COMMUNICATIONS IN PLANT SCIENCES

Plant phenolic compounds and health benefits

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The growing rate of the activities of microbes increases every day. Virtually everything that surrounds man are contaminated and polluted with these microbes. These contaminations have led to some infectious and contagious diseases some of which are curable and others deadly. The advancement in Science and Technology have helped reduced this problems to certain level. In doing this, different researches have been carried out on medicinal plants in order to combat these problems. In this research, phenolic compounds were found broadly distributed in the plant kingdom and are the most abundant secondary metabolites of plants. They are reactive metabolites in a wide range of plant-derived foods and mainly divided in four groups: phenolic acids, flavonoids, stilbenes and tannins. They work as terminators of free radicals and chelators of metal ions that are capable of catalyzing lipid oxidation. Therefore, this review examines the functional properties of phenolics and their health benefits.

Highlighted Conclusion
The introduction of natural antimicrobial and antioxidant agents that are environmental friendly and non-pollutant or contaminate the environment are inevitable.

Phenolics are one of the most common and ubiquitous groups of secondary metabolites or compounds found throughout the plant kingdom most especially vascular plants (plants containing xylem and phloem) (Boudet 2007, Harbone 1980). In recent years, many researchers have proved that fruits and vegetables are very important, and this applications depending on type, number, and mode of action of the different components present. These components are known as “phytochemicals”. They are responsible for their presumed medicinal role in the prevention of various chronic diseases including cancers and cardiovascular diseases (Karakaya 2004). Medicinal plants are known to contain high functional dietary micronutrients, fibers and phytochemicals, such as ascorbic acid, carotenoids, and phenolic compounds. These compounds individually or due to some reactions may be beneficial for health since they demonstrate antioxidative activity (Liu 2004, Syngletary et al. 2005, Percival et al. 2006, Yahia 2009).

Vascular plants synthesize a multitude of organic molecules or phytochemicals, referred to as “secondary metabolites” (Harbone and Marby 1982, Shahidi and Wanasundra 1992). These molecules are involved in a variety of roles in the life span of plants, ranging from structural ones to protection. Phenolic compounds are regarded as one of such group that are synthesized by plants during development and in response to conditions such as infection, wounding, UV radiation, etc. (Beckman 2000).Thus, the term “plant phenolics” encompasses simple phenols, phenolic acids, flavonoids, hydrolysable and condensed tannins, lignans, and lignins.

Phenolic compounds are plant secondary metabolites that constitute one of the most common and widespread groups of substances in plants. The term "phenolics" or "polyphenols" are defined as substances that possess an aromatic ring having one or more hydroxyl substituent and functional derivatives such as esters, methyl ethers, glycosides, etc. The terms phenolics and polyphenols refer to all secondary natural metabolites arising biogenetically from the shikimate-phenylpropanoids-flavonoids pathways, producing monomeric and polymeric phenols and polyphenols. Phenolics with only few hydroxyl groups are soluble in ether, chloroform, ethyl acetate, methanol, and ethanol (Van Sumere 1989). Each class of phenolic compounds has distinctive absorption characteristics (Harbone 1964, Marby et al. 1978). Plants need phenolic compounds for pigmentation, growth, reproduction, resistance to pathogens and for many other functions. These compounds form one of the main classes of secondary metabolites and several compounds have been identified with a large range of structures: monomeric, dimeric and polymeric phenolics.

Phenolics are uncommon in bacteria, fungi and algae and the classes of phenols recorded are few: flavonoids are almost completely absent. Bryophytes are regular producers of polyphenols including flavonoids, but it is in the vascular plants that the full range of polyphenols is found (Bell 1980). They may be divided into two classes: namely preformed phenolics that are synthesized during the normal development of plant tissues and induced phenolics that are synthesized by plants in response to physical injury, infection or when stressed by suitable elicitors such as heavy metal-salts, UV-irradiation, temperature, etc. (phytoalexins). Induced phenolics may also be constitutively synthesized but, additionally, their synthesis is often enhanced under biotic or abiotic stress (Harbone 1999, Dixon et al. 2002, Hammerschmidt 2003).

