

Review

Microencapsulation of Polyphenols and Their Application in Food Technology

Weronika Bińkowska ^{*}, Arkadiusz Szpicer , Adrian Stelmasiak, Iwona Wojtasik-Kalinowska ^{*} and Andrzej Półtorak 

Department of Technique and Food Development, Warsaw University of Life Sciences—SGGW, Nowoursynowska Str. 159 C Building 32, Office 0120, 02-776 Warsaw, Poland; arkadiusz_szpicer@sggw.edu.pl (A.S.); adrian_stelmasiak@sggw.edu.pl (A.S.); andrzej_poltorak@sggw.edu.pl (A.P.)

^{*} Correspondence: weronika_binkowska@sggw.edu.pl (W.B.); iwona_wojtasik-kalinowska@sggw.edu.pl (I.W.-K.)

Abstract: Microencapsulation of polyphenols is an innovative approach in food technology by which to protect these bioactive compounds from degradation and increase their bioavailability. Polyphenols, naturally occurring in plants, exhibit potent antioxidant, anti-inflammatory and anticancer properties, which make them valuable functional ingredients in foods. However, their susceptibility to external factors, such as light, temperature and pH, presents a significant challenge for their incorporation into food products. Microencapsulation, based on various techniques and carriers such as polysaccharides, proteins and lipids, allows polyphenols to be stabilized and released in a controlled manner in the digestive system. This article reviews the different microencapsulation techniques, carrier properties, and the applications of microencapsulated polyphenols in food products, including bakery, dairy and functional beverages. Additionally, the article discusses the benefits and challenges associated with this technology, highlighting its potential to improve the stability, nutritional value and sensory acceptance of food products.

Keywords: polyphenol microencapsulation; encapsulation carriers; functional food; food fortification



Citation: Bińkowska, W.; Szpicer, A.; Stelmasiak, A.; Wojtasik-Kalinowska, I.; Półtorak, A. Microencapsulation of Polyphenols and Their Application in Food Technology. *Appl. Sci.* **2024**, *14*, 11954. <https://doi.org/10.3390/app142411954>

Academic Editor: Dimitris P. Makris

Received: 20 November 2024

Revised: 13 December 2024

Accepted: 19 December 2024

Published: 20 December 2024



Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Polyphenols are a diverse group of bioactive compounds naturally found in plants, where they play a crucial role in plant metabolism and serve as protective agents against oxidative stress. [1]. Moreover, these compounds are particularly valued for their health-promoting effects in humans, which include antioxidant, anti-inflammatory, anticancer, and cardiovascular protective properties. Consequently, polyphenols are increasingly utilized in food technology, both as natural preservatives and as functional ingredients that enhance the nutritional value of food products [2,3]. Despite their considerable potential, the application of polyphenols in the food industry presents several challenges. Notably, the primary issues stem from their instability when exposed to various factors, such as light, temperature, oxygen, or changes in pH, which can lead to a loss of bioactivity during the production, storage, and processing of food products. Furthermore, polyphenols often exhibit low bioavailability, limiting their effective absorption by the human body [4,5].

In response to these challenges, microencapsulation is a technology that offers a solution. This process involves enclosing active compounds, such as polyphenols, within microscopic capsules, which protect them from degradation, allow controlled release, and improve bioavailability [6]. Importantly, microcapsules can be produced using various materials, including polysaccharides, proteins, or lipids, which serve as protective barriers while enabling the controlled release of polyphenols under specific conditions, such as in the digestive system. Thus, it is possible to preserve the biological functions of polyphenols, and consequently their health benefits, even after prolonged storage or intensive processing [7]. In recent years, the microencapsulation of polyphenols has found a wide

range of applications in various sectors of the food industry. For example, microencapsulated polyphenols are used as ingredients in functional products, such as beverages, dairy products, and bakery items, where they serve both an enriching and a protective role [8]. Additionally, microencapsulation technology has been applied to enhance the shelf life of food products by inhibiting oxidative and microbial processes [9]. Consequently, microencapsulation not only improves the stability of polyphenols but also increases the value of food products, making them more attractive to consumers seeking healthy and durable food solutions [10].

Therefore, the aim of this review article is to discuss the technology of polyphenol microencapsulation, focusing on the various encapsulation methods and their applications within the food industry. Moreover, the health benefits of microencapsulated polyphenols and the future prospects of this technology will also be discussed.

2. Materials and Methods

For the literature review, the following search objective was defined: to assess the potential use of microencapsulated polyphenols in selected foods. The inclusion criteria included the use of microencapsulated polyphenols in the study, the use of specific food matrices (baked goods, dairy products, beverages and functional foods, dietary supplements) and the availability of a full publication in English. Studies that did not consider the above factors were excluded. The Google Scholar open access database and the PubMed, Scopus, Web of Science and ScienceDirect databases were used to search for articles. Articles were searched using various combinations of keywords, as follows: polyphenols, microencapsulation, functional food, functional beverage, dairy (milk, yogurt), bakery (baked, bread, cake, cookie), and supplement (dietary supplement). The review was based primarily on recent studies published since 2020. Data extraction included article data, study aim, methodology and results. Data were organized in a database using bibliographic tools. Data were searched, extracted and reviewed by a team of researchers.

3. Polyphenols: Properties and Significance in Food

3.1. Polyphenol Classification

Polyphenols are natural chemical compounds abundant in various plant-based foods and beverages, including fruits (e.g., berries, blackcurrants, grapes), vegetables (such as onions, peppers, and broccoli), tea (particularly green and black varieties), coffee, red wine, olive oil, and nuts. According to their chemical structure, they can be divided into groups of flavonoids, phenolic acids, and non-flavonoids, including tannins, stilbenes and lignans [11]. Flavonoids form the largest group of polyphenols, one which includes subclasses of compounds such as flavonols, flavones, flavanones, flavanols, isoflavones, and anthocyanins. Their main sources include spices, vegetables, fruits, tea, and wine. Phenolic acids are the second largest group of polyphenols. They are the derivatives of hydroxybenzoic acid and hydroxycinnamic acid. They are contained mainly in coffee, cereals and some fruits. Tannins are a group of polyphenols present in tea, red wine, dark chocolate and certain fruits such as berries and grapes. Due to their high ability to combine with proteins, they cause a characteristic astringent taste [12,13]. Stilbenes, including resveratrol, are found mainly in red wine and certain berries such as blueberries and cranberries. Lignans are present in large quantities in flaxseed, as well as in seeds, nuts, whole grains and vegetables [14,15]. The main polyphenolic compounds and their food sources are presented in Figure 1.

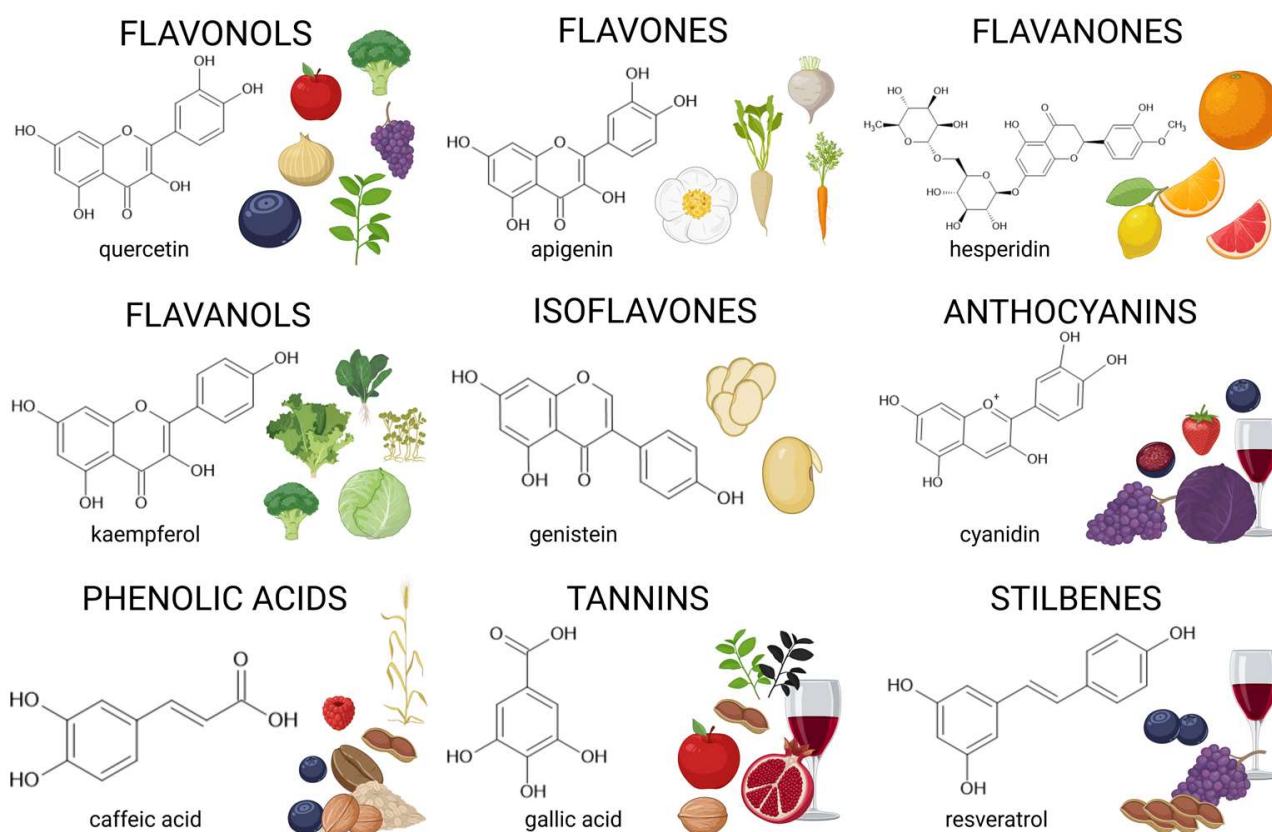


Figure 1. Key polyphenolic compounds and food sources thereof (created in BioRender. Bińkowska, W. (2025) <https://BioRender.com/o80l442>; accessed on 13 December 2024).

3.2. Biological and Functional Properties of Polyphenols

Polyphenols are a diverse group of phytochemicals known for their potent antioxidant properties. They combat oxidative stress by neutralizing reactive oxygen species (ROS), such as hydroxyl radicals and superoxide anions, which can damage cellular components like DNA, proteins, and lipids. By scavenging ROS, polyphenols protect cells from the oxidative damage that can lead to aging and various diseases. In addition to direct ROS scavenging, polyphenols chelate transition metals such as iron and copper, which are involved in free radical generation through Fenton and Haber–Weiss reactions. This further reduces oxidative damage and enhances their protective properties [16,17]. Flavonoids, a major subclass of polyphenols found in foods like citrus fruits and green tea, are particularly effective in reducing oxidative stress. They do so by modulating the expression of antioxidant enzymes such as superoxide dismutase (SOD) and catalase, which play key roles in the cellular defence against ROS. For instance, flavonoids in green tea have been shown to increase the activity of these enzymes, thereby strengthening cellular antioxidant defences and promoting health [18–21]. Besides their antioxidant activity, polyphenols are also known for their anti-inflammatory effects. These compounds inhibit pro-inflammatory signalling pathways, such as NF- κ B and COX-2. NF- κ B is a transcription factor that regulates the production of pro-inflammatory cytokines, while COX-2 is an enzyme involved in the synthesis of pro-inflammatory prostaglandins. By suppressing these pathways, polyphenols reduce the levels of inflammatory markers, such as TNF- α and IL-6, which are implicated in chronic diseases like atherosclerosis and neurodegeneration [22]. For example, studies have demonstrated that regular consumption of green tea, which contains flavonoids like epigallocatechin gallate (EGCG), can lead to a decrease in the expression of these inflammatory markers. Polyphenols also have significant anticancer properties. Resveratrol, a polyphenol found in red wine and grapes, is particularly well studied for its anticancer effects. It exerts its anticancer action by modulating the key molecular path-

ways involved in cell cycle regulation and apoptosis. Resveratrol inhibits the activity of cyclin-dependent kinases, which control cell cycle progression, and promotes apoptosis by activating caspases. Additionally, it inhibits the expression of anti-apoptotic proteins, such as Bcl-2, enhancing the susceptibility of cancer cells to programmed cell death [23]. This mechanism helps in the elimination of cancerous cells and reduces the risk of tumorigenesis, especially in colon, breast, prostate, and melanoma cancers. Furthermore, polyphenols have beneficial effects on vascular health. They enhance endothelial function by promoting the production of nitric oxide (NO), a molecule that induces vasodilation and lowers blood pressure. NO is produced by endothelial cells in response to polyphenol consumption, leading to relaxation of smooth muscle cells in blood vessels and improved blood flow. This mechanism is particularly beneficial for preventing cardiovascular diseases, as polyphenols have been shown to reduce LDL cholesterol oxidation and improve vascular elasticity. Dark chocolate, rich in polyphenols, has been linked to improved blood pressure and vascular health, demonstrating its cardioprotective effects [24,25]. In metabolic health, polyphenols improve insulin sensitivity and regulate lipid metabolism. Green tea catechins, such as EGCG, enhance insulin signalling and promote glucose uptake in muscle cells, reducing blood sugar levels, especially after meals. They also inhibit enzymes like alpha-glucosidase, which reduces postprandial glucose spikes, offering benefits for individuals with type 2 diabetes or insulin resistance [26,27]. Additionally, polyphenols such as those found in cocoa, have been shown to regulate lipid profiles by decreasing total cholesterol and triglyceride levels. Polyphenols also act as prebiotics, influencing gut microbiota composition. By promoting the growth of beneficial bacteria, such as Bifidobacterium and Lactobacillus, polyphenols contribute to a healthier gut environment. Metabolism of polyphenols by gut microbiota produces bioactive metabolites, such as phenolic acids, that further support gut health by enhancing the production of short-chain fatty acids (SCFAs), which have anti-inflammatory effects and promote intestinal barrier function. This prebiotic effect underscores the role of polyphenols in supporting digestion, immune function, and overall health [28,29]. Thus, polyphenols exert a wide range of biological and functional effects, making them valuable in the prevention and management of chronic diseases such as cancer, cardiovascular disorders, and metabolic diseases. Their ability to modulate the oxidative stress, inflammation, and cellular pathways involved in health and disease processes underscores their therapeutic potential. The classification of polyphenols and their properties are presented in Table 1.

3.3. Application of Polyphenols in Food Technology

Polyphenols play a multifaceted role in food technology due to their diverse functionalities. To provide a clearer structure and depth to their applications, this section is divided into distinct categories, highlighting their contributions across various aspects of food production and preservation.

Table 1. Polyphenol groups, exemplary compounds and their properties related to human health.

Polyphenol Groups	Subgroups	Exemplary Compounds	Sources of the Compounds	Compound Properties	References
Flavonoids	Flavonols	Quercetin Kaempferol	Onions Apples Broccoli Garlic Green tea Red wine	Antioxidant properties Anti-inflammatory and antihistamine properties (alleviation of allergy symptoms) Support of cardiovascular health by improvement of blood vessel function	[30–33]
			Green tea Black tea Cocoa Apples	Antioxidant Anti-carcinogenic Regulation of glucose levels Improvement of lipids metabolism Cardiovascular system support	
	Flavones	Apigenin	Celery Chamomile Chicory Parsley	Anti-inflammatory Anti-carcinogenic Nervous system support Sleep quality improvement Natural calming remedy	[40–46]
			Peppers Celery Thyme Chamomile Chicory	Antioxidant Anti-inflammatory Neuroprotective Gut health improvement	
	Isoflavones	Genistein Daidzein Glycitein	Soy Soy products Chickpeas Flaxseed Strawberries Raspberries Red grapes	Antioxidant Act as phytoestrogens—mimicking oestrogen activity Inhibition of the growth and regulation of the apoptosis of cancer cells Improvement of lipid profile Glucose metabolism support	[53–56]

Table 1. Cont.

Polyphenol Groups	Subgroups	Exemplary Compounds	Sources of the Compounds	Compound Properties	References
Non-flavonoids	Anthocyanins	Cyanidin Pelargonidin	Blackberries Raspberries Cherries Red grapes Black currant	High antioxidant properties Improvement of cognitive functions Cardiovascular system improvement, reducing the risk of cardiovascular diseases Eye health support	[57–61]
	Flavanones	Naringenin	Grapefruits Oranges Onions	Lipids and glucose metabolism improvement Antioxidant Anti-inflammatory Cardiovascular system improvement	[62–66]
	Tannins	Proanthocyanidin tannin Catechin tannin Gallic tannin Ellagic tannin Hydroxybenzene tannin	Red wine Green tea Black tea Cocoa Blueberries Raspberries Nuts Red grapes Pomegranates Herbs	Antioxidant Anti-inflammatory Glucose metabolism support Immune system protection Gut health improvement	[67–72]
	Stilbenes	Resveratrol Pterostilbene	Red wine Red grapes Blueberries Nuts Almonds Cocoa	Antioxidant Anti-inflammatory Blood pressure lowering Improvement of cognitive functions and neuroprotection, lowering the risk of neurodegenerative diseases	[73–79]
	Lignans	Secorin	Flaxseed Sesame Nuts Broccoli Carrots Cabbage Whole grains	Antioxidant Action as phytoestrogens—mimicking oestrogen activity Reduction of the risk of some cancers (breast, prostate) Lipid profile improvement Glucose metabolism improvement	[80–86]

Table 1. Cont.

Polyphenol Groups	Subgroups	Exemplary Compounds	Sources of the Compounds	Compound Properties	References
Phenolic acids	Hydroxycinnamic acid derivatives	Coffee acid Ferulic acid P-coumaric acid	Coffee Flaxseed Nuts Green tea Black tea	Antioxidant Blood pressure lowering Lipid profile improvement Anti-inflammatory Inhibition of cancer cell proliferation and induction of apoptosis Prebiotic function Glucose metabolism improvement	[87–91]
	Benzoic acid derivatives	Gallic acid Ellagic acid Protocatechuic acid	Green tea Black tea Nuts Pomegranates Raspberries Strawberries Herbs	Antioxidant Anti-inflammatory Anti-bacterial and anti-viral Lipids and glucose metabolism regulation Anti-carcinogenic	[92–94]

3.3.1. Preservation and Shelf-Life Extension

Polyphenols function as natural preservatives, effectively inhibiting the growth of bacteria, moulds, and yeasts. Their antibacterial, antifungal, and antioxidant properties provide a clean-label solution for extending the shelf life of food products, reducing reliance on synthetic preservatives [95,96]. The preservative effects of polyphenols stem from their ability to disrupt microbial growth and prevent oxidative degradation. By scavenging free radicals, polyphenols mitigate the oxidative processes that lead to the deterioration of fats, proteins, and other sensitive components in food [97,98]. Polyphenol-rich extracts have been successfully incorporated into a variety of food systems to prolong freshness and maintain quality. For instance, rosemary and thyme extracts are widely used in baked goods such as cookies, where they prevent lipid oxidation and stabilize flavour profiles over time. Similarly, polyphenols derived from olive leaves and olive mill wastewater have demonstrated efficacy in preserving edible oils, such as sunflower and olive oils. These compounds protect against taste changes and nutrient loss, ensuring product stability during storage. In meat products, polyphenols contribute to both microbial safety and sensory attributes. By reducing lipid oxidation, they help maintain the colour and flavour of processed meats while extending shelf life [99]. Additionally, polyphenols have been incorporated into dairy and bakery products, where they improve the structural integrity and prolong freshness. Innovative approaches, such as combining polyphenols with encapsulation techniques, have further enhanced their stability and efficacy. Encapsulation in liposomes or biodegradable polymers protects polyphenols from environmental factors, enabling their controlled release and prolonged activity in food systems. The increasing demand for natural preservatives aligns with the multifunctional benefits of polyphenols, making them indispensable in modern food technology. Future research is anticipated to focus on optimising their extraction, bioavailability, and application in diverse food matrices [100].

3.3.2. Antioxidant Activity

The antioxidant properties of polyphenols are pivotal in preventing oxidative degradation, a primary factor contributing to the loss of food quality during storage. By scavenging free radicals and inhibiting oxidation reactions, polyphenols help preserve the sensory attributes, nutritional value, and safety of various food products [101]. Lipid oxidation is a significant cause of rancidity in edible oils and fatty foods. Polyphenols, such as hydroxytyrosol from olive leaves and extracts from rosemary, effectively inhibit oxidative rancidity in products like sunflower oil and olive oil, thereby maintaining flavour stability and extending shelf life. These natural antioxidants serve as an alternative to synthetic preservatives, aligning with consumer preferences for clean-label products. In meat products, polyphenols play a dual role by preventing lipid oxidation and preserving colour and flavour. Oxidation in meat leads to off-flavours, discolouration, and nutrient loss; polyphenols counteract these effects, ensuring product stability over time. Similarly, in dairy products, polyphenols prevent the oxidative spoilage of milk fats, maintaining sensory quality and reducing waste. The efficacy of polyphenols as antioxidants can be enhanced through synergistic combinations with other natural compounds, such as ascorbic acid or tocopherols [102]. Additionally, encapsulation technologies protect polyphenols from degradation during processing and storage, allowing for their controlled release and sustained activity in food matrices. The integration of polyphenols into food systems is anticipated to expand with advances in extraction and formulation techniques. Research is focusing on tailoring polyphenol blends to specific food applications, optimising their functionality while meeting regulatory and consumer demands for natural, sustainable additives [103].

