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PLANT AND FOOD PHENOLICS – CHEMISTRY, FUNCTIONALITY AND PRACTICAL APPLICATIONS

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Review Based Book Chapter
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REVIEW BASED BOOK CHAPTER

FUNCTIONAL POLYPHENOLS: AN OVERVIEW, CLASSIFICATION AND HEALTH BENEFITS

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Abstract

In the recent decade, modern science and technological innovations has focused on development of plant-based functional products. Polyphenols have been a great importance in the daily life of humans for a long time, because of their many health-promoting properties. Among all our world species, plants are naturally recognized as a major source of polyphenols, their presence and secretions vary from plant to plant. Based on the source, polyphenols are divided into many classes but there are four major classes namely phenolic acid, flavonoids, lignans and stilbenes. They are found in low concentrations in plants and animal's sources but have enormous pharmacological, nutritional and protective effects, being used to treat and protection against many chronic diseases.

Keywords

Polyphenols, Plants, Classification, Health Properties

1. Overview of Polyphenols

Plant foods have been recognized as naturally good source of phytochemicals, polyphenols, bioactive compounds and physiologically active compounds in addition to those which are traditionally considered as nutrients (vitamins and minerals). Fruit, vegetables and whole grains contain many polyphenols such as

phenolic acid, hydroxybenzoic acid, hydroxycinnamic acid, flavonoids, flavones, flavonols, isoflavones, anthocyanidins, lignins, sesamol, pinoresinol, sinol, enterodiol, stilbenes, resveratrol and piceatannol. These compounds are most commonly found in berries, blackberries, seeds, strawberries, apricots, tea, medicinal plants, nuts, broccoli, legumes, asparagus, carrots, edible, garlic and wild flowers or buds. Products made from these fruits are also rich in polyphenols [1-4]. Polyphenols are among the most abundant secondary metabolites in nature based on the chemical structure and biosynthetic derivation. Each compound of these polyphenols contains a wide range of components with different potency. Secondary metabolites have been recognized as a rich and important source of chemical compounds with potential functional applications in different fields, including the human health. These compounds are most commonly used as anti-microbial agent, anti-cholinergic agent, nutritional supplement, anti-pathogenic agent, anti-fungal and therapeutic agent in various chemical synthesis processes. Mostly these compounds are involved in the growth and development of macro-microorganism for fermentation. Secondary metabolites have been widely used on large-scale production as important ingredients in the food production, pharmaceutical, nutraceutical and in cosmetics industries as well [5-7].

2. Classification of Polyphenols

Polyphenols are organic compounds which contain a hydroxyl group bonded to aromatic benzenoid ring or a hydrocarbon. Phenols are further classified into major groups as presented in the Figure 1 [8]. There are more than 8000 structural variants of polyphenols are identified in literature. Polyphenols have not yet been properly classified and sub categorized due to their diverse forms, structures, the number of phenolic rings which they contain and the components that bind these phenolic rings [9]. Specifically, polyphenols in plants have been classified into major structural components and are presented in Table 1.

2.1. Phenolic acid

Phenolics represent the largest and most structurally diverse group of naturally occurring plant based phenolic compounds having strong antioxidant properties. Phenolic acids are made up of aromatic rings with a carboxylic acid group (-COOH) [10]. Phenolic acid prevents cardiovascular diseases by the formation of hydrogen