In general, however, preformed antifungal phenolics are commonly sequestered in conjugated form, usually with glycosidic attachments, in vacuoles or organelles in healthy plants (Osbourn 1996, Lattanzio et al. 2001). Biotrophs may avoid the release of preformed antibiotics by minimizing the damage to the host, whereas necrotrophs are likely to cause a substantial release of these compounds. The objective of this work is to analyze the different classes of phenolic compounds and their health benefits.

SYNTHESIS PATHWAYS OF PHENOLIC COMPOUNDS

It is known that the metabolism of plants is divided in primary and secondary. The substances that are common to living things and essential to cells maintenance (lipids, proteins, carbohydrates, and nucleic acids) are originated from the primary metabolism. On the other hand, substances originated from several biosynthetic pathways and that are restricted to determined groups of organisms are results of the secondary metabolism (Vickery and Vickery 2000). Phenolic compounds are constituted in one of the biggest and widely distributed groups of secondary metabolites in plants (Scalbert and Williamson 2000).

Biogenetically, phenolic compounds proceed of two metabolic pathways: the shikimic acid pathway where, mainly, phenyl propanoids are formed and the acetic acid pathway, in which the main products are the simple phenol (Sánchez-Moreno 2002). Most plants phenolic compounds are synthesized through the phenyl propanoid pathway (Hollman 2002). The combination of both pathways leads to the formation of flavonoids, the most plentiful group of phenolic compounds in nature (Sanchez-Moreno 2002). Additionally, through the biosynthetic pathways to the flavonoids synthesis, among the not well elucidated condensation and polymerization phases, the condensed tannins or non-hydrolysable tannins are formed. Hydrolysable tannins are derivatives of gallic acid or hexahydroxydiphenic acid (Stafford 1982).

CLASSES OF PHENOLIC COMPOUNDS: FLAVONOIDS

Flavonoids are characterized as containing two or more aromatic rings, each bearing one or more phenolic hydroxyl groups, and connected by a carbon bridge (Pratt and Hudson 1990, Oboh 2006), as Figure 1. One aromatic ring (A ring) is connected to the second aromatic ring (B ring) by a carbon bridge which consists of three carbon atoms. To date, more than 6000 different flavonoids have been described and the number continues to increase (Harbone and William 2000). When the three carbon chain is connected to a hydroxyl group, they form a cyclic structure (C ring), as a 6-membered ring. Flavonoids which are widespread in the plant kingdom, serve specific functions in antimicrobial activities, flower pigmentation, UV-protection, plant defense against pathogens and legume nodulations (Dixon and Steele 1999, Martin and Appel, 2010).

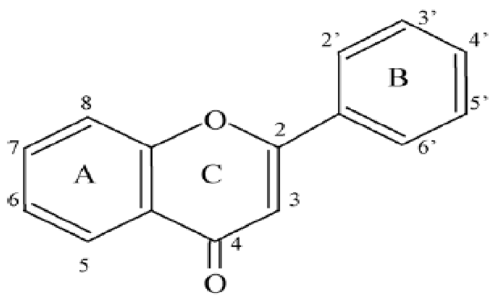


Figure 1. The basic structure of flavonoids.

They have been subdivided into subclasses, based on the position of the B ring relative to the C ring, as well as the functional groups (ketones, hydroxyls) and presence of a double bond in the C ring. These subclasses are termed flavones, isoflavones and isoflavones, flavanones, flavanols, anthocyanidins, chalcones and dihydrochalcones (Oboh 2006).

According to the degree of hydroxylation and the presence of a C2-C3 double bond in the heterocycling pyrone ring, flavonoids can be divided into 13 classes (Sanchez-Moreno 2002), the most important being represented by the flavonols, flavanols, flavones, isoflavones, anthocyanidins oranthocyanins and flavanones (Isabelle et al. 2010), as chemical structure is in Figure 2. Within these classes there are many structural variations according to the degree of hydrogenation and hydroxylation of the three ring systems of these compounds. Flavonoids also occur as sulfated and methylated derivatives, conjugated with monosaccharides and disaccharides and forming complexes with oligosaccharides, lipids, amines, carboxylic acids and organic acids, being known approximately 8000 compounds (Duthie et al. 2003).

