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Fundamentals of Polyphenols: Nomenclature, Classification and Properties

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1.1 Introduction

Polyphenols are a class of substances that are found in plants and are renowned for having antioxidant qualities [1]. The basic structure of polyphenols consists of one or more aromatic rings with hydroxyl (—OH) groups attached to them as shown in Figure 1.1, which helps to neutralize free radicals (which are highly reactive molecules that can cause damage to cells and contribute to various diseases, including cancer, heart disease, and Alzheimer's disease, etc.) [2]. In order to protect themselves against environmental factors including ultraviolet (UV) radiation, diseases, and pests, plants can produce them. Flavonoids, phenolic acids, lignans, and stilbenes are just a few of the numerous chemically different molecules that comprise the complex group of substances called polyphenols [3]. Fruits, vegetables, tea, coffee, red wine, and chocolate are a few major dietary sources of polyphenols. As per research, polyphenols may provide a wide range of health benefits [4]. For instance, it has been revealed that they possess antioxidant activity anti-inflammatory, anti-cancer, neuroprotective activity, antidiabetic activity, and cardiovascular health-promoting properties. They also reduce the heart disease risk. They may service people manage their blood sugar levels and have neuroprotection [5]. While phenols are generally safe and well-tolerated, it is

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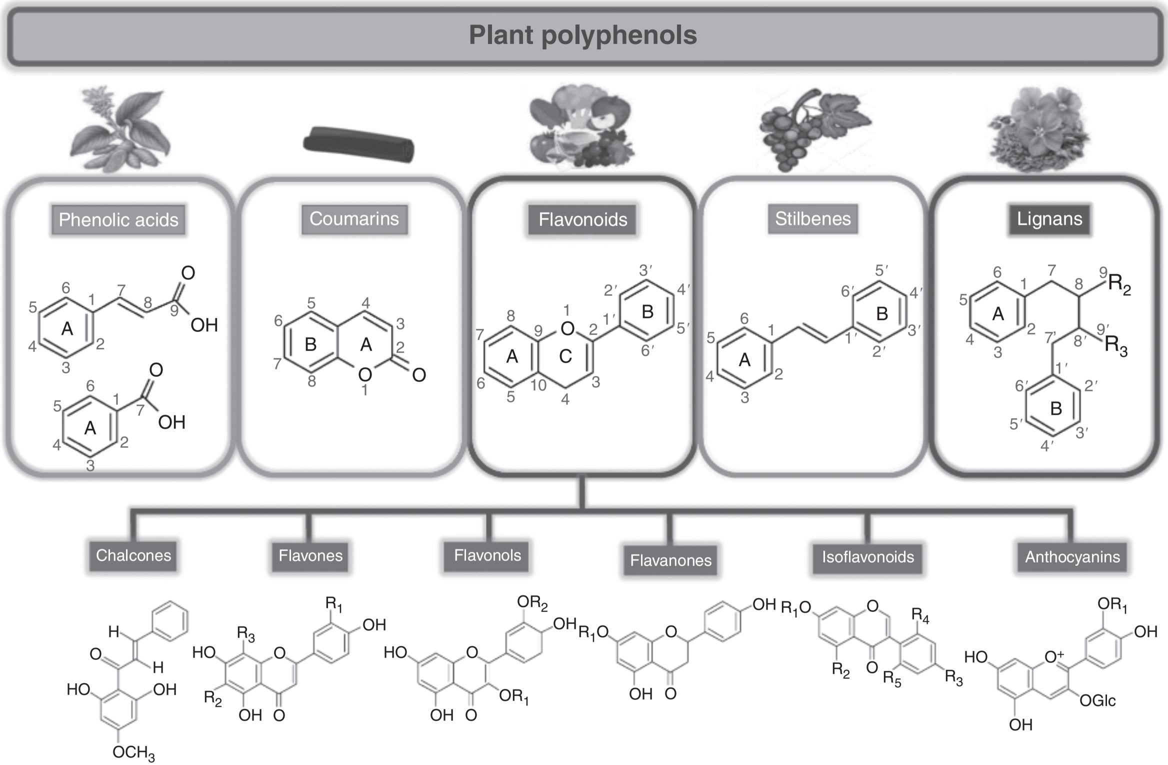

Figure 1.1 Basic structure of polyphenol. Source: Oscar Vidal-Casanella et al. [2]/Reproduced from MDPI/CC BY 4.0.

important to note that they can also interact with certain medications and affect their absorption and effectiveness. Therefore, before taking high doses of polyphenol supplements, it is essential to speak with a healthcare expert or making significant dietary changes to increase polyphenol consumption [6].

1.2 A Short History of Polyphenols

The name derives from the Ancient Greek word (*polus*, meaning "many, much") and the word "phenol," which refers to a chemical structure formed by attaching to an aromatic benzenoid (phenyl) ring to —OH group as is found in alcohols (hence the *-ol* suffix). The term "polyphenol" used since 1894 is a Greek-rooted word polus meaning many and phenol refereeing to the chemical structure formed by attaching phenyl ring to —OH group. The history of polyphenols can be traced back to ancient times when they were used for medicinal purposes and as food preservatives. One of the earliest recorded uses of polyphenols was by the ancient Egyptians, who used tannin-rich plant extracts to preserve mummies. In ancient Greece, Hippocrates, the father of modern medicine, recognized the medicinal properties of wine, which contains high levels of polyphenols. During the Middle Ages, polyphenols were used as natural remedies for a variety of ailments. For example, extracts of grape seeds were used to treat skin conditions and digestive disorders. In the 16th century, the Spanish physician Andres Laguna wrote about the medicinal properties of tea, which contains high levels of polyphenols. In the 19th and early 20th centuries, the study of polyphenols became more scientific. In 1853, the French chemist Henri Braconnot isolated tannins, which are a type of polyphenol, from oak bark. In the early 20th century, the German chemist Richard Willstätter discovered the chemical structure of flavonoids, which are another type of polyphenol. Today, research continues into the potential health benefits of polyphenols, which include reducing inflammation, improving cardiovascular health, and protecting against certain types of cancer. Polyphenols are found in a wide range of plant-based foods, including fruits, vegetables, tea, coffee, and wine and are an important part of a healthy diet as shown in Table 1.1.

Table 1.1 List of some polyphenol compounds along with their natural sources.

Polyphenols	Natural sources
Resveratrol	Grapes, red wine, peanuts, and berries
Catechins	Green tea, black tea, cocoa, and apples
Quercetin	Onions, apples, grapes, berries, broccoli, and tea
Flavonols	Onions, kale, broccoli, apples, berries, and tea
Anthocyanins	Berries, cherries, grapes, red cabbage, and eggplant

(Continued)

Table 1.1 (Continued)

Polyphenols	Natural sources
Proanthocyanidins	Grapes, red wine, cocoa, and apples
Ellagic acid	Strawberries, raspberries, pomegranates, and nuts
Curcumin	Turmeric
Chlorogenic acid	Coffee, apples, pears, and blueberries
Luteolin	Celery, parsley, thyme, and peppers
Apigenin	Parsley, celery, chamomile, and peppermint
Isoflavones	Soybeans, lentils, and chickpeas
Myricetin	Berries, grapes, and red wine
Oleuropein	Olives and olive oil
Rutin	Buckwheat, citrus fruits, and asparagus
Stilbenes	Grapes, blueberries, and red wine
Tannin	Tea, wine, and berry
Caffeic acid	Coffee, fruits, and vegetables such as tomatoes and carrot
Ferulic acid	Brown rice, oats, barley, and wheat bra
Hesperidin	Citrus fruits such as oranges and lemons
Delphinidin	Blueberries, cranberries, and grape
Epicatechin	Green tea, cocoa, and apple
Gallocatechin	Green tea, black tea, and cocoa
Isorhamnetin	Onions, grapes, and tomato sauce
Secoisolariciresinol	Flaxseed, sesame seeds, and whole grain
Prodelphinidin	Cocoa and dark chocolate
Ursolic acid	Apples, basil, and cranberries
Chrysin	Honey, propolis, and passionflower
Epigallocatechin	Green tea, black tea, and cocoa
Gallic acid	Grapes, blueberries, and green tea
Hydroxytyrosol	Olives, olive oil, and red win
Malvidin	Red grapes, blackberries, and blueberries
Piceatannol	Blueberries, and passionfruit
Theaflavins	Black tea
Hesperidin	Oranges and lemons
Lignans	Flaxseed, sesame seeds, and whole grains
Syringic acid	Walnuts, and berries such as raspberries and blackberries