free radicals from losing electron from aromatic ring, which functions as reducing agents and quench free radicals [11, 12] . The rich sources of phenolic acid are plant-based foods which includes seeds, fruits and leafy green vegetables. Phenolic acid is mainly classified into two major categories which includes hydroxybenzoic acid and hydroxycinnamic acid. Hydroxybenzoic acid containing C_1-C_6 carbon atoms is produced from benzoic acid ($C_7H_6O_2$) [13]. Gallic acid, benzoic acid, vanillic acid and ellagic acid are all classified as hydroxybenzoic acids. Grape seeds and tea seeds are high in hydrocybenzoic acid [14]. Hydroxycinnamic acid are aromatic acid containing C_6-C_3 carbon atom produced from cinnamic acid [15]. Some common examples of hydroxycinnamic acid are ferulic acid, coumaric acid, cinnamic acid and sinapinic acid [16]. Coffee, apple, cereals and berries have been recognized as a rich source of hydroxycinnamic acid [17]. These phenolic acids are high-potential sources of phytochemicals so they exhibit anti-inflammatory properties. They have capacity to protect the body from cellular damage, prevents from disturbance of reactive oxygen, heart disorders, anti-cancer and anti-diabetic properties [18].

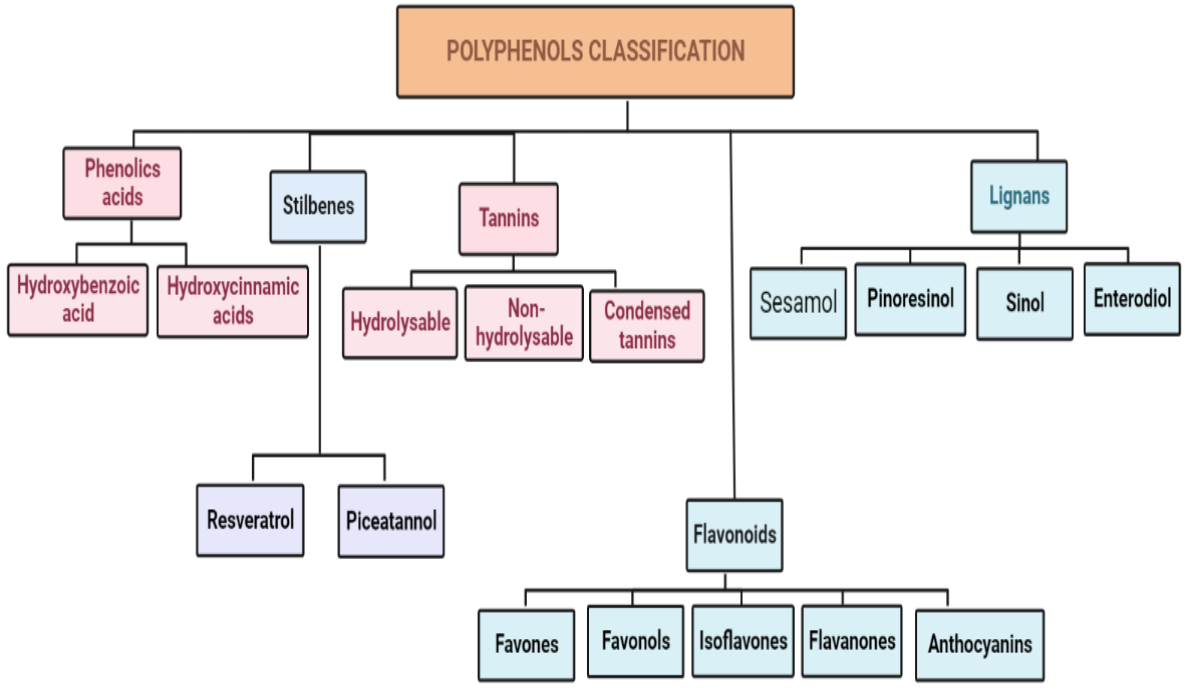


Figure 1 Systematic diagram on classification of polyphenols

2.2. Flavonoids

Flavonoids are the plant-based metabolites of polyphenolic compounds. The structural makeup of these flavonoids has 15 carbon atoms consists of two aromatic rings joined by three carbon atoms chains [19]. The classification of flavonoids is based on the attachment of B-ring on C-ring, its conformation and degree of oxidation of C-ring. The several sub-categories of flavonoids include flavones, flavonols, isoflavones and anthocyanidins [12, 16]. They are abundantly present in berries, onions, grapes, tea, apples and coca. They have variety of health benefits which includes anti-thrombogenic properties, neuroprotective properties and cell signaling activity [20].

