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Posted Date: 3 December 2024

doi: 10.20944/preprints202412.0204.v1

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Review

Polyphenols in Food Production: Enhancing Quality and Nutritional Value

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Abstract: Polyphenols are known as secondary metabolites, which are crucial bioactive compounds that enhance human health. The identification of polyphenols is generally accomplished with chromatographic methods after the food has been extracted. The extraction methods are fundamental; however, they can be used with any differences, including extractant type according to the food. Polyphenols are mostly found in some foods, including grapes, olives, cherries, and apples. Foods have divergent polyphenols, which differentiate according to the food types. Moreover, they have flavonols, flavanols, flavones, flavanones, isoflavones, and anthocyanins as various subgroups of polyphenols that can change in terms of quantity and quality with several factors, including types, growing region, germination time, and harvest season of food. The consumption of polyphenols is crucial for human health owing to their anti-cancer effect, anti-tumor effect, anti-inflammatory effect, cardiometabolic risk management, antimicrobial effect, immunomodulatory activity, and antioxidant activity. These are given attention by researchers who detect the effects of polyphenol. In the valorization of polyphenols, the consumption dose is also important to effectively benefit from the polyphenols of plant-based foods. Several *in vitro* and *in vivo* studies have tested the polyphenols' digestion ability and preservation ability in gut microbiota and their effect on the microbiota to determine the benefits and effects of polyphenols in several areas. According to these studies, polyphenols can be used to fight against the disease. In addition, divergent applications, including encapsulation and polyphenol coating, are used to stabilize, preserve, and improve the bioaccessibility of the polyphenols. Even though polyphenol-rich foods are consumed for nutrition in daily life, they are also used as nutritional ingredients in the food industry to produce functional foods, and functional foods are enriched with food by-products to enhance their nutritional value, especially in terms of polyphenols. Polyphenols also provide the preservation ability of storage and improve the bioaccessibility of bioactive ingredients in the digestion of functional foods.

Keywords: polyphenols 1; functional food 2; antioxidant activity 3; valorization 4

1. Introduction

Polyphenols are crucial plant-based compounds in several fields, including the food industry, pharmacology, and medicine [1,2]. Flavonoids, phenolic acids, polyphenolic amides, lignans, stilbenes, tannins, and curcuminoids are varieties of polyphenols [3–5]. These varieties have subtypes, such that the flavonoids have six subtypes involving flavonols, flavanols, flavones, flavanones, isoflavones, and anthocyanins, which are most frequently detected in most foods [6,7].

 doi:10.20944/preprints202412.0204.v1

Specifically, some foods, including onions, grapes, cherries, and apples, have high polyphenols [8–11]. They are used in the food industry due to their health-beneficial effects [12].

Polyphenols have divergent properties, including cardiometabolic risk management, antimicrobial effect, anti-inflammatory effect, antioxidant activity, anti-cancer effect, anti-tumor effect, prebiotic and immunomodulatory activity, essential for human and other living health [13–16]. There are several polyphenol consumption-related health studies [17,18]. In a study, catechin, a polyphenol obtained from green tea, exhibited a preventive property in obesity and related diseases, including hypercholesterolemia and hyperglycemia, when *in vivo* studies were applied to rats [19]. Also, polyphenols improve cardiometabolic risk management to avoid the risks of obesity and cholesterol by limiting insulin and cholesterol [19]. Also, apple polyphenols improved gut microbiota health and decreased appetite due to these, preventing the unstable put-on weight of the mice *in vivo* studies by applying the diet that used the high simple carbohydrate diet with polyphenols of the apple [20]. Extracted polyphenols from raspberry were used together with prebiotic fructooligosaccharides to prevent nonalcoholic fatty liver diseases by avoiding the accumulation of fats in the liver of Zucker rats [21]. In another *in vivo* study, apple polyphenols preserved the rats from neural injury, which was induced by chronic ethanol exposure [22]. This study was conducted by pursuing the daily body weight, intake of food and fluid, and consumption of ethanol. Polyphenols also demonstrate antimicrobial and anti-inflammatory effects that prevent diseases [23]. Apple polyphenols, especially phloretin, showed these effects on the respiratory pathogens that cause chronic obstructive pulmonary disorders that are bacterial-induced problems. In addition to these, blueberry has antioxidant, antimicrobial, anti-inflammatory, and anticancer activities due to its polyphenol contents [24]. In another study, blueberries' antitumor effects and immunomodulatory activities were detected, and these properties came from the polyphenols of blueberries [25].

In mice, blueberry polyphenols exhibited prebiotic activity and prevented obesity by improving fat metabolism and remodeling the gut microbiota, especially in the fecal-stage of mice [26]. Also, blueberry polyphenols extracted from fruit and leaves inhibit the neuroinflammatory response in microglia, and they can be preventive of neurological diseases, including Parkinson's and Alzheimer's disorders, that could be concluded [27]. Furthermore, the number of polyphenols can exhibit an alternative according to where they were obtained from food [28]. Polyphenol concentrations obtained from different areas, including seed, pulp, and whole fruit of the red raspberry, demonstrated diversity. In this study, different polyphenol concentrations affected the different organisms' improvement in microbiota, and also, the high-fat diet-induced obesity was balanced and inhibited by polyphenols.

Blueberries are also polyphenol-rich fruit, and several blueberries were used to obtain different polyphenols and determine divergent properties, including anti-inflammatory, antioxidant activity, and miRNA regulation or inhibition ability of the polyphenols, with several methods containing 2,2-Diphenyl-1-picrylhydrazyl (DPPH) assays for antioxidant activity [29]. Even though several polyphenols were identified in the study, phenolic acid was the most frequently detected polyphenol group. Phenolic acids affect the properties of blueberries including antioxidant activity which comes from polyphenols. However, in miRNA regulation, other compounds of the blueberries without phenolic acids were effective. Plant-based polyphenols can be combined with polyphenols obtained from other plants to enhance antioxidant activity [30]. In a study, blackberry polyphenols were combined with tea polyphenols to improve the oxidative stability of lard and olive oil [31]. The content of blackberry anthocyanins and the effect of different antioxidants on the acid degrees of lard and olive oil were determined. Also, a comparison of the anti-lipid-oxidant efficiency of several antioxidants and antioxidant capacity was searched by detecting the scavenging capacity of 2,2-Diphenyl-1-picrylhydrazyl (DPPH)-free radicals and 2,2′-Azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) cation radicals.

Polyphenol-rich foods can be added to another feed to manufacture healthy and enriched products [32–34]. In the food industry, polyphenol-rich foods are dried to use as ingredients in other feed, but the amount of the bioactive compounds in foods can degrade during drying [35]. As an example, blueberries were dried to enhance the nutritional value of the black tea [35]. In the study,

 doi:10.20944/preprints202412.0204.v1

iron-polyphenol complex formation, polyphenol profile, antioxidant activity, and sensory properties of the blueberry-added black tea were affected by drying. Also, these results not only came from drying but were also affected by fruit concentration and infusion temperature. Even though the degradation of bioactive compounds of blueberries, black tea was nutritionally enhanced with blueberries.

