Review Article

International Journal of Food, Nutrition and Dietetics
Volume 4 Number 1, January - April 2016
DOI: http://dx.doi.org/10.21088/ijfnd.2322.0775.4116.7

Plant Phenols and Their Health: Enhancing Properties

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Abstract

Phenolic compounds, found in all plants constitute an essential component of human diet. The major polyphenolic compounds found in plants are flavonoids, phenolic acids, stilbenes, chalcones, phenol alcohol and lignans. These compounds are secondary plant metabolites and possess various health benefits such as cardio protective effect, antidiabetic and anticancer properties along with high antioxidative activity. There properties make polyphenols interesting for the treatment of various diseases like cancer and also used for treatment of neurodegenerative diseases (such as Parkinson's and Alzheimer's). They have wide range of nutraceutical applications and exerts prebiotic effects as well. The antioxidative activity of phenolic compounds depends on their structure, in particular the number and position of the hydroxyl groups and the nature of substitutions on the aromatic rings. Fruits, vegetables and beverages are the chief sources of phenolic compounds in the human diet. This review is focused on plant polyphenols and discusses the aspects relative to their potential health benefits.

Keywords: Polyphenols; Antioxidant; Cardio-Protective; Neuro-Degenerative; Prebiotics; Secondary Metabolites.

Introduction

Phenolic compounds are secondary metabolites that are derivatives of the pentose phosphate, shikimate, and phenylpropanoid pathways in plants. They consist of flavan ring and contribute mainly to antioxidant property. They are essential to the physiology of plants, because of their involvement in various important functions such as growth, structure, defense, pigmentation and lignifications. The majority of polyphenols are synthesized by the highly branched phenyl propanoid pathway, which is responsible for the biosynthesis of a large number of chemical compounds with considerable structural diversity. They are major constituents of fruits, vegetables, cereals and beverages. Polyphenols may be classified as phenolic acids, flavonoids, stilbenes and lignans.

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In food, polyphenols may contribute to the bitterness, astringency, color, flavor, odor and oxidative stability. Phenolic compounds exhibit a wide range of physiological properties such as anti-allergenic, anti-artherogenic, anti-inûammatory, anti-microbial, antioxidant, anti-thrombotic, cardioprotective and vasodilatory eûects[1,2]. Polyphenols can act as metal chelators which adds to the antioxidant effects of these compounds through inhibition of transition metal-catalyzed free radical formation[3]. Polyphenols and other food phenolics is the subject of increasing scientific interest because of their possible beneficial effects on human health. These compounds are present in all plant foods but their type and levels vary based on the plant, genetic factors and environmental conditions [4].

Classification of Polyphenols

More than 8,000 polyphenolic compounds are structurally known and among them over 4000 flavonoids have been identified in various plant species. Structurally, phenolic compounds comprise an aromatic ring, bearing one or more hydroxyl substituent, and ranged from simple phenolic molecules to highly polymerized compounds. Plant phenolic compounds have a common intermediate i.e. phenylalanine, or a close precursor, shikimic acid. Primarily they occur in conjugated forms with one or more sugar residues linked to hydroxyl groups, although direct linkages of the sugar (polysaccharide or monosaccharide) to an aromatic carbon also exist. Association with other compounds like carboxylic and organic acids, amines, lipids and linkage with other phenol is also common [5]. Polyphenols are classified on the basis of the number of phenol rings that they contain the structural elements that bind these rings to one another. They are broadly divided in four classes: phenolic acids, flavonoids, stilbenes and lignans. The variations among these classes are the basic chemical skeleton as also the degree of oxidation, hydroxylation, methylation, glycosylation and the possible connections to other molecules [6]. They are a diverse group of chemicals having one feature in common, which is the presence of at least one aryl ring to which a minimum one hydroxyl group is attached. The most common polyphenols are classified in Figure 1 and their structures represented in Figure 2.