3.3.3. Antimicrobial Properties

Polyphenols exhibit significant antimicrobial activity, making them a promising tool for enhancing food safety. Their mechanisms of action include disrupting microbial cell

membranes, inhibiting metabolic enzymes, and damaging the genetic material of microorganisms [104,105]. Polyphenols, such as flavonoids, tannins, and phenolic acids, interact with the lipids and proteins of microbial cell membranes, altering their permeability. This process compromises membrane integrity, leading to the leakage of ions and nutrients, ultimately causing cell death. Moreover, polyphenols inhibit the enzymes crucial for microbial metabolism, such as ATPases, thereby limiting the microbes' ability to replicate and survive. Thanks to their antimicrobial properties, polyphenols are widely utilised in various food products to mitigate spoilage and contamination risks. For instance, rosemary and green tea extracts effectively suppress the growth of bacteria such as *Listeria monocytogenes* and *Escherichia coli* in processed meats. Similarly, polyphenols from pomegranate and grape seeds are employed as natural antimicrobial agents in beverages and dairy products [106]. The increasing consumer demand for clean-label products has driven the adoption of polyphenols as natural preservatives. Their application allows manufacturers to eliminate synthetic preservatives, such as nitrates and benzoates, while enhancing the health benefits of food products. Despite their advantages, the use of polyphenols in the food industry faces challenges such as chemical instability and limited water solubility. Encapsulation techniques, including those associated with liposomes and nanoparticles, have been developed to overcome these limitations, improving the bioavailability and efficacy of polyphenols. As extraction technologies and food formulations evolve, the application of polyphenols in the food industry is expected to grow. Research is increasingly focusing on the synergistic effects of polyphenols with other natural bioactive compounds, which may lead to the development of more effective and versatile solutions [107].

3.3.4. Colour Stabilization and Enhancement

Polyphenols play a vital role in enhancing the visual appeal of food products by contributing to vibrant and stable colours. This is particularly important as consumers often associate colour with freshness, quality, and flavour [108,109]. Flavonoids, especially anthocyanins, are among the most prominent polyphenols contributing to the pigmentation of fruits and vegetables. Anthocyanins impart red, purple, and blue hues to products such as berries, grapes, and cherries, significantly enhancing their marketability. Their natural colour intensity makes them ideal for use in processed foods and beverages, offering an attractive alternative to synthetic dyes [110]. Polyphenols are increasingly used as natural colourants in food formulations, meeting the demand for clean-label products. For example, extracts from red cabbage, blackcurrant, and hibiscus, which are rich in anthocyanins, are employed to provide vibrant colours in confectionery, yoghurts, and soft drinks [111,112]. In addition to enhancing colour, polyphenols contribute to colour stability, which is particularly important in products susceptible to discolouration during storage. For instance, anthocyanins stabilise the colour of fruit-based beverages, preventing the browning caused by enzymatic oxidation. Similarly, in confectionery and jams, polyphenols help maintain a consistent appearance by interacting with other food components to form stable colour complexes. Recent advancements have focused on improving the stability of polyphenol-based colourants under varying pH, temperature, and light conditions. Encapsulation techniques, such as microencapsulation and nano-emulsions, have been utilised to protect polyphenols from degradation, ensuring their longevity in food products. As consumer demand for natural and sustainable additives continues to grow, the use of polyphenol-based colourants is expected to expand. Research into optimising their extraction and application, as well as exploring new sources of vibrant polyphenols, remains a focus of innovation in food technology [113,114].

3.3.5. Oxidation Inhibition in Fats and Oils

Polyphenols play a crucial role in stabilising fats and oils by inhibiting oxidative degradation, a process that compromises flavour, aroma, and nutritional quality. Their application is particularly valuable in high-fat products and frying oils, where oxidative stability is a persistent challenge [115–118]. The antioxidant activity of polyphenols in fats

and oils is attributed to their ability to scavenge free radicals, chelate metal ions, and inhibit lipid peroxidation. By donating hydrogen atoms, polyphenols neutralise reactive oxygen species, thereby interrupting the chain reactions that lead to the formation of harmful secondary oxidation products. The incorporation of polyphenol-rich extracts from plant by-products, such as grape seeds, olive leaves, and olive mill wastewater, has proven effective in reducing oxidation rates. For instance, grape polyphenols enhance the stability of frying oils by delaying the onset of rancidity, which extends the usability and sensory quality of the oils [119]. Similarly, olive-derived polyphenols help maintain the freshness and nutritional value of products like olive oil and margarine during storage. In addition to edible oils, polyphenols are also utilised in high-fat foods such as mayonnaise, butter, and spreads, where they act as natural stabilisers to prevent oxidative spoilage and extend shelf life. Emerging technologies have enhanced the effectiveness of polyphenols in fat stabilisation. Encapsulation methods, such as liposomal delivery systems and spray drying, protect polyphenols from degradation and ensure their gradual release into lipid matrices. As sustainability becomes a priority in the food industry, the use of polyphenols derived from agricultural by-products offers an eco-friendly solution for oxidation inhibition. Ongoing research aims to optimise extraction techniques and explore novel polyphenol sources, further broadening their applications in fat and oil stabilisation [120].

3.3.6. Structural Improvement and Texture Modification

Polyphenols influence the structural properties and texture of food products by interacting with proteins, fats, and polysaccharides. These interactions can result in significant improvements in the stability, texture, and overall quality of a wide range of food products [121]. One of the key functions of polyphenols is their ability to stabilise emulsions, preventing phase separation and enhancing the homogeneity of emulsified products. For instance, polyphenols from grape seeds and green tea have been shown to improve the stability of oil-in-water emulsions in dressings, mayonnaise, and sauces. This stabilising effect ensures that the emulsion remains uniform, contributing to both the sensory appeal and shelf life of the product [122]. Polyphenols also contribute to the structural integrity of gel-based foods, such as jellies, jams, and desserts. When combined with polysaccharides like pectin or agar, polyphenols can enhance gel formation, resulting in more stable and resilient gels. This effect is particularly beneficial in products that require a firm and consistent texture [123,124]. For example, polyphenols from tea and pomegranate extracts have been found to increase the firmness of gels, ensuring they retain their shape and texture during storage. Polyphenols interact with proteins to form more stable structures, which is particularly important in protein-based gels such as those derived from egg whites. These interactions help improve the texture and consistency of gelled products, contributing to their firmness and smoothness. Studies have shown that polyphenols can enhance the gel strength of egg white-based products, which is beneficial in applications such as desserts and baked goods. In meat products, polyphenols are known to improve water retention and enhance firmness, leading to improved texture and juiciness. For instance, the incorporation of polyphenol-rich extracts from fruits such as pomegranate or grape seeds has been shown to increase the water-holding capacity of meat, thereby improving its tenderness and mouthfeel [125]. Additionally, polyphenols help reduce the loss of moisture during cooking, which is crucial for maintaining the juiciness and overall quality of meat products. With advances in food technology, the potential applications of polyphenols for structural and texture modification continue to expand. Research into polyphenol-protein, polyphenol-carbohydrate, and polyphenol-fat interactions is ongoing, with the aim of developing new formulations that can further enhance the texture and sensory properties of food products. Moreover, innovations such as encapsulation technologies are being explored to protect polyphenols during processing, ensuring their effectiveness in improving food structure and texture [126].

3.3.7. Nutritional Enrichment and Functional Foods

Incorporating polyphenols into food products enhances their nutritional profile, catering to the increasing consumer demand for functional foods that support health and well-being. These bioactive compounds are recognised for their antioxidant, anti-inflammatory, and cardioprotective properties, making them highly desirable ingredients in a range of health-oriented food products, including beverages, snacks, yoghurts, and dietary supplements [127–132]. The antioxidant capabilities of polyphenols are central to their inclusion in functional foods. By neutralising harmful free radicals, polyphenols help mitigate oxidative stress, which has been linked to the development of various chronic diseases, including cardiovascular conditions, diabetes, and cancer. Additionally, the anti-inflammatory properties of polyphenols, such as those found in flavonoids and phenolic acids, contribute to reducing inflammation in the body, which is crucial for the prevention of inflammatory diseases. Polyphenols, particularly those found in red wine, tea, and certain fruits, have been extensively studied for their cardioprotective effects. These compounds can help reduce the risk of cardiovascular diseases by improving endothelial function, reducing blood pressure, and lowering cholesterol levels. For example, anthocyanins from berries and flavonoids from cocoa have been shown to enhance vascular health and reduce the risk of heart disease. Polyphenols are increasingly incorporated into functional foods designed to promote health and prevent disease. In beverages, such as fruit juices, teas, and smoothies, polyphenols serve as natural antioxidants, contributing to the nutritional value and health benefits of the product. In dairy products like yoghurts, polyphenols help modulate gut health by promoting beneficial microbiota and offering anti-inflammatory effects. Furthermore, polyphenols are being included in snacks and dietary supplements aimed at providing convenient, health-promoting solutions for consumers seeking to improve their diet without resorting to synthetic additives. Enriching food products with polyphenols offers a natural alternative to synthetic additives while simultaneously boosting the health benefits of the product. Polyphenol-enriched functional foods have gained popularity in the wellness market, where consumers are increasingly prioritising nutrition and natural ingredients. For instance, the addition of green tea polyphenols to snacks, cereals, and protein bars provides an easy way for consumers to access the health benefits of these compounds. The potential of polyphenols as functional ingredients continues to grow, with ongoing research focused on optimising their extraction, bioavailability, and effectiveness in various food matrices. As demand for functional foods increases, future innovations may include the development of novel polyphenol-enriched products that deliver enhanced health benefits in a more bioavailable form, improving their overall impact on consumer health [133].

4. Microencapsulation of Polyphenols

4.1. Microencapsulation Techniques

Microencapsulation is a technique of enclosing the active substances (e.g., polyphenols) in a thin-film structure, forming microcapsules. The purpose of microencapsulation is to protect the substances from adverse external conditions, such as light, oxygen, high temperature and pH changes [134,135]. The process also allows for the controlled release of substances, which increases their bioavailability and biological effectiveness [136,137]. Microencapsulation is based on several key principles. It ensures that bioactives are protected from degradation, allowing their retention of health properties for a longer periods of time [138]. Further, with the proper design of capsules, the active substances can be released under specific conditions, improving their bioavailability [139]. From a technology approach, microcapsules should retain their stability both during storage and food processing in order to preserve their health promoting properties. Moreover, the materials used to produce microcapsules should be safe for health, which is particularly important for food applications [140]. Microencapsulation can be carried out using a variety of methods that vary in terms of technique, materials and applications. The microencapsulation methods

include spray drying, freeze drying, emulsion-based encapsulations, encapsulation by entrapment in liposomes, coacervation, fluidized bed coating and ionic gelation [141,142].

Extrusion is a process in which a mixture of ingredients (active ingredients, encapsulating materials and possible additives) is heated and passed through moulds to form microcapsules. This is one of the simplest methods, but may require high temperatures, which can affect the stability of some polyphenols [143]. The efficiency of the protection of polyphenols using this method is at an average level. Taking into consideration the degradation of polyphenols caused by high temperature, the biggest limitation of this method is the need for temperature monitoring and optimization during the process [144].

In the emulsion-based method, the active ingredient is dissolved in oil and then emulsified in water using emulsifiers. This process allows the formation of microemulsions, which can then be hardened to form microcapsules. This method is particularly useful for polyphenols with low water solubility. Emulsification is an effective method for the microencapsulation of polyphenolic compounds under various conditions. An important advantage of polyphenols is their high stability, which supports their efficacy in various applications. However, the primary limitations of this approach include the necessity of using suitable emulsifiers and stabilizers to maintain their functionality and bioavailability. [145,146].

Spray drying is one of the most widely used microencapsulation methods, involving spraying a solution of the active ingredient in hot air, which leads to the evaporation of the solvent and the formation of microcapsules. This method is effective in preserving the properties of polyphenols but can lead to their degradation if the drying temperature is too high. For this reason, it is necessary to monitor and optimize the temperature used in order to limit thermal degradation of bioactive compounds, which can be a significant limitation [10,147].

The freeze-drying process involves freezing the material containing the active substances and then evaporating the water by sublimation, which is the transition of water directly from a solid state to a gaseous state. During this process, the active substances, encapsulated in a protective matrix remain stable, as the action of low temperature and vacuum minimizes their degradation. However, the freeze-drying process requires specialized equipment and a large amount of energy, making it time consuming and generating high cost, which can be a disadvantage of this method [148,149].

Electro-spraying is a technique that uses an electric field to create micro- and nano-capsules through the atomisation of a solution. After dissolving the active ingredients in a polymer matrix, e.g., alginate or chitosan, the solution is passed through a capillary to which a high voltage is applied. The force of the electric field breaks the liquid into tiny droplets, which are transformed into particles under drying, resulting in the formation of capsules. This method allows the production of highly stable capsules with a uniform particle size [150,151]. Micro-fluidization is a technique based on passing fluids through a system of microchannels at high pressure to form emulsions, nanoparticles or microcapsules. The active ingredients are dissolved or suspended in an aqueous or oil phase and then combined with a matrix material. The mixture is passed through microchannels in a microfluidizer at a pressure of 10,000 to 30,000 psi. The high shear stresses break up the larger particles into nano- or microparticles, which are stabilised by the coating material. This method produces stable emulsions and capsules with uniform particle size and high bioavailability [152,153].

4.2. Encapsulation Carriers

Microencapsulation is a technology that enables the protection and controlled release of bioactive compounds, such as polyphenols, by enclosing them within a carrier material. In particular, the selection of an appropriate encapsulation carrier is essential for determining the stability, bioavailability, and release profile of polyphenols. Moreover, the carriers used for microencapsulation can vary widely, including carbohydrates, proteins, lipids,

and biopolymers, each offering unique benefits and limitations based on their structural properties and interactions with polyphenols [154,155].

4.2.1. Carbohydrates

Carbohydrates are among the most commonly used materials in microencapsulation, especially in the food industry, due to their low cost, availability, and safety. For instance, maltodextrin and various starches are commonly employed as efficient encapsulation agents for polyphenols, ensuring their stability and controlled release in food products. [156–158]. Notably, maltodextrin, a polysaccharide derived from starch, is widely used for spray-drying encapsulation. Its high water-solubility, low viscosity, and neutral taste make it an ideal carrier for polyphenols, particularly in the creation of powders. As a result, maltodextrin forms a protective barrier around the polyphenol molecules, shielding them from environmental factors such as heat, oxygen, and light, which can lead to degradation. Additionally, maltodextrin improves the flow properties and stability of encapsulated products, which are critical during storage [154,158,159]. Similarly, starch, another commonly used carbohydrate, offers diverse structural forms (e.g., native, modified, or resistant starches) and has excellent film-forming capabilities. In particular, starch-based carriers protect polyphenols from enzymatic breakdown and environmental stressors while also enabling the gradual release of the active compounds during digestion. Moreover, the encapsulation efficiency of starch is often enhanced by modifying it with other agents, such as β -cyclodextrins, which form inclusion complexes with polyphenols, further improving their solubility and protection [154,158–161].

4.2.2. Proteins

Proteins, such as casein and gelatine, are effective encapsulation carriers due to their amphiphilic nature, which allows them to interact with both hydrophobic and hydrophilic compounds. This characteristic makes them ideal for stabilising polyphenols, which are often hydrophobic and prone to oxidation [160,162]. For instance, casein, a milk-derived protein, has been shown to encapsulate polyphenols effectively through methods such as spray drying and coacervation. Furthermore, casein molecules naturally form micelles in aqueous environments, which can trap polyphenols within their structure, providing physical and chemical protection. Moreover, casein can enhance the bioavailability of polyphenols by improving their solubility in the gastrointestinal tract [154,162]. Similarly, gelatine, derived from collagen, is another protein frequently used for microencapsulation. Thanks to its ability to form strong gels and films, it is suitable for encapsulating polyphenols in both aqueous and lipid-based systems. Gelatine encapsulation not only protects polyphenols from oxidation but also enhances their controlled release by responding to environmental changes, such as temperature and pH. For instance, polyphenols encapsulated in gelatine can be released in a controlled manner during digestion, optimizing their bioactivity and improving their absorption in the gastrointestinal tract. [154,157,159].

4.2.3. Lipids

Lipid-based carriers, such as lecithin, play a pivotal role in encapsulating hydrophobic compounds such as polyphenols. One of the primary advantages of lipid encapsulation is the improvement in solubility, protection from oxidative degradation, and enhancement of bioavailability [163,164]. For instance, lecithin, a natural phospholipid, is commonly used in emulsification-based encapsulation techniques. It is notable for its ability to form stable bilayer structures, similar to cell membranes, which can encapsulate polyphenols within their hydrophobic core. This not only protects polyphenols from degradation but also facilitates their absorption in the body by mimicking natural biological transport mechanisms. Consequently, lecithin-based systems have been applied in various food products, such as functional beverages and supplements, to deliver polyphenols with improved stability and bioavailability [165,166]. Furthermore, lipid-based encapsulation allows for the formation of liposomes and nano-emulsions, which are highly effective at

encapsulating polyphenols [167]. These systems offer an additional benefit by providing sustained release profiles, where the encapsulated polyphenols are gradually released into the digestive system, ensuring a longer-lasting bioactive effect [168,169].

4.2.4. Biopolymers

In addition, biopolymers, such as chitosan, are increasingly being utilised in microencapsulation due to their biocompatibility, biodegradability, and functional versatility. For example, chitosan, derived from chitin, a natural polymer found in the shells of crustaceans, is particularly noted for its ability to form strong, stable films that can protect polyphenols from degradation [156]. Moreover, chitosan is a positively charged polysaccharide that readily interacts with negatively charged polyphenols through electrostatic interactions. This interaction allows for efficient encapsulation and enhanced stability in aqueous environments [170]. Additionally, chitosan encapsulation offers controlled release properties, as the polymer is sensitive to pH changes, enabling the release of polyphenols in specific areas of the gastrointestinal tract. Notably, chitosan has also been shown to possess antimicrobial properties, which can further enhance the shelf life and safety of encapsulated polyphenols [171,172].

4.3. Impact of Carriers on Polyphenol Stability and Release

The selection of an appropriate carrier material is critical for ensuring the stability and controlled release of encapsulated polyphenols. For instance, carbohydrate carriers, such as maltodextrin and starch, are excellent for stabilising polyphenols in dry formulations, protecting them from environmental degradation. Nevertheless, these carriers may not always provide sufficient control over release kinetics, particularly in liquid systems [173]. On the other hand, protein-based carriers, such as casein and gelatine, offer more versatile release mechanisms. In particular, they can protect polyphenols from oxidation and enzymatic breakdown while allowing for controlled release, particularly in response to digestive conditions. Moreover, the amphiphilic nature of proteins enables them to interact with both hydrophobic and hydrophilic polyphenols, improving their encapsulation efficiency and bioavailability [174]. Similarly, lipid-based carriers, particularly lecithin, are highly effective at encapsulating hydrophobic polyphenols and improving their solubility and absorption in the body. These carriers are particularly well-suited for liquid formulations and offer sustained release profiles. Likewise, biopolymer carriers like chitosan provide pH-sensitive release mechanisms, which can enhance the targeted delivery of polyphenols to specific regions of the digestive tract, optimising their bioactive effects [173]. In conclusion, the choice of encapsulation carrier significantly influences the stability, bioavailability, and controlled release of polyphenols. For example, carbohydrates provide good protection in dry systems, proteins offer versatile release in both aqueous and solid matrices, lipids enhance the absorption of hydrophobic polyphenols, and biopolymers such as chitosan enable targeted release in the digestive system. Thus, each carrier type brings unique advantages that can be tailored to the specific application and desired release profile of polyphenols in food products [174]. Table 2 presents the carriers, applications and challenges of applying microencapsulation of polyphenols in food technology.

4.4. Comparative Analysis of Encapsulated and Non-Encapsulated Polyphenols

The encapsulation of polyphenols represents a transformative advancement in food technology, addressing several limitations of their native forms. This section provides a comprehensive comparison of encapsulated and non-encapsulated polyphenols, focusing on their activity, stability, bioavailability, and controlled release [175].