Polyphenols may be degraded or inhibited in their bioavailability during digestion or storage [36]. Different methods are used to preserve polyphenols, including encapsulation and microencapsulation. Encapsulation is a method to improve the stability and bioaccessibility of polyphenols in food by applying any material [37]. In a study, strawberry juice was encapsulated by freeze drying, which is a drying method that used pea protein and okra mucilage as encapsulating material [38]. At the end of the study, the polyphenols of strawberries and their antioxidant activity were preserved, and the bioaccessibility and stability of the polyphenols were increased. In another study, green tea was encapsulated by spray drying to enhance the efficiency assessment of the polyphenols. Another encapsulation method, microencapsulation, is an application to increase the shelf life of foods, especially in the food industry [39]. It can be used to preserve the bioactive ingredients of foods, including polyphenols. In a study, green tea leaf extract was extracted with supercritical fluid extraction, and then encapsulated by spray drying, which used carrier materials such as maltodextrin, gum arabic, and chitosan with different ratios [39]. The encapsulation was applied due to the sensitivity of green tea to environmental conditions containing high temperature, pH, and oxygen. As a result, the encapsulation efficiency was 71.41%–88.04% for total phenolic content and 29.52%–38.05% for antioxidant activity. It also preserved the total catechin, total phenolic content, and antioxidant activity at a temperature determined for this study (below 25 °C).

Divergent extraction methods and processes are used to obtain polyphenols according to the conformation and ingredients of foods [40,41]. Blueberries were extracted using natural deep eutectic and conventional solvents as extractants [42]. The most successful solvents were determined to be natural deep eutectic solvents due to the high obtaining capacity of the total phenolic content, total flavonoid content, total anthocyanin content, anti-radical activity, reducing power, and metal chelating activity of the blueberries. In another study, different extraction solvents were used, and optimum conditions were determined to obtain high levels of antioxidant phenolic compounds and antioxidant activity in strawberry fruits [43]. The solvents that have different polarities were used to determine the best one, and the best usable solvent was chosen as acetone for strawberries. Also, optimum extraction conditions containing extraction time, temperature, and liquid/solid ratio were detected. Additionally, the optimum extraction conditions were determined for raspberry leaves with different extraction methods or extractants, and the study also determined that steam explosion pretreatment was suitable to improve the accessibility of the polyphenols of the food [44].

The consumption dose of polyphenols is an important determinant to demonstrate the divergent properties of polyphenols containing antioxidant activity, antimicrobial activity, and anti-inflammatory effect [45,46]. In a study applied to the rats, three different doses of blueberries were fed to rats, and dose-dependent polyphenol concentrations were obtained. In the rats' colons after different dose intakes, a high amount of cinnamic and hippuric acids and a low amount of phenolic acids, flavonols, and anthocyanins were obtained according to the dose of blueberry polyphenols. Also, some polyphenols among these arrived at saturation degrees while different doses of polyphenols were taken. In another study, saturated fat was applied to rats with polyphenol intake [47]. In conclusion, cecal microbiota activity, lipid metabolism, and inflammation degrees were divergent when two different doses of raspberry polyphenols were taken. While lipid metabolism was provided with two different doses, the health-promoting effect of the polyphenols was obtained with high doses fed.

Moreover, polyphenol-rich food products are used to preserve other foods by using these products as packaging material [48]. In a study, chitosan-based apple peel polyphenols were used as a protective material for strawberries by coating, and it preserved the strawberries during the storage period [49]. The coating was prepared by applying chitosan, which was dissolved in acetic acid solution (1.0%, v/v) and stirred, then glycerol (30%, w/w) was added to the solution. Additionally, apple peel polyphenols were integrated into the solution. After that, the strawberries were disinfected with a 2% NaClO solution and dried slowly. After these, prepared strawberries coated with the solution containing the apple polyphenols were drained and dried. Finally, the strawberries were packaged in polypropylene plastic trays and stored at 20 °C. In conclusion, the application preserved the strawberries in terms of bioactive compounds, and it decreased the degradation of the properties and ingredients of the food.

This review article examines the polyphenol ingredients of several types of food used in the food industry. It explains the effective factors that affect the amount and type of food and determines the impact of polyphenols on polyphenol-enriched products and functional foods. Also, the valorization of waste polyphenol-rich foods is briefly exemplified with functional food production.

2. Polyphenols in Foods

There has been enhanced demand for research and consumption of functional foods [50–52]. Food polyphenols are used in several industries, including medicine and the food industry, thanks to their divergent effects and properties. These are antimicrobial properties, antioxidant activity, anti-inflammatory effects, anti-cancer effects, etc. [53,54]. When compared with other food ingredients, food polyphenols exhibit a variety of polyphenol types, including anthocyanins, flavonoids, and flavonoids [55,56]. Also, according to food types, several extraction methods and solvents are used to obtain divergent polyphenol types (Table 1) [57].

Table 1. Polyphenols extraction methods and properties.

Food	Polyphenols	Extraction methods	Studied effect or property of food polyphenols	References
Walnut	-Ellagic acid -strictinin -3-Methoxy-5,7,3′,4′-tetrahydroxy-flavon -gallic acid -ellagic acid pentoside, etc,.	-Folin–Ciocalteu method for total phenolic content -Reverse-phase high-performance liquid chromatography high-resolution Fourier transform mass spectrometry to identify polyphenols -100 % hexane (1:10 w/v) as extractant	Exhibit inhibition of human intestinal glucose transport, human α-glucosidase activities, and human salivary and pancreatic α-amylases	[58]
Blackberry	-Anthocyanins -Cyanidin-3-*O*-glucoside, -cyanidin-3-*O*-rutinoside -Ellagitannins -Catechins etc.	-Flash chromatography and mass spectrometry - 70% acetone as extractant	Exhibit antioxidant activity	[59]
Black raspberry	-Cyanidin-3, 5-O-diglucoside -Pedunculagin/casuariin -Caffeoyl-hexoside -Sanguiin H-6, etc.	-Ultra-high-performance liquid chromatography quadrupole time-of-flight mass spectrometry/ mass spectrometry -The divergent percentage of Methanol, acetone, and ethanol with 30% water	Exhibit health-promoting effect on gut microbiota	[60]
Red Onion Peels	-Benzoic acid -Rosmarinic acid -Quercetin -Rutin -Pyrogallol -Quercetin -Quercetin derivatives	-High-performance liquid chromatography analysis -Ultrasound- and enzymatic-assisted extractions with 80% ethanol	Exhibit antioxidant activity	[10]

