphenol extraction

Despite the significant advancements in polyphenol extraction for augmenting food lipid quality, a number of obstacles and opportunities exist for future research and application. This section discusses a few of these obstacles and offers prospective future perspectives.

6.1 Stability and preservation

The stability of polyphenols during processing, storage, and in the presence of other food components is one of the greatest obstacles to utilising polyphenols to enhance lipid quality. Polyphenols are susceptible to degradation and oxidation, which result in diminished efficacy and bioactivity. Strategies to improve polyphenol stability, such as encapsulation techniques and the development of protective delivery systems, require investigation [35, 36].

Although numerous extraction techniques have been devised, achieving high extraction yield and efficiency remains a challenge. Optimal polyphenol extraction necessitates the optimization of extraction parameters, the selection of suitable solvents, and the investigation of innovative extraction techniques [37].

The selective extraction of particular polyphenols from complex food matrices is a challenge that must be addressed. Different polyphenols exhibit distinct bioactivities, and the extraction selectivity of these polyphenols can affect the final product's desired functional properties. It is of interest to develop extraction methods that target specific polyphenols while preserving integrity [27, 37].

6.2 Standardisation and quality control

Standardisation of polyphenol extraction protocols and the establishment of quality control measures are required to ensure consistent and reliable extraction results. The development of analytical methods and the establishment of quality standards will contribute to the reproducibility and comparability of research findings [38].

6.3 Sustainability and green technologies

As the demand for sustainable and environmentally benign practices increases, it is necessary to develop green extraction technologies that minimise energy consumption, solvent usage, and refuse production. The investigation of alternative solvents, such as supercritical fluids and natural deep eutectic solvents, can provide environmentally preferable alternatives for polyphenol extraction [39].

6.4 Industrial implementation and scalability

Although polyphenol extraction techniques have demonstrated promise in laboratory studies, implementation on an industrial scale poses challenge [40]. Scaling up the extraction process while maintaining its efficacy, cost-effectiveness, and product quality requires additional research and development.

Future research need to concentrate on addressing these obstacles and investigating new opportunities in polyphenol extraction for the enhancement of lipid quality. The development of advanced extraction technologies, the investigation of synergistic effects of polyphenols with other bioactive compounds, and the application of computational modelling and artificial intelligence to optimise extraction processes are potential future research directions [30].

Despite the progress made in the extraction of polyphenols to improve the lipid quality of foods, several challenges and future perspectives remain. Key areas requiring attention include stability and preservation, extraction efficiency, selectivity and specificity, standardisation and quality control, sustainability and green technologies, industrial implementation, and scalability. Addressing these obstacles and investigating new research avenues will pave the way for advances in polyphenol extraction techniques and contribute to the development of lipid-based food products with enhanced health benefits.

6.5 Challenges

While the extraction of polyphenols for improving food lipid quality holds great promise, there are several challenges that need to be addressed. One major challenge is the variability of polyphenol content in different food sources. The composition and concentration of polyphenols can vary significantly, making it challenging to establish standardised extraction protocols. Additionally, the stability of polyphenols during extraction and processing can be compromised due to sensitivity to environmental factors, such as light, heat, and pH.

Another challenge is the selection of appropriate extraction technologies. Various extraction methods, including conventional techniques (solvent extraction) and emerging green technologies (supercritical fluid extraction, ultrasound-assisted extraction), are available. However, the choice of the most suitable extraction method depends on factors such as the target polyphenol, the food matrix, the desired yield, and the cost-effectiveness of the process. Optimization of extraction conditions is crucial to achieve high extraction efficiency and preserve the integrity of polyphenols.

Furthermore, the scale-up of polyphenol extraction processes from lab-scale to industrial scale presents challenges. Industrial production requires higher through put and cost-effective operations, while maintaining the quality and bioactivity of extracted polyphenols. Ensuring scalability and reproducibility while meeting regulatory requirements can be demanding.

6.6 Future perspectives

Despite the challenges, there are several exciting future research directions that can advance the field of polyphenol extraction and its application in enhancing food lipid quality.

One area of interest is the development of novel extraction techniques that offer improved efficiency, selectivity, and sustainability. Techniques such as microwave-assisted extraction, enzyme-assisted extraction, and pulsed electric field extraction show promise in enhancing polyphenol extraction yields and reducing processing time and solvent consumption.

The utilisation of by-products and waste materials as potential sources of polyphenols is gaining attention. Researchers are exploring the valorisation of agricultural residues, food processing by-products, and plant waste materials for the extraction of polyphenols. This approach not only reduces waste but also offers economic and environmental benefits.

The application of advanced analytical techniques for the characterisation of polyphenols is another avenue for future research. High-performance liquid chromatography (HPLC), gas chromatography–mass spectrometry (GC–MS), and nuclear magnetic resonance (NMR) spectroscopy enable the identification and quantification of specific polyphenols and metabolites, providing insights into bioavailability and potential health benefits.