2.2.1. Flavonols

Flavonols are a group from flavonoids family that contains a double bond between C_2-C_3 and C_4 carbonyl atoms. The sub categories of flavonols are quercetin, kaempferol and myricetin, that have a potential to cure and prevent cardiovascular diseases, heart related disorder, prevents blood clotting and human gingival diseases. Flavonoids are found in a variety of fruits and vegetables, including Kale, onion, black rice, lettuce, and tomatoes [9, 21, 22].

2.2.2. Isoflavones

Isoflavones are phytoestrogens, which are called as nonsteroidal plant-derived compounds belongs to *Fabaceae* family. Isoflavones replaces the phenyl group with 2 phenyl-4H-1benzopyr-4-one structures [23]. Phenylpropanoid pathway is used for the production of isoflavones which contributes in the production of flavone groups. The rich sources of isoflavones are soyabean and it composed of 2 important components which are daidzein and genistein. Isoflavones possess chemo-protective properties and used to treat the menopause disorders, heat diseases, metabolic bone disease and cancer [24].

2.2.3. Flavanones

Tomatoes, citrus fruits and some fragrant plants contains flavanones, which fall under the category of flavonoids. They have characteristic flavor properties and are important component in human health. In lemons, oranges and grape fruits, the major flavanones components are eriodyctiol, hesperidin and naringenin, respectively [9]. Flavanones are also subjected to the chemical reactions such as glycosylation,

hydroxylation and o-methylation. The rich sources of flavonoids are bergamot and citrus juices. They are beneficial over cardiac metabolism such as fatty acid profile and lipoproteins. They prevent and cure cardiovascular diseases by lower the measuring cholesterol levels [11,16, 25].

2.2.4. Anthocyanidins

Anthocyanidins are pigments that are mainly crucial for the coloring (pink, red and purple) of different fruits and vegetables. The rich sources of anthocyanidins are radish, berries, cherries and beetroot [26]. They have potential antioxidant properties. They are further sub-categorized into variety of components such as cyaniding glycosides, kaempferol and many other flavanols. Anthocyanidins consumption results in lowering the cholesterol level, triglycerides level and increasing high-density lipoproteins in cholesterol [27, 28].

2.2.5. Flavones

Flavones are found in variety of food including celery, cereals, broccoli and parsley. The outer covering of citrus family contains abundant number of flavones. Flavones shows anti-coronary artery diseases effect [29]. A flavone component Tangerine stimulates the expansion of smooth muscles in the body, by inhibiting platelet synthesis that leads to restenosis and atherogenesis. Nobiletin-rich citrus fruits can help prevent cancer, inflammation and aids in platelet activation [30].

2.3. Lignin

A collection of complex organic compounds in plant tissues are known as lignin. Lignin is involved in the production of cell wall in plants and trees. They have significant role in plants and trees in terms of providing strength and stiffness to trees. A Swiss botanist A P Candolle first discovered Lignin in 1813. A heterogeneous polymer lignin is derived from signal precursors that are cross linked in various ways [31]. Coniferyl alcohol, sinapyl alcohol, and paracoumaryl alcohol are the three forms of cross-links that may be formed from phenylpropane. Lignin is one such source that deserves special mention due to its accessibility, ecological compatibility, low cost and abundance. Flaxseeds, clove, tomatoes, peaches, apples, and a few berries are all high in lignin. The lignin has tremendous industrials applications in pharmaceutical and food [16, 32, 33].