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	-ρ-Coumaric acid			
Lentil (*Lens culinaris*)	-Total phenolic compounds	-Folin–Ciocalteu for total phenolic content -Acetone: water (80 : 20 v/v) as an extractant	Exhibit antioxidant activity	[13]
Raspberry Flower Petals	-(+)-catechin -(−)-epicatechin -Procyanidin B4 -Procyanidin C3 -Sanguiin H-6 -Lambertianin C -(−)-epicatechin-3,5-di-O-gallate -Kaempferol-7-O-glucoside -Naringenin-7-O-glucoside, etc,.	-High-performance liquid chromatography and liquid chromatography-mass spectrometry to identify polyphenols -The Folin–Ciocalteu method for total polyphenol content -Methanol as an extractant	Exhibit antioxidant activity, lipid peroxidation inhibitory activity, and inhibitory activity against cervical cancer (HeLa S3) cells	[14]
Chinese raspberry	-Gallic acid -Epicatechin -Ellagic acid -Rutin -Quercetin 3-O-glucoside -Avicularin -Kaempferol-7-O-glucuronide -Quercetin-7-O-glucuronide, etc,.	-High-performance liquid chromatography to identify polyphenols -A method that used acidic methanol (1% [v/v] HCl) for total anthocyanin content -The Al $(NO3)_3$–NaOH assay for total flavonoid content -Folin-Ciocalteu's total polyphenol content colorimetric method for -70% (V/V) ethanol solution as extractant	Exhibit antioxidant activity and cytotoxic effect	[15]
Roasted hazelnut skin	-Gallic acid -Protocatechuic acid -Catechin -Epicatechin -Quercetin	-Spectrophotometry for total polyphenolic content -High-performance liquid chromatography to identify polyphenols -Pure ethanol as an extractant	Exhibit antioxidant activity	[61]
Welsh Onion (*Allium fistulosum*) leaves	-Total phenolic content -Total anthocyanin content -Especially Cyanidin and quercetin-3-glucoside	-Ultra-high-performance liquid chromatography-electrospray ionization positive mode-orbitrap mass spectrometry analysis -70% *v/v* ethanol as extractant	Exhibit antioxidant activity	[62]
Pecan	-Total phenolic content	-Folin-Ciocaulteu's method for total phenolic content -Acetone/deionized water/acetic acid (70:29.5:0.5, v/v/v) at a ratio of 6:10 (w/v) as extractant	Exhibit α-Amylase inhibitory, and α-Glucosidase inhibitory effects in starch digestion	[63]
Star anise (*Illicium verum*)	-Gallic acid -4-Hydroxybenzoic acid -Catechin -Chlorogenic acid -Caffeic acid -Syringic acid -Vanillic acid	-High-performance liquid chromatography to identify polyphenols -Distilled water as an extractant	Exhibit antioxidant, anti-Obesity, and hypolipidemic effects	[64]

 doi:10.20944/preprints202412.0204.v1

	-*p*-Coumaric acid -Salicylic acid -Rutin, etc.			
Domestic Norwegian Apple (*Malus* × *domestica* Borkh.)	-Chlorogenic acid -3-*O*-caffeoylquinic acid -Phlorizin -Quercetin 3-*O*-glucoside -Quercetin 3-*O*-rhamnoside -5-*O*-caffeoylquinic acid -phloretin	-Ultra-high-performance liquid chromatography system-linear trap quadrupole to identify polyphenols -Acidified methanol/water solution (70/30 with 0.1% hydrochloric acid to pH 2) as extractant	Exhibit antioxidant activity	[53]
Blueberry (*Vaccinium* spp.)	-Delphinidin-3-glucoside -Quercetin 3-O-galactoside -Pelargonidin-3-O-galactoside -Malvidin-3-O-glucose -Phenylpropanoid compound chlorogenic acid isomers -Flavonoid substance epicatechin gallate -Kaempferol-3-rhamnoside	-High-performance liquid chromatography analysis and mass spectrometry -Acidified methanol (0.3% HCl [v/v]) as the main extractant	Exhibit antioxidant activity, antitumor activity, and immune function of anthocyanins	[65]
Black Bean (*Phaseolus vulgaris* L.)	-malvidin-3-glucoside -cyanidin-3-glucoside -delphinidin-3-glucoside -petunidin-3-O-β glucoside -Catechin -Delphinidin 3-Glucoside -Myricetin -Sinapic acid, etc.	-Folin–Ciocalteu's method for polyphenols -pH differential method (AOAC Official Method 2005.02) for total anthocyanins -Electrospray Ionization Mass Spectrometry analysis to identify phenolic compounds -Ethanol-water (50:50 *v/v*) as an extractant in supercritical fluid extraction	Exhibit antioxidant activity and anti-aging potential	[66]
Chickpea hull	- gallic acid - rutin, etc.	-Ultra-high-performance liquid chromatography to identify polyphenols -Acetone, water, and acetic acid (70:29.5:0.5, v/v/v) as extractant	Exhibit the anti-inflammatory and antioxidant properties	[67]
Spanish Almonds	-(+)-Catechin -(−)-Epicatechin -Isorhamnetin-3-*O*-glucoside -Kaempferol-3-*O*-glucoside -Isorhamnetin-3-*O*-rutinoside -Sum Flavan-3-ols -Sum Flavanols	-Spectrophotometric techniques with the modified Folin Ciocalteu method for total polyphenol determination -Zhishen, Meng Cheng, and Jianming method that was modified by Jahanbani-Esfahlan and Jamei for total flavonoid determination -Ribéreau-Gayon and Stonestreet for total proanthocyanidin determination -Hydrochloric acid, water, and methanol (3.7:46.3:50, *v/v/v*) solution as extractant	Exhibit the antioxidant activity	[68]

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Flax (*Linum usitatissimum* L.) Seed	-oleocanthal -oleuropein -hesperetin -ursolic acid -amentoflavone -quercetin-3-*O*-glucoside -quercetin-3-*O*-glucuronic acid -kaempferol-3-*O*-glucose -quercetin-3-O-hexose-deoxyhexose, etc,.	-Liquid chromatography with tandem mass spectrometry analysis to identify polyphenols -70% methanol as extractant	Exhibit antidiabetic effect, anti-inflammatory effect, α-Amylase inhibitory activity, and α-Glucosidase inhibitory activity	[69]
Egyptian chia (*Salvia hispanica* L.) seeds	-Gallic acid -Protocatechuic acid -*p*-hydroxybenzoic acid -Chlorogenic acid -Catechin -Quercetin -Apigenin -Kaempferol	-Distilled water, NaNO2, 10% AlCl3, and 1.0 M NaOH in a method used for total flavonoid content -Folin-Ciocalteu method for total phenolic content -High-performance liquid chromatography to identify polyphenols -80% methanol as extractant	Exhibit antimicrobial effect and antioxidant activity	[70]
Oregano (*Lippia palmeri* Watts)	-Total polyphenol content -Total flavonoid content	-The Folin-Ciocalteu method for total polyphenol content -The method based on aluminum chloride for total flavonoid content -Ethanol (100%) as extractant	Exhibit antioxidant activity, intestinal and immunobiological effects	[71]
Sweet basil leaves (Ocimum basilicum L.)	-Tannins -Flavonoids	-Phytochemical analysis to detect secondary metabolites -The Folin-Ciocalteu method for total polyphenol content -The method based on aluminum chloride for total flavonoid content -Ethanol 70% as an extractant	Exhibit antioxidant activity	[72]
Raspberry leaf	-Quercetin -Kaempferol -Procyanidin B1 -Catechin -Epicatechin -Gallic acid -Chlorogenic acid -*p*-Coumaric acid -Protocatechuic acid -Caffeic acid, etc,.	-High-performance liquid chromatography-mass spectrometer to identify polyphenols -60% ethanol as extractant with ultrasonic power	Exhibit anti-pathogen activity and intestinal healthy	[1]
Artichoke	-Luteolin -Luteolin-O-glycoside -Luteolin-7-O-rutinoside -Apigenin, etc.	-High-performance liquid chromatography/electrospray ionization tandem mass spectrometry -High-Performance Liquid Chromatography methanol as extractant	Exhibit hepatoprotective activity	[73]
Egg Plant Varieties and	-Total phenolic content -Total flavonoid content	-Methanolic extraction by using methanol/water (80%, v/v) as an extractant	Exhibit antioxidant activity	[74]