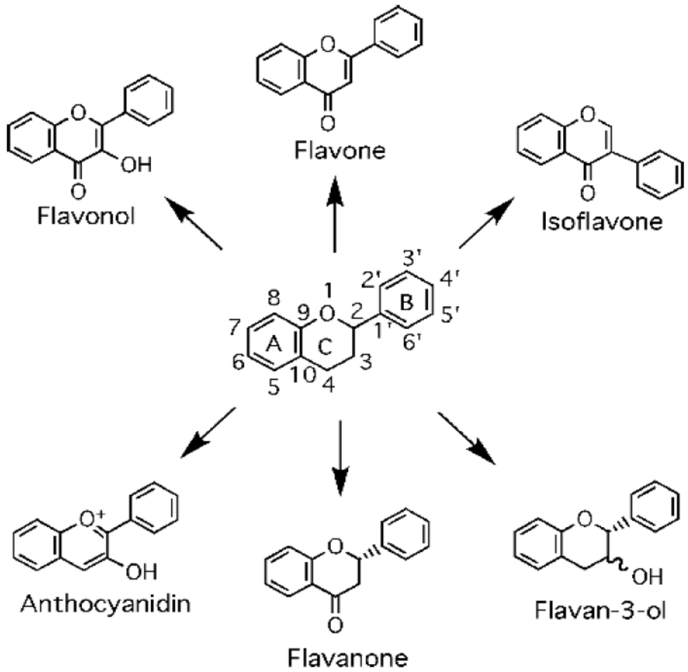


Figure 2. Chemical structures of the main classes of flavonoids.

While members of certain classes of flavonoids (eg., flavonones) are colourless, the other (anthocyanins) are always coloured, such as flowers pigments and other plant parts (Harbone 1980). Flavonoids are important constituents of the human diet (Hertog et al., 1998, Duthie et al. 2003), and are the most widely distributed phenolic compounds in plant foods and also the most studied ones (Jovanovic et al. 1994).

TANNINS

Tannins are phenolic compounds of molecular weight from intermediate to high (500-3000D) (Sanchez-Moreno 2002) and can be classified into two major groups: hydrolysable tannins and non-hydrolysable or condensed tannins (Chung et al. 1998), as chemical structure are in the Figure 3. There is a third group of tannins, phlorotannins, which are only found in brown seaweeds and are not commonly consumed by humans (Ragan et al. 1986). The hydrolysable tannins have a centre of glucose or a polyhydric alcohol partially or completely esterified with gallic acid or hexahydroxydiphenic acid, forming gallotannins and ellagitannins, respectively (Okuda et al. 1995). These metabolites are readily hydrolyzed with acids, bases or enzymes. The best known hydrolysable tannin is the tannic acid, which is a gallotannin consisting of a pentagalloyl glucose molecule that can additionally be esterified with another five units of gallic acid (Bravo 1998). The condensed tannins are polymers of catechin and/or leucoanthocyanidin, not readily hydrolyzed by acid treatment, and constitute the main phenolic fraction responsible for the characteristics of astringency of the vegetables. Although the term condensed tannins is still widely used, the chemically more descriptive term "proanthocyanidins" has gained more acceptance. These substances are polymeric flavonoids that form the anthocyanidins pigments. The proanthocyanidins most widely studied are based on flavan-3-ols (-)-epicatechin and (+)-catechin (Stafford 1982).