2.4. Stilbenes

Stilbenes ($C_{14}H_{12}$) are a group of metabolites obtained from phenols. Stilbenes are chemical compounds with compact structure, a central ethylene portion and one phenyl group. The phenyl group is found at the carbon double bond ends. Tran's stilbenes are the popular name for stilbenes [34]. They have anti-biotic, anti-inflammatory, anti-viral, anti-bacterial, anti-thrombic, anti-carcinogenic, anti-oxidant, anti-angiogenic, anti-cancer and lipid powering properties. A clinical research work indicated that supplementing of these compounds in the feed moderate the risk of cardiovascular disorders, acute vascular inflammation, atherosclerosis, chronic cancers, diabetes, oxidative stress, skin disorders and stimulate the nonspecific immunity [35].

3. Health Benefits of Functional Polyphenols

'Polyphenols' are compounds found in plants that give health benefits. Phytonutrients are not nutrients but natural substances because they are produced by specialized cells rather than metabolism. They are not vital for plants therefore are different from primary plant compounds. Phytonutrients perform functions as pest repellents and growth regulators in plants. They are found in low concentrations in plants and possess pharmaceutical effects. Since antiquity, these effects have been used in naturopathy and this pharmaceutical character is found in medicinal herbs and spices. By using some sensitive analytical methods, many of these substances could be analyzed. Polyphenols can promote health or deteriorate health depending on the dosage. The pharmacological effects of phytochemicals have been studied on tissue cultures and animals. Taking polyphenols as fruits, legumes, nuts, herbs and spices reduces cardiovascular disease according to the epidemiological results in past [21, 36, 37].

Identification of the health benefits of polyphenols is necessary for the development of drug and functional food. For the identification of health benefits of polyphenols, many in vitro methods have been found but there is still space for more research because of high cost and low productivity. In silico methods, three approaches are using molecular, chemical or ethnopharmacological data. All these approaches have not been used together rather an integrated in silico approach is used of either chemical, ethnopharmacological or molecular analysis. Chemical properties were analyzed to see their oral bioavailability, effect on tissues and drug availability. All

these techniques can also be used in combination to the health benefits. Polyphenols are also used in lowering blood cholesterol levels for a long time. They are considered safe and effective. Firstly, used as a pharmaceutical ingredient, phytosterols are now added to food products. At the presently used levels, they have been found safe with no harmful health effects [38, 39].

Low density lipids oxidation in human body is a crucial factor in the development of atherosclerosis inflammatory disease. High antioxidant potential of polyphenols inhibits LDL oxidation and prevents cardiovascular diseases by anti-inflammatory action of polyphenols. Some powerful polyphenols from onions and tea "Quercetin" prevents and cure from coronary heart diseases by inhibiting thrombosis [40]. The polyphenols showed protective effect on human cancer cells and development of number of tumor cells production. Many polyphenolic compounds including quercetin, lignans, isoflavones and curcumin are involved in the prevention of mouth, stomach, liver, skin and lungs cancer [41]. The polyphenols from soybean such as epicatechin gallate, tannic acid and catechin inhibits glycosidases and glucose transporter by the strong antioxidant potential, thus helps in the treatment and prevention of type 1 and type 2 diabetes [42]. Fruits and vegetables contain high levels of polyphenols and flavonoids that have anti-aging properties and showed neuro-protective effects against damage to the brain cells and oxidative damage of neurons (Figure 2) [41].

The secondary metabolite compounds of polyphenols function as protecting agents and are typically organic compounds produced through the biosynthesis of primary metabolites provides the first point of evidence for evolution. The secondary metabolites play an essential role in human physiology and also have potential health benefits in human. The secondary metabolites work as anti-inflammatory, anti-carcinogenic, anti-oxidant, anti-amebic agent, anti-malarial, anti-hepatotoxic and anti-hypertensive agent in various processing and cosmetics industries [43, 44]. Dramatically in the past decades, researchers and consumers have become increasingly interested in phytochemicals and their components such as and through functional products because they provide of the numerous health benefits. These compounds play critical role in the biosynthetic pathways, functions, mechanisms of actions in the living systems as well as have potential for medicinal, industrial, and commercial applications. Many clinical research studies have indicated an inverse

correlation between secondary metabolites consumption and chronic degenerative disorders like that heart disorders, diabetes mellitus type 1, cancers, osteoporosis, metabolic disorders and neurodegenerative diseases [45, 46].