1.3 Fundamental of Polyphenols

A class of naturally occurring substances called polyphenols are present in plants and are distinguished by having many phenolic rings. They may be found in a variety of fruits, vegetables, cereals, tea, coffee, wine, and other plant-based meals [7]. They are also extensively spread throughout the plant world. One or more aromatic rings with —OH groups attached compose up the fundamental structure of polyphenols [8]. These —OH groups give polyphenols their antioxidant capabilities, which aid in the body's ability to combat free radicals and oxidative stress. Based on their chemical structure, polyphenols may be divided into a number of distinct classes, including flavonoids, phenolic acids, lignans, and stilbenes. The most prevalent and most researched class of polyphenols are flavonoids, which are further divided into subcategories including flavones, flavanones, and flavonol. Deep research has been done on polyphenols' possible on health advantages, which are mostly related to their anti-inflammatory and antioxidant characteristics [9, 10]. Many chronic diseases, such as cancer, heart disease, and neurological illnesses have been proven to be protected against by them. Polyphenols have a variety of different biological effects that have been discovered in addition to their antioxidant capabilities [11]. For instance, modify the activity of enzymes involved in cell signaling, control gene expression, and interact with the body's proteins and lipids. The bioavailability of polyphenols might change based on the dietary source and processing techniques. it is important to note. For example, certain polyphenols are better absorbed when taken cooked as opposed to raw, while others are more accessible when consumed along with other nutrients like fat. You may improve your general health and well-being by including a range of foods high in polyphenols in your diet.

1.4 Nomenclature of Polyphenols

The nomenclature of polyphenols can be complex and varies depending on a specific type of polyphenol. However, there are some general rules that are commonly used to name these compounds. Polyphenols are frequently named based on their chemical structure, which usually contains multiple phenolic rings. The simplest polyphenols, such as catechins and flavanols, are named according to the number and position of the —OH groups on the phenolic rings. For example, catechins have two —OH groups on adjacent carbon atoms, while flavanols have —OH groups on different carbon atoms. The number and position of the —OH groups on the phenolic rings of more complex polyphenols, such as flavonoids and phenolic acids, are used to designate them. For instance, the flavonoid quercetin is so called because of the —OH groups that are located at positions 3, 5, 7, and 4′ on its flavone ring (numbering starts at the top of the ring and proceeds clockwise).

Polyphenols may be given names based on their biological function or place of origin. For example, curcumin, a phenolic molecule included in turmeric, has anti-inflammatory effects, whereas resveratrol is a stilbene polyphenol found in red wine and grapes. Moreover, shorthand acronyms or chemical symbols can be used to identify polyphenols, such as epigallocatechin gallate (EGCG) (a catechin present in green tea) or gallic acid equivalents (a measure of total polyphenol content in a food or beverage) [12–14]. The nomenclature of polyphenols can be complex, and naming conventions can vary depending on the specific type of polyphenol and the context in which it is being used. However, understanding the basic principles of polyphenol naming can help to clarify the structure and properties of these important plant-based compounds.

1.5 Classification of Polyphenols

Polyphenols can be classified based on their chemical structure and properties. Figure 1.2 shows some of the common classifications of polyphenols [15]:

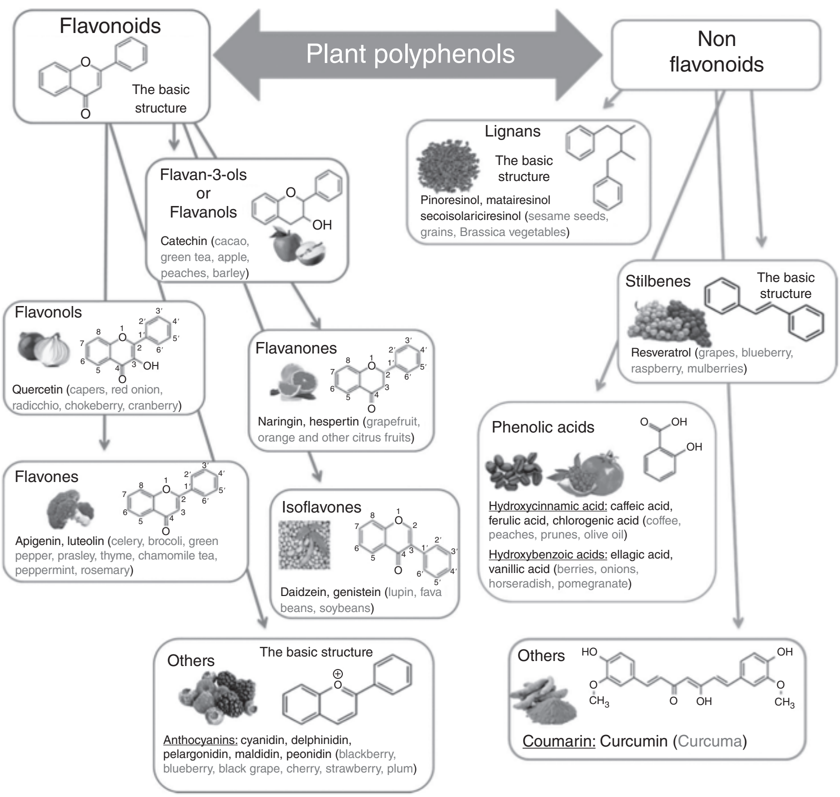

Figure 1.2 Classification of polyphenols. Source: Rosaria Meccariello et al. [15]/ Reproduced from MDPI/CC BY 4.0.

1.5.1 Flavonoids

The most well-known and well-researched class of polyphenols is flavonoids. They may be identified by their two aromatic rings joined by a three-carbon chain, which makes up their fundamental chemical structure. Depending on their chemical structure, flavonoids may be further divided into a number of subgroups, including flavones, flavonols, flavanones, flavan-3-ols (catechins), isoflavones, anthocyanidins, and anthocyanins. Moreover, sources from plants have given the identification of over 4000 flavonoids. Flavonols, between C3 and C2, a double bond could be observed, and a OH group is linked at C3. The majority of flavonoids found in various dietary sources are flavonols. These compounds are mostly found in onions however, leeks Kale, lettuce, tomatoes and broccoli also contain flavonols [16]. Flavanones due to their distinct patterns of substitution, flavanones exhibit a wide range of substituted derivatives (such as prenylated and benzylated flavanones). The most typical type of glycosylated flavanones has a disaccharide substitution at the C7 position. Most flavanones are present in aglycone forms and are primarily present in citrus fruits, such as oranges and lemons (e.g., hesperidin) [16, 17].

Flavones have a double bond between the C2 and C3 atoms, a carbonyl group at the C4 position, and ring B linked to the heterocyclic ring at the C2 location. Lutein and apigenin are the two key flavones. Moreover, ring B (in isoflavones) is attached to the heterocyclic ring (C3 position) rather than the C2 as in other classes, and an oxygen atom is placed in the C4 position [16, 18]. Flavanols (flavan-3-ols) have a saturated heterocyclic ring, a —OH group at position C3, and no double bond between C2 and C3. catechins' characterization derives from the ability to explain two chiral centers, unlike other types of flavonoids. Only aglycones, a kind of flavanol, are present in food (the glycosylated state is excluded). Moreover, they can be found in polymeric forms known as tannins and in monomeric forms known as catechins and epicatechins. epicatechins are diastereoisomers and have a —OH group linked to the C3 position. Epicatechin has the cis configuration of the stereoisomers (+)-epicatechin and (−)-epicatechin, whereas the catechin isomer has the Trans configuration of two stereoisomers, (+)-catechin and (−)-catechin. These structures, which are referred to as tannins in connection to polymeric flavanols, have excellent water solubility and a relatively high molecular weight. With the help of the B ring, ring C is joined to its C3 edge in isoflavones. Legumes are a rich source of these substances as well. While soybeans are the major supply for food. isoflavones have a greater impact on health. Together with glycitein, two more important isoflavones present in soy are daidzein and genistein. Such compounds can also be found in red clovers.

The most common types of isoflavone-aglycones are 7-*O*-glucosides and 6″-*O*-malonyl-7-*O*-glucosides. Dalbergin is the main neo-flavonoid found in plant-based meals [19–21]. The presence of two double bonds in the heterocyclic rings of anthocyanidins and anthocyanins sets them apart from other flavonoids. The hydroxylation and methoxylation patterns on ring B define anthocyanins, which are anthocyanidins in their glycosylated form. A range of anthocyanins are produced by differences in the number of hydroxylated groups, the kind, and the quantity of linked sugar units to their structures. Often, monosaccharides like glucose, galactose, and arabinose make up bonded sugar units. The majority of the colors seen are attributed to molecules called glycosylated anthocyanins, which are water-soluble pigments found in vibrant flowers and fruits [17, 21].