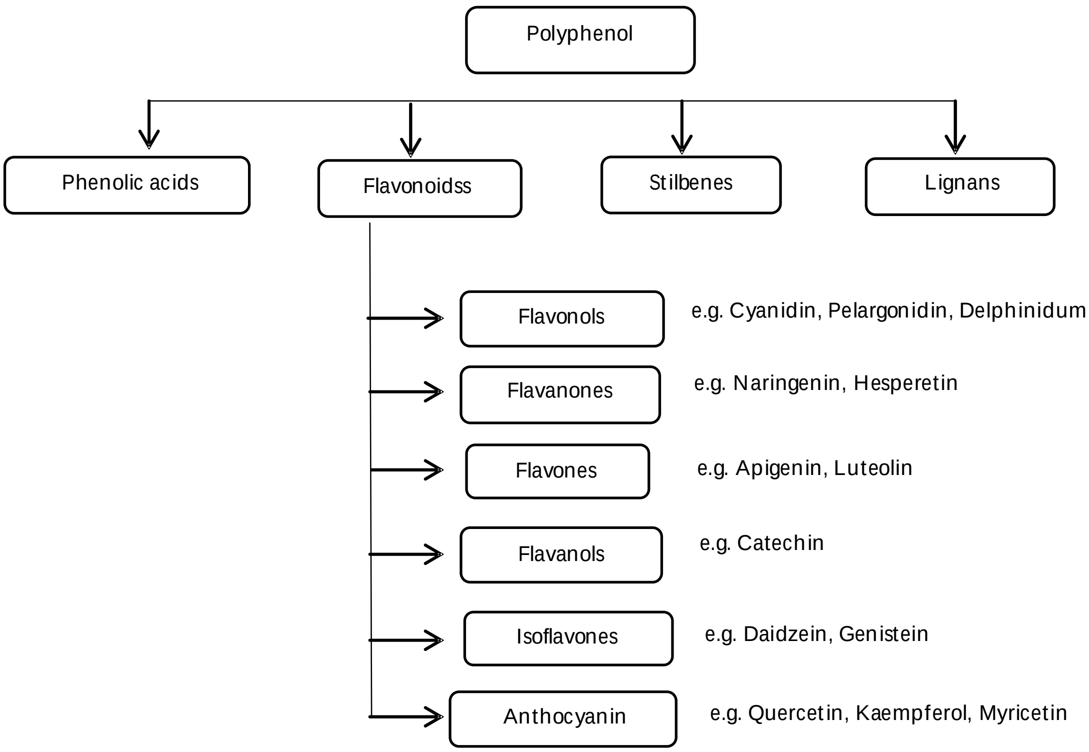

Fig. 1: Classification of polyphenols

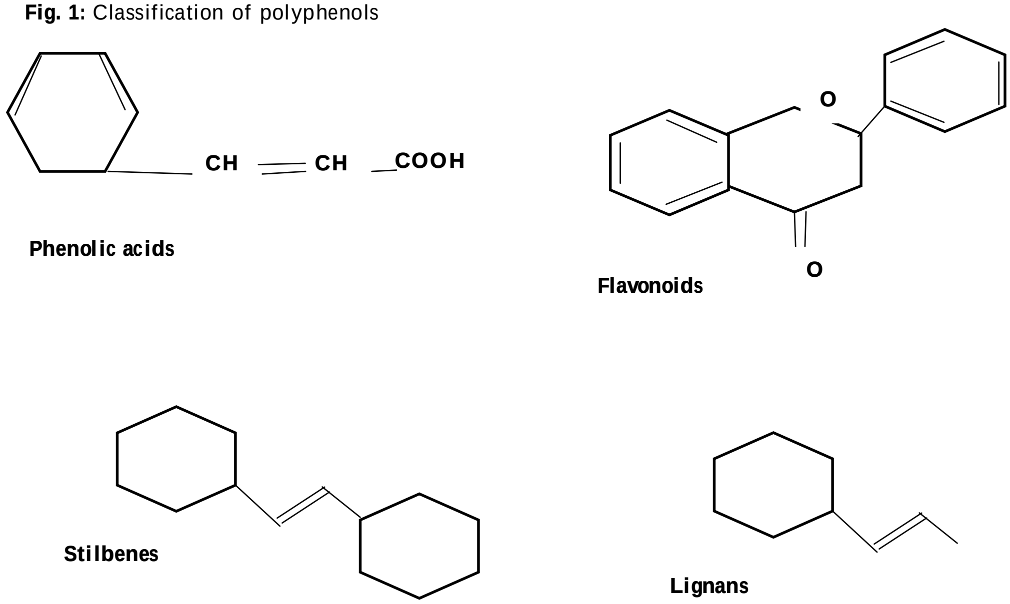

Fig. 2: Structure of selected polphenols

Phenolic Acids

Phenolic acids contain two distinguishing constitutive carbon frameworks; hydroxycinnamic (C_6C_3) and hydroxybenzoic (C_6C_1) structure. Phenolic acids have antioxidant properties due to their high redox potential, which allows them to act as reducing agents and singlet oxygen quenchers [7]. They can be hydrolyzed by acid, alkali and enzyme. Caffeic acid, gallic acid, ferulic acid are some common phenolic acids.

Flavonoids

Flavonoids constitute the largest class of phenolic compounds. They have the C6–C3–C6 general structural backbone in which the two C6 units (Ring A and Ring B) are of phenolic nature [8]. Due to the hydroxylation pattern and variations in the chromane ring (Ring C), flavonoids can be further divided into different sub-groups such as flavonols, flavones, flavanones, flavanols, isoflavones and anthocyanins [9], of which ûavones and ûavonols occur most widely. Flavonoids are produced by a combination of two mechanisms. The A ring of flavonoids is acetate-derived (resorcinol or phloroglucinol) while the B ring is produced via the shikimic acid pathway. Flavonoids can be sugar-free (aglycones) or glycosylated. The sugar moiety is usually glucose, but flavonoid glycosides containing rhamnose, xylose, arabinose, galactose, galacturonic acid or glucuronic acid also exit. Flavonols are the class of flavonoids, which have a 3-hydroxyflavone backbone and are present in wide variety of fruits and vegetable. Quercetin and kaempferol are the most common flavonol aglycones that have at least 279 and 347 different glycosidic combinations, respectively.Flavones mainly consist of glycosides of luteolin, tangeretin and apigenin. The only important