Polyphenols are celebrated for their potent antioxidant, antimicrobial, and anti-inflammatory properties. However, their effectiveness in food applications is often compromised by environmental stressors, including heat, oxygen, and pH fluctuations. In their non-encapsulated state, polyphenols degrade rapidly, which diminishes their activity over time [176,177]. Encapsulation, particularly through methods such as spray drying,

coacervation, or liposomal entrapment, offers a solution by enhancing their bioactive potency. For instance, encapsulated polyphenols consistently maintain higher antioxidant capacity during extended storage [178]. This improvement is attributed to the protective physical barrier formed by encapsulation, which shields polyphenols from oxidative stress and other destabilizing conditions [179]. Moreover, studies indicate that encapsulated polyphenols are more resistant to environmental degradation, thereby preserving their functionality more effectively than their non-encapsulated counterparts [180,181].

Stability, bioavailability, and release dynamics are pivotal to the application of polyphenols in food systems. Non-encapsulated polyphenols often suffer rapid degradation under light, oxygen, or heat exposure, significantly restricting their utility in processed foods. Encapsulation mitigates these challenges by creating robust protective barriers through techniques such as nanoparticle carriers or emulsions, thus prolonging shelf life and enhancing product reliability [176,182]. Bioavailability, defined as the fraction of an active compound absorbed and utilized by the body, presents another critical limitation for non-encapsulated polyphenols. Their poor water solubility, rapid gastrointestinal degradation, and swift metabolism hinder absorption. In contrast, encapsulation enhances solubility and provides protection against the stomach's acidic environment, enabling delivery to the intestine, where absorption is more efficient. Notably, encapsulated resveratrol has been shown to achieve up to a threefold increase in bioavailability compared with its free form, demonstrating the efficacy of encapsulation in overcoming bioavailability barriers [183]. Additionally, controlled release is a key advantage of encapsulation, allowing for the gradual and targeted delivery of polyphenols either within food matrices or during digestion. This capability not only optimizes the functional benefits of polyphenols but also ensures a sustained impact over time. For example, encapsulated quercetin has demonstrated a slow-release profile, extending its antioxidant activity in fortified beverages. Such innovations are particularly valuable in the development of functional foods and nutraceuticals, where consistent performance is critical [175].

The effectiveness of polyphenols in food systems is strongly influenced by their interaction with specific food matrices. Non-encapsulated polyphenols frequently encounter issues such as precipitation, flavour alteration, and reduced solubility. Encapsulation addresses these limitations by modulating interactions between polyphenols and their surrounding environment [184]. In dairy products, encapsulated polyphenols have demonstrated enhanced stability and bioactivity retention during storage. They also minimize unfavourable interactions with proteins and lipids, preserving the sensory and nutritional qualities of the product. Similarly, in baked goods, encapsulation improves thermal stability, enabling polyphenols to retain their antioxidant properties even after exposure to high baking temperatures [185,186]. In beverage applications, where stability and solubility are paramount, encapsulated polyphenols effectively prevent precipitation and degradation. This ensures the production of visually appealing and stable products. Furthermore, encapsulation masks undesirable flavours, such as bitterness, while preserving functional benefits. This is especially beneficial for teas, juices, and functional beverages, where taste and appearance significantly influence consumer acceptance [187]. In lipid-based matrices like oils and spreads, encapsulated polyphenols act as efficient antioxidants, reducing lipid oxidation and thereby extending shelf life. Encapsulation also facilitates the uniform distribution of polyphenols, which is a challenge with their non-encapsulated forms. These enhancements contribute to improved product performance and consumer satisfaction [188]. Encapsulation technologies are highly adaptable and can be tailored to meet the specific requirements of various food products. This versatility not only enhances the functional properties of polyphenols but also increases their compatibility with diverse food systems, ultimately improving product quality and consumer acceptability [189].

Table 2. Microencapsulation of polyphenols: carriers, applications, and challenges in food technology.

Carrier Type	Examples	Characteristics	Production Methods	Applications	Advantages	Challenges	Impact on Polyphenols	References
Carbohydrates	Maltodextrin, starch (native, modified, resistant), β -Cyclodextrin, alginate pectin, gum arabic, alginate complex, cellulose derivative	High water solubility Low viscosity Neutral taste	Spray drying Freeze drying Coacervation	Functional Powders (e.g., matcha) Nutraceuticals (curcumin tablets) Beverages (fortified juices, sports drinks)	Protects polyphenols from degradation, cost-effective, excellent film-forming abilities, enhanced solubility Enhances flow properties and stability during storage Pectin and gum arabic are particularly effective for stabilizing emulsions and powders, enhancing bioavailability	Limited control over release in liquid systems, Possible incomplete protection during long-term storage Susceptible to environmental factors like moisture in certain cases	Maintains stability during processing Potentially slower release rates	[161,190–195]
Proteins	Casein, gelatine, whey protein isolate (WPI), soy protein isolate (SPI), zein (corn protein), egg albumin, pea protein, silk fibroin	Amphiphilic nature Strong gel-forming abilities High emulsifying capacity	Coacervation Spray drying Gelation	Dairy products (yogurt) Supplements (protein powders) Snacks (protein bars)	Protects polyphenols from oxidation Enables controlled release Improves solubility Amphiphilic nature enables interaction with both hydrophobic and hydrophilic polyphenols, enhances bioavailability Zein and silk fibroin offer excellent encapsulation properties, especially for hydrophobic polyphenols	Denaturation during processing Possible allergenicity Possible interaction with other food components May affect sensory properties of final product	Enhanced bioavailability Controlled release in response to digestive conditions	[159,162,191,194,196–198]

Table 2. Cont.

Carrier Type	Examples	Characteristics	Production Methods	Applications	Advantages	Challenges	Impact on Polyphenols	References
Lipids	Lecithin, liposomes, nano-emulsions, phospholipids, phytosterols, omega-3 fatty acids, medium chain triglycerides (MCTs)	Forms stable bilayers Emulsifying properties Biodegradable	Emulsification Liposome formation	Functional beverages (liposomal curcumin drinks) Dressings (polyphenol-enriched vinaigrettes) Nutraceuticals (soft gels)	Protects hydrophobic polyphenols Facilitates absorption Provides sustained release Improves solubility and absorption of hydrophobic polyphenols, offers sustained release Enhances bioactive effects of polyphenols, supports liquid formulations, and has synergistic health benefits	High cost of nano-emulsion production, potential stability issues in emulsified systems Expensive May require emulsifiers or stabilizers to maintain stability over time	Increases solubility and absorption Protects against oxidation	[146,163,199–203]
Biopolymers	Chitosan, alginate, carrageenan, polylactic acid (PLA), xanthan gum, pullulan, agar, gelatine–polysaccharide blends	Biocompatible and biodegradable Strongly film-forming Mucoadhesive properties	Ionic gelation Spray drying Coacervation	Functional foods (probiotic yogurt) Drug delivery (resveratrol capsules) Edible films (fruit coatings)	Efficiently interacts with polyphenols pH-sensitive release mechanisms Antimicrobial properties Biodegradable, offers controlled release, protects polyphenols in pH-sensitive environments Versatile applications, used in both liquid and solid formulations, suitable for temperature-sensitive compounds	Susceptible to mechanical stress during processing Potential issues with large-scale industrial application Costly production of some biopolymers Possible interaction with food matrix affecting release kinetics	Maintains polyphenol stability Controlled release in gastrointestinal tract	[171,192,199, 204–208]

5. Applications of Microencapsulated Polyphenols in Food

5.1. Bakery Products

In bakery products such as bread and pastries, polyphenols can interact with starch, affecting its texture and structure during and after baking. The addition of polyphenols can lead to a softer, crispier texture and can contribute to lowering the glycaemic index of baked goods [209,210]. Plant extracts rich in polyphenols, such as those from cinnamon or tea, are therefore sometimes used as functional additives in bakery products [211–213]. These polyphenols can also reduce retrogradation—the hardening and aging of starch-based products such as bread and pasta—thus helping bread stay fresh longer [214]. However, the direct use of polyphenols in food products is often difficult due to their sensitivity to environmental factors. Exposure to light, oxygen and high temperatures during food processing and storage can degrade polyphenols, reducing their beneficial effects and decreasing their stability. For this reason, microencapsulation technology is often used to protect polyphenols from these external stressors [215,216]. Research on the application of microencapsulated polyphenols has primarily investigated their impact on the sensory attributes of baked goods, their influence on microbiological stability, as well as their potential to reduce the glycaemic index and prolong the shelf life of bakery products. One of the most significant properties of polyphenols in food products, including bread, is their capacity to lower the glycaemic index. Research has examined the effects of microencapsulated polyphenols extracted from plant sources on reducing the glycaemic index. The addition of extracts was found to inhibit α -amylase and α -glucosidase, which led to the reduction of starch digestion, resulting in a lowering of the glycaemic index [217–219]. Some studies have examined the effect of microencapsulated polyphenols on the texture and structure of bread. It has been shown that polyphenols can bind to starch, leading to reduced retrogradation, resulting in longer freshness and better texture of the product [220,221]. In studies on bakery products such as cookies, the effect of microencapsulated polyphenols on the sensory properties and stability of these products was analysed. It was found that polyphenols improved the taste and aroma of the products, as well as their shelf life [222,223]. The studies also examined whether microencapsulated polyphenols have an antimicrobial effect in baked goods, helping to reduce the growth of microorganisms, which contributes to the safety and shelf life of the products [224,225]. Sensory tests were conducted in several studies to assess consumer acceptance of baked goods enriched with microencapsulated polyphenols. The results were found to show that the products were well received, suggesting that microencapsulated polyphenols can improve not only the nutritional value, but also the taste and appeal of bakery products [221,225–227]. Through this research, microencapsulated polyphenols are showing potential in the baking industry to help improve the quality, safety and nutritional value of baked goods. The addition of polyphenols resulted in improved nutritive and sensory characteristics, and improved shelf-life of the products, which is particularly important in the context of the growing interest in safe and healthy foods.

5.2. Dairy Products

Polyphenols show beneficial effects on dairy products, both in terms of their quality and nutritional value [228,229]. Due to their antioxidant properties, they can prevent the oxidation of fats in dairy products, which is particularly important for milk, yogurt or cheese. Protection against oxidation helps maintain the freshness and flavour of products, and increases their shelf life [230–232]. In dairy products such as creams and sauces, polyphenols can enhance emulsion stability, which affects texture uniformity and prevents precipitation of ingredients. Polyphenols can affect the texture and consistency of dairy products such as yogurts and cheeses, improving their density and stability, resulting in a better sensory experience for consumers [233,234]. Polyphenols can also interact with the fermentation microflora in yogurts and cheeses, which can improve the fermentation process and affect the sensory and health properties of these products. Some polyphenols may have prebiotic effects, promoting the growth of beneficial bacteria in the gut, further

contributing to digestive health [235–237]. Existing research has analysed the use of microencapsulated polyphenols, such as those derived from green tea or berries, in yogurt production. The study conducted by El-Messery et al. (2019) showed that the addition of microencapsulated polyphenols can increase the antioxidant activity of yogurt, without impairing its physical properties, and thus serve as a functional ingredient to enrich healthy yogurts [186]. Some studies have investigated the effect of microencapsulated polyphenols on the quality of cheese. It has been found that the addition of polyphenols can improve the texture of cheese, prolong its shelf life and increase its antioxidant properties, which affect the taste and flavour of the final product [238–240]. The studies have shown that microencapsulated polyphenols can promote emulsion stability, improve flavour and extend the shelf life of milk and dairy drinks [241–243]. Studies on ice cream and milk-based desserts have analysed the effects of microencapsulated polyphenols on their sensory properties and stability. It was found that these additives can improve taste, texture and nutritional properties [244–246]. The research also focused on evaluating the effect of microencapsulated polyphenols in dairy products for their antimicrobial activity. It has been shown that polyphenols can reduce the growth of pathogens in yogurts and cheeses, which increases the microbiological safety of these products [247–252]. This research highlights the potential of microencapsulated polyphenols as promising additives in the dairy industry, offering improvements in the quality, nutritional value and shelf life of dairy products.

5.3. Functional Beverages

Functional beverages are one of the primary applications of microencapsulated polyphenols in the food industry. Polyphenols, known for their antioxidant properties, are widely used to enhance the health benefits of beverages such as juices, energy drinks, and isotonic drinks. However, polyphenols are highly sensitive to environmental factors such as light, oxygen, and heat, which can significantly degrade their bioactivity during processing and storage. Microencapsulation offers a solution by providing a protective barrier that preserves polyphenols' stability in these beverages [173,185]. For instance, the encapsulation of polyphenols in liposomes or nano-emulsions can protect them from oxidation and degradation during the thermal processing of juices [243]. Additionally, encapsulation allows for controlled release, which ensures that the polyphenols remain bioactive until consumed [253]. In addition to improving the stability of bioactive compounds, encapsulation also enhances the sensory attributes of functional beverages. Unencapsulated polyphenols often impart a bitter taste, which can negatively affect consumer acceptance. Encapsulating these compounds in lipid-based carriers or carbohydrate matrices can mask the bitterness, improving the overall flavour profile of the beverage. This is particularly important in isotonic drinks, where maintaining a balanced flavour while delivering health benefits is key [254,255]. Furthermore, encapsulation improves the bioavailability of polyphenols in beverages. Many polyphenols are hydrophobic and poorly absorbed in the gastrointestinal tract. By encapsulating them in carriers like lecithin or whey protein isolate, their solubility is enhanced, leading to better absorption and increased health benefits. Examples of products on the market utilizing this technology include enhanced water beverages and sports drinks fortified with encapsulated green tea extracts or resveratrol [185].

5.4. Dietary Supplements and Functional Foods

Dietary supplements and functional foods represent another growing sector for the application of microencapsulated polyphenols. These products aim to deliver concentrated doses of bioactive compounds, including polyphenols, to support health and well-being. However, as with beverages, the stability and bioavailability of polyphenols in supplements can be compromised due to environmental conditions and interactions with other ingredients [2]. Microencapsulation significantly improves the effectiveness of polyphenol-based supplements. For instance, polyphenols encapsulated in biopolymers like chitosan or alginate not only protect them from degradation but also provide targeted release in specific areas of the gastrointestinal tract. This targeted delivery enhances the bioactive effect of the

polyphenols, allowing them to reach the bloodstream more effectively [256]. Additionally, encapsulation helps in developing sustained-release formulations. In supplements such as capsules or tablets, encapsulated polyphenols can be engineered to release gradually, providing long-lasting health benefits. This is particularly advantageous for polyphenols like curcumin, which has a short half-life in the body. Through encapsulation, curcumin can maintain its therapeutic levels in the bloodstream over a longer period [257]. Moreover, the sensory properties of functional foods are also improved through encapsulation. Polyphenols, when incorporated into food products like protein bars or fortified snacks, may impart undesirable flavours or cause textural issues. Microencapsulation prevents these negative sensory impacts by masking the taste or altering the release mechanism, ensuring that the polyphenols are only released once consumed and digested [7]. On the market, a variety of functional foods and dietary supplements incorporate encapsulated polyphenols. For example, supplements containing encapsulated grape seed extract or green tea polyphenols are popular for their antioxidant properties. Similarly, functional food products like breakfast cereals and protein bars are often enriched with encapsulated resveratrol or quercetin to enhance their health-promoting qualities [193,197].

6. Benefits and Challenges of Polyphenols Microencapsulation

6.1. Benefits

The application of microencapsulation technology offers numerous advantages, with one of its primary benefits being the effective protection of polyphenols against degradation. Plant extracts rich in polyphenols are highly susceptible to oxidation and degradation when exposed to environmental factors such as light, elevated temperatures, and oxygen. Microencapsulation creates a protective barrier that preserves the biological activity of polyphenols for a longer period of time. As a result, food products enriched with microencapsulated polyphenols can exhibit better antioxidant properties, which contributes to their longer shelf life and stability [149,258–260].

Further, microencapsulation allows for the controlled release of polyphenols, meaning that the substances can be released under appropriate conditions, such as during digestion. This strategy can increase the bioavailability of polyphenols in the body, which translates into their beneficial effects on health. In the case of foods such as bread or yogurt, microencapsulation can ensure that polyphenols are gradually released, improving their bioavailability [261,262].

Microencapsulated polyphenols can significantly enrich the nutritional value of food products. Because polyphenols have health improving properties, their addition to foods can help promote healthy lifestyles [263,264]. For example, bakery products enriched with microencapsulated polyphenols can support cardiovascular health, lower blood pressure, and have a beneficial effect on lipid profile [265].

Microencapsulation can also improve the sensory properties of food products. Polyphenols can impart specific flavours and aromas to foods. Microencapsulation can control the intensity of these flavours, making it possible to create more appealing products for consumers. In addition, by stabilizing flavours, unwanted changes in taste during storage can be avoided [266,267].

Thanks to the antioxidant effect of microencapsulated polyphenols, the shelf life of food products can be extended. Protecting against fat oxidation in dairy, meat and bakery products is crucial to maintaining their quality and freshness [268]. Microencapsulation makes it possible to increase the resistance of products to microbial spoilage, which is important for a longer shelf life [269,270].

6.2. Challenges

One of the main challenges associated with the microencapsulation of polyphenols is production costs. The microencapsulation process requires specialized equipment and materials, which can raise costs compared with traditional food processing methods. The

food industry, especially for small producers, may find it difficult to introduce microencapsulated polyphenols due to high investment costs [271,272].

Another crucial factor to achieving effective polyphenol protection is the choice of the right microencapsulation materials. These materials must be biocompatible, non-toxic and well tolerated by the human body. However, not all materials are equally effective in protecting polyphenols from degradation, which can affect their bioavailability and efficacy [273]. Therefore, further research is needed to optimize encapsulating materials.

Although microencapsulation allows for the controlled release of polyphenols, there are challenges in optimizing this process. The release can be too fast or too slow, affecting the effectiveness of the polyphenols. There is a need for further research on release mechanisms to better understand the possible adjustment of the microencapsulation process for different food applications [274,275].

Another obstacle to the introduction of microencapsulated polyphenols into food products is consumer acceptance. Changes in food formulation, including the introduction of new additives, may cause reluctance among consumers [140,276,277]. Therefore, it is important to conduct information and education activities to convince consumers of the health benefits of microencapsulated polyphenols.

In the context of the growing importance of sustainability, microencapsulation of polyphenols must also address the environmental and social aspects of production. The selection of raw materials, the production process and the environmental impact should be taken into account to ensure that microencapsulated polyphenols are produced in an environmentally friendly manner [278–280].

Equally important are the difficulties associated with scaling up processes from the laboratory to industrial production. Microencapsulation techniques require the use of specialized equipment that may not be easily available on an industrial scale. The transition from laboratory to mass production requires significant technological investment and optimization of process parameters. In addition, some techniques have low capacities, which may limit large-scale production.

From a technological point of view, the cost of materials—both core and matrix of the capsules, as well as the energy consumption of microencapsulation processes—is also a limitation. This generates additional costs for the final product, which may result in a negative perception from consumers. In addition, material losses are significant in some processes, which reduces the overall production effectiveness. In order to reduce the impact of these difficulties, it is possible to optimize encapsulation processes, use industrial waste as encapsulation materials, automate production lines and further research and develop microencapsulation techniques [143,281,282].

Table 3 presents the possible applications, benefits and challenges of the use of microencapsulated polyphenols in food technology.

Table 3. Applications, benefits, and challenges of microencapsulated polyphenols in food technology.

Application	Description	Examples of Polyphenols	Benefits	Potential Challenges	Literature References
Antioxidants	Microencapsulation enhances the stability of polyphenols with antioxidant properties, allowing them to be effectively used in foods to inhibit lipid oxidation processes and prevent protein and vitamin degradation, preserving sensory quality and nutritional value	Quercetin, resveratrol, ellagic acid, epicatechin, flavonols (e.g., kaempferol), catechins, tannins	Enrichment of food products with antioxidants that extend their shelf life by delaying oxidation processes, protecting against spoilage and sensory changes (taste, aroma, colour), which is crucial in high-fat foods	Sensitivity of polyphenols to high temperatures and humidity during thermal processing and storage, which may lead to capsule breakdown	[201,283–285]

Table 3. Cont.