The secondary metabolites are most widely distributed in edible plants that play an important role as defense components against ultraviolet radiation and in food that provide beneficial health effects on human, and also inhibit the activity of microbial pathogens [47]. In recent decades, many observational and experimental studies have shown that long-term consumption of foods rich in polyphenol compounds provides some protection against many diseases like that inflammations, skin disorders, heart diseases, hypertension, metabolic disorders, neurodegenerative diseases, chronic cancers and diabetes. Therefore, many health organizations, researchers, food processing and other industries are more interested in the development of functional food products by the addition of polyphenols and other food phenolics [15, 48, 49].

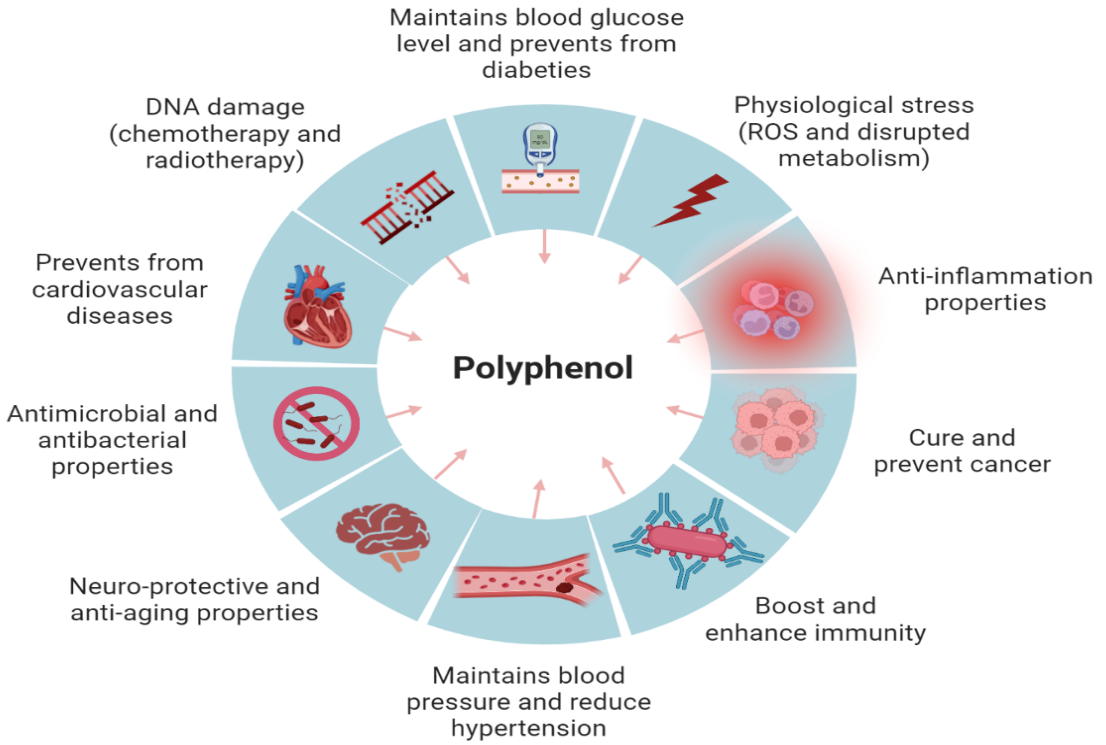
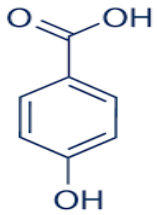
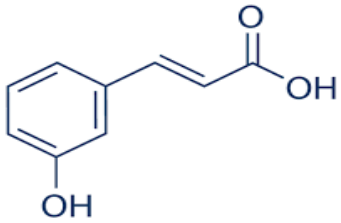
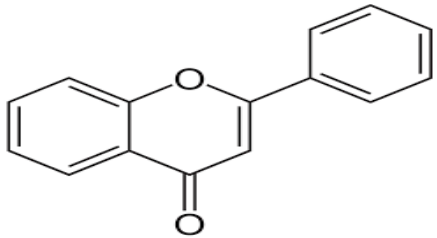
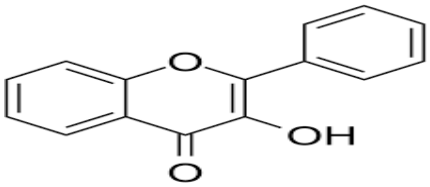
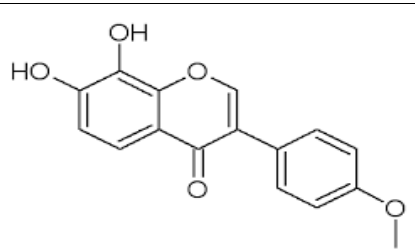
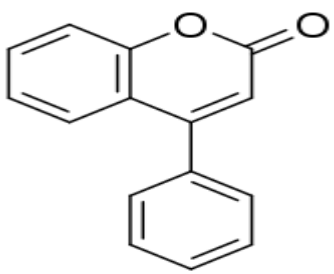
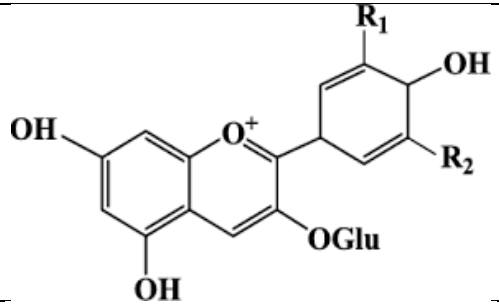
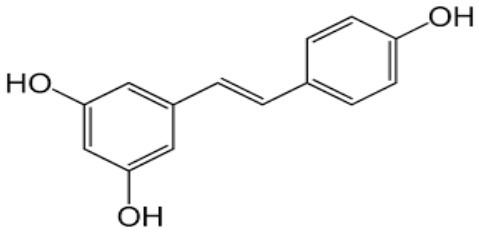
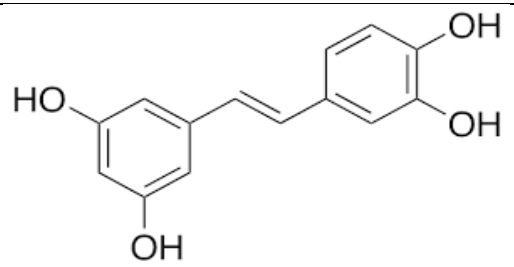
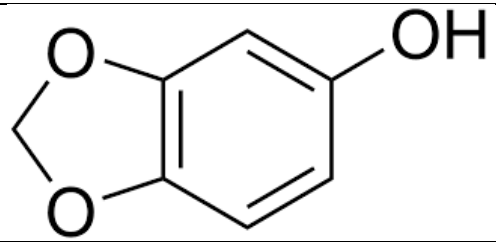
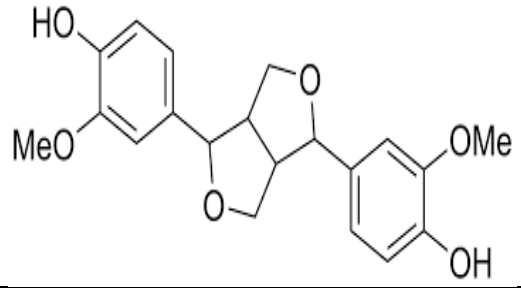
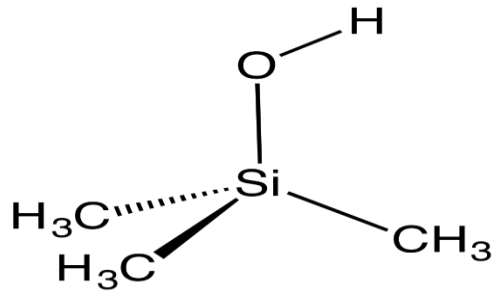