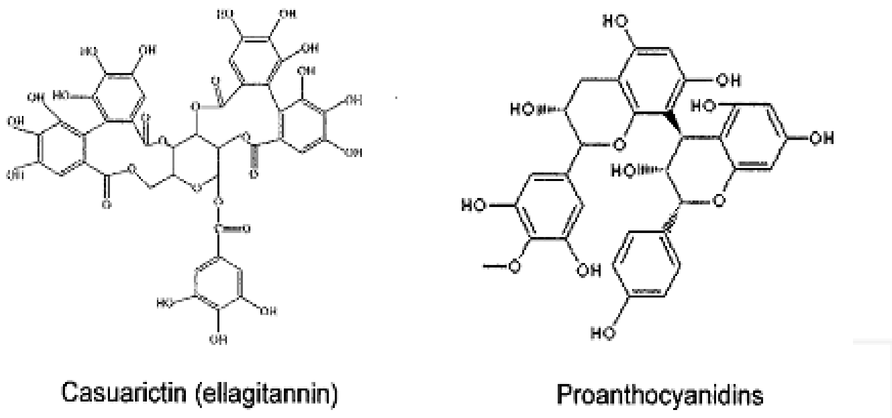
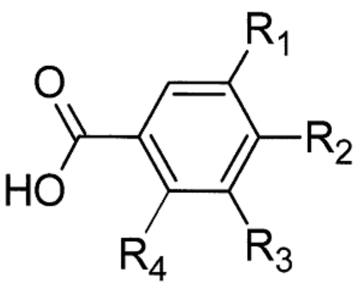


Figure 3. Chemical structures of hydrolysable tannin (left) and non-hydrolysable or condensed tannins (right).

PHENOLIC ACIDS

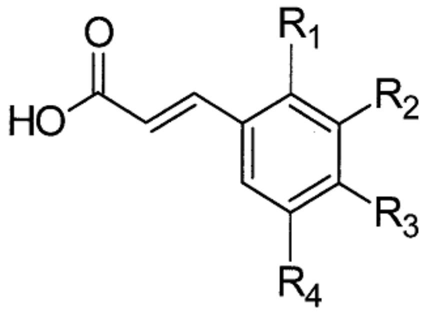
Phenolic acids can be divided into two groups: benzoic acids and cinnamic acids and derivatives thereof. The benzoic acids have seven carbon atoms (C6-C1) and are the simplest phenolic acids found in nature. Cinnamic acids have nine carbon atoms (C6-C3), but the most commonly found in vegetables are with seven. These substances are characterized by having a benzenic ring, a carboxylic group and one or more hydroxyl and/or methoxyl groups in the molecule (Yang et al. 2001).

The general formulas and names of the main benzoic and cinnamic acids are found in Figures 4 and 5, respectively. In the group of benzoic acids the ones that stand out are protocatechuic acids, vanillic acids, syringic acid, gentisic acid, salicylic acid, p-hydroxybenzoic acid and gallic acid (Sanchez-Moreno 2002). Cinnamic acids rarely found free in plants. They are generally in the form of esters, along with a cyclic alcohol-acid, such as quinic acid to form the isochlorogenic acid, neochlorogenic acid, cripto chlorogenic acid and chlorogenic acid, a caffeoyl ester, which is the most important combination (Bravo 1998).



Salicylic acid (R_4 = OH, R_1, R_2, R_3 = H);
Gentisic acid (R_1, R_3 = OH; R_2, R_4 = H);
p-Hydroxybenzoic acid (R_2 = OH, R_1, R_3, R_4 = H);
Protocatechuic acid (R_1, R_2 = OH; R_3, R_4 = H);
Vanillic acid (R_1 = OCH_3, R_2 = OH; R_3, R_4 = H);
Gallic acid (R_1, R_2, R_3 = OH; R_4 = H);
Syringic acid (R_1, R_3 = OCH_3; R_2 = OH; R_4 = H)

Figure 4. The general formulas and names of the main benzoic acids.



Ceramic acid (R_1 = R_2 = R_3 = R_4 = H)
o-Coumaric acid (R_1 = OH; R_2, R_3, R_4 = H)
m-Coumaric acid (R_2 = OH; R_1, R_3, R_4 = H)
p-Coumaric acid (R_3 = OH; R_1, R_2, R_4 = H)
Caffeic acid (R_2 = R_3 = OH; R_1, R_4 = H)
Ferulic acid (R_2 = OCH_3; R_3 = OH; R_1, R_4 = H)
Sinapic acid (R_2 = R_4 = OCH_3; R_3 = OH; R_1 =H)

Figure 5. The general formulas and names of the main cinnamic acids.