Application	Description	Examples of Polyphenols	Benefits	Potential Challenges	Literature References
Flavour and aroma enhancement	Microencapsulated polyphenols enable controlled release of flavour and aromatic compounds, improving the sensory quality of food and ensuring greater consumer acceptance. They can also mask undesirable tastes, such as bitterness	Gallic acid, epicatechin, chlorogenic acid, proanthocyanidins, apigenin	Potential to modify the flavour profile of products, enabling the creation of appealing food products, while also masking the bitterness of some polyphenols. Polyphenols may act synergistically with other ingredients to create more complex flavour profiles	Optimisation of concentrations to avoid excessive flavour intensity and interactions between polyphenols and other ingredients, which may affect stability and release	[285–288]
Health Benefits	Polyphenols have proven anti-inflammatory, anticancer, and cardiovascular-supporting properties, and microencapsulation increases their bioavailability by protecting them from degradation in the digestive tract, enhancing their health effects	Polyphenols from green tea (epigallocatechin gallate), anthocyanins, flavonoids, rosmarinic acid, quercetin, resveratrol	Enrichment of food products with bioactive compounds that support health through antioxidant and free-radical scavenging actions, which may contribute to the prevention of chronic diseases, such as cardiovascular diseases, diabetes, and cancer	Varied bioavailability depending on the food matrix and individual consumer physiological traits. The need to develop optimised therapeutic doses	[201,289–291]
Colour Stabilisation	Microencapsulation protects the polyphenols responsible for natural colours (e.g., anthocyanins) from external factors, such as light, oxygen, and temperature, helping to maintain the aesthetic appeal of the product over a more extended period	Anthocyanins (from berries, red cabbage, aronia), flavonoids, ferulic acid	Preservation of an attractive appearance in products (especially beverages, juices, fruit preserves), which is an important factor in consumer purchasing decisions. Microencapsulation supports colour stability during storage, protecting against fading and loss of intensity	Sensitivity to pH changes that may impact colour stability. Polyphenols may degrade under light and heat exposure	[159,292]

Table 3. Cont.

Application	Description	Examples of Polyphenols	Benefits	Potential Challenges	Literature References
Antimicrobial Protection	Polyphenols exhibit antibacterial and antifungal properties, and their microencapsulation enables controlled release, supporting food preservation without the need for artificial preservatives	Ferulic acid, flavonoids, protocatechuic acid, rutin, caffeic acid, procyanidins	Reducing the risk of food spoilage thanks to the ability of microencapsulated polyphenols to inhibit bacterial and fungal growth. This contributes to extending product shelf life and reducing losses associated with spoilage	Efficacy may vary depending on the type of microorganisms and food matrix. Need to investigate potential side effects with long-term use.	[289,292–294]

7. Conclusions

Microencapsulation of polyphenols offers innovative opportunities in the application of these compounds in the food industry, enabling better utilization of their health-promoting properties. Polyphenols are widely valued for their antioxidant, anti-inflammatory and anti-cancer activities, but their instability to light, temperature and low bioavailability pose challenges in their direct use in food. Microencapsulation technology solves these problems by protecting polyphenols from external agents and enabling their controlled release in the digestive system. The use of different carriers, such as polysaccharides, proteins and lipids, provides a wide range of possibilities to modify the properties of the capsules, adapting them to different food products, including bakery products, dairy products and functional beverages.

The advantages of microencapsulation include increasing the stability of polyphenols, extending their shelf life in food products, and improving their bioavailability, which contributes to higher nutritional value and better sensory acceptance. In addition, microencapsulation allows for the controlled release of polyphenols, which can enhance their biological efficacy. Disadvantages of this technology, however, include high production costs, the need for specialized equipment, and the risk of incomplete protection or too rapid a release of active ingredients in some food matrices. Despite these challenges, microencapsulated polyphenols have the potential to become an important ingredient in modern food products, joining the trend of functional and health foods.

Author Contributions: Conceptualization, W.B.; methodology, W.B.; investigation, W.B.; resources, W.B.; data curation, W.B.; writing—original draft preparation, W.B., A.S. (Arkadiusz Szpicer) and A.S. (Adrian Stelmasiak); writing—review and editing, W.B., A.S. (Arkadiusz Szpicer), and I.W.-K.; visualization, W.B.; supervision, A.S. (Arkadiusz Szpicer) and A.P.; project administration, W.B.; funding acquisition, A.S. (Arkadiusz Szpicer) and I.W.-K. All authors have read and agreed to the published version of the manuscript.

Funding: Research financed by the Polish Ministry of Science and Higher Education within funds of the Faculty of Human Nutrition and Consumer Sciences, Warsaw University of Life Sciences (WULS), for scientific research.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The authors declare the availability of the data and material.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Alu'datt, M.H.; Alrosan, M.; Gammoh, S.; Tranchant, C.C.; Alhamad, M.N.; Rababah, T.; Zghoul, R.; Alzoubi, H.; Ghatasheh, S.; Ghazlan, K.; et al. Encapsulation-Based Technologies for Bioactive Compounds and Their Application in the Food Industry: A Roadmap for Food-Derived Functional and Health-Promoting Ingredients. *Food Biosci.* **2022**, *50*, 101971. [\[CrossRef\]](#)
2. Dahiya, D.; Terpou, A.; Dasenaki, M.; Nigam, P.S. Current Status and Future Prospects of Bioactive Molecules Delivered through Sustainable Encapsulation Techniques for Food Fortification. *Sustain. Food Technol.* **2023**, *1*, 500–510. [\[CrossRef\]](#)
3. Aatif, M. Current Understanding of Polyphenols to Enhance Bioavailability for Better Therapies. *Biomedicines* **2023**, *11*, 2078. [\[CrossRef\]](#) [\[PubMed\]](#)
4. Akbarbaglu, Z.; Peighambaroust, S.H.; Sarabandi, K.; Jafari, S.M. Spray Drying Encapsulation of Bioactive Compounds within Protein-Based Carriers; Different Options and Applications. *Food Chem.* **2021**, *359*, 129965. [\[CrossRef\]](#) [\[PubMed\]](#)
5. Qazi, H.J.; Ye, A.; Acevedo-Fani, A.; Singh, H. Delivery of Encapsulated Bioactive Compounds within Food Matrices to the Digestive Tract: Recent Trends and Future Perspectives. *Crit. Rev. Food Sci. Nutr.* **2024**, 1–22. [\[CrossRef\]](#)
6. Bińkowska, W.; Szpicer, A.; Wojtasik-Kalinowska, I.; Półtorak, A. Innovative Methods of Encapsulation and Enrichment of Cereal-Based Pasta Products with Biofunctional Compounds. *Appl. Sci.* **2024**, *14*, 1442. [\[CrossRef\]](#)
7. Chen, L.; Gnanaraj, C.; Arulselvan, P.; El-Seedi, H.; Teng, H. A Review on Advanced Microencapsulation Technology to Enhance Bioavailability of Phenolic Compounds: Based on Its Activity in the Treatment of Type 2 Diabetes. *Trends Food Sci. Technol.* **2019**, *85*, 149–162. [\[CrossRef\]](#)
8. Khan, M.K.; Ahmad, K.; Hassan, S.; Imran, M.; Ahmad, N.; Xu, C. Effect of Novel Technologies on Polyphenols during Food Processing. *Innov. Food Sci. Emerg. Technol.* **2018**, *45*, 361–381. [\[CrossRef\]](#)
9. Shavisi, N.; Khanjari, A.; Basti, A.A.; Misaghi, A.; Shahbazi, Y. Effect of PLA Films Containing Propolis Ethanolic Extract, Cellulose Nanoparticle and Ziziphora Clinopodioides Essential Oil on Chemical, Microbial and Sensory Properties of Minced Beef. *Meat Sci.* **2017**, *124*, 95–104. [\[CrossRef\]](#)
10. Piñón-Balderrama, C.I.; Leyva-Porras, C.; Terán-Figueroa, Y.; Espinosa-Solís, V.; Álvarez-Salas, C.; Saavedra-Leos, M.Z. Encapsulation of Active Ingredients in Food Industry by Spray-Drying and Nano Spray-Drying Technologies. *Processes* **2020**, *8*, 889. [\[CrossRef\]](#)
11. Albuquerque, B.R.; Heleno, S.A.; Oliveira, M.B.P.P.; Barros, L.; Ferreira, I.C.F.R. Phenolic Compounds: Current Industrial Applications, Limitations and Future Challenges. *Food Funct.* **2021**, *12*, 14–29. [\[CrossRef\]](#) [\[PubMed\]](#)
12. Bajić, M.; Oberlintner, A.; Körge, K.; Likozar, B.; Novak, U. Formulation of Active Food Packaging by Design: Linking Composition of the Film-Forming Solution to Properties of the Chitosan-Based Film by Response Surface Methodology (RSM) Modelling. *Int. J. Biol. Macromol.* **2020**, *160*, 971–978. [\[CrossRef\]](#) [\[PubMed\]](#)
13. Pittari, E.; Moio, L.; Piombino, P. Interactions between Polyphenols and Volatile Compounds in Wine: A Literature Review on Physicochemical and Sensory Insights. *Appl. Sci.* **2021**, *11*, 1157. [\[CrossRef\]](#)
14. Andargie, M.; Vinas, M.; Rathgeb, A.; Möller, E.; Karlovsky, P. Lignans of Sesame (*Sesamum indicum* L.): A Comprehensive Review. *Molecules* **2021**, *26*, 883. [\[CrossRef\]](#) [\[PubMed\]](#)
15. Oluwole, O.; Fernando, W.B.; Lumanlan, J.; Ademuyiwa, O.; Jayasena, V. Role of Phenolic Acid, Tannins, Stilbenes, Lignans and Flavonoids in Human Health—A Review. *Int. J. Food Sci. Technol.* **2022**, *57*, 6326–6335. [\[CrossRef\]](#)
16. Trigo, J.P.; Alexandre, E.M.C.; Saraiva, J.A.; Pintado, M.E. High Value-Added Compounds from Fruit and Vegetable by-Products—Characterization, Bioactivities, and Application in the Development of Novel Food Products. *Crit. Rev. Food Sci. Nutr.* **2020**, *60*, 1388–1416. [\[CrossRef\]](#) [\[PubMed\]](#)
17. Imchen, T.; Singh, K.S. Marine Algae Colorants: Antioxidant, Anti-Diabetic Properties and Applications in Food Industry. *Algal Res.* **2023**, *69*, 102898. [\[CrossRef\]](#)
18. Kardum, N.; Takić, M.; Šavikin, K.; Zec, M.; Zdunić, G.; Spasić, S.; Konić-Ristić, A. Effects of Polyphenol-Rich Chokeberry Juice on Cellular Antioxidant Enzymes and Membrane Lipid Status in Healthy Women. *J. Funct. Foods* **2014**, *9*, 89–97. [\[CrossRef\]](#)
19. Musolino, V.; Gliozzi, M.; Bombardelli, E.; Nucera, S.; Carresi, C.; Maiuolo, J.; Mollace, R.; Paone, S.; Bosco, F.; Scarano, F.; et al. The Synergistic Effect of Citrus Bergamia and Cynara Cardunculus Extracts on Vascular Inflammation and Oxidative Stress in Non-Alcoholic Fatty Liver Disease. *J. Tradit. Complement. Med.* **2020**, *10*, 268–274. [\[CrossRef\]](#)
20. Mokra, D.; Joskova, M.; Mokry, J. Therapeutic Effects of Green Tea Polyphenol (–)-Epigallocatechin-3-Gallate (EGCG) in Relation to Molecular Pathways Controlling Inflammation, Oxidative Stress, and Apoptosis. *Int. J. Mol. Sci.* **2023**, *24*, 340. [\[CrossRef\]](#)
21. Tang, G.; Xu, Y.; Zhang, C.; Wang, N.; Li, H.; Feng, Y. Green Tea and Epigallocatechin Gallate (Egcg) for the Management of Nonalcoholic Fatty Liver Diseases (Nafld): Insights into the Role of Oxidative Stress and Antioxidant Mechanism. *Antioxidants* **2021**, *10*, 1076. [\[CrossRef\]](#) [\[PubMed\]](#)
22. Brglez Mojzer, E.; Knez Hrnič, M.; Škerget, M.; Knez, Ž.; Bren, U. Polyphenols: Extraction Methods, Antioxidative Action, Bioavailability and Anticarcinogenic Effects. *Molecules* **2016**, *21*, 901. [\[CrossRef\]](#) [\[PubMed\]](#)
23. Bhosale, P.B.; Ha, S.E.; Vetrivel, P.; Kim, H.H.; Kim, S.M.; Kim, G.S. Functions of Polyphenols and Its Anticancer Properties in Biomedical Research: A Narrative Review. *Transl. Cancer Res.* **2020**, *9*, 7619–7631. [\[CrossRef\]](#)
24. Di Lorenzo, C.; Colombo, F.; Biella, S.; Stockley, C.; Restani, P. Polyphenols and Human Health: The Role of Bioavailability. *Nutrients* **2021**, *13*, 273. [\[CrossRef\]](#) [\[PubMed\]](#)
25. Lapuente, M.; Estruch, R.; Shahbaz, M.; Casas, R. Relation of Fruits and Vegetables with Major Cardiometabolic Risk Factors, Markers of Oxidation, and Inflammation. *Nutrients* **2019**, *11*, 2381. [\[CrossRef\]](#)

26. Xu, R.; Bai, Y.; Yang, K.; Chen, G. Effects of Green Tea Consumption on Glycemic Control: A Systematic Review and Meta-Analysis of Randomized Controlled Trials. *Nutr. Metab.* **2020**, *17*, 56. [\[CrossRef\]](#) [\[PubMed\]](#)
27. Bié, J.; Sepodes, B.; Fernandes, P.C.B.; Ribeiro, M.H.L. Polyphenols in Health and Disease: Gut Microbiota, Bioaccessibility, and Bioavailability. *Compounds* **2023**, *3*, 40–72. [\[CrossRef\]](#)
28. Rana, A.; Samtiya, M.; Dhewa, T.; Mishra, V.; Aluko, R.E. Health Benefits of Polyphenols: A Concise Review. *J. Food Biochem.* **2022**, *46*, e14264. [\[CrossRef\]](#)
29. Mithul Aravind, S.; Wichienchot, S.; Tsao, R.; Ramakrishnan, S.; Chakkaravarthi, S. Role of Dietary Polyphenols on Gut Microbiota, Their Metabolites and Health Benefits. *Food Res. Int.* **2021**, *142*, 110189. [\[CrossRef\]](#)
30. Do Socorro Chagas, M.S.; Behrens, M.D.; Moragas-Tellis, C.J.; Penedo, G.X.M.; Silva, A.R.; Gonçalves-De-Albuquerque, C.F. Flavonols and Flavones as Potential Anti-Inflammatory, Antioxidant, and Antibacterial Compounds. *Oxid. Med. Cell. Longev.* **2022**, *2022*, 9966750. [\[CrossRef\]](#)
31. Barreca, D.; Trombetta, D.; Smeriglio, A.; Mandalari, G.; Romeo, O.; Felice, M.R.; Gattuso, G.; Nabavi, S.M. Food Flavonols: Nutraceuticals with Complex Health Benefits and Functionalities. *Trends Food Sci. Technol.* **2021**, *117*, 194–204. [\[CrossRef\]](#)
32. Akintemi, E.O.; Govender, K.K.; Singh, T. A DFT Study of the Chemical Reactivity Properties, Spectroscopy and Bioactivity Scores of Bioactive Flavonols. *Comput. Theor. Chem.* **2022**, *1210*, 113658. [\[CrossRef\]](#)
33. Gervasi, T.; Calderaro, A.; Barreca, D.; Tellone, E.; Trombetta, D.; Ficarra, S.; Smeriglio, A.; Mandalari, G.; Gattuso, G. Biotechnological Applications and Health-Promoting Properties of Flavonols: An Updated View. *Int. J. Mol. Sci.* **2022**, *23*, 1710. [\[CrossRef\]](#)
34. Kim, J.M.; Heo, H.J. The Roles of Catechins in Regulation of Systemic Inflammation. *Food Sci. Biotechnol.* **2022**, *31*, 957–970. [\[CrossRef\]](#)
35. Pedro, A.C.; Maciel, G.M.; Rampazzo Ribeiro, V.; Haminiuk, C.W.I. Fundamental and Applied Aspects of Catechins from Different Sources: A Review. *Int. J. Food Sci. Technol.* **2020**, *55*, 429–442. [\[CrossRef\]](#)
36. Paiva, L.; Lima, E.; Motta, M.; Marccone, M.; Baptista, J. Variability of Antioxidant Properties, Catechins, Caffeine, L-Theanine and Other Amino Acids in Different Plant Parts of Azorean Camellia Sinensis. *Curr. Res. Food Sci.* **2020**, *3*, 227–234. [\[CrossRef\]](#) [\[PubMed\]](#)
37. Bae, J.; Kim, N.; Shin, Y.; Kim, S.-Y.; Kim, Y.-J. Activity of Catechins and Their Applications. *Biomed. Dermatol.* **2020**, *4*, 8. [\[CrossRef\]](#)
38. Musial, C.; Kuban-Jackowska, A.; Gorska-Ponikowska, M. Beneficial Properties of Green Tea Catechins. *Int. J. Mol. Sci.* **2020**, *21*, 1744. [\[CrossRef\]](#)
39. Ganeshpurkar, A.; Saluja, A. The Pharmacological Potential of Catechin Aditya. *Indian J. Biochem. Biophys.* **2022**, *57*, 505–511. [\[CrossRef\]](#)
40. Li, Z.; Zhou, J.; Ji, L.; Liang, Y.; Xie, S. Recent Advances in the Pharmacological Actions of Apigenin, Its Complexes, and Its Derivatives. *Food Rev. Int.* **2023**, *39*, 6568–6601. [\[CrossRef\]](#)
41. Chen, P.; Chen, F.; Guo, Z.L.; Lei, J.; Zhou, B. Recent Advancement in Bioeffect, Metabolism, Stability, and Delivery Systems of Apigenin, a Natural Flavonoid Compound: Challenges and Perspectives. *Front. Nutr.* **2023**, *10*, 1221227. [\[CrossRef\]](#) [\[PubMed\]](#)
42. Kashyap, P.; Shikha, D.; Thakur, M.; Aneja, A. Functionality of Apigenin as a Potent Antioxidant with Emphasis on Bioavailability, Metabolism, Action Mechanism and in Vitro and in Vivo Studies: A Review. *J. Food Biochem.* **2022**, *46*, e13950. [\[CrossRef\]](#) [\[PubMed\]](#)
43. Abid, R.; Ghazanfar, S.; Farid, A.; Sulaman, S.M.; Idrees, M.; Amen, R.A.; Muzammal, M.; Shahzad, M.K.; Mohamed, M.O.; Khaled, A.A.; et al. Pharmacological Properties of 4', 5, 7-Trihydroxyflavone (Apigenin) and Its Impact on Cell Signaling Pathways. *Molecules* **2022**, *27*, 4304. [\[CrossRef\]](#) [\[PubMed\]](#)
44. Kim, J.K.; Park, S.U. Recent Insights into the Biological Functions of Apigenin. *EXCLI J.* **2020**, *19*, 984–991. [\[CrossRef\]](#) [\[PubMed\]](#)
45. Mushtaq, Z.; Sadeer, N.B.; Hussain, M.; Mahwish; Alsagaby, S.A.; Imran, M.; Mumtaz, T.; Umar, M.; Tauseef, A.; Al Abdulmonem, W.; et al. Therapeutical Properties of Apigenin: A Review on the Experimental Evidence and Basic Mechanisms. *Int. J. Food Prop.* **2023**, *26*, 1914–1939. [\[CrossRef\]](#)
46. Özsel ÖZCAN, F.; Aldemir, O.; Karabulut, B. Flavones (Apigenin, Luteolin, Chrysin) and Their Importance for Health. *Mellifera* **2020**, *2020*, 16–27.
47. Caporali, S.; De Stefano, A.; Calabrese, C.; Giovannelli, A.; Pieri, M.; Savini, I.; Tesauro, M.; Bernardini, S.; Minieri, M.; Terrinoni, A. Anti-Inflammatory and Active Biological Properties of the Plant-Derived Bioactive Compounds Luteolin and Luteolin 7-Glucoside. *Nutrients* **2022**, *14*, 1155. [\[CrossRef\]](#)
48. Ahmadi, S.M.; Farhoosh, R.; Sharif, A.; Rezaie, M. Structure-Antioxidant Activity Relationships of Luteolin and Catechin. *J. Food Sci.* **2020**, *85*, 298–305. [\[CrossRef\]](#)
49. De Stefano, A.; Caporali, S.; Di Daniele, N.; Rovella, V.; Cardillo, C.; Schinzari, F.; Minieri, M.; Pieri, M.; Candi, E.; Bernardini, S.; et al. Anti-Inflammatory and Proliferative Properties of Luteolin-7-O-Glucoside. *Int. J. Mol. Sci.* **2021**, *22*, 1321. [\[CrossRef\]](#) [\[PubMed\]](#)
50. Taheri, Y.; Sharifi-Rad, J.; Antika, G.; Yilmaz, Y.B.; Tumer, T.B.; Abuhamdah, S.; Chandra, S.; Saklani, S.; Kiliç, C.S.; Sestito, S.; et al. Paving Luteolin Therapeutic Potentialities and Agro-Food-Pharma Applications: Emphasis on in Vivo Pharmacological Effects and Bioavailability Traits. *Oxid. Med. Cell. Longev.* **2021**, *2021*, 1987588. [\[CrossRef\]](#)