 doi:10.20944/preprints202412.0204.v1

Spinach Varieties				
Clove (Syzygium aromaticum) and Thyme (Thymus vulgaris)	-Total phenolic content -Total flavonoid compounds	-Folin-Ciocalteu method for total phenolic compounds -Aluminum chloride colorimetric method for total flavonoid compounds -95% ethyl alcohol as extractant	Exhibit antioxidant and antibacterial activities	[75]
Turmeric (*Curcuma longa*)	-Gallic acid -Epicatechin -Protocatechuic acid -Catechin -Chlorogenic acid -Ferulic acid -Coumarin -Rutin, etc.	-The Folin-Ciocalteu method for total phenolic content -High-performance liquid chromatography to identify polyphenols - Ethanol (80%) as an extractant in ultrasound-assisted and conventional solvent extraction	Exhibit antioxidant and antiproliferative activities	[76]
Strawberry	-Pelargonidin 3-O-glucoside and Pelargonidin-derivative -Cyanidin 3-O-glucoside and cyanidin-derivative -Gallic acid	-pH differential method for total monomeric anthocyanin content -High-performance liquid chromatography-diode array detection for anthocyanins -Folin-Ciocalteu method for total phenolic content -70% ethanol as extractant	Exhibit antioxidant activity	[77]
Young apple	-Procyanidin B1 -(-)-Epigallocatechin -(+)-Catechin -Procyanidin B2 -Chlorogenic acid -4-*p*-coumaroylquinic acid -(-)-Epicatechin -Caffeic acid -Quercetin, etc,.	-High-performance liquid chromatography to identify polyphenols -The Folin-Ciocalteu method for total polyphenol content -70% ethyl alcohol solution as extractant	Exhibit α-glucosidase inhibitory effect	[9]
Strawberry Tree Fruits (*Arbutus unedo* L.)	-Rutin -Cyanidin-3-glucoside -Quercetin-3-Xylosidase -Cyanidin-30.5-diglucoside -Quercetin-3-galactoside, etc,.	-High-performance liquid chromatography to identify polyphenols -The method based on aluminum chloride for total flavonoid content -Folin Ciocalteu method for total phenol content -pH differential method for total anthocyanins -Acetone/water (70:30, *v/v*) as extractant	Exhibit antioxidant activities	[78]
Highbush blueberries	-Total polyphenol fraction -Anthocyanin-enriched fraction -Proanthocyanidin-enriched fraction	-High-performance liquid chromatography -70% (v/v) acetone as main extractant After acetone extraction - Methanol for total polyphenol fraction	Exhibit antimicrobial and anti-inflammatory effects	[79]

		- 50% (v/v) ethanol for anthocyanin-enriched fraction -80% (v/v) acetone for proanthocyanidin-enriched fraction		
Red Raspberry	-Quercetin -Myricetin -Ellagic acid -(+)-Catechin -(−)-Epicatechin -Cyanidin 3-*O*-β-D-glucoside -Cyanidin 3-*O*-β-D-glucoside equivalent	-High-performance liquid chromatography to identify polyphenols -Folin Ciocalteu method for total phenolic content -Acidified methanol (0.5% acetic acid) as an extractant	Exhibit the inhibition of NLRP3 inflammasome activation	[3]

Fruits are polyphenol-rich foods, and they are used to obtain the polyphenols . Several different methods and solvents similar to each other are applied to obtain polyphenols from food . In a study, blueberries were freeze-dried and their polyphenols were extracted and determined [65,80]. Firstly, blueberries were frozen with liquid nitrogen, and freeze-drying and powder were obtained. Then, acidified methanol (0.3% HCl [v/v]) was used as the main extractant, which was used to wash the powder, and the extractant evaporated. Anthocyanin was obtained with lower layer separation of the previous process, ethyl acetate addition, supernatant separation, supernatant drying, powder obtained from the previous step, and freeze drying, respectively. Also, an AB-8-type macroporous adsorption resin and the eluent were especially used to purify the anthocyanins. Blueberry polyphenols were obtained with partially different pathways. Initially, dry blueberries were washed with anhydrous ethanol and filtered to completely mix polyphenols and extractants. After that, the extracted liquid was evaporated, and the dried substance was washed with petroleum ether to distract the lipids. Then, ethyl acetate was added, and other future pathways were the same as anthocyanin extraction and purification except for the eluent types of purification. Identification of polyphenols was performed with high-performance liquid chromatography and mass spectrometry. At the end of the study, delphinidin-3-glucoside, quercetin 3-O-galactoside, pelargonidin-3-O-galactoside, malvidin-3-O-glucose, phenylpropanoid compound chlorogenic acid isomers, flavonoid substance epicatechin gallate, and kaempferol-3-rhamnoside were especially obtained. Additionally, antioxidant activity, antitumor activity, and immune function of anthocyanins and other polyphenols were studied and characterized.

The solvent or extractant used can demonstrate differences even in the same types of food. For instance, in research on blueberries, acetone was used as an extractant different from the previous study [79]. Also, in this study, the total polyphenol fraction, anthocyanin-enriched fraction, and proanthocyanidin-enriched fraction of blueberries were applied separately using different solvents. At the endpoint, these polyphenols' antimicrobial and anti-inflammatory effects were studied. In a study about blackberry polyphenols, several polyphenols, including anthocyanins, cyanidin-3-*O*-glucoside, cyanidin-3-*O*-rutinoside, ellagitannins, catechins, etc., were extracted with 70% acetone [81]. Flash chromatography and mass spectrometry were used to identify polyphenols, and the antioxidant activity of polyphenols was determined and searched in this study.

Moreover, in another study, strawberry polyphenols, including total polyphenol fraction, anthocyanin-enriched fraction, and proanthocyanidin-enriched fraction, were detected, and the antioxidant activity of these polyphenols was determined [82]. The determination was acquired using the pH differential method for total monomeric anthocyanin content, high-performance liquid chromatography-diode array detection for anthocyanins, and the folin-Ciocalteu method for total phenolic content. Polyphenols in black raspberries were detected in another study [60]. Methanol, acetone, and ethanol with 30% water were used as extractants to obtain polyphenols, and ultra-high-performance liquid chromatography quadrupole time-of-flight mass spectrometry/ mass spectrometry was used to identify polyphenols. As a consequence, divergent polyphenols containing

 doi:10.20944/preprints202412.0204.v1

cyanidin-based anthocyanins, multiple ellagitannins, free ellagic acid, gallic acid, 3,4-dihydroxybenzoic acid, 4-hydroxyphenyl acetic acid, ferulic acid, rutin, and quercetin were detected, and their health-promoting activity on gut microbiota was determined in an *in vitro* study. Polyphenols were also detected in apple fruits [20]. The effect of apple polyphenols on the microbiota and appetite was studied. The ameliorated high-carbohydrate diet-induced body weight gain of the mice was decreased with polyphenol consumption by regulating the microbiota and appetite.