STILBENES

Stilbenes are structurally characterized by the presence of a 1,2-diphenylethylene nucleus with hydroxyl groups substituted on the aromatic rings. They exist in the form of monomers or oligomers. The best known compound is trans-resveratrol, possessing a trihydroxystilbene skeleton (Han et al. 2007). The major dietary sources of stilbenes include grapes, wine, soy, peanuts, and peanut products (Cassidy et al. 2000).

HEALTH BENEFITS OF PHENOLIC COMPOUNDS

The possible health benefits of dietary phenolics depend on their absorption and metabolism, which in turn are determined by their structure including their conjugation with other phenolics, degree of glycosilation/acylation, molecular size and solubility.

ANTIMICROBIAL ACTIVITIES OF PHENOLIC COMPOUNDS

The plants have been recognized for their antimicrobial activity. This makes them significantly important in the field of medical microbiology. Many research groups have isolated and identified the structures of some chemical components possessing antifungal, antiviral and antibacterial activity. This property of these chemical components enables them to be used extensively in the area of nutrition, food safety, and health. The antiviral effect of Senna alata plants was shown in a study carried out by (Wang et al. 2000). All the chemical components, with some exceptions, are used in the therapy for viral disease and are effective against a number of viral infections. Naturally occurring chemical components are Quercetin, Naringin, Hesperetin, and Catechin and they possess a variable spectrum of antiviral activities.

Naturally occurring Flavonoids have been recognized for their antimicrobial activity. This makes them significantly important in the field of medical microbiology. Many research groups have isolated and identified the structures of Flavonoids possessing antifungal, antiviral and antibacterial activity (Prior et al. 2001). These properties of Flavonoids enable them to be used extensively in the area of nutrition, food safety, and health. The antiviral effect of Flavonoids was shown in a study carried out by (Wang et al. 2000). All the Flavonoids, with some exceptions, are used in the therapy for viral disease and are effective against a number of viral infections. Naturally occurring Flavonoids such as Quercetin, Naringin, Hesperetin, and Catechin possess a variable spectrum of antiviral activity. Owing to the widespread ability of flavonoids to inhibit spore germination of plant pathogens, they have been proposed for use against fungal pathogens of man (Harbone and Marby 1982, Zhang et al. 2003).

ANTIOXIDANT ACTIVITIES OF PHENOLIC COMPOUNDS

Phenolic compounds are well known for their antioxidant activities. Antioxidants are compounds that protect the cells against the oxidative effect of reactive oxygen species, such as singlet oxygen, peroxyl radical, hydroxyl radical, superoxide radical, nitric oxide and peroxynitrite. The impaired balance between these reactive oxygen species and antioxidants results in a condition commonly referred to as oxidative stress. This oxidative stress may lead to cellular damage which is linked to various health deficits such as diabetes, cancer, cardiovascular disorders, neurodegenerative disorders and aging (Cook and Saman 1996). Furthermore, oxidative stress can damage many biological molecules. Proteins and DNA are significant targets of cellular injury. Antioxidants interfere with radical producing systems and increase the function of endogenous antioxidants, protecting the cells from damage by these free radicals. Intake of Flavonoids via fruits, vegetables and whole grains helps to increase levels of anti-oxidants in the body (Cook and Saman 1996). Flavonoids such as Myricetin, Quercetrin and Rutin help inhibit the production of superoxide radicals.

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CONCLUSION

The advancement in the world has led to the production of synthetic drugs. The consistent use of these drugs have increased the development of drug resistance in human pathogens as well as the unwanted side effects of some commonly used synthethic antimicrobial agents prompted the search for natural antimicrobial agents for effectiveness and safety. The discovery of phenolic compounds in plant has tremendously reduced the side effects encountered from synthetic drugs. All the classes of phenolic compounds showed important health benefits, this is due to the important chemical characteristics or functional groups present. In view of this, the Scientist have discovered that in order for man to survive these conditions, the introduction of natural antimicrobial and antioxidant agents that are environmental friendly and non-pollutant or contaminate the environment are inevitable.

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