51. Wang, Z.; Zeng, M.; Wang, Z.; Qin, F.; Chen, J.; He, Z. Dietary Luteolin: A Narrative Review Focusing on Its Pharmacokinetic Properties and Effects on Glycolipid Metabolism. *J. Agric. Food Chem.* **2021**, *69*, 1441–1454. [\[CrossRef\]](#) [\[PubMed\]](#)
52. Muruganathan, N.; Dhanapal, A.R.; Baskar, V.; Muthuramalingam, P.; Selvaraj, D.; Aara, H.; Abdullah, M.Z.S.; Sivanesan, I. Recent Updates on Source, Biosynthesis, and Therapeutic Potential of Natural Flavonoid Luteolin: A Review. *Metabolites* **2022**, *12*, 1145. [\[CrossRef\]](#)
53. Kim, I.S. Current Perspectives on the Beneficial Effects of Soybean Isoflavones and Their Metabolites on Plants. *Food Sci. Biotechnol.* **2022**, *31*, 515–526. [\[CrossRef\]](#) [\[PubMed\]](#)
54. Gómez-Zorita, S.; González-Arceo, M.; Fernández-Quintela, A.; Eseberri, I.; Trepiana, J.; Portillo, M.P. Scientific Evidence Supporting the Beneficial Effects of Isoflavones on Human Health. *Nutrients* **2020**, *12*, 3853. [\[CrossRef\]](#) [\[PubMed\]](#)
55. Kim, I.S.; Kim, C.H.; Yang, W.S. Physiologically Active Molecules and Functional Properties of Soybeans in Human Health—A Current Perspective. *Int. J. Mol. Sci.* **2021**, *22*, 4054. [\[CrossRef\]](#) [\[PubMed\]](#)
56. Hsiao, Y.H.; Ho, C.T.; Pan, M.H. Bioavailability and Health Benefits of Major Isoflavone Aglycones and Their Metabolites. *J. Funct. Foods* **2020**, *74*, 104164. [\[CrossRef\]](#)
57. Ockermann, P.; Headley, L.; Lizio, R.; Hansmann, J. A Review of the Properties of Anthocyanins and Their Influence on Factors Affecting Cardiometabolic and Cognitive Health. *Nutrients* **2021**, *13*, 2831. [\[CrossRef\]](#) [\[PubMed\]](#)
58. Tena, N.; Martín, J.; Asuero, A.G. State of the Art of Anthocyanins: Antioxidant Activity, Sources, Bioavailability, and Therapeutic Effect in Human Health. *Antioxidants* **2020**, *9*, 451. [\[CrossRef\]](#)
59. Verediano, T.A.; Stampini Duarte Martino, H.; Dias Paes, M.C.; Tako, E. Effects of Anthocyanin on Intestinal Health: A Systematic Review. *Nutrients* **2021**, *13*, 1331. [\[CrossRef\]](#)
60. Garcia, C.; Blesso, C.N. Antioxidant Properties of Anthocyanins and Their Mechanism of Action in Atherosclerosis. *Free Radic. Biol. Med.* **2021**, *172*, 152–166. [\[CrossRef\]](#)
61. Mattioli, R.; Francioso, A.; Mosca, L.; Silva, P. Anthocyanins: A Comprehensive Review of Their Chemical Properties and Health Effects on Cardiovascular and Neurodegenerative Diseases. *Molecules* **2020**, *25*, 3809. [\[CrossRef\]](#) [\[PubMed\]](#)
62. Singh, S.; Sharma, A.; Monga, V.; Bhatia, R. Compendium of Naringenin: Potential Sources, Analytical Aspects, Chemistry, Nutraceutical Potentials and Pharmacological Profile. *Crit. Rev. Food Sci. Nutr.* **2023**, *63*, 8868–8899. [\[CrossRef\]](#) [\[PubMed\]](#)
63. Sharma, A.; Bhardwaj, P.; Arya, S.K. Naringin: A Potential Natural Product in the Field of Biomedical Applications. *Carbohydr. Polym. Technol. Appl.* **2021**, *2*, 100068. [\[CrossRef\]](#)
64. Cai, J.; Wen, H.; Zhou, H.; Zhang, D.; Lan, D.; Liu, S.; Li, C.; Dai, X.; Song, T.; Wang, X.; et al. Naringenin: A Flavanone with Anti-Inflammatory and Anti-Infective Properties. *Biomed. Pharmacother.* **2023**, *164*, 114990. [\[CrossRef\]](#) [\[PubMed\]](#)
65. Stabrauskiene, J.; Kopustinskiene, D.M.; Lazauskas, R.; Bernatoniene, J. Naringin and Naringenin: Their Mechanisms of Action and the Potential Anticancer Activities. *Biomedicines* **2022**, *10*, 1686. [\[CrossRef\]](#) [\[PubMed\]](#)
66. Shilpa, V.S.; Shams, R.; Dash, K.K.; Pandey, V.K.; Dar, A.H.; Ayaz Mukarram, S.; Harsányi, E.; Kovács, B. Phytochemical Properties, Extraction, and Pharmacological Benefits of Naringin: A Review. *Molecules* **2023**, *28*, 5623. [\[CrossRef\]](#)
67. Fraga-Corral, M.; Otero, P.; Echave, J.; Garcia-Oliveira, P.; Carpena, M.; Jarboui, A.; Nuñez-Estevéz, B.; Simal-Gandara, J.; Prieto, M.A. By-Products of Agri-Food Industry as Tannin-Rich Sources: A Review of Tannins' Biological Activities and Their Potential for Valorization. *Foods* **2021**, *10*, 137. [\[CrossRef\]](#) [\[PubMed\]](#)
68. Fabbri, M.; D'amico, F.; Barone, M.; Conti, G.; Mengoli, M.; Brigidi, P.; Turrone, S. Polyphenol and Tannin Nutraceuticals and Their Metabolites: How the Human Gut Microbiota Influences Their Properties. *Biomolecules* **2022**, *12*, 875. [\[CrossRef\]](#)
69. Fraga-Corral, M.; Otero, P.; Cassani, L.; Echave, J.; Garcia-Oliveira, P.; Carpena, M.; Chamorro, F.; Lourenço-Lopes, C.; Prieto, M.A.; Simal-Gandara, J. Traditional Applications of Tannin Rich Extracts Supported by Scientific Data: Chemical Composition, Bioavailability and Bioaccessibility. *Foods* **2021**, *10*, 251. [\[CrossRef\]](#) [\[PubMed\]](#)
70. Pizzi, A. Tannins Medical / Pharmacological and Related Applications: A Critical Review. *Sustain. Chem. Pharm.* **2021**, *22*, 100481. [\[CrossRef\]](#)
71. Zhang, L.; Guan, Q.; Jiang, J.; Khan, M.S. Tannin Complexation with Metal Ions and Its Implication on Human Health, Environment and Industry: An Overview. *Int. J. Biol. Macromol.* **2023**, *253*, 127485. [\[CrossRef\]](#)
72. Sharma, K.; Kumar, V.; Kaur, J.; Tanwar, B.; Goyal, A.; Sharma, R.; Gat, Y.; Kumar, A. Health Effects, Sources, Utilization and Safety of Tannins: A Critical Review. *Toxin Rev.* **2021**, *40*, 432–444. [\[CrossRef\]](#)
73. Mompeo, O.; Spector, T.D.; Hernandez, M.M.; Le Roy, C.; Istas, G.; Le Sayec, M.; Mangino, M.; Jennings, A.; Rodriguez-Mateos, A.; Valdes, A.M.; et al. Consumption of Stilbenes and Flavonoids Is Linked to Reduced Risk of Obesity Independently of Fiber Intake. *Nutrients* **2020**, *12*, 1871. [\[CrossRef\]](#) [\[PubMed\]](#)
74. Duta-Bratu, C.G.; Nitulescu, G.M.; Mihai, D.P.; Olaru, O.T. Resveratrol and Other Natural Oligomeric Stilbenoid Compounds and Their Therapeutic Applications. *Plants* **2023**, *12*, 2935. [\[CrossRef\]](#) [\[PubMed\]](#)
75. Al-Khayri, J.M.; Mascarenhas, R.; Harish, H.M.; Gowda, Y.; Lakshmaiah, V.V.; Nagella, P.; Al-Mssallem, M.Q.; Alessa, F.M.; Almaghasla, M.I.; Rezk, A.A.S. Stilbenes, a Versatile Class of Natural Metabolites for Inflammation—An Overview. *Molecules* **2023**, *28*, 3786. [\[CrossRef\]](#) [\[PubMed\]](#)
76. Kluska, M.; Jabłońska, J.; Prukala, W. Analytics, Properties and Applications of Biologically Active Stilbene Derivatives. *Molecules* **2023**, *28*, 4482. [\[CrossRef\]](#) [\[PubMed\]](#)
77. Benbouguerra, N.; Hornedo-Ortega, R.; Garcia, F.; El Khawand, T.; Saucier, C.; Richard, T. Stilbenes in Grape Berries and Wine and Their Potential Role as Anti-Obesity Agents: A Review. *Trends Food Sci. Technol.* **2021**, *112*, 362–381. [\[CrossRef\]](#)

78. Navarro-Orcajada, S.; Conesa, I.; Vidal-Sánchez, F.J.; Matencio, A.; Albaladejo-Maricó, L.; García-Carmona, F.; López-Nicolás, J.M. Stilbenes: Characterization, Bioactivity, Encapsulation and Structural Modifications: A Review of Their Current Limitations and Promising Approaches. *Crit. Rev. Food Sci. Nutr.* **2023**, *63*, 7269–7287. [\[CrossRef\]](#) [\[PubMed\]](#)
79. Teka, T.; Zhang, L.; Ge, X.; Li, Y.; Han, L.; Yan, X. Stilbenes: Source Plants, Chemistry, Biosynthesis, Pharmacology, Application and Problems Related to Their Clinical Application—A Comprehensive Review. *Phytochemistry* **2022**, *197*, 113128. [\[CrossRef\]](#) [\[PubMed\]](#)
80. Soleymani, S.; Habtemariam, S.; Rahimi, R.; Nabavi, S.M. The What and Who of Dietary Lignans in Human Health: Special Focus on Prooxidant and Antioxidant Effects. *Trends Food Sci. Technol.* **2020**, *106*, 382–390. [\[CrossRef\]](#)
81. Jang, W.Y.; Kim, M.Y.; Cho, J.Y. Antioxidant, Anti-Inflammatory, Anti-Menopausal, and Anti-Cancer Effects of Lignans and Their Metabolites. *Int. J. Mol. Sci.* **2022**, *23*, 15482. [\[CrossRef\]](#) [\[PubMed\]](#)
82. Senizza, A.; Rocchetti, G.; Mosele, J.I.; Patrone, V.; Callegari, M.L.; Morelli, L.; Lucini, L. Lignans and Gut Microbiota: An Interplay Revealing Potential Health Implications. *Molecules* **2020**, *25*, 5709. [\[CrossRef\]](#) [\[PubMed\]](#)
83. Gao, Z.; Cao, Q.; Deng, Z. Unveiling the Power of Flax Lignans: From Plant Biosynthesis to Human Health Benefits. *Nutrients* **2024**, *16*, 3520. [\[CrossRef\]](#) [\[PubMed\]](#)
84. Plaha, N.S.; Awasthi, S.; Sharma, A.; Kaushik, N. Distribution, Biosynthesis and Therapeutic Potential of Lignans. *3 Biotech* **2022**, *12*, 255. [\[CrossRef\]](#) [\[PubMed\]](#)
85. Kose, L.P.; Gulcin, I. Evaluation of the Antioxidant and Antiradical Properties of Some Phyto and Mammalian Lignans. *Molecules* **2021**, *26*, 7099. [\[CrossRef\]](#)
86. Ražná, K.; Nůžková, J.; Vargaová, A.; Harenčár, Á.; Bjelková, M. Biological Functions of Lignans in Plants. *Agriculture* **2021**, *67*, 155–165. [\[CrossRef\]](#)
87. Leonard, W.; Zhang, P.; Ying, D.; Fang, Z. Tyramine-Derived Hydroxycinnamic Acid Amides in Plant Foods: Sources, Synthesis, Health Effects and Potential Applications in Food Industry. *Crit. Rev. Food Sci. Nutr.* **2022**, *62*, 1608–1625. [\[CrossRef\]](#)
88. da Silva, A.P.G.; Sganzerla, W.G.; John, O.D.; Marchiosi, R. A Comprehensive Review of the Classification, Sources, Biosynthesis, and Biological Properties of Hydroxybenzoic and Hydroxycinnamic Acids. *Phytochem. Rev.* **2023**. [\[CrossRef\]](#)
89. Leonard, W.; Zhang, P.; Ying, D.; Fang, Z. Hydroxycinnamic Acids on Gut Microbiota and Health. *Compr. Rev. Food Sci. Food Saf.* **2021**, *20*, 710–737. [\[CrossRef\]](#) [\[PubMed\]](#)
90. Coman, V.; Vodnar, D.C. Hydroxycinnamic Acids and Human Health: Recent Advances. *J. Sci. Food Agric.* **2020**, *100*, 483–499. [\[CrossRef\]](#)
91. Sova, M. Activities and Health Benefits of Hydroxycinnamic Acids and Their Metabolites. *Nutrients* **2020**, *12*, 2190. [\[CrossRef\]](#)
92. Krátký, M.; Konečná, K.; Brokešová, K.; Maixnerová, J.; Trejtnar, F.; Vinšová, J. Optimizing the Structure of (Salicylide-neamino)Benzoic Acids: Towards Selective Antifungal and Anti-Staphylococcal Agents. *Eur. J. Pharm. Sci.* **2021**, *159*, 105732. [\[CrossRef\]](#) [\[PubMed\]](#)
93. Salleh, F.; Lani, M.N.; Chilek, T.Z.T.; Kamaruding, N.A.; Ismail, N. Lactic Acid Bacteria Producing Sorbic Acid and Benzoic Acid Compounds from Fermented Durian Flesh (Tempoyak) and Their Antibacterial Activities Against Foodborne Pathogenic Bacteria. *Appl. Food Biotechnol.* **2021**, *8*, 121–132. [\[CrossRef\]](#)
94. Rashmi, H.B.; Negi, P.S. Phenolic Acids from Vegetables: A Review on Processing Stability and Health Benefits. *Food Res. Int.* **2020**, *136*, 109298. [\[CrossRef\]](#) [\[PubMed\]](#)
95. Makhuvele, R.; Naidu, K.; Gbashi, S.; Thipe, V.C.; Adebo, O.A.; Njobeh, P.B. The Use of Plant Extracts and Their Phytochemicals for Control of Toxigenic Fungi and Mycotoxins. *Heliyon* **2020**, *6*, e05291. [\[CrossRef\]](#) [\[PubMed\]](#)
96. Katalinić, V.; Možina, S.S.; Skroza, D.; Generalić, I.; Abramović, H.; Miloš, M.; Ljubenkov, I.; Piskernik, S.; Pezo, I.; Terpin, P.; et al. Polyphenolic Profile, Antioxidant Properties and Antimicrobial Activity of Grape Skin Extracts of 14 Vitis Vinifera Varieties Grown in Dalmatia (Croatia). *Food Chem.* **2010**, *119*, 715–723. [\[CrossRef\]](#)
97. Difonzo, G.; Squeo, G.; Pasqualone, A.; Summo, C.; Paradiso, V.M.; Caponio, F. The Challenge of Exploiting Polyphenols from Olive Leaves: Addition to Foods to Improve Their Shelf-Life and Nutritional Value. *J. Sci. Food Agric.* **2021**, *101*, 3099–3116. [\[CrossRef\]](#)
98. El Moudhen, H.; El Idrissi, Y.; Belmaghraoui, W.; Belhoussaine, O.; El Guezane, C.; Bouayoun, T.; Harhar, H.; Tabyaoui, M. Olive Mill Wastewater Polyphenol-Based Extract as a Vegetable Oil Shelf Life Extending Additive. *J. Food Process. Preserv.* **2020**, *44*, e14990. [\[CrossRef\]](#)
99. Ofosu, F.K.; Daliri, E.B.M.; Elahi, F.; Chelliah, R.; Lee, B.H.; Oh, D.H. New Insights on the Use of Polyphenols as Natural Preservatives and Their Emerging Safety Concerns. *Front. Sustain. Food Syst.* **2020**, *4*, 525810. [\[CrossRef\]](#)
100. Rathee, P.; Sehrawat, R.; Rathee, P.; Khatkar, A.; Akkol, E.K.; Khatkar, S.; Redhu, N.; Türkcanoğlu, G.; Sobarzo-Sánchez, E. Polyphenols: Natural Preservatives with Promising Applications in Food, Cosmetics and Pharma Industries; Problems and Toxicity Associated with Synthetic Preservatives; Impact of Misleading Advertisements; Recent Trends in Preservation and Legislation. *Materials* **2023**, *16*, 4793. [\[CrossRef\]](#)
101. Kozłowska, M.; Żbikowska, A.; Gruczyńska, E.; Żontała, K.; Półtorak, A. Effects of Spice Extracts on Lipid Fraction Oxidative Stability of Cookies Investigated by DSC. *J. Therm. Anal. Calorim.* **2014**, *118*, 1697–1705. [\[CrossRef\]](#)
102. Gutiérrez-Del-río, I.; López-Ibáñez, S.; Magadán-Corpas, P.; Fernández-Calleja, L.; Pérez-Valero, Á.; Tuñón-Granda, M.; Miguélez, E.M.; Villar, C.J.; Lombó, F. Terpenoids and Polyphenols as Natural Antioxidant Agents in Food Preservation. *Antioxidants* **2021**, *10*, 1264. [\[CrossRef\]](#) [\[PubMed\]](#)