1.5.2 Nonflavonoids

Nonflavonoids consist mostly of a single aromatic ring. Stilbenes, lignans, and phenolic acids are examples of nonflavonoid chemicals. Phenolic acids, mostly derivatives of benzoic acid and cinnamic acid, make up the bulk of this group's chemical composition.

Phenolic acids: One or more —OH groups are connected to a single aromatic ring, which distinguishes phenolic acids from other polyphenols. These may be found in a variety of plant-based foods, such as grains, fruits, and vegetables. Gallic acid and hydroxycinnamic acids are the two most prevalent forms of phenolic acids (e.g. caffeic acid) [22].

Stilbenes: A class of polyphenols known as stilbenes is distinguished by two aromatic rings joined by a double bond. The most popular stilbene is resveratrol, which may be found in red wine, peanuts, and grapes. Many possible health advantages, such as anti-inflammatory and antioxidant capabilities, have been associated with resveratrol [23].

Lignans: Lignans are polyphenols that resemble phenolic acids structurally but are joined by a carbon–carbon bond. Foods including flaxseed, sesame seeds, whole grains, and some vegetables contain them. Bacteria in the stomach break down lignans to create enterolignans, which have been found to improve health [24].

1.6 Extraction Methods of Polyphenols

1.6.1 Ultrasonic-Assisted Extraction of Polyphenols

A popular and effective method for extracting polyphenols from plant sources is ultrasonic-assisted extraction (UAE) shown in Figure 1.3 [25]. It is a simple, quick, non-destructive, and energy-saving technique that can increase the polyphenols' extraction yield as well as quality. The frequency, power, duration, and solvent type used in UAE all have a significant effect on the quantity and quality of the polyphenols that are extracted. First, a dry, ground-up sample of plant materials is collected and combined with an appropriate extraction solvent in a process known as UAE. For polyphenol extraction, ethanol, methanol, and water are frequently used as solvents. The most used solvent for polyphenol extraction is ethanol. Put the

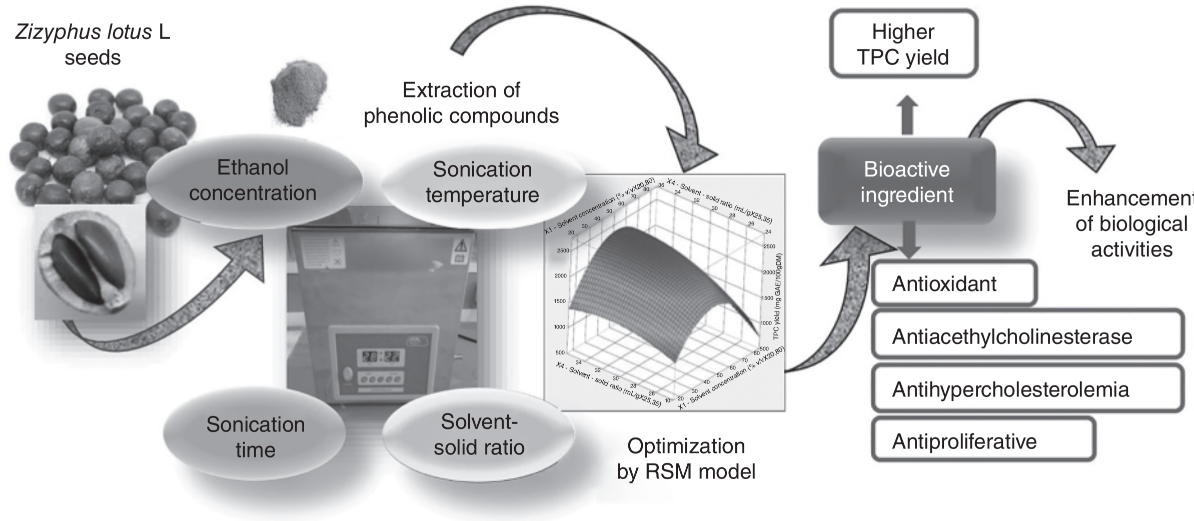

Figure 1.3 Ultrasonic assisted extraction of polyphenols. Source: Farida Berkani et al. [25]/Reproduced from MDPI/CC BY 4.0.

sample in an ultrasonic bath and sonicate it. The ultrasonic waves help to break down the cell walls and facilitate the release of polyphenols from the plant material. The extract is then filtered via filter paper or a syringe filter to remove any insoluble material. Make the extract more concentrated by using a vacuum concentrator or a rotary evaporator. UAE functions on the basic premise that high-frequency sound waves cause cavitation bubbles to form in the solvent, which then violently collapses, producing strong shear forces that rupture the cell walls of the plant material and release the desired chemicals. The mass transfer and solubility of the polyphenols in the solvent are also increased by the ultrasonic vibrations, leading to a faster and more efficient extraction. For example, compared to traditional solvent extraction, ultrasonic-assisted polyphenol extraction from mulberry leaves and grape skins and seeds produced considerably greater yields and total polyphenol contents. Yet, it was shown that a frequency of 40 kHz produced the best extraction yield and antioxidant activity when polyphenols were extracted from bamboo leaves. Methanol was the most efficient solvent for extraction of polyphenols from pomegranate peels when compared to conventional solvent extraction methods. Polyphenols from different plant materials such as EGCG from green tea leaves, quercetin from onion peel, anthocyanins from purple sweet potato, chlorogenic acid from *Eucommia ulmoides* olive leaves, catechins from grape seeds and Rutin from *Sophora japonica* L. flowers can be extracted.

1.6.2 Microwave-Assisted Extraction of Polyphenols

In the late 1980s, microwave-assisted extraction of polyphenols from natural products was introduced. As a result of technical advancements, today it is one of the most common and economical extraction techniques. Microwave-assisted extraction is a widely used technique for the extraction of polyphenols from plant materials. Microwave energy is used in microwave-assisted extraction to heat the solvent and the sample, speeding up the extraction process. In order to increase the extraction yield and quality of polyphenols, microwave-assisted extraction has been recommended as a simpler, quicker, non-destructive, less time-consuming, and energy-efficient method. Microwave-assisted extraction involves heating the solvent and the sample in a microwave oven, where the microwave energy causes the solvent to heat and release its polyphenols as shown in Figure 1.4 [26]. The extraction is usually done at a temperature of 50–100 °C and a pressure of 1–2 bar. The extraction time might vary based on the sample and the solvent employed. Microwave-assisted extraction factors like power, duration, and solvent type may all be optimized to increase extraction efficiency and aid in the production of new functional foods and nutraceuticals. Microwave-assisted extraction is based on the use of microwaves to produce an electromagnetic field that causes the polar molecules in the solvent to spin and produce heat. The target chemicals are released into the solvent as a result of the plant material's cell walls rupturing due

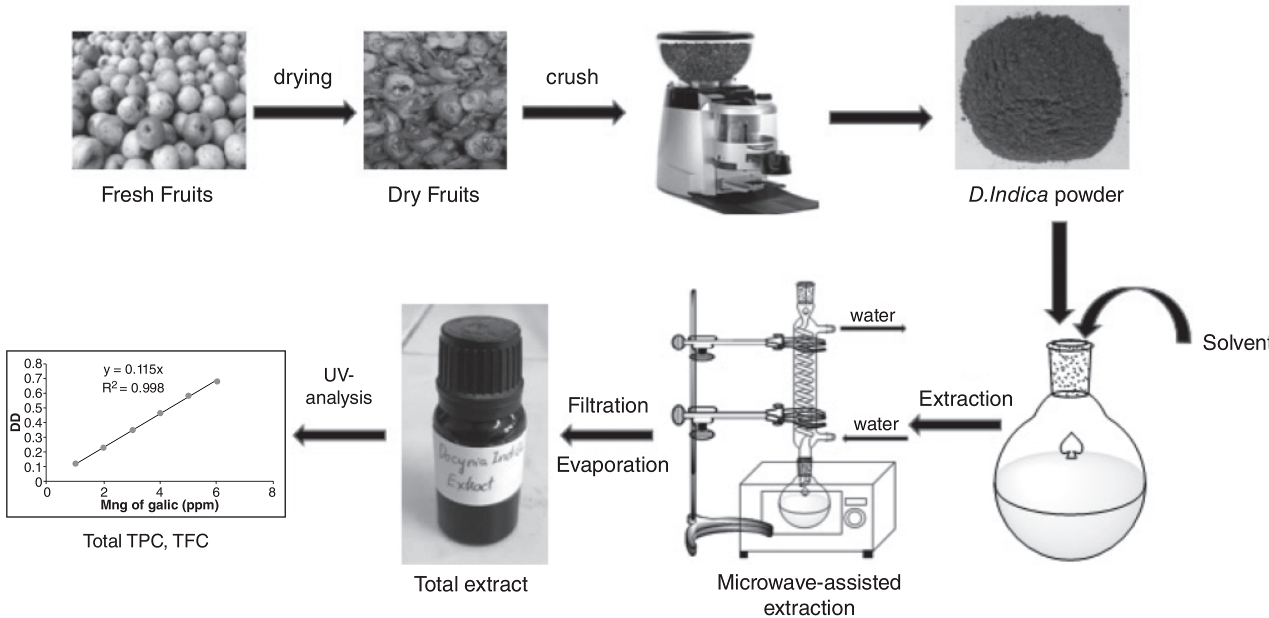

Figure 1.4 Microwave assisted extraction polyphenols. Source: Xuan Duy Le et al. [26]/Reproduced from MDPI/CC BY 4.0.