edible sources of flavones identified are parsley and celery. Flavanones are generally glycosylated by a disaccharide at position 7, either a neo-hesperidose, which imparts a bitter taste (such as to naringin in grapefruit), or a rutinose, which is flavorless. The main aglycones are naringenin in grapefruit, hesperidins in oranges, and eriodictyol in lemons [10]. Isoflavones have structural similarities to estrogens i.e. hydroxyl groups in the C7 and C4 positions like estradiol molecule. Genistein and daidzein are the two main isoflavones found in soya along with glycetein, biochanin A and formononetin. Flavanols exist in monomer (catechins) as well as polymer form (proanthocyanidins). Catechin and epicatechin are the main flavanols in fruits, whereas gallocatechin, epigallocatechin, and epigallocatechin-gallate are found in certain seeds of leguminous plants and more importantly in tea [11, 12].

Proanthocyanidins, which are also known as condensed tannins, are dimers, oligomers, and polymers of catechins that are bound together by links between C4 and C8 (or C6). Anthocyanins are pigments dissolved in the vacuolar sap of the epidermal tissues of flowers and fruits, to which they impart a pink, red, blue, or purple color. Cyanidin is the most common anthocyanidin in foods. Anthocyanins are found mainly in the skin, except for certain types of red fruit, in which they also occur in the flesh (cherries and strawberries). Wine contains anthocyaninsthat are transformed into various complex structures as the wine aged [13].

Stilbenes

Stilbenes contain two phenyl moieties connected by a two-carbon methylene bridge. Stilbenes exist as stereoisomers and naturally occurring stilbenes are present in the Transform. They occur in free and glycosylated forms and as dimeric, trimeric and polymeric stilbenes, also called viniferins [14].