Furthermore, vegetables are polyphenol-rich foods. In a study about artichokes, high-performance liquid chromatography methanol was used as an extractant, and high-performance liquid chromatography/electrospray ionization tandem mass spectrometry was applied to identify the polyphenol types [73]. Divergent polyphenols, including luteolin, luteolin-O-glycoside, luteolin-7-O-rutinoside, apigenin, etc., were obtained and characterized. Deals with these polyphenols and the hepatoprotective activity of these were searched. In a study, polyphenols were extracted with 70% *v/v* ethanol, and antioxidant activity was determined from Welsh onion (*Allium fistulosum*) leaves [62]. Total phenolic and anthocyanin contents, especially cyanidin and quercetin-3-glucoside, were obtained by applying ultra-high-performance liquid chromatography-electrospray ionization positive mode-orbitrap mass spectrometry analysis. Red onions were extracted to obtain their polyphenols, including benzoic acid, rosmarinic acid, quercetin, rutin, pyrogallol, quercetin, quercetin derivatives, and ϱ-Coumaric acid [10]. Identification and determination were provided with high-performance liquid chromatography analysis and ultrasound- and enzyme-assisted extractions with 80% ethanol. In addition, the antioxidant activity of polyphenols was even detected. In another study, *Hettiarachchi et al*. determined the total phenolic content and total flavonoid content, including gallic acid, quercetin-3-glucoside, quercetin-3-rhamnoside, and myricetin-3-galactoside, of eggplant and spinach varieties, and their antioxidant activity was exhibited [74]. This result was obtained with methanolic extraction by methanol/water (80%, v/v) as an extractant.

Legumes have several polyphenolic ingredients, including black beans, lentils, and chickpeas. In a study, black beans were used to extract polyphenols, which were used to determine their antioxidant activity and anti-aging potential [66]. The extractant of this study especially was ethanol-water (50:50 *v/v*) in supercritical fluid extraction. Folin-Ciocalteu's method was used for polyphenols, the pH differential method (AOAC Official Method 2005.02) for total anthocyanins and electrospray ionization mass spectrometry analysis to identify phenolic compounds. Malvidin-3-glucoside, cyanidin-3-glucoside, delphinidin-3-glucoside, petunidin-3-O-β glucoside, catechin, delphinidin 3-Glucoside, myricetin, sinapic acid, etc. were determined at the end of the study with several extraction methods. Chickpea hull as a legume was extracted with acetone, water, and acetic acid (70:29.5:0.5, v/v/v) [67]. Ultra-high-performance liquid chromatography was used to identify the polyphenols, and gallic acid and rutin were especially determined. Also, the antioxidant and anti-inflammatory potentials of the polyphenols were determined.

Nuts and seeds are rich in polyphenols and are used in several functional foods due to their beneficial properties for humans. In a study, the walnuts were searched in terms of polyphenols and extracted with 100% hexane (1:10 w/v) [58]. The Folin-Ciocalteu method was used to determine total polyphenol content, and the identification of polyphenols was provided by reverse-phase high-performance liquid chromatography and high-resolution Fourier transform mass spectrometry. In conclusion, ellagic acid, strictinin, 3-methoxy-5,7,3′,4′-tetrahydroxy-flavone, gallic acid, ellagic acid pentoside, etc. were determined, and these polyphenols of walnuts inhibited human intestinal glucose transport, human α-glucosidase activities, and human salivary and pancreatic α-amylases. In another study, the polyphenols of hazelnut skin were determined, and their antioxidant activity was detected [61]. Hazelnut skins were roasted before extraction by pure ethanol was applied, and several types of polyphenols, including gallic acid, protocatechuic acid, catechin, epicatechin, and quercetin, were identified with high-performance liquid chromatography. Also, the total polyphenolic content was determined by spectrophotometry, and the antioxidant activity of specified polyphenols was detected. According to a study, pecan polyphenols inhibit the enzyme activity that deals with starch digestion [63]. In the survey, acetone/deionized water/acetic acid (70:29.5:0.5, v/v/v) at a ratio of 6:10 (w/v) solution was used as extractant and total phenolic content was detected by

Folin-Ciocaulteu's method. Furthermore, *in vitro* studies were applied for scratch digestion and the polyphenols of pecan controlled blood glucose. In addition, flax (*Linum usitatissimum* L.) seeds were used to obtain polyphenols, and antidiabetic and anti-inflammatory effects of the polyphenols were determined in a study [83]. For extraction of the seeds, 70% methanol was applied, and liquid chromatography with tandem mass spectrometry analysis identified the polyphenols of the seeds, including oleocanthal, oleuropein, hesperetin, ursolic acid, amentoflavone, quercetin-3-*O*-glucoside, quercetin-3-*O*-glucuronic acid, kaempferol-3-*O*-glucose, quercetin-3-*O*-hexose-deoxyhexoside, etc. For this research, *in vitro* and *in vivo* experiments were applied, and the effects of polyphenols were determined. Particularly, some enzyme activities, including α-Amylase inhibitory activity and α-Glucosidase inhibitory activity, were examined.

Additionally, herbs and spices have polyphenols, and these are used in several functional foods due to their various properties [84]. In a study, the antioxidant and antibacterial activity of clove (*Syzygium aromaticum*) and thyme (*Thymus vulgaris*) extracts were determined [75]. 95% ethyl alcohol was used as an extractant. The folic-Ciocalteu method was applied to determine total phenolic compounds, and the aluminum chloride colorimetric method was used to determine the total flavonoid compounds of the clove and thyme. Another food in this part is star anise. Star anise (*Illicium verum*) was extracted with distilled water, and high-performance liquid chromatography was used to determine polyphenols including gallic acid, 4-Hydroxybenzoic acid, catechin, chlorogenic acid, caffeic acid, syringic acid, vanillic acid, *p*-Coumaric acid, salicylic acid, rutin, etc. [64]. Also, antioxidant, anti-obesity, and hypolipidemic effects were detected in the research with a high-fat-sugar diet-induced obesity rat model. In another study, oregano leaves were extracted with ethanol (100%), and the bioactive components were determined by gas chromatography-mass spectrometry; total polyphenol content was detected with the Folin-Ciocalteu method; and total flavonoid content was determined with the process based on aluminum chloride [71]. Also, antioxidant activity and the internal and immunobiological effects of oregano bioactive ingredients, especially polyphenols, were examined and obtained. In another study, the polyphenols of sweet basil leaves (*Ocimum basilicum* L.) were extracted with 70% ethanol, and phytochemical analysis was applied to detect secondary metabolites including tannins and flavonoids as polyphenols [72]. The Folin-Ciocalteu method for total polyphenol content and the process based on aluminum chloride for total flavonoid content were utilized.

3. Several Factors of Polyphenols

Several parameters, including growing region, seasons, maturity, and obtained stage of plant-based food, change polyphenol quantities and types. The polyphenol concentration can change with the foods' ripening and maturity stages [85]. The growth process of the food was divided into several parts. The highest level of the polyphenols, especially flavan-3-ol derivatives, was determined in the early improvement stage of the food. In conclusion, the polyphenol quantity of the food decreased towards the end of the ripening. In a study, the maturity period of the blackberries was divided into three stages [86]. Total phenolic content and total flavonoid content diminished, while total anthocyanin content and soluble solids rose from the first stage to the final stage of the maturity of blackberries.