to heat. Also, microwaves promote the solubility and mass transfer of the polyphenols in the solvent, leading to a more rapid and efficient extraction. For extracting polyphenols from various plant sources, the method of microwave-assisted extraction may be used to extract a number of different polyphenols. For instance, polyphenols from Brazilian red propolis may be extracted via microwave-assisted extraction, which breaks down the cell walls and releases the desired chemicals. Another method of extracting polyphenols from black rice used microwave radiation to make cell membranes more permeable, which facilitated the ability for the polyphenols to permeate into the solvent for the conformation of the influence of microwave-assisted extraction parameters (power, duration, and solvent type), power of 500 W resulted in the maximum extraction quantity and antioxidant properties of polyphenols extract from grape pomace and comparing extraction efficiency of polyphenols. A wider range of polyphenols from blackcurrant leaves and from rose hips can be extracted by using microwave-assisted extraction producing higher yields of polyphenols as compared to other methods.

1.6.3 Supercritical Fluid Extraction of Polyphenols

Supercritical fluid extraction uses supercritical fluids as solvents to extract bioactive substances from a variety of plant materials in a generally safe, effective, and eco-friendly way. Due to their potential health advantages, polyphenols are one of the most investigated groups of bioactive compounds extracted by supercritical fluid extraction. Gases that have been compressed above their critical point to the point where they behave like both a gas and a liquid are known as supercritical fluids. In the process of extracting polyphenols, a number of supercritical fluids are applied, including supercritical carbon dioxide ($SC–CO_2$), supercritical water, supercritical ethanol, and supercritical propane. Due to its low toxicity, nonflammability, and availability, $SC–CO_2$ is the most often utilized supercritical fluid in supercritical fluid extraction. As per the literature, the plant material is prepared by drying and crushing into a fine powder to improve the extraction surface area as shown in Figure 1.5 [27]. Loading the extraction vessel: The ground plant material is placed into the extraction vessel, which is commonly a stainless-steel column or an extraction cell. Purging the vessel: Any air or moisture that could be present in the system is removed by purging the vessel with the supercritical fluid. Extraction: To reach the supercritical state, the supercritical fluid is heated and pressured until it can behave as both a liquid and a gas. It is then injected into the extraction tank, where it dissolves the polyphenols from the plant material. Supercritical fluid extraction has the benefit of producing significant yields of pure extracts with low solvent residues. Tea leaves, grape seeds, rosemary leaves, and red grape pomace have all been demonstrated to be excellent sources of polyphenols that may be extracted by supercritical fluid extraction. Several parameters, including the extraction pressure, temperature, and time, affect the yield and

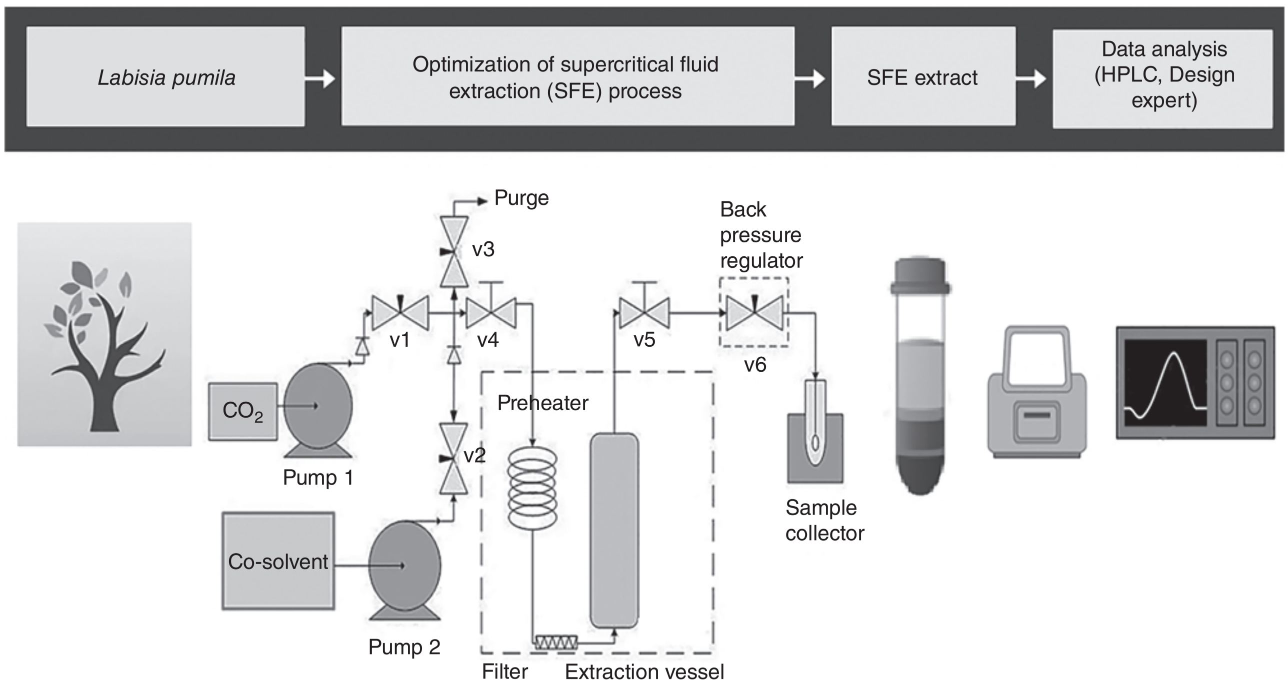

Figure 1.5 Supercritical fluid extraction of polyphenols. Source: (Reproduced from CCBY 4.0; No permission Needed) Radzali et al. [27].

composition of the extracts as well as the type of plant material used. Additionally, specific polyphenols may be specifically extracted via supercritical fluid extraction, which might be helpful for manufacturing. The obtained polyphenols can be purified and concentrated further using methods such as solid-phase extraction (SPE), chromatography, or evaporation.

1.6.4 SPE of Polyphenols

One popular and effective method for separating and purifying different compounds from complex mixtures, including polyphenols, is SPE as shown in Figure 1.6 [28]. Polyphenols from plant extracts can be selectively extracted and concentrated through SPE. The SPE procedure involves the use of a SPE cartridge or column packed with a stationary phase material that is selective for the target component, often a silica-based material(s). When the sample is put into the column, the undesired components are removed by washing with a solvent that is only susceptible to the desired compound(s). Finally, the target compound(s) are eluted from the column with a solvent that is appropriate for downstream analysis or application. A frequently utilized stationary phase material for SPE in the case of polyphenols is C18-bonded silica, which is hydrophobic in nature and selective for substances with polar functional groups, such as phenolic —OH groups. In the SPE, the polyphenol-containing sample is placed into the SPE column, which contains C18-bonded silica stationary phase material. Through hydrophobic interactions between the C18 groups and the phenolic —OH groups of the polyphenols, the sample's polyphenols interact with the stationary phase material. When the sample has been loaded, the undesirable components in the sample are removed by washing the column with a solvent that is selective for the target compound(s). The solvent used for washing depends on the physicochemical properties of the sample and the stationary phase material. Normally, washing is done with water, acetonitrile, or methanol. And thereafter, the hydrophobic contacts between the target polyphenols and the stationary phase material are broken by a solvent and the target polyphenols are eluting from the column. Elution can be carried out using solvents like acetone, methanol, or ethanol. The type of polyphenols and stationary phase component must be considered while selecting a solvent. Polyphenols can isolate and purify from different extracts such as blackcurrant pomace and hawthorn extract with a C18 column by using SPE methods. Several polyphenols can be extracted by using SPE such as flavonoids from tea leaves grape seeds and citrus peels. Phenolic acids from olive oil coffee beans and blackberries. Stilbenes from grape skins and peanut skins, tannins from pomegranate, green tea, and wine. Anthocyanins from blueberries, blackcurrants and black carrots, proanthocyanidins from cranberry pomace cocoa beans, and grape seeds