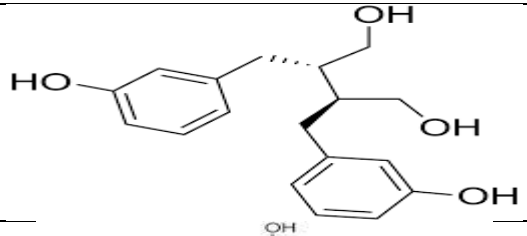
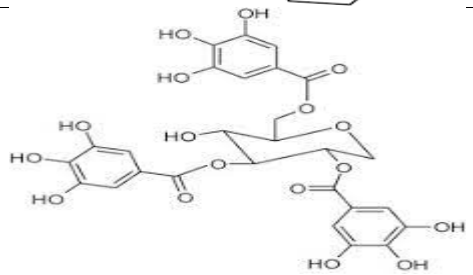
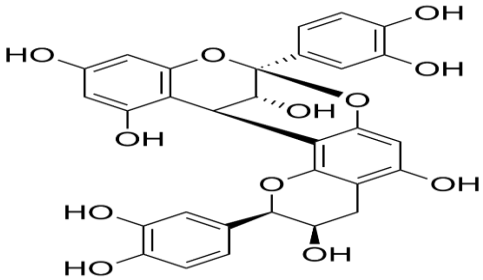
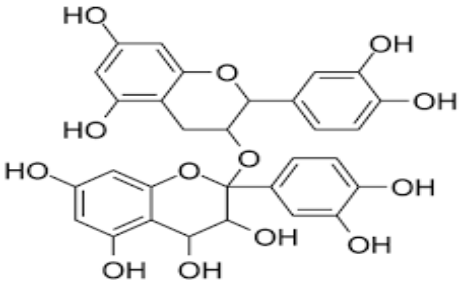
Figure 2 Potential health benefits of polyphenols

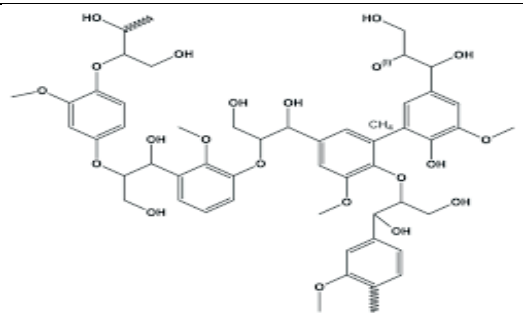
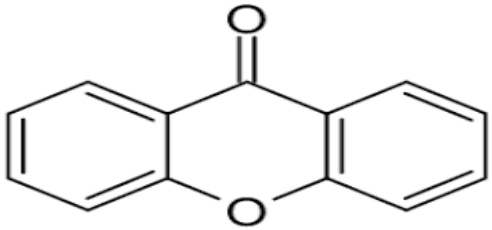
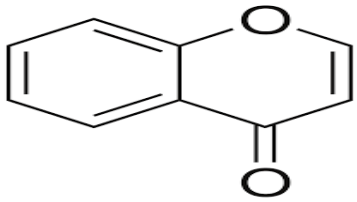
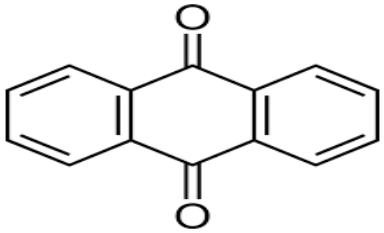
Table 1 Briefly explains the classification of polyphenols along with the major components present, its chemical structure, advantages and presence of these polyphenols in various fruits and vegetables