The concentration of plant polyphenols can demonstrate differences according to the growing and maturity environment [87]. In a study, red raspberries were cultivated in several conditions by changing temperature, light intensity, and wavelength. Blue light was chosen as the best environment in which 7 to obtain maximum polyphenol contents, especially flavan-3-ol derivatives of red raspberries. In another study, the divergent maturity stage at the harvest of gariguette strawberries affects the bioactive compounds, especially polyphenols [88]. These maturity stages were chosen as the turning stage and fully ripe. At the end of the study, fully ripe harvested food had more polyphenols, especially hydroxycinnamic acids, than the turning stage. Additionally, several bioactive properties of the strawberries, including vitamin C, organic acids, and volatiles, were detected in divergent amounts by different maturity stages.

 doi:10.20944/preprints202412.0204.v1

Despite using the same food, the polyphenols vary depending on the growing region [89]. In a study, ripened wild strawberry (*Arbutus unedo L.)* was used to determine the effects of different growing regions on the polyphenolic ingredients [89]. The strawberries were taken from three forests: Achakar, Qsar Kbir, and Chaoun-Qalaa. As a result of this study, some polyphenols, including tannins, anthocyanins, catechic tannins, gallic tannins, coumarins, and anthraquinones, did not show any differentiation related to growing regions. However, Quinones polyphenol exhibited that the strawberry obtained from the Achakar forest did not have this polyphenol compared to other strawberries from the Qsar Kbir and Chaoun-Qalaa forests. Also, the strawberries' total polyphenol, flavonoid, anthocyanin, tannin, and antioxidant activity were differentiated with growing regions. The best results were demonstrated with the strawberries obtained from the Chaoun-Qalaa forest when paying attention to total polyphenol content and flavonoid content; with Achakar forest strawberries when paying attention to antioxidant activity and tannin content; and with partial Qsar Kbir forest strawberries dealing with the anthocyanin content of the strawberries. In another study, strawberry tree fruits (*Arbutus unedo* L.) obtained from five divergent areas (Chefchaouen, Moulay Driss Zerhoun, Laanoucer, El Ksiba, and Tahnaout) were examined based on their antioxidant activity, organic acid, and phenolic composition [78]. As a result, total phenols were determined in the trees that were taken from the Laanoucer, Moulay Driss Zerhoun, Chefchaouen, Thnaout, and El Ksiba; total flavonoids of the trees in the Thnaout, Moulay Driss Zerhoun, Laanoucer, Chefchaouen, and El Ksiba; and total anthocyanins of the trees in the Moulay Driss Zerhoun, Thnaout, Chefchaouen, Laanoucer, and El Ksiba with decreasing, respectively. Also, antioxidant activity was significantly high in the tree obtained from the Moulay Driss Zerhoun region.

Ingredients of the foods, especially polyphenols, change according to seasons, which have different environmental conditions [90]. In a study, the biological activity, aroma, and polyphenols of white strawberries changed according to the climate condition and growth location of the fruit [90]. Also, the growing year of foods is an effective parameter for obtaining polyphenols [82]. Researchers used strawberries harvested in 2014 and 2015 to extract the polyphenols. The total anthocyanin and phenolic content of the strawberries harvested in 2015 was higher than that of 2014. Still, the lower content of cyanidin-based forms was obtained in strawberries harvested in 2015.

The food types demonstrate differentiation deals with their polyphenol ingredients compared with each other [82]. In a study, several cultivars of the strawberry were used to obtain the polyphenols [82]. According to the results, each cultivar gave a different total phenolic content, total anthocyanin content, and antioxidant activity, despite all cultivars being strawberries. Additionally, eleven different Spanish almonds with specific genotypes were extracted for their polyphenols in another study [91]. In conclusion, the number and types of polyphenols, including (+)-Catechin, (−)-Epicatechin, isorhamnetin-3-O-glucoside, kaempferol-3-*O*-rutinoside, isorhamentin-3-*O*-rutinoside, sum Flavan-3-ols, sum Flavanols of the Spanish almonds were different from each other due to their divergent genotypes. In another study, divergent polyphenols were obtained from several blackberries (*Rubus* spp.) fruit cultivars, including Cheste, Triple Crown, Navaho, Loch Ness, Thornfree, and Ouachita (10.3390/horticulturae9050556). As a result of the study, several anthocyanins, including cyanidin-3-glucoside, cyanidin-3-O-arabinoside, cyanidin-3-O-(malonyl)glucoside, cyanidin-3-O-(dioxalyl)glucoside, and cyanidin-3-rutinoside, exhibited alternative concentrations in each cultivar when compared with others. According to these results, foods from the same types could have different types and concentrations of polyphenols.

The polyphenolic compounds can vary with extraction types, including ultrasound-assisted and conventional solvent extractions [76]. In a study, turmeric (*Curcuma longa*) was extracted using divergent extraction methods, including ultrasound-assisted and conventional solvent extractions [76]. In conclusion, the concentration of gallic acid, protocatechuic acid, catechin, chlorogenic acid, epicatechin, ferulic acid, coumarin, and rutin was detected more in ultrasound-assisted extraction than in conventional solvent extraction, even though some of these polyphenols were not detected in conventional solvent extraction. Despite these, some polyphenols, including curcumin, myricetin, cinnamic acid, genistein, and quercetin, were determined in ultrasound-assisted extraction non or less than in conventional solvent extraction. In another study, garden blackberries (*Rubus fruticosus*

 doi:10.20944/preprints202412.0204.v1

L.) were extracted with different extraction solvents, including 80% (*v*/*v*) ethanol, 70% (*v*/*v*) acetone + 2% (*v*/*v*) acetic acid, 60% (*v*/*v*) methanol + 3% (*v*/*v*) formic acid, and 90% (*v*/*v*) acetonitrile + 10% (*v*/*v*) 6 molar HCl [92]. At the end of the study, the maximum anthocyanin, flavonoid, and polyphenol contents of garden blackberries were extracted with 90% (*v*/*v*) acetonitrile + 10% (*v*/*v*) 6 molar HCl.

Foods have different sizes and shapes, despite the same food, and the size of foods is effective on the achievement of polyphenols [75]. In a study, clove and thyme were prepared as a whole, and powder and different extracts were used to obtain polyphenols [75]. As a result, whole and powdered versions of these foods showed differentiation in terms of the phenolic and flavonoid compounds. Generally, the powder of these foods had more phenolic and flavonoid compounds than the whole. Also, extracts were effective in the concentration of phenolic and flavonoid compounds in the foods. While ethanolic extract was the best extraction to obtain these compounds from thyme, essential oil extract was the best to get from clove among ethanolic extract, aqua extract, and essential oil extracts.

The germination day is another parameter to obtain maximum polyphenolic ingredients [93]. Separately, ten days of germinated Egyptian chia seeds (*Salvia hispanica* L.) were examined to understand the importance of the germination day on the polyphenols [70]. The total phenolic and flavonoid contents increased from 0 to 7 germination days; however, these contents decreased from 7 to 10 days.