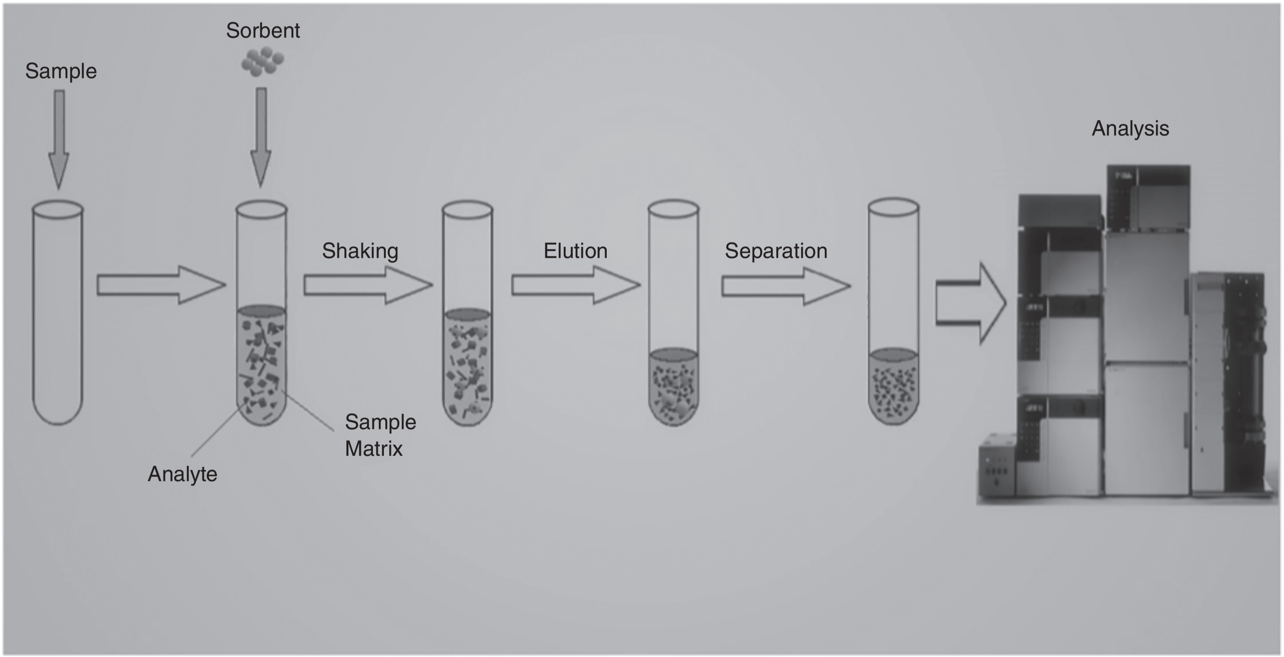

Figure 1.6 Solid phase extraction. Source: Piotr Ścigalski et al. [28]/Reproduced from MDPI/CC BY 4.0.

1.6.5 Solvent Extraction of Polyphenols

Solvent extraction persists as a common approach for extracting polyphenols from plant sources, and continuing studies are taking place to optimize the process for optimal yield and purity of these beneficial components. Polyphenols are hydrophilic substances that dissolve in polar solvents like methanol and water. However, the presence of other plant substances including lipids, pigments, and carbohydrates may limit the extraction of polyphenols. Therefore, organic solvents are used to selectively extract polyphenols from the plant matrix. The efficiency of the extraction process may depend on the solvent type and plant material composition. For instance, polar polyphenols are simpler to isolate using high-polarity solvents like methanol and ethanol, but non-polar polyphenols are easier to extract using solvents such as ethyl acetate. Solvent extraction is a multi-step procedure that includes processes like organic solvent penetration as shown in Figure 1.7 [29]: The polyphenols are dissolved by the organic solvent penetrating the plant material. Diffusion: The dissolved polyphenols diffuse from the plant material into the solvent. Partitioning: Polyphenols partition between the solvent and the plant material, with the solvent containing a larger proportion of the polyphenols. Evaporation of the solvent: The polyphenols are concentrated by evaporating the solvent. Filtration or centrifugation is used to separate the concentrated polyphenols from the plant material in a solid–liquid separation process.

1.7 Solubility of Polyphenols

The bioavailability and effectiveness of polyphenols are significantly influenced by their solubility. Polyphenols have a diverse structure and their solubility properties can vary widely depending on their chemical structure and environmental variables. The presence of non-polar functional groups like methyl, ethyl, and propyl groups gives them a hydrophobic character. Moreover, the presence of many phenol rings in polyphenols increases their molecular weight and size., polyphenols have also the capacity to create intermolecular interactions including hydrogen bonds and hydrophobic interactions, which can cause aggregation and precipitation in aqueous solutions. Some such polyphenols can also form complexes with metal ions, such as complex as, a result many polyphenols have low water solubility. Low-soluble polyphenols could only absorb a little amount in the digestive system and might not reach the target tissues in high enough quantities to activate their therapeutic action. They can be turned more soluble by a variety of methods, including chemical structural changes, the use of suitable solvents or solubilizing agents, or physical treatments. The solubility can also be enhanced by either changing their chemical structure or using any suitable solvent like adding

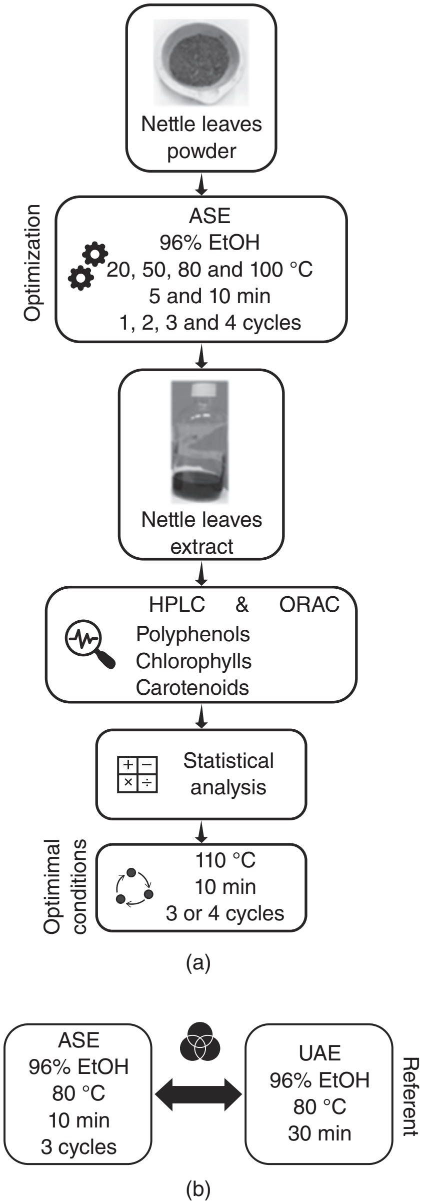

Figure 1.7 Solvent extraction. Source: (Reproduced from CCBY 4.0; No permission Needed) Repajić et al. [29].

sulfonic acid or carboxylic acid, polyphenols can be changed into more water-soluble forms. Similarly, by using solubilizing substances like cyclodextrins (CDs), surfactants, or polymers or by using physical processes like sonication or high-pressure homogenization, many environmental factors, including pH, temperature, and the presence of other matrix constituents, can also have an impact on the solubility of polyphenols. For instance, some polyphenols' solubility might be increased in acid conditions, while other polyphenols might be more soluble in alkaline pH ranges.

1.7.1 Chemical Modification

The solubility of polyphenols can be increased by chemical modification, which can increase their use in a variety of applications. The chemical structure of polyphenols is changed by chemical treatment. The polyphenol molecule is modified chemically by the addition of polar functional groups. To introduce negatively charged groups, for example, sulfonation, carboxylation, or phosphorylation can be used, while amino or —OH groups can be added to improve the polarity of the molecule. These additional functional groups can improve the interactions between the polyphenols and the water molecules, to enhance the solubility of polyphenols in water. Another strategy is to add a sugar molecule to the polyphenol and change its structure through a process called glycosylation. By adding a polar sugar moiety to the hydrophobic polyphenol, which enhances the molecule's solubility and stability, this modification increases the solubility of polyphenols in water. The solubility of polyphenols including quercetin, EGCG, and resveratrol has been shown to be enhanced by glycosylation. The bioavailability and stability of polyphenols can both be improved by improving their solubility by chemical modification. Similarly, galloylation, the addition of gallic acid to polyphenols like catechins, can increase their stability and antioxidant activity by increasing the amount of —OH groups available for hydrogen bonding.