Serial No.	Polyphenols	Categories	Chemical Structures	Advantages	Occurrence	References
1	**Phenolic acids**	Hydroxybenzoic acid		High antioxidant potential, prevents cardiovascular diseases and cancer	Grape seeds, tea seeds	[8]
		Hydroxycinnamic acid		Strong anti-inflammatory properties, high antidiabetic properties and antimicrobial activities	Kiwi, apple, berries and coffee	[50]
2	**Flavonoids**	Flavones		Cardiovascular properties and neuroprotective	Tomatoes, onions, lettuce and kale	[11, 21]
		Flavonols		Reduces the risk of cardiovascular and cancer diseases and show high antidiabetic activities, prevents from CAD	Cereals, citrus family and broccoli	[11]

		Isoflavones		Prevents hormonal disorders, breast and prostate cancer and cardiovascular diseases	Soyabean	[51]
		Flavanones		Reduced lipid level and prevents cardiovascular diseases	Lemons, oranges and grape fruits	[52]
		Anthocyanins		Antimicrobial properties, anticancer and antidiabetic activities, prevents cardiovascular diseases	Beetroot, cherries, strawberries and berries	[53]
3	**Stilbenes**	Resveratrol		Lowers blood pressure, helps in preventing cardiovascular diseases and skin cancer	Grapes, berries and wine	[54]

		Piceatannol		High antioxidant activity, wound healing properties and anticancer activity	Grapes, red wine and white tea	[55]
4	**Lignans**	Sesamol		Shows antimutagenic activity, prevents cancer and cardiovascular diseases	Sesame oil and sesame seeds	[56, 57]
		Pinoresinol		Shows human health promoting activities	Sesame seed oil, olive oil	[58]
		Sinol		Good for brain heath, improves digestion and prevents cardiovascular diseases	Grapes, pear, cherries and cereals	[59]

		Enterodiol		High antioxidant activity, prevents cancer and cardiovascular diseases	Nuts, legumes, cereals and vegetables	[8]
5	**Tannins**	Hydrolysable		Strong antioxidant, show high anti-inflammatory properties, anti-cancer properties	Oak wood, sumac, gallnuts	[60]
		Non-hydrolysable		High antioxidant properties, improves intestinal heath and improves absorption	Chocolates, coffee, pear apples, legumes and coca	[61]
		Condensed tannins		Involves in the inhibition of microbial growth, show high anti-microbial properties	Barley, grapes, tea and wine	[62]

6	**Lignins**	-		Maintains blood glucose level, improves digestion and prevents from cancer and cardiovascular diseases	Whole grains, legumes, seeds and vegetables	
7	**Xanthones**	-		Strong anti-oxidant potential, anti-fungal and anti-microbial properties	Fruits and vegetables especially mangosteen	[63]
8	**Chromones**	-		Strong antioxidant activities, prevents from cardiovascular diseases and cancer	Oils, spices, legumes and fruits	[64-66]
9	**Anthra quinones**	-		Antioxidant, anti-inflammatory and anti-cancer properties	Coca, tea, bean, apple and onions	[67]

4. Conclusion

In this century, the researcher and scientist are gaining more interest in the utilization, quantifications, extractions and functionality of polyphenols in different nutrient enriched products. Mostly of these polyphenols has been used for health improvement due to their functional properties. Observation and experimental research showed that a high diet intake of polyphenols reduced the risk of many disorders in humans due to higher biological activity. Further clinical research can be conducted on the limitation of their use and to evaluate their toxic effect in the humans and animals.

Author Contributions

Conceptualization, M.A.R.; validation, A.S. and S.A.; writing—original draft preparation, M.A.R. and H.A.; writing—review and editing, J.M.R. I.H. and F.A.K..; visualization, M.A.R.

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Conflicts of Interest

The authors declare no conflict of interest.

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