103. Costa, M.; Sezgin-Bayindir, Z.; Losada-Barreiro, S.; Paiva-Martins, F.; Saso, L.; Bravo-Díaz, C. Polyphenols as Antioxidants for Extending Food Shelf-Life and in the Prevention of Health Diseases: Encapsulation and Interfacial Phenomena. *Biomedicines* **2021**, *9*, 1909. [\[CrossRef\]](#)
104. Daglia, M. Polyphenols as Antimicrobial Agents. *Curr. Opin. Biotechnol.* **2012**, *23*, 174–181. [\[CrossRef\]](#) [\[PubMed\]](#)
105. Xie, Y.; Chen, J.; Xiao, A.; Liu, L. Antibacterial Activity of Polyphenols: Structure-Activity Relationship and Influence of Hyperglycemic Condition. *Molecules* **2017**, *22*, 1913. [\[CrossRef\]](#) [\[PubMed\]](#)
106. Davidova, S.; Galabov, A.S.; Satchanska, G. Antibacterial, Antifungal, Antiviral Activity, and Mechanisms of Action of Plant Polyphenols. *Microorganisms* **2024**, *12*, 2502. [\[CrossRef\]](#)
107. Rathod, N.B.; Elabed, N.; Punia, S.; Ozogul, F.; Kim, S.K.; Rocha, J.M. Recent Developments in Polyphenol Applications on Human Health: A Review with Current Knowledge. *Plants* **2023**, *12*, 1217. [\[CrossRef\]](#) [\[PubMed\]](#)
108. Jiang, Z.; Han, Z.; Zhu, M.; Wan, X.; Zhang, L. Effects of Thermal Processing on Transformation of Polyphenols and Flavor Quality. *Curr. Opin. Food Sci.* **2023**, *51*, 101014. [\[CrossRef\]](#)
109. de Araújo, F.F.; de Paulo Farias, D.; Neri-Numa, I.A.; Pastore, G.M. Polyphenols and Their Applications: An Approach in Food Chemistry and Innovation Potential. *Food Chem.* **2021**, *338*, 127535. [\[CrossRef\]](#) [\[PubMed\]](#)
110. Luzardo-Ocampo, I.; Ramírez-Jiménez, A.K.; Yañez, J.; Mojica, L.; Luna-Vital, D.A. Technological Applications of Natural Colorants in Food Systems: A Review. *Foods* **2021**, *10*, 634. [\[CrossRef\]](#) [\[PubMed\]](#)
111. Lund, M.N. Reactions of Plant Polyphenols in Foods: Impact of Molecular Structure. *Trends Food Sci. Technol.* **2021**, *112*, 241–251. [\[CrossRef\]](#)
112. Soares, S.; Brandão, E.; Guerreiro, C.; Soares, S.; Mateus, N.; De Freitas, V. Tannins in Food: Insights into the Molecular Perception of Astringency and Bitter Taste. *Molecules* **2020**, *25*, 2590. [\[CrossRef\]](#) [\[PubMed\]](#)
113. Dabas, D. Polyphenols as Colorants. *Adv. Food Technol. Nutr. Sci. Open J.* **2018**, S1–S6. [\[CrossRef\]](#)
114. Magalhães, D.; Gonçalves, R.; Rodrigues, C.V.; Rocha, H.R.; Pintado, M.; Coelho, M.C. Natural Pigments Recovery from Food By-Products: Health Benefits towards the Food Industry. *Foods* **2024**, *13*, 2276. [\[CrossRef\]](#) [\[PubMed\]](#)
115. Li, M.; Ritzoulis, C.; Du, Q.; Liu, Y.; Ding, Y.; Liu, W.; Liu, J. Recent Progress on Protein-Polyphenol Complexes: Effect on Stability and Nutrients Delivery of Oil-in-Water Emulsion System. *Front. Nutr.* **2021**, *8*, 765589. [\[CrossRef\]](#) [\[PubMed\]](#)
116. Dai, T.; Li, T.; Li, R.; Zhou, H.; Liu, C.; Chen, J.; McClements, D.J. Utilization of Plant-Based Protein-Polyphenol Complexes to Form and Stabilize Emulsions: Pea Proteins and Grape Seed Proanthocyanidins. *Food Chem.* **2020**, *329*, 127219. [\[CrossRef\]](#)
117. Büyüç, M.; Ata, A.; Yemenicioğlu, A. Application of Pectin-Grape Seed Polyphenol Combination Restores Consistency and Emulsion Stability and Enhances Antioxidant Capacity of Reduced Oil Aquafaba Vegan Mayonnaise. *Food Bioprod. Process.* **2024**, *144*, 123–131. [\[CrossRef\]](#)
118. Büyüç, M.; Yemenicioğlu, A. Stabilisation of Extra Virgin Olive Oil-in-Water Emulsions Prepared by Citrus Pectin Using Green Tea and Grape Seed Phenolic Extracts and Catechin. *Int. J. Food Sci. Technol.* **2024**, *59*, 5767–5776. [\[CrossRef\]](#)
119. Blasi, F.; Cossignani, L. An Overview of Natural Extracts with Antioxidant Activity for the Improvement of the Oxidative Stability and Shelf Life of Edible Oils. *Processes* **2020**, *8*, 956. [\[CrossRef\]](#)
120. Trajkovska, M.; Derwiche, F.; Grigorakis, S.; Makris, D.P. Natural Phenolic Acids as Effective Bulk Oil Antioxidants: Oxidative Stability Modeling Using Olive Kernel Oil as a Case Study. *Appl. Sci.* **2024**, *14*, 6508. [\[CrossRef\]](#)
121. Hussein, A.S.; Mostafa, S.; Fouad, S.; Hegazy, N.A.; Zaky, A.A. Production and Evaluation of Gluten-Free Pasta and Pan Bread from Spirulina Algae Powder and Quinoa Flour. *Processes* **2023**, *11*, 2899. [\[CrossRef\]](#)
122. Xue, H.; Zhang, G.; Han, T.; Li, R.; Liu, H.; Gao, B.; Tu, Y.; Zhao, Y. Improvement of Gel Properties and Digestibility of the Water-Soluble Polymer of Tea Polyphenol-Egg White under Thermal Treatment. *Food Chem.* **2022**, *372*, 131319. [\[CrossRef\]](#) [\[PubMed\]](#)
123. Szpicer, A.; Onopiuk, A.; Barczak, M.; Kurek, M. The Optimization of a Gluten-Free and Soy-Free Plant-Based Meat Analogue Recipe Enriched with Anthocyanins Microcapsules. *LWT* **2022**, *168*, 113849. [\[CrossRef\]](#)
124. Jiang, R.; Wang, H.; Su, S.; Li, R.; Hu, Y.; Zhu, M.; Duan, Y.; Xiao, Z.; Gao, Y. Effects of the Tea Polyphenol Content on the Properties and Structural Characteristics of Simulated Meat. *Futur. Foods* **2022**, *5*, 100150. [\[CrossRef\]](#)
125. Zhang, K.; Huang, J.; Wang, D.; Wan, X.; Wang, Y. Covalent Polyphenols-Proteins Interactions in Food Processing: Formation Mechanisms, Quantification Methods, Bioactive Effects, and Applications. *Front. Nutr.* **2024**, *11*, 1371401. [\[CrossRef\]](#) [\[PubMed\]](#)
126. Liu, R.; Yan, X.; Liu, Z.; McClements, D.J.; Liu, F.; Liu, X. Fabrication and Characterization of Functional Protein-Polysaccharide-Polyphenol Complexes Assembled from Lactoferrin, Hyaluronic Acid and (-)-Epigallocatechin Gallate. *Food Funct.* **2019**, *10*, 1098–1108. [\[CrossRef\]](#) [\[PubMed\]](#)
127. Novais, C.; Molina, A.K.; Abreu, R.M.V.; Santo-Buelga, C.; Ferreira, I.C.F.R.; Pereira, C.; Barros, L. Natural Food Colorants and Preservatives: A Review, a Demand, and a Challenge. *J. Agric. Food Chem.* **2022**, *70*, 2789–2805. [\[CrossRef\]](#)
128. Szpicer, A.; Onopiuk, A.; Wojtasik-Kalinowska, I.; Półtorak, A. Red Grape Skin Extract and Oat β -Glucan in Shortbread Cookies: Technological and Nutritional Evaluation. *Eur. Food Res. Technol.* **2021**, *247*, 1999–2014. [\[CrossRef\]](#)
129. Wojtasik-Kalinowska, I.; Onopiuk, A.; Szpicer, A.; Wierzbicka, A.; Półtorak, A. Frozen Storage Quality and Flavor Evaluation of Ready to Eat Steamed Meat Products Treated with Antioxidants. *CYTA J. Food* **2021**, *19*, 152–162. [\[CrossRef\]](#)
130. Wojtasik-Kalinowska, I.; Marcinkowska-Lesiak, M.; Onopiuk, A.; Szpicer, A.; Wierzbicka, A.; Półtorak, A. The Effect of Solanum Lycopersicum, L. Extract on Quality and Flavor Stability of Ready to Eat Meat Products. *Anim. Sci. Pap. Rep.* **2022**, *40*, 423–438.

131. Zambrano, Y.; Mariotti-Celis, M.S.; Bouchon, P. 3G Extruded Snacks Enriched with Catechin for High Antioxidant Capacity. *LWT* **2024**, *192*, 115674. [\[CrossRef\]](#)
132. Ahmad, M.; Gani, A. Development of Novel Functional Snacks Containing Nano-Encapsulated Resveratrol with Anti-Diabetic, Anti-Obesity and Antioxidant Properties. *Food Chem.* **2021**, *352*, 129323. [\[CrossRef\]](#)
133. Ruskovska, T.; Maksimova, V.; Milenkovic, D. Polyphenols in Human Nutrition: From the in Vitro Antioxidant Capacity to the Beneficial Effects on Cardiometabolic Health and Related Inter-Individual Variability—An Overview and Perspective. *Br. J. Nutr.* **2020**, *123*, 241–254. [\[CrossRef\]](#)
134. Dhakal, S.P.; He, J. Microencapsulation of Vitamins in Food Applications to Prevent Losses in Processing and Storage: A Review. *Food Res. Int.* **2020**, *137*, 109326. [\[CrossRef\]](#) [\[PubMed\]](#)
135. Heck, R.T.; Lorenzo, J.M.; Dos Santos, B.A.; Cichoski, A.J.; de Menezes, C.R.; Campagnol, P.C.B. Microencapsulation of Healthier Oils: An Efficient Strategy to Improve the Lipid Profile of Meat Products. *Curr. Opin. Food Sci.* **2021**, *40*, 6–12. [\[CrossRef\]](#)
136. Cao, H.; Saroglu, O.; Karadag, A.; Diaconeasa, Z.; Zoccatelli, G.; Conte-Junior, C.A.; Gonzalez-Aguilar, G.A.; Ou, J.; Bai, W.; Zamarioli, C.M.; et al. Available Technologies on Improving the Stability of Polyphenols in Food Processing. *Food Front.* **2021**, *2*, 109–139. [\[CrossRef\]](#)
137. Rajam, R.; Kumar, S.B.; Prabhasankar, P.; Anandharamakrishnan, C. Microencapsulation of Lactobacillus Plantarum MTCC 5422 in Fructooligosaccharide and Whey Protein Wall Systems and Its Impact on Noodle Quality. *J. Food Sci. Technol.* **2015**, *52*, 4029–4041. [\[CrossRef\]](#) [\[PubMed\]](#)
138. Ćujić-Nikolić, N.; Stanisavljević, N.; Šavikin, K.; Kalušević, A.; Nedović, V.; Bigović, D.; Janković, T. Application of Gum Arabic in the Production of Spray-Dried Chokeberry Polyphenols, Microparticles Characterisation and in Vitro Digestion Method. *Lek. Sirovine* **2018**, *2020*, 9–16. [\[CrossRef\]](#)
139. Tylkowski, B.; Tsibranska, I. Polyphenols Encapsulation—Application of Innovation Technologies to Improve Stability of Natural Products. *Phys. Sci. Rev.* **2019**, *1*, 1–13. [\[CrossRef\]](#)
140. Wang, Z.; Zhou, D.; Liu, D.; Zhu, B. Food-Grade Encapsulated Polyphenols: Recent Advances as Novel Additives in Foodstuffs. *Crit. Rev. Food Sci. Nutr.* **2023**, *63*, 11545–11560. [\[CrossRef\]](#) [\[PubMed\]](#)
141. Bodbodak, S.; Nejatian, M.; Ghandehari Yazdi, A.P.; Kamali Roust, L.; Rafiee, Z.; Jalali-Jivan, M.; Kharazmi, M.S.; Jafari, S.M. Improving the Thermal Stability of Natural Bioactive Ingredients via Encapsulation Technology. *Crit. Rev. Food Sci. Nutr.* **2022**, *64*, 2824–2846. [\[CrossRef\]](#) [\[PubMed\]](#)
142. Subramani, T.; Ganapathyswamy, H. An Overview of Liposomal Nano-Encapsulation Techniques and Its Applications in Food and Nutraceutical. *J. Food Sci. Technol.* **2020**, *57*, 3545–3555. [\[CrossRef\]](#) [\[PubMed\]](#)
143. Choudhury, N.; Meghwal, M.; Das, K. Microencapsulation: An Overview on Concepts, Methods, Properties and Applications in Foods. *Food Front.* **2021**, *2*, 426–442. [\[CrossRef\]](#)
144. Nickerson, M.; Yan, C.; Cloutier, S.; Zhang, W. *Protection and Masking of Omega-3 and -6 Oils via Microencapsulation*; Elsevier Inc.: Amsterdam, The Netherlands, 2014; ISBN 9780124045682.
145. Mohammadalinejad, S.; Kurek, M.A. Microencapsulation of Anthocyanins—Critical Review of Techniques and Wall Materials. *Appl. Sci.* **2021**, *11*, 3936. [\[CrossRef\]](#)
146. Lu, W.; Kelly, A.L.; Miao, S. Emulsion-Based Encapsulation and Delivery Systems for Polyphenols. *Trends Food Sci. Technol.* **2016**, *47*, 1–9. [\[CrossRef\]](#)
147. Saavedra-Leos, M.Z.; Leyva-Porras, C.; Toxqui-Terán, A.; Espinosa-Solis, V. Physicochemical Properties and Antioxidant Activity of Spray-Dry Broccoli (*Brassica oleracea* Var Italica) Stalk and Floret Juice Powders. *Molecules* **2021**, *26*, 1973. [\[CrossRef\]](#) [\[PubMed\]](#)
148. Arenas-Jal, M.; Suñé-Negre, J.M.; García-Montoya, E. An Overview of Microencapsulation in the Food Industry: Opportunities, Challenges, and Innovations. *Eur. Food Res. Technol.* **2020**, *246*, 1371–1382. [\[CrossRef\]](#)
149. Baerle, A. Microencapsulation of Functional Components in the Food Technology: Partially Optimistic View. *J. Eng. Sci.* **2021**, *28*, 139–157. [\[CrossRef\]](#) [\[PubMed\]](#)
150. Niu, B.; Shao, P.; Luo, Y.; Sun, P. Recent Advances of Electrospayed Particles as Encapsulation Systems of Bioactives for Food Application. *Food Hydrocoll.* **2020**, *99*, 105376. [\[CrossRef\]](#)
151. Wang, P.; Ding, M.; Zhang, T.; Wu, T.; Qiao, R.; Zhang, F.; Wang, X.; Zhong, J. Electrospaying Technique and Its Recent Application Advances for Biological Macromolecule Encapsulation of Food Bioactive Substances. *Food Rev. Int.* **2022**, *38*, 566–588. [\[CrossRef\]](#)
152. Kumar, A.; Dhiman, A.; Suhag, R.; Sehrawat, R.; Upadhyay, A.; McClements, D.J. Comprehensive Review on Potential Applications of Microfluidization in Food Processing. *Food Sci. Biotechnol.* **2022**, *31*, 17–36. [\[CrossRef\]](#) [\[PubMed\]](#)
153. Kavinila, S.; Nimbkar, S.; Moses, J.A.; Anandharamakrishnan, C. Emerging Applications of Microfluidization in the Food Industry. *J. Agric. Food Res.* **2023**, *12*, 100537. [\[CrossRef\]](#)
154. Yang, B.; Dong, Y.; Wang, F.; Zhang, Y. Nanoformulations to Enhance the Bioavailability and Physiological Functions of Polyphenols. *Molecules* **2020**, *25*, 4613. [\[CrossRef\]](#)
155. Dwivedi, K.P.; Jaiswal, S. Microencapsulation: Application and Recent Advances-A Review Review Article Microencapsulation: Application and Recent Advances—A Review. *Int. J. Med. Pharm. Res.* **2023**, *4*, 1–7.
156. Estevinho, B.M.A.N.; Rocha, F.A.N.; Santos, L.M.D.S.; Alves, M.A.C. Using Water-Soluble Chitosan for Flavour Microencapsulation in Food Industry. *J. Microencapsul.* **2013**, *30*, 571–579. [\[CrossRef\]](#) [\[PubMed\]](#)

157. Wang, L.; Li, T.; Wu, C.; Fan, G.; Zhou, D.; Li, X. Unlocking the Potential of Plant Polyphenols: Advances in Extraction, Antibacterial Mechanisms, and Future Applications. *Food Sci. Biotechnol.* **2024**, 1–25. [\[CrossRef\]](#)
158. Caban, M.; Lewandowska, U. Encapsulation of Polyphenolic Compounds Based on Hemicelluloses to Enhance Treatment of Inflammatory Bowel Diseases and Colorectal Cancer. *Molecules* **2023**, *28*, 4189. [\[CrossRef\]](#)
159. Ijod, G.; Nawawi, N.I.M.; Anwar, F.; Rahim, M.H.A.; Ismail-Fitry, M.R.; Adzahan, N.M.; Azman, E.M. Recent Microencapsulation Trends for Enhancing the Stability and Functionality of Anthocyanins: A Review. *Food Sci. Biotechnol.* **2024**, *33*, 2673–2698. [\[CrossRef\]](#)
160. Sorita, G.D.; Leimann, F.V.; Ferreira, S.R.S. Phenolic Fraction from Peanut (*Arachis hypogaea* L.) By-Product: Innovative Extraction Techniques and New Encapsulation Trends for Its Valorization. *Food Bioprocess. Technol.* **2023**, *16*, 726–748. [\[CrossRef\]](#)
161. Ahmad, M.; Mudgil, P.; Gani, A.; Hamed, F.; Masoodi, F.A.; Maqsood, S. Nano-Encapsulation of Catechin in Starch Nanoparticles: Characterization, Release Behavior and Bioactivity Retention during Simulated in-Vitro Digestion. *Food Chem.* **2019**, *270*, 95–104. [\[CrossRef\]](#) [\[PubMed\]](#)
162. Xiao, Y.; Ahmad, T.; Belwal, T.; Aadil, R.M.; Siddique, M.; Pang, L.; Xu, Y. A Review on Protein Based Nanocarriers for Polyphenols: Interaction and Stabilization Mechanisms. *Food Innov. Adv.* **2023**, *2*, 193–202. [\[CrossRef\]](#)
163. Pimentel-Moral, S.; Teixeira, M.C.; Fernandes, A.R.; Arráez-Román, D.; Martínez-Férez, A.; Segura-Carretero, A.; Souto, E.B. Lipid Nanocarriers for the Loading of Polyphenols—A Comprehensive Review. *Adv. Colloid. Interface Sci.* **2018**, *260*, 85–94. [\[CrossRef\]](#) [\[PubMed\]](#)
164. Patel, P.; Garala, K.; Singh, S.; Prajapati, B.G.; Chittasupho, C. Lipid-Based Nanoparticles in Delivering Bioactive Compounds for Improving Therapeutic Efficacy. *Pharmaceutics* **2024**, *17*, 329. [\[CrossRef\]](#)
165. Mall, J.; Naseem, N.; Haider, F.; Rahman, A.; Khan, S.; Naaz, S.S. Nanostructured Lipid Carriers as a Drug Delivery System: A Comprehensive Review with Therapeutic Applications. *Ageing Res. Rev.* **2023**, 101865. [\[CrossRef\]](#)
166. Haider, M.; Abdin, S.M.; Kamal, L.; Orive, G. Nanostructured Lipid Carriers for Delivery of Chemotherapeutics: A Review. *Pharmaceutics* **2020**, *12*, 288. [\[CrossRef\]](#) [\[PubMed\]](#)
167. Stefanov, S.R.; Andonova, V.Y. Lipid Nanoparticle Drug Delivery Systems: Recent Advances in the Treatment of Skin Disorders. *Pharmaceutics* **2021**, *14*, 1083. [\[CrossRef\]](#) [\[PubMed\]](#)
168. Odriozola-Serrano, I.; Oms-Oliu, G.; Martín-Belloso, O. Nanoemulsion-Based Delivery Systems to Improve Functionality of Lipophilic Components. *Front. Nutr.* **2014**, *1*, 24. [\[CrossRef\]](#) [\[PubMed\]](#)
169. Li, G.; Zhang, Z.; Liu, H.; Hu, L. Nanoemulsion-Based Delivery Approaches for Nutraceuticals: Fabrication, Application, Characterization, Biological Fate, Potential Toxicity and Future Trends. *Food Funct.* **2021**, *12*, 1933–1953. [\[CrossRef\]](#) [\[PubMed\]](#)
170. Elsabee, M.Z.; Abdou, E.S. Chitosan Based Edible Films and Coatings: A Review. *Mater. Sci. Eng. C* **2013**, *33*, 1819–1841. [\[CrossRef\]](#) [\[PubMed\]](#)
171. Meng, Q.; Zhong, S.; Wang, J.; Gao, Y.; Cui, X. Advances in Chitosan-Based Microcapsules and Their Applications. *Carbohydr. Polym.* **2023**, *300*, 120265. [\[CrossRef\]](#) [\[PubMed\]](#)
172. Goy, R.C.; De Britto, D.; Assis, O.B.G. A Review of the Antimicrobial Activity of Chitosan. *Polimeros* **2009**, *19*, 241–247. [\[CrossRef\]](#)
173. Liu, Q.; Huang, H.; Chen, H.; Lin, J.; Wang, Q. Food-Grade Nanoemulsions: Preparation, Stability and Application in Encapsulation of Bioactive Compounds. *Molecules* **2019**, *24*, 4242. [\[CrossRef\]](#) [\[PubMed\]](#)
174. Du, Z.; Liu, J.; Zhang, H.; Chen, Y.; Wu, X.; Zhang, Y.; Li, X.; Zhang, T.; Xiao, H.; Liu, B. L-Arginine/L-Lysine Functionalized Chitosan-Casein Core-Shell and PH-Responsive Nanoparticles: Fabrication, Characterization and Bioavailability Enhancement of Hydrophobic and Hydrophilic Bioactive Compounds. *Food Funct.* **2020**, *11*, 4638–4647. [\[CrossRef\]](#) [\[PubMed\]](#)
175. Munin, A.; Edwards-Lévy, F. Encapsulation of Natural Polyphenolic Compounds—A Review. *Pharmaceutics* **2011**, *3*, 793–829. [\[CrossRef\]](#)
176. Ali Redha, A.; Kodikara, C.; Cozzolino, D. Does Encapsulation Improve the Bioavailability of Polyphenols in Humans? A Concise Review Based on In Vivo Human Studies. *Nutrients* **2024**, *16*, 3625. [\[CrossRef\]](#) [\[PubMed\]](#)
177. Fabrikov, D.; Varga, Á.T.; García, M.C.V.; Béltéky, P.; Kozma, G.; Kónya, Z.; López Martínez, J.L.; Barroso, F.; Sánchez-Muros, M.J. Antimicrobial and Antioxidant Activity of Encapsulated Tea Polyphenols in Chitosan/Alginate-Coated Zein Nanoparticles: A Possible Supplement against Fish Pathogens in Aquaculture. *Environ. Sci. Pollut. Res.* **2024**, *31*, 13673–13687. [\[CrossRef\]](#) [\[PubMed\]](#)
178. Yin, Z.; Zheng, T.; Ho, C.T.; Huang, Q.; Wu, Q.; Zhang, M. Improving the Stability and Bioavailability of Tea Polyphenols by Encapsulations: A Review. *Food Sci. Hum. Wellness* **2022**, *11*, 537–556. [\[CrossRef\]](#)
179. Li, N.; Wang, C.; Feng, B.; Bi, Y.; Kong, F.; Wang, Z.; Tan, S. Application of Nanoencapsulation Technology to Improve the Stability and Bioactivity of Tea Polyphenols. *Food Biosci.* **2023**, *55*, 103076. [\[CrossRef\]](#)
180. Gorinstein, S.; Park, Y.S.; Heo, B.G.; Namiesnik, J.; Leontowicz, H.; Leontowicz, M.; Ham, K.S.; Cho, J.Y.; Kang, S.G. A Comparative Study of Phenolic Compounds and Antioxidant and Antiproliferative Activities in Frequently Consumed Raw Vegetables. *Eur. Food Res. Technol.* **2009**, *228*, 903–911. [\[CrossRef\]](#)
181. Salami, M.; Heidari, B.; Tan, H. Comparative Profiling of Polyphenols and Antioxidants and Analysis of Antiglycation Activities in Rapeseed (*Brassica napus* L.) under Different Moisture Regimes. *Food Chem.* **2023**, *399*, 133946. [\[CrossRef\]](#)
182. Diederich, M.; Noworyta, K. Natural Compounds as Inducers of Cell Death. *Nat. Compd. Inducers Cell Death* **2012**, *1*, 1–518. [\[CrossRef\]](#)
183. Ben Alaya, I.; Alves, G.; Lopes, J.; Silva, L.R. Use of Encapsulated Polyphenolic Compounds in Health Promotion and Disease Prevention: Challenges and Opportunities. *Macromol* **2024**, *4*, 805–842. [\[CrossRef\]](#)