1.7.2 Solubilizing Agents

To increase the solubility of polyphenols, solubilizing agents such CDs, surfactants, and polymers are used. CDs are cyclic oligosaccharides composed of glucose units. They possess a hydrophilic outer surface and a hydrophobic cavity that may trap hydrophobic compounds like polyphenols, to increase their water solubility. The solubility and stability of polyphenols including curcumin, EGCG, and resveratrol have been improved by CDs in a variety of experiments. Surfactants are compounds that possess both hydrophilic and hydrophobic characteristics. They have the capacity to form micelles, which are tiny aggregates capable of dissolving hydrophobic substances in water. It has been found that surfactants like sodium dodecyl sulfate and Tween 80 can increase the solubility of polyphenols including

EGCG, quercetin, and genistein. Polymers are large, repetitive units that can bind to polyphenols to make them more soluble in water. In order to solubilize polyphenols, two most common polymers polyethylene glycol (PEG) and polyvinylpyrrolidone are used. For example, PEGylation can enhance the solubility and stability of curcumin. It is important to note that the use of solubilizing agents can affect the stability and bioactivity of polyphenols, and the choice of solubilizing agent depends on the specific polyphenol and the intended application.

1.7.3 Physical Treatment

Sonication, high-pressure processing (HPP), and grinding are referring to physical treatment of polyphenols to improve the solubility of polyphenols. Sonication is a method that creates cavitation by using high-frequency sound waves, which can break down polyphenol aggregates and improve their solubility in water. Whereas grinding is a physical treatment technique that includes decreasing the particle size of polyphenols to increase their surface area and enhance their solubility in water, HPP is a non-thermal process technique that employs high pressure to modify the structure of polyphenols and increase their solubility in water. HPP and sonication can be used to increase the solubility and stability of polyphenols such EGCG, resveratrol, and quercetin, while grape seeds can be ground to increase the solubility of their polyphenols. Physical processing techniques can affect the chemical and physical properties of polyphenols, which may have an effect on their bioactivity and efficiency. To obtain the required solubility improvement while limiting degradation or other negative consequences, the physical treatment parameters, including temperature, pressure, and time, must also be optimized.

1.7.4 Solubility of Polyphenols by pH Adjustment

The solubility of polyphenols can be increased by pH change, which ionizes the compounds and makes them more soluble in water. At various pH levels, polyphenols' —OH groups can ionize and improve their solubility. In general, polyphenols are more soluble at higher pH levels because the —OH groups are deprotonated and become negatively charged. Thus, increasing pH levels the not only enhances the solubility but also contribute well to the effectiveness of substances. This can be seen by increasing the pH of quercetin, whose solubility is increased from 0.45 mg/mL at pH 3.0 to 3.16 mg/mL at pH 9.0. The solubility of resveratrol has also been found to rise at pH levels higher than its pK_a. Adjusting the pH can also help to minimize the interactions in the presence of other compounds that affect solubility, such as proteins or carbohydrates. To increase their solubility without compromising the polyphenols' bioactivity, it is important to determine the optimal pH settings for each given polyphenol to achieve the required solubility.

1.7.5 Co-solvents

Co-solvents increase the solubility of poorly soluble compounds in a solvent by lowering intermolecular interactions and increasing the molecular gap that is accessible to solute molecules. They can also act as solubilizing agents for compounds that are insoluble in water. Polyphenols have a low solubility in aqueous solutions because of their hydrophobic nature; co-solvents have been commonly used to increase the solubility. Due to its great solubility in water and capacity to create hydrogen bonds with both the solute and water molecules, ethanol is one of the most often used co-solvents. Methanol, propylene glycol, glycerol, and PEG are also used as co-solvents. It has been proven that co-solvent systems considerably improve the solubility of different polyphenols. For instance, a 50% (v/v) ethanol/water combination may improve quercetin's solubility from 1.7 g/mL in water to 90 g/mL. Similar to this, curcumin, a polyphenol included in turmeric, becomes more soluble when mixed with 10% (v/v) PEG 400 and water, rising from 11 g/mL in water to 26 mg/mL. The stability and bioactivity of polyphenols may be potentially suffered from the use of co-solvents. In order to optimize solubility, the kind and quantity of co-solvent should be carefully selected. Co-solvents that produce reactive oxygen species (ROS) might potentially reduce polyphenols' antioxidant activity.

1.8 Flavor and Color of Polyphenols

1.8.1 Flavor

Several plant-based meals and beverages benefit from the bitterness, astringency, sweetness, and scent that polyphenols provide. Understanding the role of polyphenols in food flavor can aid in the development of new foods and the improvement of current products. For instance, the polyphenol catechin is mostly responsible for the bitterness of green tea, whereas tannins, another kind of polyphenol, are predominantly responsible for the astringency of red wine. In addition to flavonoids like rutin, quercetin, and kaempferol, steviol glycosides, a kind of polyphenol found in the leaves of the stevia plant, are frequently utilized as natural sweeteners while Resveratrol and anthocyanins, present in red wine, are mostly responsible for the aroma. while in black tea, the aroma is attributed to theaflavins, a type of polyphenol that is formed during the oxidation process. In addition to their direct influence on flavor, polyphenols have the potential to interact with other flavor components in foods and beverages, influencing overall flavor perception. For instance, it has been observed that the presence of polyphenols in red wine interacts with the aroma compounds in the wine, changing the overall flavor profile as shown Table 1.2.

Table 1.2 Some common polyphenols and their complementary taste.

Polyphenols	Taste
Catechins	Bitter, astringent taste
Flavanols	Bitter or astringent taste
Tannins	Puckering taste and can be quite bitter
Quercetin	Slightly bitter, quite astringent
Anthocyanins	Slightly sweet or tart flavor

1.8.2 Color of Polyphenols

Several plant-based foods and beverages have different colors because of polyphenols. They can range in color from yellow to red to blue, depending on the specific type of polyphenol present as shown in Table 1.3. Anthocyanins are responsible for the red, blue, and purple colors in many fruits and vegetables, including berries, grapes, and eggplants. However, several fruits and vegetables, including onions, apples, and citrus fruits, have a yellow color because of flavonols. It is revealed that a number of factors, including processing methods and storage environments, can affect the color of polyphenols. The color of tea polyphenols, for example, can be influenced by the type of tea, the temperature and time of boiling, and the presence of other compounds in the tea. Depending on their chemical composition, they can be any hue from yellow to red to purple to even black.

Table 1.3 Some of the common polyphenols with their complementary colors.

Polyphenol	Color
Flavonols	Yellow
Anthocyanins	Red, purple, and blue
Hydroxycinnamic acids	Often yellow in color
Flavan-3-ols (catechins)	Usually colorless, but can appear yellow or brown in some cases
Stilbenes	Colorless or pale yellow
Hydroxycinnamic acids	Yellow
Carotenoids	Yellow to orange to red
Tannins	Range in color from yellow to brown
Lignans	Usually colorless or pale yellow
Ellagitannins	Often red or purple in color
Proanthocyanidins	Range in color from yellow to red to blue

1.9 Health-Promoting Properties of Polyphenols

Polyphenols have a variety of health-promoting qualities. Below are a few of polyphenols' main characteristics and some of the common properties are tabulated in Table 1.4.

1.9.1 Antioxidative Properties

Polyphenols have been extensively studied for their antioxidant properties, which are believed to contribute to their potential health benefits [30]. Antioxidants are compounds that protect cells from damage caused by free radicals, which are unstable molecules that can damage cells and contribute to the development of various diseases. Among the most valued characteristics of polyphenols is their

Table 1.4 Polyphenols with health-promoting activity.