Lignans

Lignans are polyphenolic substances derived from phenylalanine via dimerization of substituted cinnamic acid. Lignans come under the class of phytoestrogens such as secoisolariciresinol, pinoresinol, steganacin and sesamin and its richest dietary source is linseed. Secoisolariciresinol from flaxseed reportedly slows the growth of human breast cancer in mice [15].

Polyphenols and Human Diseases

Evidence suggests that there is a strong relationship between consumption of polyphenol-rich food and reducing the risk of chronic human diseases. Polyphenols may increase plasma antioxidant capacity and help in reducing oxidative stress,therefore limiting the risk of various degenerative diseases [16]. This may be because of the reducing property of polyphenols their effect on the absorption of pro-oxidative food components such as iron[1,17]. The structural modulation/ modiûcation of polyphenol compounds could provide potential inhibition against bacterial pathogens such as *Streptococcus mutans* and *Mycobacterium tuberculosis* [18]. Cocoa polyphenol pentamers significantly reduced biofilm formation and acid production by *S. mutans* and *S. sanguinis*. Polyphenolic compounds in wine are affected by climate, CO_2 level and region [19]. Warmer climate lowered the antioxidant capacity value, but retained good bioavailability. Polyphenols occurring in cocoa, coffee and tea had major role in prevention of cariogenic processes due to their antibacterial action [20]. Tea polyphenols exert anti-caries effect via antimicrobial mode of action, galoyl esters of epicatechin, epigallocatechin and gallocatechin showing increased antibacterial activity. Tea polyphenols also exhibit an antidepressant activity, which may relate to the alteration of monoaminergic response and antioxidant defenses [21]. Polyphenols reportedly have the potential to reduce cervical cancer by induction of apoptosis, growth arrest, and inhibition of DNA synthesis and modulation of signal transduction pathways. They can interfere with each stage of carcinogenesis: initiation, promotion and progression to prevent cancer development [22].

Cardio-Protective Effect

Polyphenols exerts an additive/ or synergistic protective effects on cardiovascular system and limit the incidence of coronary heart diseases. Cardiovascular disease (CVD) risks include arthrosclerosis, low density lipoprotein (LDL) oxidation, endothelial disfunctioning, platelet aggregation, and inflammatory reactions [17,23]. Atherosclerosis is a chronic inflammatory disease that develops in lesion-prone regions of medium-sized arteries that leads to acute myocardial infarction, unstable angina and sudden cardiac death [24] . It wasfound thatmoderate consumption of red wine (contains polyphenols, melatonin and phytosterol) provides beneficial effect on heart health [25]. Polyphenols are potent inhibitors of LDL oxidation which plays a key role in the development of atherosclerosis [26]. Other mechanisms by which polyphenols may be protective against CVDs are antioxidant, anti-platelet, anti-inflammatory effects, increasing high density lipoprotein (HDL) level and improving endothelial function [27]. Polyphenols may also contribute to stabilization of the atheroma plaque. Quercetin, the abundant polyphenol in onion inhibits the expression of metalloproteinase 1 (MMP1) that has been recognized to play an important role in matrix remodeling in cardiac disease stress and the disruption of atherosclerotic plaques that leads to CVDs [28]. It also blocks the H_2O_2- induced inflammatory response that contributes to prevent ischemic reperfusion injury in cardiomyocytes [29]. The complex biochemical composition of onion altered the individual fatty acid profile when given along with high cholesterol diet in rats [30]. Raisins (160g/d for 6 weeks) significantly lowered the level of proinflammatory cytokine and a cellular adhesion molecule in volunteers [31]. The lower level of soluble intercellular molecule can potentially prevent the progression of atherosclerosis by decreasing the adhesion of monocytes to the vascular endothelium. Tea polyphenols increase artery dilation, improve endothelial dysfunction, estrogen like activity and decrease blood pressure [32]. Tea catechins inhibit the invasion and proliferation of the smooth muscle cells in the arterial wall that contribute to slow down the formation of the atheromatous lesion [33]. EGCG from tea function as a proxidant and plays an important role in lipid metabolism [34]. It was reported that consumption of red wine or non-alcoholic wine reduces bleeding time and platelet aggregation [35]. Polyphenols can improve endothelial dysfunction associated with different risk factors for atherosclerosis before the formation of plaque [36]. It was demonstrated that resveratrol improves the vasodilatory function, cardiac hypertrophy and attenuates the development of hypertension [37]. The compound also stimulates Ca^{++}activated K^+ channels and enhances nitric oxide signaling in the endothelium, by which it exerts vasorelaxant activity[38,39]. Resveratrol is attributed to the low incidence of CVD despite the intake of high-fat diet and smoking among the people of France [40]. Oxidation of LDL particles is strongly associated with the risk of coronary heart diseases and myocardial infarctions. The intake of phenol-rich virgin olive oil decreasedtotal cholesterol (TC), LDL-cholesterol and triglyceride levels and substantially increased HDL-cholesterol concentration in rats. [41] Epidemiological and clinical studies revealed that polyphenol fraction of extra virgin oil reduces the incidence of CVDs by regulating the blood pressure through the release of potent vasodilator and vasoconstrictor or other agents such as nitric oxide and endothelin-1 [42].