184. Zabet, G.L.; Schaefer Rodrigues, F.; Polano Ody, L.; Vinicius Tres, M.; Herrera, E.; Palacin, H.; Córdova-Ramos, J.S.; Best, I.; Olivera-Montenegro, L. Encapsulation of Bioactive Compounds for Food and Agricultural Applications. *Polymers* **2022**, *14*, 4194. [[CrossRef](#)] [[PubMed](#)]
185. Silva, S.; Veiga, M.; Costa, E.M.; Oliveira, A.L.S.; Madureira, A.R.; Pintado, M. Nanoencapsulation of Polyphenols towards Dairy Beverage Incorporation. *Beverages* **2018**, *4*, 61. [[CrossRef](#)]
186. El-Messery, T.M.; El-Said, M.M.; Demircan, E.; Özçelik, B.; El-Messery, T.M.; El-Said, M.M.; Demircan, E.; Özçelik, B. Microencapsulation of Natural Polyphenolic Compounds Extracted from Apple Peel and Its Application in Yoghurt. *Acta Sci. Pol. Technol. Aliment.* **2019**, *18*, 25–34. [[CrossRef](#)]
187. Ozdal, T.; Yolci-Omeroglu, P.; Tamer, E.C. Role of Encapsulation in Functional Beverages. In *Biotechnological Progress and Beverage Consumption: Volume 19: The Science of Beverages*; Grumezescu, A.M., Holban, A.M., Eds.; Elsevier Inc.: Duxford, UK, 2019; pp. 195–232. ISBN 9780128166789.
188. Ou, J. Incorporation of Polyphenols in Baked Products. In *Advances in Food and Nutrition Research*; Granato, D., Ed.; Elsevier Inc.: Duxford, UK, 2021; Volume 98, pp. 207–252.
189. Bobrysheva, T.; Anisimov, G.; Zolotareva, M.; Evdokimov, I.; Budkevich, R.; Muravyev, A. Encapsulated Polyphenols in Functional Food Production. *Foods Raw Mater.* **2024**, *13*, 18–34. [[CrossRef](#)]
190. Lian, F.; Gong, E.; Liang, H.; Lin, Y.; Chen, J.; He, Y.; Hebelstrup, K.H.; Xia, W. Nano-Encapsulation of Polyphenols in Starch Nanoparticles: Fabrication, Characterization and Evaluation. *Food Funct.* **2022**, *13*, 7762–7771. [[CrossRef](#)] [[PubMed](#)]
191. Shahidi, F.; Naczk, M. *Phenolics in Food and Nutraceuticals*, 1st ed.; Shahidi, F., Naczk, M., Eds.; CRC Press LLC: London, UK, 2004; Volume 16, ISBN 2013206534.
192. Yeh, Y.M.; Tsai, T.Y.; Yang, C.Y. Encapsulation and Release Kinetics of Polyphenols and P-Coumaric Acid Extracted from Phyllostachys Makinoi by Ultrasonic-Pretreatment Autoclaving. *LWT Food Sci. Technol.* **2022**, *167*, 113838. [[CrossRef](#)]
193. Popović, D.A.; Milinčić, D.D.; Pešić, M.B.; Kalušević, A.M.; Tešić, Ž.L.; Nedović, V.A. Encapsulation Technologies for Polyphenol-Loaded Microparticles in Food Industry. In *Green Food Processing Techniques: Preservation, Transformation and Extraction*; Chemat, F., Vorobiev, E., Eds.; Academic Press: London, UK, 2019; pp. 335–367. ISBN 9780128153536.
194. Gomes, A.; Sobral, P.J.D.A. Plant Protein-Based Delivery Systems: An Emerging Approach for Increasing the Efficacy of Lipophilic Bioactive Compounds. *Molecules* **2022**, *27*, 60. [[CrossRef](#)]
195. Pinho, E.; Grootveld, M.; Soares, G.; Henriques, M. Cyclodextrins as Encapsulation Agents for Plant Bioactive Compounds. *Carbohydr. Polym.* **2014**, *101*, 121–135. [[CrossRef](#)] [[PubMed](#)]
196. Saroglu, O.; Tav, B.; Yildirim, R.M.; Karadag, A. Microencapsulation of Olive Mill Wastewater in Saccharomyces Cerevisiae Cells by Spray Drying and in Vitro Bioaccessibility of Phenolic Compounds. *Food Funct.* **2023**, *14*, 3746–3759. [[CrossRef](#)]
197. Li, C.; Chen, L.; McClements, D.J.; Peng, X.; Xu, Z.; Meng, M.; Ji, H.; Qiu, C.; Long, J.; Jin, Z. Encapsulation of Polyphenols in Protein-Based Nanoparticles: Preparation, Properties, and Applications. *Crit. Rev. Food Sci. Nutr.* **2023**, *64*, 11341–11355. [[CrossRef](#)]
198. Wang, X.; Chen, C.; Bao, Y.; Wang, Y.; Leonidovna Strakh, Y. Encapsulation of Three Different Types of Polyphenols in Casein Using a Customized PH-Driven Method: Preparation and Characterization. *Food Res. Int.* **2024**, *189*, 114547. [[CrossRef](#)]
199. Garavand, F.; Jalai-Jivan, M.; Assadpour, E.; Jafari, S.M. Encapsulation of Phenolic Compounds within Nano/Microemulsion Systems: A Review. *Food Chem.* **2021**, *364*, 130376. [[CrossRef](#)]
200. Ozkan, G.; Kostka, T.; Esatbeyoglu, T.; Capanoglu, E. Effects of Lipid-Based Encapsulation on the Bioaccessibility and Bioavailability of Phenolic Compounds. *Molecules* **2020**, *25*, 5545. [[CrossRef](#)] [[PubMed](#)]
201. Zhou, H.; Zheng, B.; McClements, D.J. Encapsulation of Lipophilic Polyphenols in Plant-Based Nanoemulsions: Impact of Carrier Oil on Lipid Digestion and Curcumin, Resveratrol and Quercetin Bioaccessibility. *Food Funct.* **2021**, *12*, 3420–3432. [[CrossRef](#)]
202. Verônica Cardoso de Souza, B.; de Moraes Sousa, M.; Augusto Gasparotto Sattler, J.; Cristina Sousa Gramoza Vilarinho Santana, A.; Bruno Fonseca de Carvalho, R.; de Sousa Lima Neto, J.; de Matos Borges, F.; Angelica Neri Numa, I.; Braga Ribeiro, A.; César Cunha Nunes, L. Nanoencapsulation and Bioaccessibility of Polyphenols of Aqueous Extracts from Bauhinia Forficata Link. *Food Chem. Mol. Sci.* **2022**, *5*, 100144. [[CrossRef](#)] [[PubMed](#)]
203. Borges, A.; de Freitas, V.; Mateus, N.; Fernandes, I.; Oliveira, J. Solid Lipid Nanoparticles as Carriers of Natural Phenolic Compounds. *Antioxidants* **2020**, *9*, 998. [[CrossRef](#)] [[PubMed](#)]
204. Jiang, M.; Zhang, Y. Biopolymer-Based Encapsulation of Anthocyanins as Reinforced Natural Colorants for Food Applications. *J. Agric. Food Res.* **2023**, *11*, 100488. [[CrossRef](#)]
205. Liang, J.; Yan, H.; Puligundla, P.; Gao, X.; Zhou, Y.; Wan, X. Applications of Chitosan Nanoparticles to Enhance Absorption and Bioavailability of Tea Polyphenols: A Review. *Food Hydrocoll.* **2017**, *69*, 286–292. [[CrossRef](#)]
206. Comunian, T.A.; Favaro-Trindade, C.S. Microencapsulation Using Biopolymers as an Alternative to Produce Food Enhanced with Phytosterols and Omega-3 Fatty Acids: A Review. *Food Hydrocoll.* **2016**, *61*, 442–457. [[CrossRef](#)]
207. Gali, L.; Pirozzi, A.; Donsi, F. Biopolymer- and Lipid-Based Carriers for the Delivery of Plant-Based Ingredients. *Pharmaceutics* **2023**, *15*, 927. [[CrossRef](#)]
208. Buljeta, I.; Pichler, A.; Šimunović, J.; Kopjar, M. Polysaccharides as Carriers of Polyphenols: Comparison of Freeze-Drying and Spray-Drying as Encapsulation Techniques. *Molecules* **2022**, *27*, 5069. [[CrossRef](#)]
209. Czubaszek, A.; Czaja, A.; Sokół-Lętowska, A.; Kolniak-Ostek, J.; Kucharska, A.Z. Quality of Bread Enriched with Microencapsulated Anthocyanin Extracts during in Vitro Simulated Digestion. *J. Cereal Sci.* **2023**, *113*, 103724. [[CrossRef](#)]

210. Mirab, B.; Ahmadi Gavlighi, H.; Amini Sarteshnizi, R.; Azizi, M.H.; Udenigwe, C.C. Production of Low Glycemic Potential Sponge Cake by Pomegranate Peel Extract (PPE) as Natural Enriched Polyphenol Extract: Textural, Color and Consumer Acceptability. *LWT* **2020**, *134*, 109973. [\[CrossRef\]](#)
211. Nhung, T.T.N.; Chau, N.T.B.; Hien, L.T.M.; Linh, V.T.H.; Le Ha, N.; Dong, D.T.A. Characteristics of Sponge Cake Preserved by Green Tea Extract Powder. *J. Food Process. Preserv.* **2022**, *46*, e16939. [\[CrossRef\]](#)
212. Ramadan, M.M.; El Haggag, E.F.; Mohamed, R.S.; Mahmoud, K.F.; Mabrouk, A.M.; Hussien, A.G.; Mahmoud, A.E.; Mohawed, O.A.M.; El-Messery, T.M. Development of a Functional Cake with Probiotics and Micro-Encapsulated Essential Oils: Evaluation of Nutritional Properties, Liver Protection, and Immune Boosting. *Heliyon* **2024**, *10*, e22918. [\[CrossRef\]](#)
213. Pasrija, D.; Ezhilarasi, P.N.; Indrani, D.; Anandharamakrishnan, C. Microencapsulation of Green Tea Polyphenols and Its Effect on Incorporated Bread Quality. *LWT* **2015**, *64*, 289–296. [\[CrossRef\]](#)
214. Zhao, J.W.; Chen, J.; Hu, W.X.; Chen, L.; Chen, F.S. Effect of Polyphenolic Compounds on Starch Retrogradation and in Vitro Starch Digestibility of Rice Cakes under Different Storage Temperatures. *Food Biophys.* **2022**, *17*, 26–37. [\[CrossRef\]](#)
215. Papillo, V.A.; Locatelli, M.; Travaglia, F.; Bordiga, M.; Garino, C.; Coisson, J.D.; Arlorio, M. Cocoa Hulls Polyphenols Stabilized by Microencapsulation as Functional Ingredient for Bakery Applications. *Food Res. Int.* **2018**, *115*, 511–518. [\[CrossRef\]](#) [\[PubMed\]](#)
216. Kamali Roustae, L.; Bodbodak, S.; Nejatian, M.; Ghandehari Yazdi, A.P.; Rafiee, Z.; Xiao, J.; Jafari, S.M. Use of Encapsulation Technology to Enrich and Fortify Bakery, Pasta, and Cereal-Based Products. *Trends Food Sci. Technol.* **2021**, *118*, 688–710. [\[CrossRef\]](#)
217. Li, H.; Yue, Y.; Jiang, Y.; Wu, Y.; Zhang, M.; Zeng, X.; Zhao, W. Colloid-Encapsulated Sugarcane Polyphenols and Their Impact on in Vitro Starch Digestibility: Enhancing Bioaccessibility and α -Amylase Inhibitory Effect. *Int. J. Food Sci. Technol.* **2024**, *59*, 8864–8875. [\[CrossRef\]](#)
218. Liu, S.; Sun, H.; Ma, M.; Mu, T. Effects of Dietary Fibres, Polyphenols and Proteins on the Estimated Glycaemic Index, Physico-chemical, Textural and Microstructural Properties of Steamed Bread. *Int. J. Food Sci. Technol.* **2024**, *59*, 4041–4052. [\[CrossRef\]](#)
219. Gani, A.; Jan, R.; Ashwar, B.A.; ul Ashraf, Z.; Shah, A.; Gani, A. Encapsulation of Saffron and Sea Buckthorn Bioactives: Its Utilization for Development of Low Glycemic Baked Product for Growing Diabetic Population of the World. *LWT* **2021**, *142*, 111035. [\[CrossRef\]](#)
220. Van Ngo, T.; Kusumawardani, S.; Kunyane, K.; Luangsakul, N. Polyphenol-Modified Starches and Their Applications in the Food Industry: Recent Updates and Future Directions. *Foods* **2022**, *11*, 3384. [\[CrossRef\]](#) [\[PubMed\]](#)
221. Bińkowska, W.; Szpicer, A.; Stelmasiak, A.; Wojtasik-Kalinowska, I.; Półtorak, A. Utilization of Microencapsulated Polyphenols to Enhance the Bioactive Compound Content in Whole Grain Bread: Recipe Optimization. *Appl. Sci.* **2024**, *14*, 10156. [\[CrossRef\]](#)
222. Kaewmaanee, T.; Jennifer, A.O. Storage Stability, Gastrointestinal Release and Sensory Properties of Cookies Incorporated with Protein-Based Moringa Oleifera Leaf Extract Microcapsule. *Chiang Mai Univ. J. Nat. Sci.* **2020**, *19*, 139–154. [\[CrossRef\]](#)
223. Bińkowska, W.; Szpicer, A.; Stelmasiak, A.; Wojtasik-Kalinowska, I.; Półtorak, A. Innovative Application of Microencapsulated Polyphenols in Cereal Products: Optimization of the Formulation of Dairy- and Gluten-Free Pastry. *J. Food Process Eng.* **2024**, *47*, e14685. [\[CrossRef\]](#)
224. Ab Rashid, S.; Tong, W.Y.; Leong, C.R.; Abdul Ghazali, N.M.; Taher, M.A.; Ahmad, N.; Tan, W.N.; Teo, S.H. Anthocyanin Microcapsule from Clitoria Ternatea: Potential Bio-Preservative and Blue Colorant for Baked Food Products. *Arab. J. Sci. Eng.* **2021**, *46*, 65–72. [\[CrossRef\]](#)
225. Safaa, S.A.; Ahmed, Z.S.; Abd El-Kader, A.E.; Mohamed, R.K. Characterization of Physicochemical, Antioxidant, and Sensory Quality of Cookies Enriched with Microencapsulated Ginger Extracts as a Functional Ingredient. *Egypt. J. Chem.* **2024**, *67*, 525–535. [\[CrossRef\]](#)
226. Ciont, C.; Difonzo, G.; Pasqualone, A.; Chis, M.S.; Ranga, F.; Szabo, K.; Simon, E.; Naghiu, A.; Barbu-Tudoran, L.; Caponio, F.; et al. Phenolic Profile of Micro- and Nano-Encapsulated Olive Leaf Extract in Biscuits during in Vitro Gastrointestinal Digestion. *Food Chem.* **2023**, *428*, 136778. [\[CrossRef\]](#) [\[PubMed\]](#)
227. Kaderides, K.; Mourtzinou, I.; Goula, A.M. Stability of Pomegranate Peel Polyphenols Encapsulated in Orange Juice Industry By-Product and Their Incorporation in Cookies. *Food Chem.* **2020**, *310*, 125849. [\[CrossRef\]](#)
228. Ferguous, H.; Mehryar, G.; Ibrahim, S.A. The Antimicrobial and Antioxidation Activities of Olive Pomace Extract in Pasteurized White Cheese. *Jordan J. Agric. Sci.* **2023**, *19*, 355–364. [\[CrossRef\]](#)
229. Marino, V.M.; Rapisarda, T.; Caccamo, M.; Valenti, B.; Priolo, A.; Luciano, G.; Natalello, A.; Campione, A.; Pauselli, M. Effect of Dietary Hazelnut Peels on the Contents of Fatty Acids, Cholesterol, Tocopherols, and on the Shelf-Life of Ripened Ewe Cheese. *Antioxidants* **2021**, *10*, 538. [\[CrossRef\]](#)
230. Helal, A.; Cattivelli, A.; Conte, A.; Tagliazucchi, D. In Vitro Bioaccessibility and Antioxidant Activity of Phenolic Compounds in Coffee-Fortified Yogurt. *Molecules* **2022**, *27*, 6843. [\[CrossRef\]](#) [\[PubMed\]](#)
231. Alamoudi, S.A.; Saad, A.M.; Alsubhi, N.H.; Alrefaei, G.I.; Al-Quwaie, D.A.; Binothman, N.; Aljadani, M.; Alharbi, M.; Alanazi, H.; Babalghith, A.O.; et al. Upgrading the Physicochemical and Sensory Quality of Yogurt by Incorporating Polyphenol-Enriched Citrus Pomaces with Antioxidant, Antimicrobial, and Antitumor Activities. *Front. Nutr.* **2022**, *9*, 999581. [\[CrossRef\]](#) [\[PubMed\]](#)
232. Arfaoui, L. Total Polyphenol Content and Radical Scavenging Activity of Functional Yogurt Enriched with Dates. *Czech J. Food Sci.* **2020**, *38*, 287–292. [\[CrossRef\]](#)
233. Du, H.; Yang, H.; Wang, X.; Zhu, F.; Tang, D.; Cheng, J.; Liu, X. Effects of Mulberry Pomace on Physicochemical and Textural Properties of Stirred-Type Flavored Yogurt. *J. Dairy Sci.* **2021**, *104*, 12403–12414. [\[CrossRef\]](#) [\[PubMed\]](#)