4. Application of Polyphenols in the Food Industry

Polyphenols in plant-based foods are used in the food industry to enhance functional foods, food preservation and stability, and food packaging (**Figure 1)** [94,95]. Also, they increase the shelf life of the foods and their beverages or functional food processing and the bioaccessibility of the food ingredients [96,97]. The effects of polyphenols are degraded by digestion, and this digestion activity on antioxidant activity and bioaccessibility of polyphenols were examined [98]. This accessibility problem could be prevented by several methods, including microencapsulation or only encapsulation [39,99]. Also, the nano-chitosan and chitosan coating were used to preserve the polyphenol ingredients of the foods [100]. These preventive studies, which are applied to the polyphenols of foods, can be used in functional food and polyphenol-rich product manufacturing due to the positive effect of these methods on the preservation of polyphenols [101]. Also, polyphenols were used for the packaging and preservation of food, including strawberries, besides their own highly bioactive ingredients [49]. Additionally, for the industrial usage of the food polyphenols, divergent technologies, including freezing, thermal treatments, and high-pressure processing, were used, and the effects of the technologies on the apple and strawberries were determined [102]. Different technologies provide several results that differ according to the fruits and their bioactive ingredients, especially polyphenols. As a result of the study, these technologies could be used in the food industry to produce effective foods.

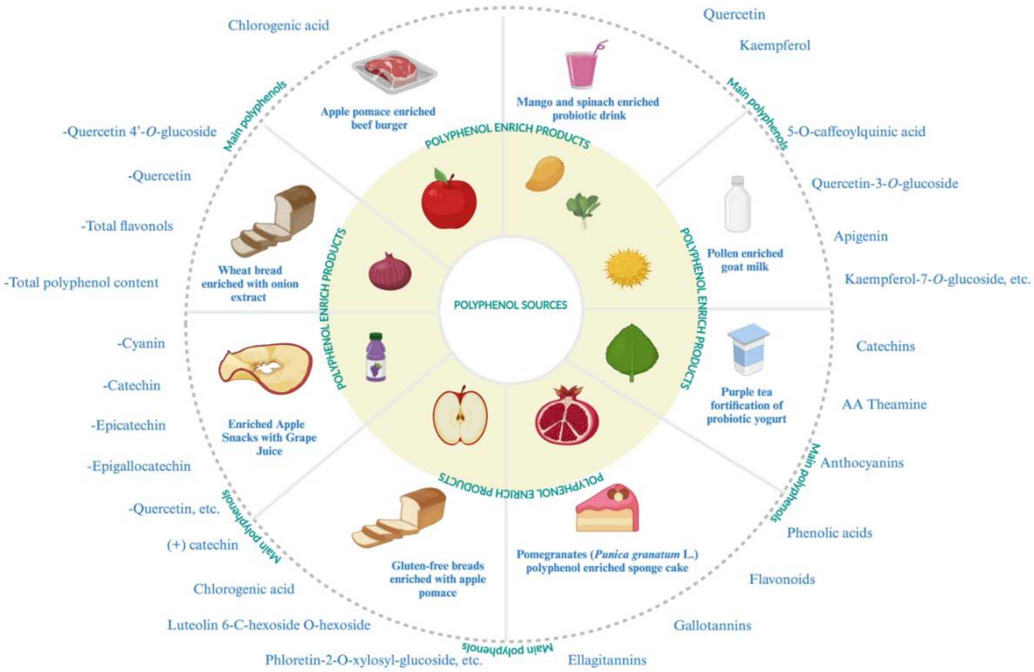

Figure 1. Functional foods containing common polyphenol sources and the main types of.polyphenols they contain.

4.1. Functional Foods and Polyphenol-Enriched Products

Polyphenols have several health-promoting properties including anti-aging effect, anti-inflammatory, and anti-cancer effects [103–105]. For these reasons, functional foods and polyphenol-enriched products are manufactured in diets **(Table 2)** [52,106,107]. In a study, raspberry polyphenols were added to probiotic dairy products fortified with oat bran, and a functional food was produced for effective diets [107]. Also, this study examined and reported the effect of oat bran and probiotics on polyphenolic ingredients. Antioxidant activity and polyphenols were preserved at the specific storage conditions determined in the study. In another functional food production, fermented mango (*Mangifera indica*) and spinach flour (*Amaranthus*) were used to enrich probiotic drinks in terms of polyphenols [108]. *Lactobacillus paracasei* was incubated for 60 hours in anaerobic conditions at a temperature of 30-32 °C. The polyphenol ingredients of the functional drink were determined by high-performance liquid chromatography. As a result of the study, the ability of lipid profile improvement and stabilization of the blood sugar fluctuation of the functional drink as anti-diabetic properties were searched and determined.

Table 2. Polyphenol usage in the food industry.

Product types	Polyphenols	Outcome	References
Purple tea fortification of probiotic yogurt	-Polyphenols -Catechins -AA Theamine -Anthocyanins	-The tea polyphenols did not affect the probiotics in storage -Increased the beneficial bacteria -Decreased the pathogens in gut microbiota	[109]
Microencapsulated Asiatic Pennywort (*Centella asiatica)* fortified chocolate oat milk beverage	-Asiatic acid -Asiaticoside -Benzoic acid -Caffeic acid -Catechin -Chlorogenic acid -Gallic acid -Kaempferol -Luteolin	-Preserved the polyphenolic ingredients of the food	[36]

	-Madecassic -*p*-Coumaric acid -Quercetin -Rutin		
Polyphenol enriched milk	-Rutin -Cyanidin-3-rutinoside -Procyanidin B1 -Delphinidin-3-rutinoside -Gallic acid, etc.	-Increased the bioaccessibility and antioxidant activity of food ingredients	[48]
Sports nutrition milk enriched with blackberry	-Phenolics -Flavonoids -Anthocyanins	-Enhanced the bioaccessibility of the polyphenols of the blackberry and the protection of anthocyanins in digestion	[110]
Blackberry juice with apple fibers	-Anthocyanins -Flavanols -Phenolic acids -Dihydrochalcones	-Showed high antioxidant activity and inhibition of α-amylase enzymes	[111]
Apple pomace enriched beef burger	-Chlorogenic acid -Quercetin-3-*O*-glucoside -Phloridzin	-Demonstrated the high total phenol content, antioxidant activity, and antioxidant compounds, including quercetin derivatives, chlorogenic acid, and phloridzin in the enriched beef burger	[35]
Oat bran fortified raspberry probiotic dairy drinks	-Phenolic acids -Flavonoids -Phytic acid, etc.	-Did not cause any negative effect on the polyphenolic ingredients of functional food in storage	[107]
Fermented mango (*Mangifera indica*) and spinach flour (*Amaranthus*) enriched probiotic drink	-Quercetin -Kaempferol	-Improved lipid profiles -Stabilized blood sugar fluctuations so that they can be anti-diabetics	[108]
Polyphenols enriched ice cream, yogurt, and buttermilk with black carrot (*Daucus carota* L.) concentrate	-Total phenols -Total flavonoids -Anthocyanins	-Enhanced the mineral content (Mg and Fe), polyphenols, and antioxidant activity of dairy products	[112]
Gluten-free breads enriched with apple pomace	-Luteolin 6-C-hexoside *O*-hexoside -Chlorogenic acid -(+) catechin -Phloretin-2-*O*-xylosyl-glucoside, etc.	-Improved the nutritional value of the bread in terms of especially polyphenols -Demonstrated high antioxidant activity and polyphenolic ingredients	[113]
Spent Coffee Grounds-Enriched Cookies	-Melanoidins -Chlorogenic acid -5-caffeoylquinic acid -Phenolic acids, etc.	-Improved the polyphenolic ingredients of the food -Enhanced the bioaccessibility and antioxidant activity of the cookies	[7]
Pollen-enriched goat milk	-5-O-caffeoylquinic acid -Quercetin-3-*O*-glucoside -Apigenin -Kaempferol-7-*O*-glucoside, etc.	-Enhanced the antioxidant activity and bioaccessibility in digestion	[33]
Olive leaves and olive mill wastewater-enriched gluten-free breadsticks	-Total polyphenol content	-Demonstrated antioxidant activity and high polyphenol bioaccessibility in the breadsticks	[30]
Grape pomace and olive pomace enriched tagliatelle pasta	-Quercetin -Kaempferol -Delphinidin-3-*O*-glucoside -Petunidin-3-*O*-glucoside, etc.	-Improved the nutritional value of the food	[114]