Polyphenols	Properties
Resveratrol	Antioxidative, anti-inflammatory, and anti-cancer
Quercetin	Antioxidative, anti-inflammatory, and anti-cancer
Catechins	Cardiovascular, antioxidative, anti-inflammatory, and anti-cancer
Curcumin	Neuroprotective, anti-inflammatory, antioxidant, and anti-cancer
Anthocyanins	Cardiovascular, antioxidative, anti-inflammatory, and anti-cancer
Epigallocatechin gallate	Neuroprotective, cardiovascular, antioxidative, anti-inflammatory, and anti-cancer
Ellagic acid	Anti-inflammatory, antioxidative, and anti-cancer
Proanthocyanidins	Neuroprotective, cardiovascular, antioxidative, anti-inflammatory, and anti-cancer
Kaempferol	Cardiovascular, antioxidative, anti-inflammatory, and anti-cancer
Genistein	Neuroprotective, cardiovascular, antioxidative, anti-inflammatory, and anti-cancer, reduces risk of chronic diseases
Chlorogenic acid	Cardiovascular, anti-inflammatory, antioxidative, anti-cancer, reduces risk of chronic diseases
Myricetin	Cardiovascular, anti-inflammatory, antioxidative, anti-cancer, reduces risk of chronic diseases
Luteolin	Cardiovascular, anti-inflammatory, antioxidative, anti-cancer, reduces risk of chronic diseases
Apigenin	Cardiovascular, anti-inflammatory, antioxidative, anti-cancer
Isoflavones	Cardiovascular, anti-inflammatory, antioxidative, anti-cancer
Procyanidins	Cardiovascular, anti-inflammatory, antioxidative, anti-cancer, reduces risk of chronic diseases

potential antioxidative activity. These substances exhibit a variety of biological activities associated with the human body, which is mostly due to their antioxidative properties. Free radicals in the body are often produced by reactive forms of oxygen (ROS). They are produced when molecules of molecular oxygen progressively decay in one-electron processes. Nitric acid, nitrogen dioxide, and nitrogen oxide are all reactive forms of nitrogen (reactive nitrogen species (RNS)) that are harmful to human health. Equally damaging the organic radicals produced when ROS and RNS interact with organic compounds [31, 32]. The imbalance between the generation and deactivation of ROS can cause a variety of illnesses [33]. Cellular lipids, nucleic acids, and proteins can all be oxidized by free radicals. They aid in the mutagenesis, carcinogenesis, and onset of disorders like Parkinson's and Alzheimer's as well as the aging of cell proteins. Moreover, they raise the risk of cardiovascular problems, possibly through weakening cellular membranes and oxidizing LDL lipoprotein [32].

Many in vitro, animal, and human research have been done to look into the antioxidant properties of polyphenols. As an illustration, it has been discovered that blueberry polyphenols showed high antioxidant activity, as determined by their capacity to scavenge free radicals and prevent lipid peroxidation [34]. Similarly, green tea polyphenols have strong antioxidant activity, as determined by their capacity to scavenge free radicals and lessen oxidative stress in rats [35]. From the conclusion of these studies, we can say that one of the primary processes through which polyphenols may boost health is by acting as antioxidants, which lower the risk of chronic diseases including cancer, cardiovascular disease, and neurological disorder.

1.9.2 Anti-inflammatory Properties

As the body's initial reflex action to an infection or damage, inflammation is important for both the immune system's innate and adaptive responses. The intricate biological reaction of vascular tissues to adverse stimuli, such as infections, injured or tumoral cells, or allergens, is what distinguishes it [36]. Many health advantages of polyphenols are well-known, including their ability to reduce inflammation. However, chronic inflammation has been linked to a number of diseases, including autoimmune disorders, cancer, and cardiovascular disease etc. [36, 37]. Numerous inflammatory mechanisms in the body have been revealed to be regulated by polyphenols. The synthesis of pro-inflammatory cytokines, chemokines, and enzymes can be inhibited by these substances. Nuclear factor kappa B (NF-B), a transcription factor important in the control of inflammation, can also be inhibited by polyphenols. Moreover, polyphenols have the ability to activate Nrf2, a transcription factor that controls the body's anti-inflammatory and antioxidant pathways [38, 39].

The anti-inflammatory properties of various polyphenols have been studied in several research. The production of pro-inflammatory cytokines including interleukin-1 beta (IL-1), interleukin-6 (IL-6), and tumor necrosis factor-alpha (TNF-alpha) has been demonstrated to be inhibited by resveratrol which is present in grapes, berries, and peanuts [40]. The formation of prostaglandin E2, a pro-inflammatory mediator, has been demonstrated to be inhibited by another polyphenol called quercetin, which is present in onions, apples, and berries [41].

In vitro and in vivo studies have revealed that the polyphenol curcumin, which is present in turmeric, reduces NF-B activation and the production of pro-inflammatory cytokines [42]. Also, it has been revealed that the flavonoid a class of polyphenolic compound, which is present in several fruits, vegetables, and beverages, has anti-inflammatory properties. For instance, apigenin, a flavonoid present in parsley, celery, and chamomile, has been demonstrated to reduce the synthesis of pro-inflammatory cytokines including IL-1, IL-6, and TNF- in both in vitro and in vivo [43]. All these studies indicate that polyphenols also have anti-inflammatory properties through a number of different mechanisms and also these substances may be used to both prevent and treat chronic inflammatory disorders.

1.9.3 Anti-cancer Properties

By helping cell senescence and death, regulating autophagy, and preventing cancer cell growth and migrations, polyphenols show their promise as an anti-cancer treatment. By an increase in ROS and a decrease in cellular antioxidants [44]. Like the interaction glutathione with chemotherapeutic drugs, and the maintenance or reverse of multi-drug resistance, they can cause cellular stress and catabolism. Their potential for health benefits, including anti-cancer action, has been thoroughly investigated. A variety of polyphenols present in natural sources such as resveratrol can be found in berries, peanuts, and grapes [45], curcumin and Epigallocatechin-3-gallate (EGCG) which is found in turmeric and green tea [46, 47]. Quercetin is found in various plant sources, including apples, onions, and green tea. Kaempferol is found in various fruits, vegetables, and herbs [48, 49]. Certain polyphenols have been proven to have anti-cancer efficacy in a number of cancer types, including colon, breast, lung, colorectal, and prostate cancer [50]. Through controlling many signaling pathways, such as NF-kB, PI3K/AKT, MAPK/ERK, and Wnt/β-catenin, these polyphenols promote cell cycle arrest and death in cancer cells and also increase the efficiency of chemotherapy medications and radiation therapy in the treatment of cancer [51]. Most of the polyphenols have shown promising anti-cancer activity in various types of cancer.

1.9.4 Cardiovascular Health

Both the oxidative stress and ROS have been strongly linked to endothelial damage, the development of atherosclerosis, injury in prolonged myocardial infarction, and ischemic recovery in the treatment of cardiovascular diseases [44].

An increasing number of studies indicate that polyphenols may help in cardiovascular health improvement. A major contributing element to the development of cardiovascular disease is endothelial dysfunction [52]. By improving the generation of nitric oxide, lowering oxidative stress, and decreasing inflammation, polyphenols have been proven to enhance endothelial function and also lowering blood pressure, Cardiovascular disease is significantly increased by having high blood pressure [53]. It has been shown that polyphenols, particularly flavonoids, reduce blood pressure by relaxing blood vessels and enhancing endothelial function [54]. A polyphenol-rich extract from grape seeds and beverages has been shown in a randomized controlled experiment to significantly enhance endothelial function and decrease oxidative stress in individuals with metabolic syndrome [55]. Also, it has been shown that polyphenols contain antioxidant capabilities, which can aid in lowering oxidative stress and preventing cardiovascular system damage. Inflammation is thought to be a major factor in the development of cardiovascular disease. The anti-inflammatory properties of certain polyphenols have been discovered to help decrease inflammation and guard against cardiovascular system harm [56]. While elevated lipid levels, or dyslipidemia, are a significant risk factor for cardiovascular disease. It has been discovered that polyphenols particularly flavonoids, can enhance lipid profiles by lowering cholesterol and triglycerides and raising HDL cholesterol such as flavonoid-rich cocoa products can significantly improve the lipid profile in people with hypertension [57]. Results showed that polyphenols can also be used to improve the endothelial function, lower the blood pressure, reduce the oxidative stress, lessen the inflammation, and improve the lipid profiles, thus help to improve the overall cardiovascular health. Consuming foods and drinks high in polyphenols may help lower your chance of getting cardiovascular disease.

1.9.5 Neuroprotective Properties

The brain is more vulnerable to oxidative stress than other organs due to the low activity of the antioxidant defense system. To activate their neuroprotective properties, polyphenols interact with a variety of brain targets. The term "neuroprotection" describes a substance's ability to shield neurons against harm or death brought on by a number of stresses, including oxidative stress, inflammation, and toxicity. With promising findings, polyphenols' neuroprotective activity has been thoroughly investigated in both in vitro and in vivo models.