234. Deng, Y.; Zhao, G.; Cheng, K.; Shi, C.; Xiao, G. Effect of Apple Polyphenols on the Antioxidant Activity and Structure of Three-Dimensional Printed Processed Cheese. *Foods* **2023**, *12*, 1731. [\[CrossRef\]](#)
235. Shori, A.B. Storage Quality and Antioxidant Properties of Yogurt Fortified with Polyphenol Extract from Nutmeg, Black Pepper, and White Pepper. *Electron. J. Biotechnol.* **2022**, *57*, 24–30. [\[CrossRef\]](#)
236. Gaglio, R.; Restivo, I.; Barbera, M.; Barbaccia, P.; Ponte, M.; Tesoriere, L.; Bonanno, A.; Attanzio, A.; Di Grigoli, A.; Francesca, N.; et al. Effect on the Antioxidant, Lipoperoxyl Radical Scavenger Capacity, Nutritional, Sensory and Microbiological Traits of an Ovine Stretched Cheese Produced with Grape Pomace Powder Addition. *Antioxidants* **2021**, *10*, 306. [\[CrossRef\]](#) [\[PubMed\]](#)
237. Ardabilchi Marand, M.; Amjadi, S.; Ardabilchi Marand, M.; Roufegarinejad, L.; Jafari, S.M. Fortification of Yogurt with Flaxseed Powder and Evaluation of Its Fatty Acid Profile, Physicochemical, Antioxidant, and Sensory Properties. *Powder Technol.* **2020**, *359*, 76–84. [\[CrossRef\]](#)
238. Soliman, T.N.; Mohammed, D.M.; El-Messery, T.M.; Elaaser, M.; Zaky, A.A.; Eun, J.B.; Shim, J.H.; El-Said, M.M. Microencapsulation of Plant Phenolic Extracts Using Complex Coacervation Incorporated in Ultrafiltered Cheese Against AlCl₃-Induced Neuroinflammation in Rats. *Front. Nutr.* **2022**, *9*, 929977. [\[CrossRef\]](#) [\[PubMed\]](#)
239. Farrag, A.F.; Zahran, H.A.; Al-Okbay, M.F.; El-Sheikh, M.M.; Soliman, T.N. Physicochemical Properties of White Soft Cheese Supplemented with Encapsulated Olive Phenolic Compounds. *Egypt. J. Chem.* **2020**, *63*, 2921–2931. [\[CrossRef\]](#)
240. Azarashkan, Z.; Motamedzadegan, A.; Ghorbani-HasanSaraei, A.; Biparva, P.; Rahaiee, S. Investigation of the Physicochemical, Antioxidant, Rheological, and Sensory Properties of Ricotta Cheese Enriched with Free and Nano-Encapsulated Broccoli Sprout Extract. *Food Sci. Nutr.* **2022**, *10*, 4059–4072. [\[CrossRef\]](#) [\[PubMed\]](#)
241. El-Messery, T.M.; Aly, E.; López-Nicolas, R.; Sánchez-Moya, T.; Ros, G. Bioaccessibility and Antioxidant Activity of PCL-Microencapsulated Olive Leaves Polyphenols and Its Application in Yogurt. *J. Food Sci.* **2021**, *86*, 4303–4315. [\[CrossRef\]](#)
242. Liu, C.; Nguyen, B.V.; Diep, T.T.; Yoo, M.J.Y. Interaction between Bovine Serum Albumin in Fresh Milk Cream and Encapsulated and Non-Encapsulated Polyphenols of Tamarillo. *Antioxidants* **2023**, *12*, 1611. [\[CrossRef\]](#)
243. Do Carmo, L.B.; Benincá, D.B.; Grancieri, M.; Pereira, L.V.; Lima Filho, T.; Saraiva, S.H.; Silva, P.I.; Oliveira, D.d.S.; Costa, A.G.V. Green Coffee Extract Microencapsulated: Physicochemical Characteristics, Stability, Bioaccessibility, and Sensory Acceptability through Dairy Beverage Consumption. *Int. J. Environ. Res. Public Health* **2022**, *19*, 13221. [\[CrossRef\]](#)
244. Makouie, S.; Alizadeh, M.; Khosrowshahi, A.; Maleki, O. Physicochemical, Textural, and Sensory Characteristics of Ice Cream Incorporated with *Nigella sativa* Seed Oil Microcapsules. *J. Food Process. Preserv.* **2021**, *45*, e15804. [\[CrossRef\]](#)
245. Shamshad, A.; Butt, M.S.; Nayik, G.A.; Al Obaid, S.; Ansari, M.J.; Karabagias, I.K.; Sarwar, N.; Ramniwas, S. Effect of Storage on Physicochemical Attributes of Ice Cream Enriched with Microencapsulated Anthocyanins from Black Carrot. *Food Sci. Nutr.* **2023**, *11*, 3976–3988. [\[CrossRef\]](#) [\[PubMed\]](#)
246. Ghandehari Yazdi, A.P.; Barzegar, M.; Ahmadi Gavlighi, H.; Sahari, M.A.; Mohammadian, A.H. Physicochemical Properties and Organoleptic Aspects of Ice Cream Enriched with Microencapsulated Pistachio Peel Extract. *Int. J. Dairy Technol.* **2020**, *73*, 570–577. [\[CrossRef\]](#)
247. Popescu, L.; Cojocari, D.; Lung, I.; Kacso, I.; Ciorîță, A.; Ghendov-Mosanu, A.; Balan, G.; Pintea, A.; Sturza, R. Effect of Microencapsulated Basil Extract on Cream Cheese Quality and Stability. *Molecules* **2023**, *28*, 3305. [\[CrossRef\]](#)
248. Popescu, L.; Cojocari, D.; Ghendov-Mosanu, A.; Lung, I.; Soran, M.L.; Oprea, O.; Kacso, I.; Ciorîță, A.; Balan, G.; Pintea, A.; et al. The Effect of Aromatic Plant Extracts Encapsulated in Alginate on the Bioactivity, Textural Characteristics and Shelf Life of Yogurt. *Antioxidants* **2023**, *12*, 893. [\[CrossRef\]](#) [\[PubMed\]](#)
249. Hashim, A.F.; Abd-Rabou, A.A.; El-Sayed, H.S. Functional Nanoemulsion and Nanocomposite Microparticles as an Anticancer and Antimicrobial Agent: Applied in Yogurt. *Biomass Convers. Biorefinery* **2024**, *14*, 13233–13249. [\[CrossRef\]](#)
250. Azarashkan, Z.; Farahani, S.; Abedinia, A.; Akbarmivehie, M.; Motamedzadegan, A.; Heidarbeigi, J.; Hayaloglu, A.A. Co-Encapsulation of Broccoli Sprout Extract Nanoliposomes into Basil Seed Gum: Effects on In Vitro Antioxidant, Antibacterial and Anti-Listeria Activities in Ricotta Cheese. *Int. J. Food Microbiol.* **2022**, *376*, 109761. [\[CrossRef\]](#)
251. El-Sayed, S.M.; Kholif, A.M.M.; El-Sayed, H.S.; Youssef, A.M. Augmenting the Quality and Shelf Life of Ras Cheese by Adding Microencapsulated Allspice Berry Extract Nanoemulsion. *Food Bioprocess. Technol.* **2024**. [\[CrossRef\]](#)
252. Pérez-Soto, E.; Cenobio-Galindo, A.d.J.; Espino-Manzano, S.O.; Franco-Fernández, M.J.; Ludeña-Urquiza, F.E.; Jiménez-Alvarado, R.; Zepeda-Velázquez, A.P.; Campos-Montiel, R.G. The Addition of Microencapsulated or Nanoemulsified Bioactive Compounds Influences the Antioxidant and Antimicrobial Activities of a Fresh Cheese. *Molecules* **2021**, *26*, 2170. [\[CrossRef\]](#)
253. Naumovski, N.; Mellor, D.D.; Ranadheera, C.S. Functional Beverages, from Idea to Functionality. *Beverages* **2020**, *6*, 71. [\[CrossRef\]](#)
254. Crowe, K.M. Designing Functional Foods with Bioactive Polyphenols: Highlighting Lessons Learned from Original Plant Matrices. *J. Hum. Nutr. Food Sci.* **2013**, *1*, 1018.
255. Berretta, A.A.; De Lima, J.A.; Falcão, S.I.; Calhelha, R.; Amorim, N.A.; Gonçalves, I.S.; Zamarrenho, L.G.; Barud, H.d.S.; Bastos, J.K.; De Jong, D.; et al. Development and Characterization of High-Absorption Microencapsulated Organic Propolis EPP-AF[®] Extract (i-CAPs). *Molecules* **2023**, *28*, 7128. [\[CrossRef\]](#) [\[PubMed\]](#)
256. Colombo, R.; Moretto, G.; Pellicorio, V.; Papetti, A. Globe Artichoke (*Cynara scolymus* L.) By-Products in Food Applications: Functional and Biological Properties. *Foods* **2024**, *13*, 1427. [\[CrossRef\]](#)
257. Berraquero-García, C.; Pérez-Gálvez, R.; Espejo-Carpio, F.J.; Guadix, A.; Guadix, E.M.; García-Moreno, P.J. Encapsulation of Bioactive Peptides by Spray-Drying and Electrospraying. *Foods* **2023**, *12*, 2005. [\[CrossRef\]](#)

258. Xie, A.; Zhao, S.; Liu, Z.; Yue, X.; Shao, J.; Li, M.; Li, Z. Polysaccharides, Proteins, and Their Complex as Microencapsulation Carriers for Delivery of Probiotics: A Review on Carrier Types and Encapsulation Techniques. *Int. J. Biol. Macromol.* **2023**, *242*, 124784. [\[CrossRef\]](#)
259. Kiprono, S.; Wambani, J.; Rono, J.; Langat, V.; Shi, Z.; Raballah, E.; Yang, G. Microencapsulation of Probiotics and Their Application: A Review of the Literature. *ES Food & Agroforestry* **2024**, *17*, 1106. [\[CrossRef\]](#)
260. Kaushalya, K.G.D.; Rupasinghe, H.P.V. Health Benefits of Microencapsulated Dietary Polyphenols: A Review. *Food Rev. Int.* **2024**, *40*, 2079–2102. [\[CrossRef\]](#)
261. Mehran, M.; Masoum, S.; Memarzadeh, M. Improvement of Thermal Stability and Antioxidant Activity of Anthocyanins of Echium Amoenum Petal Using Maltodextrin/Modified Starch Combination as Wall Material. *Int. J. Biol. Macromol.* **2020**, *148*, 768–776. [\[CrossRef\]](#)
262. Mehta, N.; Kumar, P.; Verma, A.K.; Umaraw, P.; Kumar, Y.; Malav, O.P.; Sazili, A.Q.; Domínguez, R.; Lorenzo, J.M. Microencapsulation as a Noble Technique for the Application of Bioactive Compounds in the Food Industry: A Comprehensive Review. *Appl. Sci.* **2022**, *12*, 1424. [\[CrossRef\]](#)
263. Raj, G.V.S.B.; Dash, K.K. Dragon Fruit Peel Extract Microcapsule Incorporated Pearl Millet and Dragon Fruit Pulp Powder Based Functional Pasta: Formulation, Characterization, and Release Kinetics Study. *Food Sci. Biotechnol.* **2023**, *32*, 779–792. [\[CrossRef\]](#) [\[PubMed\]](#)
264. Ćorković, I.; Pichler, A.; Ivić, I.; Šimunović, J.; Kopjar, M. Microencapsulation of Chokeberry Polyphenols and Volatiles: Application of Alginate and Pectin as Wall Materials. *Gels* **2021**, *7*, 231. [\[CrossRef\]](#)
265. Adefegha, S.A.; Salawi, A.; Bumrungpert, A.; Khorasani, S.; Torkaman, S.; Mozafari, M.R.; Taghavi, E. Nano Micro Biosystems Encapsulation of Polyphenolic Compounds for Health Promotion and Disease Prevention: Challenges and Opportunities. *Nano Micro Biosyst.* **2022**, *2022*, 1–12.
266. Ozkan, G.; Franco, P.; De Marco, I.; Xiao, J.; Capanoglu, E. A Review of Microencapsulation Methods for Food Antioxidants: Principles, Advantages, Drawbacks and Applications. *Food Chem.* **2019**, *272*, 494–506. [\[CrossRef\]](#) [\[PubMed\]](#)
267. Verni, M.; Demarinis, C.; Rizzello, C.G.; Pontonio, E. Bioprocessing to Preserve and Improve Microalgae Nutritional and Functional Potential: Novel Insight and Perspectives. *Foods* **2023**, *12*, 983. [\[CrossRef\]](#) [\[PubMed\]](#)
268. Kozłowska, M.; Żbikowska, A.; Szpicer, A.; Póltorak, A. Oxidative Stability of Lipid Fractions of Sponge-Fat Cakes after Green Tea Extracts Application. *J. Food Sci. Technol.* **2019**, *56*, 2628–2638. [\[CrossRef\]](#)
269. Altissimi, C.; Roila, R.; Ranucci, D.; Branciar, R.; Cai, D.; Paulsen, P. Preventing Microbial Growth in Game Meat by Applying Polyphenolic Extracts from Olive Mill Vegetation Water. *Foods* **2024**, *13*, 658. [\[CrossRef\]](#) [\[PubMed\]](#)
270. Gorzin, M.; Saeidi, M.; Javidi, S.; Seow, E.K.; Abedinia, A. Nanoencapsulation of Oliveria Decumbens Vent./Basil Essential Oils into Gum Arabic/Maltodextrin: Improved In Vitro Bioaccessibility and Minced Beef Meat Safety. *Int. J. Biol. Macromol.* **2024**, *270*, 132288. [\[CrossRef\]](#)
271. Rokkam, M.; Kumar Vadaga, A. A Brief Review on the Current Trends in Microencapsulation. *J. Pharma Insights Res.* **2024**, *02*, 108–114. [\[CrossRef\]](#)
272. Lobel, B.T.; Baiocco, D.; Al-Sharabi, M.; Routh, A.F.; Zhang, Z.; Cayre, O.J. Current Challenges in Microcapsule Designs and Microencapsulation Processes: A Review. *ACS Appl. Mater. Interfaces* **2024**, *16*, 40326–40355. [\[CrossRef\]](#)
273. Samborska, K.; Boostani, S.; Geranpour, M.; Hosseini, H.; Dima, C.; Khoshnoudi-Nia, S.; Rostamabadi, H.; Falsafi, S.R.; Shaddel, R.; Akbari-Alavijeh, S.; et al. Green Biopolymers from By-Products as Wall Materials for Spray Drying Microencapsulation of Phytochemicals. *Trends Food Sci. Technol.* **2021**, *108*, 297–325. [\[CrossRef\]](#)
274. Huang, K.; Yuan, Y.; Baojun, X. A Critical Review on the Microencapsulation of Bioactive Compounds and Their Application. *Food Rev. Int.* **2023**, *39*, 2594–2634. [\[CrossRef\]](#)
275. Mohamadzadeh, M.; Fazeli, A.; Shojaosadati, S.A. Polysaccharides and Proteins-Based Bionanocomposites for Microencapsulation of Probiotics to Improve Stability and Viability in the Gastrointestinal Tract: A Review. *Int. J. Biol. Macromol.* **2024**, *259*, 129287. [\[CrossRef\]](#)
276. Tomé, A.C.; da Silva, F.A.; Monteiro, M.L.G.; Mársico, E.T. Evaluating Microencapsulated Oregano (*Origanum vulgare*) Aqueous Extract as a Bioactive Ingredient on the Overall Quality of Ready-to-Cook Fish Products Made from Tilapia Byproduct during Frozen Storage. *Appl. Food Res.* **2023**, *3*, 100274. [\[CrossRef\]](#)
277. Singh, K.; Adhikari, B.; Low, J.; Brennan, M.A.; Newman, L.; Brennan, C.S.; Utama-ang, N. Development, Characterization, and Consumer Acceptance Evaluation of Thermally Stable Capsule Beads Containing Mixed Extracts of Green Tea and Turmeric. *Scientific Reports* **2023**, *13*, 19299. [\[CrossRef\]](#)
278. Makhathini, N.; Kaseke, T.; Fawole, O.A. Microencapsulation of Organic Pomegranate Peel Extract for a Food Circular Economy: Effects of Wall Materials on Powder Functional Attributes, Antioxidant Activity and Antimicrobial Property against Foodborne Pathogens. *J. Agric. Food Res.* **2023**, *14*, 100780. [\[CrossRef\]](#)
279. Bergesse, A.E.; Asensio, C.M.; Quiroga, P.R.; Ryan, L.C.; Grosso, N.R.; Nepote, V. Microencapsulation of Phenolic Compounds Extracted from Soybean Seed Coats by Spray-Drying. *J. Food Sci.* **2023**, *88*, 4457–4471. [\[CrossRef\]](#) [\[PubMed\]](#)
280. Hoskin, R.T.; Grace, M.H.; Xiong, J.; Lila, M.A. Spray-Drying Microencapsulation of Blackcurrant and Cocoa Polyphenols Using Underexplored Plant-Based Protein Sources. *J. Food Sci.* **2023**, *88*, 2665–2678. [\[CrossRef\]](#)
281. Thiruvalluvan, M.; Kaur, B.P.; Singh, A.; Kumari, S. Enhancement of the Bioavailability of Phenolic Compounds from Fruit and Vegetable Waste by Liposomal Nanocarriers. *Food Sci. Biotechnol.* **2024**, *33*, 307–325. [\[CrossRef\]](#)

282. Singh, P.; Pandey, V.K.; Singh, R.; Dar, A.H. Spray-Freezing-Drying as Emerging and Substantial Quality Enhancement Technique in Food Industry. *Food Sci. Biotechnol.* **2024**, *33*, 231–243. [[CrossRef](#)] [[PubMed](#)]
283. Ricci, A.; Arboleda Mejia, J.A.; Versari, A.; Chiarello, E.; Bordoni, A.; Parpinello, G.P. Microencapsulation of Polyphenolic Compounds Recovered from Red Wine Lees: Process Optimization and Nutraceutical Study. *Food Bioprod. Process.* **2022**, *132*, 1–12. [[CrossRef](#)]
284. Pastrana-Bonilla, E.; Akoh, C.C.; Sellappan, S.; Krewer, G. Phenolic Content and Antioxidant Capacity of Muscadine Grapes. *J. Agric. Food Chem.* **2003**, *51*, 5497–5503. [[CrossRef](#)]
285. Soares, S.; Kohl, S.; Thalmann, S.; Mateus, N.; Meyerhof, W.; De Freitas, V. Different Phenolic Compounds Activate Distinct Human Bitter Taste Receptors. *J. Agric. Food Chem.* **2013**, *61*, 1525–1533. [[CrossRef](#)]
286. Abdel-Samie, M.A.S.; Wan, J.; Huang, W.; Chung, O.K.; Xu, B. Effects of Cumin and Ginger as Antioxidants on Dough Mixing Properties and Cookie Quality. *Cereal Chem.* **2010**, *87*, 454–460. [[CrossRef](#)]
287. Jang, Y.; Koh, E. Effect of Encapsulation on Stability of Anthocyanins and Chlorogenic Acid Isomers in Aronia during in Vitro Digestion and Their Transformation in a Model System. *Food Chem.* **2024**, *434*, 137443. [[CrossRef](#)] [[PubMed](#)]
288. Wu, X.; Gu, L.; Prior, R.L.; McKay, S. Characterization of Anthocyanins and Proanthocyanidins in Some Cultivars of Ribes, Aronia, and Sambucus and Their Antioxidant Capacity. *J. Agric. Food Chem.* **2004**, *52*, 7846–7856. [[CrossRef](#)]
289. Magnus, S.; Gazdik, F.; Anjum, N.A.; Kadlecova, E.; Lackova, Z.; Cernei, N.; Brtnicky, M.; Kynicky, J.; Klejdus, B.; Necas, T.; et al. Assessment of Antioxidants in Selected Plant Rootstocks. *Antioxidants* **2020**, *9*, 209. [[CrossRef](#)] [[PubMed](#)]
290. Namal Senanayake, S.P.J. Green Tea Extract: Chemistry, Antioxidant Properties and Food Applications—A Review. *J. Funct. Foods* **2013**, *5*, 1529–1541. [[CrossRef](#)]
291. Kuhlmann, A.; Röhl, C. Phenolic Antioxidant Compounds Produced by in Vitro Cultures of Rosemary (*Rosmarinus officinalis*) and Their Anti-Inflammatory Effect on Lipopolysaccharide-Activated Microglia. *Pharm. Biol.* **2006**, *44*, 401–410. [[CrossRef](#)]
292. Sapiststein, H.D. Bioactives in Wheat Bran. In *Food Science*; Elsevier Ltd.: Cambridge, UK, 2015; Volume 2–4, pp. 268–276. ISBN 9780123947864.
293. Rakić, S.; Janković, S.; Marčetić, M.; Živković, D.; Kuzevski, J. The Impact of Storage on the Primary and Secondary Metabolites, Antioxidant Activity and Digestibility of Oat Grains (*Avena sativa*). *J. Funct. Foods* **2014**, *7*, 373–380. [[CrossRef](#)]
294. Vázquez-Núñez, M.d.l.Á.; Aguilar-Zárate, M.; Gómez-García, R.; Reyes-Luna, C.; Aguilar-Zárate, P.; Michel, M.R. The Specific Encapsulation of Procyanidins from Litchi Peel and Coffee Pulp Extracts via Spray-Drying Using Green Polymers. *Polymers* **2023**, *15*, 3823. [[CrossRef](#)]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.