Functional beef burgers formulated with chia seeds and goji puree	-Carotenoids -Chlorogenic acid -Caffeic acids -Quercetin -Kaempferol	-Enhanced bioaccessibility of polyphenols	[106]
Pomegranates (*Punica granatum* L.) polyphenol enriched sponge cake	-Phenolic acids -Flavonoids -Gallotannins -Ellagitannins	-Enhanced the nutritional value and total phenolic ingredient -Inhibited of α-Glucosidase and α-amylase -Showed high digestibility ability	[115]
Rye snacks enriched with seaweed extract	-Total phenolic content	-Enriched antioxidant activity, oxidative stability ability, and preventive effect from diseases -Promoted the enhancement of the nutritional value and preservation of convenience food	[95]
Enriched Apple Snacks with Grape Juice	-Cyanin -Catechin -Epicatechin -Epigallocatechin -Quercetin, etc.	-Improved the polyphenolic ingredients of the product -Demonstrated high antioxidant capacity and bioaccessibility of the polyphenols in the digestion of the snacks	[4]
Olive leaf extract-enriched taralli	-Total Phenols -Total Flavonoids -Oleuropein, etc.	-Increased the bioaccessibility of the nutritional contents and antioxidant activity of the food	[40]
Partially deoiled chia flour-enriched wheat pasta	-Quinic acid -Caffeic acid -Ferulic acid -Methylquercetin, etc.	-Improved nutritional value -Enhanced bioaccessibility in digestion	[56]
Wheat bread enriched with onion extract	-Quercetin 4'-*O*-glucoside -Quercetin -Total flavonols -Total polyphenol content	-Demonstrated the high antioxidant activity and polyphenolic ingredients in storage	[41]
Berry fruits-enriched pasta	-Total polyphenol content -Anthocyanins	-Enhanced the nutritional value, bioaccessibility, antioxidant activity, and bioavailability of the pasta	[57]

Different compositions of the added material to polyphenols are important for maximum accessibility to these in functional foods or polyphenol-enriched products [110]. In a study, several milk compositions, including full-fat, semi-skimmed, skimmed, or high-protein milk, were used to produce functional sport-supported beverages enhanced with blackberry polyphenols [110]. Adding the milk to polyphenols preserved the polyphenols in digestion and increased the bioaccessibility of these due to the preservation ability of the milk fat from degradation in digestion. Full fat exhibited the best preservation at the end of the study with *in vitro* digestion. In another study about milk and polyphenol interaction, bioaccessibility and antioxidant activity were increased in digestion, which was determined with an *in vitro* study [48]. Blackcurrant polyphenols were bonded with milk proteins, including whey protein and especially casein, to improve bioaccessibility and antioxidant activity. This interaction showed the best bioaccessibility and antioxidant activity compared to alone milk and blackcurrant digestion. Also, the polyphenol-protein interaction lowered the degradation of milk and increased the resistance of the milk.

Functional yogurts can also be produced with polyphenols to enhance the activity and preservation of the yogurt [109]. Firstly, yogurt fermented with probiotic culture and purple tea polyphenols extracted. The polyphenols did not have any effect on the probiotics in yogurt, while they increased the beneficial bacteria, including *Lactobacillus* and *Bifidobacterium genera,* and decreased the pathogens, including *Staphylococcus, Helicobacter, Mycoplasma,* and *Aerococcus,* in the gut microbiota.

Several waste products and by-products are manufactured in the food industry [114]. These should be used in alternative ways, including functional food production [116]. In a study about grape seeds, which are waste products, muffins produced with different flours were enriched with grape seed extract to enhance the nutritional value of the products [116]. Whole wheat flour, whole siyez wheat flour, and whole oat flour were used to produce muffins, and better antioxidant activity and total phenolic content were best in the muffins prepared with whole oat flour.

In a study, blackberry juice was encapsulated with apple fibers to carry the polyphenols [111]. The effect of different amounts of fiber on polyphenols was detected, and a high amount of fiber demonstrated a negative effect on the polyphenol carry and preservation. The functional food was produced with apple fibers and blackberries. The antioxidant activity and inhibition of α-amylase were determined in the food. In another study, pomegranate (*Punica granatum* L.) peel extract was used as a natural polyphenol source to enrich the sponge cake [115]. In the analysis, pomegranate peel extract showed high yeast α-glucosidase and α-amylase inhibitory effects, and a decrease in the GI and starch hydrolysis index of the cake was determined. Also, the digestibility of the cake increased with polyphenol enrichment in this study.

The gluten-free bread is a functional food, especially in diet, and the bread can be improved with polyphenol-rich foods [113]. In a study, gluten-free bread was prepared with apple pomace to enhance the nutritional value of the food [113]. The identification of the polyphenols was applied to the bread, and several types of flavonols, phenolic acids, flavan-3-ols, and dihydrochalcones were determined, and the gluten-free bread was improved in terms of antioxidant activity and polyphenolic contents.

4. Conclusion

Plant-based foods have been used for nutrition for several, even more than millions of years. They are rich in bioactive components that have several different effects and activities, including anti-cancer effect, anti-tumor effect, anti-inflammatory effect, cardiometabolic risk management, antimicrobial effect, immunomodulatory activity, antioxidant activity, and antiradical activity. The most common bioactive compound of plants is polyphenols, and they have been used for several reasons to improve human health and food quality. They also have several subgroups, including anthocyanins and flavonols, and several types of polyphenols, including rutin and quercetin, are found in food. Moreover, the amount and type of the polyphenols demonstrate divergent results according to the type of food, and some factors of polyphenols differentiate the polyphenols, including germination day, harvested year, ripening, and growing region. Also, the effects of polyphenols on diseases and gut microbiota are investigated *in vivo, in vitro*, or in any other experiments. Also, the stability and bioaccessibility of the polyphenols were searched and detected, and alternative ways, including encapsulation and coating, were enhanced. The extraction of polyphenols is basic process; however it exhibits inconsistencies for several characteristic processes, including extractant type. In addition, the characterization of polyphenols is applied with a chromatographic method, which discrepancies according to the type of food and its conformation. In addition, polyphenols are used in the food industry, especially in functional food production, and functional food enrichment is provided by polyphenol-rich foods and their by-products. Also, enhanced functional food achievements the stability, bioaccessibility, and especially high nutritional value to consume in any field containing diets.

Author Contributions: : Conceptualization, S.K., S.S., and N.C.; writing—original draft preparation, N.C., M.B., and S.S.; writing—review and editing, S.K., S.S., M.B., and N.C.; visualization, N.C., S.S., and S.K. All authors have read and agreed to the published version of the manuscript.

Funding: This article received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

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

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