One of the main processes is their ability to neutralize free radicals and decrease oxidative stress, which is a significant cause of neurodegenerative disorders including Alzheimer's and Parkinson's disease. Moreover, polyphenols have been demonstrated to modify a number of signaling pathways involved in apoptosis and inflammation, which strengthens their neuroprotective effects. In animal models of neurodegenerative disorders, polyphenols have been demonstrated in several studies to improve cognition and memory. A polyphenol resveratrol has been proven, for instance, to improve cognition and lower amyloid-beta levels in a mouse model of Alzheimer's disease [58]. Similarly, a rat model of Parkinson's disease has demonstrated that the polyphenol epigallocatechin-3-gallate (EGCG) enhances spatial memory and lowers oxidative stress [59].

Polyphenols have been found to protect against neuronal damage brought on by ischemia, traumatic brain injury, and other stressors in addition to their benefits on cognitive performance. In a rat model of traumatic brain injury, quercetin, a polyphenol present in fruits and vegetables, has been demonstrated to decrease neuronal damage and increase functional recovery [60]. Similarly, in animal models of ischemic stroke, curcumin, a polyphenol present in turmeric, has been demonstrated to lessen brain damage and enhance functional results [61].

Additionally, Rutin (flavonoid) [62], Luteolin (flavone) [63], and Caffeic acid (hydroxycinnamic) possess antioxidative, anti-inflammatory, and neuroprotective properties. It can prevent neuroinflammation and neurodegeneration by inhibiting the activation of microglia and improving cognitive function. and reducing oxidative stress. From the above evidences, polyphenols are a prospective challenger for the prevention and treatment of neurodegenerative disorders due to their neuroprotective properties [64].

1.9.6 Anti-diabetic Activity

The ability of a drug or molecule to reduce blood sugar levels and control diabetes symptoms is referred to as anti-diabetic activity. Diabetes is a long-term metabolic condition defined by increased blood glucose levels brought on by the body's inefficiency in producing or using insulin. Anti-diabetic medications can function in a number of different ways, including increasing insulin secretion, enhancing insulin sensitivity, preventing glucose absorption, or lowering hepatic glucose synthesis. Polyphenols exhibit a range of anti-diabetic activities [65]. The majority of polyphenols have anti-diabetic properties by increasing insulin sensitivity, decreasing oxidative stress, and improving glucose metabolism [66]. Increasing insulin levels is one of the ways that polyphenols work to prevent diabetes. The insulin signaling pathway may be activated by polyphenols, which enable the body's cells to use glucose more effectively. The expression of several genes involved in glucose metabolism can also be altered by polyphenols, which enhance cells' ability to absorb glucose. It has been shown that polyphenols such as flavonoids, phenolic acids, and stilbenes increase the absorption and utilization of glucose in peripheral tissues including skeletal muscle and adipose tissue [67, 68]. These substances also help pancreatic beta-cells produce more insulin, which improves glucose homeostasis. By preventing the digestion and absorption of carbohydrates, polyphenols also have anti-diabetic effects. Alpha-amylase and alpha-glucosidase, two enzymes involved in the breakdown of carbohydrates, have been demonstrated to be inhibited by polyphenols such catechins, procyanidins, and anthocyanins. Polyphenols slow down the rate of sugar absorption in the small intestine by inhibiting these enzymes, resulting in lower postprandial glucose levels [69].

In both animal models as well as human clinical testing, several researchers have looked at whether polyphenols have any anti-diabetic properties. For instance, one study found that supplementing obese rats with green tea extract high in catechins increased their ability to tolerate glucose and maintained their insulin sensitivity [70]. Another study found that type 2 diabetic individuals with resveratrol supplementation had better glycemic control and insulin sensitivity [71]. Polyphenols also have anti-inflammatory and antioxidant qualities, which can help with diabetes control and prevention in addition to these processes [38]. Persistent low-grade inflammation and oxidative stress have been shown to advance type 2 diabetes by causing beta-cell dysfunction and insulin resistance [72]. It has been demonstrated that polyphenols like curcumin, resveratrol, and quercetin can lower inflammation and oxidative stress by altering several signaling pathways and gene expression patterns. These activities make polyphenols promising candidates for the prevention and management of diabetes.

1.9.7 Anti-microbial Properties

A substance's capacity to destroy or slow down the growth of microorganisms, such as bacteria, viruses, fungi, and parasites, is referred to as antimicrobial activity [73]. To prevent and control microbial infections and diseases, antimicrobial compounds are widely used in a wide range of industries, including medicine, agriculture, and the food industry. Many polyphenols exhibit significant antimicrobial activity, including disrupting the cell membrane and enzymatic activity of microorganisms, which can be attributed to their ability to interfere with various cellular processes in microorganisms [74, 75]. The disruption of microorganisms' cell membranes is one mechanism by that polyphenols exert their antimicrobial properties [75]. Reports suggested that polyphenols like tannins and flavonoids react with the lipid bilayer of bacterial cell membranes, thus damaging the membrane and allowing the internal contents to leak thus interfering with the cell's regular functions and causing bacterial death. Moreover, polyphenols have the ability to damage fungal cell walls by affecting their functionality [76, 77].

Polyphenols also exhibit antimicrobial activity by interfering with the enzymatic activity of microorganisms. Like DNA gyrase and topoisomerase IV, two enzymes involved in bacterial DNA replication and transcription, have been revealed to be inhibited by polyphenols such as catechins and resveratrol. This stops the growth and reproduction of bacteria. In addition, chitinase, an enzyme necessary for the production of fungal cell walls, is reduced by polyphenols [78]. Many researchers have proven in vivo and in vitro antibacterial properties of polyphenols. For example, resveratrol exhibited powerful antibacterial action against several bacterial strains, including methicillin-resistant *Staphylococcus aureus* and vancomycin-resistant *Enterococcus faecalis* [79]. EGCG, a polyphenol included in green tea, was shown to reduce the development and virulence of the fungus *Candida albicans* [80].

1.10 Skin Benefits of Polyphenols

The biggest organ in the human body, skin protects internal organs, controls body temperature, and serves as a barrier to potentially harmful environmental factors. Polyphenols have numerous skin benefits, including their photoprotective, skin whitening, wound healing, anti-inflammatory and antioxidant effects. Consuming foods high in polyphenols like green tea, chocolate, and berries as well as skincare products containing polyphenols may help maintain healthy skin and prevent skin problems. Photoprotective effects: Skin damage from UV light from the sun can contribute to premature aging, sunburns, and skin cancer. It has been demonstrated that polyphenols have photoprotective properties, which means they can help in shielding the skin from UV damage. EGCG, a polyphenol present in green tea, can prevent UV-induced DNA damage and shield the body from the damaging effects of UV radiation. Skin whitening effects: Common skin conditions like hyperpigmentation can be caused by a number of different factors, including hormone fluctuations, UV exposure, and inflammation. Polyphenols, such as flavonoids and catechins, have skin-whitening effects by inhibiting the activity of tyrosinase, an enzyme involved in melanin production. Wound healing effects: meaning they can contribute to promoting skin damage healing. Epicatechin, a polyphenol contained in cocoa, can accelerate the healing of wounds by increasing angiogenesis (the formation of new blood vessels), collagen production, and skin cell proliferation. Anti-inflammatory effects: Acne, rosacea, and psoriasis are just a few of the skin conditions that are frequently brought on by inflammation. Due to their anti-inflammatory properties, polyphenols can help to reduce skin irritation. Resveratrol and quercetin have the ability to block inflammatory pathways and lower the generation of cytokines that are pro-inflammatory and Antioxidant effects: The powerful antioxidant properties of polyphenols are known to help protect the skin from oxidative stress brought on by free radicals. Flavonoids and phenolic acids are examples of polyphenols that can scavenge free radicals and stop oxidative damage to the skin.

1.11 Conclusions

The discussion in this chapter demonstrates that polyphenols are a group of chemical compounds that are prevalent in plants and that, because of their antioxidant capabilities, have a significant impact on human health. They are divided into categories according to how many phenol rings they contain, including simple phenols, flavonoids, and tannins. Polyphenols, which are extensively distributed across the plant kingdom, are what give fruits, vegetables, and alcoholic beverages their distinct hues, smells, and scents. The capacity of polyphenols to scavenge free radicals, which are highly reactive entities that can harm cells and tissues, is thought to be the cause of their antioxidant capabilities. Numerous health advantages of polyphenols have been demonstrated, including a decreased risk of chronic diseases like cancer, cardiovascular disease, and neurological disorders. Fruits, vegetables, nuts, tea, coffee, wine, and other common dietary sources of polyphenols include tea, coffee, and wine. Polyphenol bioavailability varies based on the particular component and the dietary matrix it is found in. The basic concepts of polyphenols will be introduced in this chapter, followed by a thorough discussion of their nomenclature, classification, and properties with an emphasis on their potential as dietary antioxidants and their significance to human health.

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