Furthermore, the development of encapsulation technologies for polyphenols can improve stability and controlled release in food products. Encapsulation techniques, such as spray drying, coacervation, and Nano emulsion, protect polyphenols from degradation and enhance functionality in food matrices.

In the challenges related to polyphenol extraction, such as variability in polyphenol content, selection of suitable extraction technologies, and scalability, is essential for the successful implementation of polyphenols in improving food lipid quality. Future research efforts should focus on the development of novel extraction techniques, utilisation of by-products, advanced analytical characterisation, and encapsulation technologies. By overcoming these challenges and exploring new opportunities, the field of polyphenol extraction can advance, leading to innovative and sustainable approaches for enhancing food lipid quality.

7. Future research directions in polyphenol extraction for lipid quality enhancement

The goal of ongoing research into polyphenol extraction is to further enhance the process's efficacy, sustainability, and scalability. The following are possible directions for future research in this field:

Enzyme-assisted extraction, intermittent electric fields, and pressurised liquid extraction are a few of the novel extraction techniques being investigated by scientists. These techniques offer benefits such as reduced extraction time, increased yield, and improved bioavailability of polyphenols [41, 42].

Further optimisation of extraction parameters, such as solvent selection, extraction time, temperature, and pressure, can assist in maximising polyphenol yield and quality. Design of experiments (DoE) and response surface methodology (RSM) are important optimisation tools for these extraction procedures [28, 38].

7.1 Advances in encapsulation techniques

Encapsulation of polyphenols can enhance stability and bioavailability, allowing them to be incorporated into a wider array of lipid-based products. For the development of effective delivery systems, nanoparticles, microencapsulation, and emulsion based systems are of interest [27, 39].

7.2 Exploration of underutilised sources

Research into underutilised plant sources abundant in polyphenols can increase the availability of renewable resources for extraction. By utilising these sources, researchers can discover novel polyphenols with distinct properties and optimise extraction techniques [30, 40].

7.3 Considerations regarding the sustainability and scalability of polyphenol extraction

As the demand for polyphenols rises, it is crucial that extraction processes consider sustainability and scalability, particularly for industrial applications. Important factors include:

The development of environmentally favourable extraction techniques that minimise solvent usage, energy consumption, and refuse production is crucial. Bashari et al. [41] and Chiorcea-Paquim et al. [42] report that subcritical water extraction, solid phase extraction, and green solvents contribute to the sustainability of polyphenol extraction.

Utilising by-products generated during the extraction process, such as fruit husks, pomace, and seed residues, reduces waste and improves the economic viability of extraction. The overall sustainability of the process can be improved by extracting polyphenols from these by-products [43, 44].

Life Cycle Assessment: Conducting life cycle assessments (LCAs) of polyphenol extraction processes allows for the evaluation of environmental impacts throughout the entire lifecycle, from the production of primary materials to extraction and refuse management. LCAs provide insightful information for optimising processes and making informed decisions [45, 46].

8. Conclusion

This chapter examines the definition of polyphenols and significance in enhancing the lipid quality of food. It has investigated the role of moisture, dehydrating temperature, and extraction technology in the extraction of polyphenols from food sources. In addition, the factors influencing polyphenol content, the effect of moisture on extraction, the mechanisms of polyphenol degradation, strategies for moisture control, and the intricate interactions between polyphenols, extraction technology, moisture, and drying temperature. In addition, examples of effective food applications in which polyphenol extraction was used to improve lipid quality.

The primary findings of this chapter emphasise the significant impact of polyphenol extraction techniques on the need for improvement as limited research finding are available. Polyphenols have been shown to enhance the sensory qualities, stability, and health-promoting properties of lipids in a variety of food applications. By incorporating polyphenol extracts into olive oil, meat and poultry products, dairy products, dietary supplements, and bakery and confectionary products, lipid stability and oxidative stability can be improved, resulting in enhanced overall quality and a longer shelf life.

In addition, this chapter has illuminated the significance of moisture, dehydrating temperature, and extraction technology in polyphenol extraction processes. Controlling the moisture content is essential for preventing polyphenol degradation and oxidation, as it plays a vital role in extraction efficiency. Moisture can be effectively controlled and polyphenol extraction optimised using techniques such as dehydration and pre-treatment.

Future research directions in polyphenol extraction for the enhancement of lipid quality include the development of novel extraction techniques, optimisation strategies, advances in encapsulation techniques, and the exploration of underutilised sources. These developments seek to improve the efficacy, sustainability, and scalability of polyphenol extraction processes, resulting in higher extraction yields and higher-quality polyphenols for a variety of applications.

The extraction of polyphenols has significant implications for the food industry. The incorporation of polyphenol-rich extracts into food products is a natural and sustainable method for improving lipid quality, oxidative stability, and lipid oxidation inhibition. This not only contributes to the sensory qualities and expiration life of food products but also provides consumers with potential health benefits.

By utilising the power of polyphenols, the food industry can enhance the quality and stability of lipid-based products, thereby providing consumers with healthier and more appetising options.

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