Anti-Cancer Effect

Plant polyphenols represents a unique class of phytochemicals that possess excellent anti-oxidant and anti-inflammatory properties and also modulate cell signaling pathways that lead to anti-cancer effects. Polyphenols induce a reduction of the number of tumors and their growth, resulting in a protective effect at various sites including mouth, stomach, duodenum, colon, liver, lung, mammary gland or skin [43]. Many polyphenols such as quercetin, catechins, isoflavones, lignans, flavanones, curcumin, ellagic acid, epigallocatechin-3-gallate (EGCG) in green tea, resveratrol and red wine polyphenols have proven anticancer effects [17]. Several mechanisms of action have been identified for chemoprevention effect of polyphenols. Plant polyphenols act as antioxidants, reducing free radicals and reactive oxygen species (ROS), and leading to a decrease in their damaging effects on DNA. Plant polyphenols modulate the expression of enzyme involved in inactivation of carcinogens through hormonal control, detoxification and endogenous antioxidant system [44]. The anticancer mechanism of plant polyphenols involve mobilization of endogenous copper, possibly chromatin bound copper and their consequent pro-oxidant action [45]. They can form potentially toxic quinones in the body that are substrates for these enzymes. It has been demonstrated that tea catechins have anticancer activity when given to men with high-grade prostate intraepithelial neoplasia (PIN) in the form of capsules [46]. Black tea polyphenols were found to inhibit proliferation and increase apoptosis in Du 145 prostate carcinoma cells. Insulin like growth factor 1 plays important role in signal transduction pathway, which caused proliferation of carcinoma cells [47]. Black tea polyphenol was found to inhibit the prostate carcinoma cells by blocking the Insulin like growth factor (IGF)-1, at a dose of 40 mg/ml [48]. Quercetin has also been reported to possess anticancer property against benzopyrene induced lung carcinogenesis in mice, mainly due to its free radical scavenging activity [49]. When combination of quercetin and green tea was given their chemo protective role was improved in non-toxic manner [50]. Resveratrol prevents all stages of development of cancer and has been found to be effective in most types, including lung, skin, breast, prostate, gastric and colorectal cancers. It has also been shown to suppress angiogenesis, metastasis and modulate multiple pathways involved in cell growth, apoptosis and inflammation. Apple pomace containing 63.8% procyanidins has cytotoxicity effect in bladder cancer cells that is associated with apoptosis G_2/M arrest and mitotic catastrophe. It also altered the mitochondrial function and ROS generation [51].

Anti-Diabetic Effect

Diabetes mellitus is one of the metabolic disorders characterized by impairment in glucose metabolism that leads to hyperglycemia. Hyperglycemia is associated with long term damage, dysfunction and eventually the failure of vital organs [49, 52]. Retinopathy is a persistent damage to retina of eye that seen in hypertension or diabetes. Long term diabetes leads to nephropathy in which the renal functions are altered or disturbed and neuropathy which is associated with the risks of amputations, foot ulcers and features of autonomic disturbance including sexual dysfunctions. Numerous studies reported the anti-diabetic effects of polyphenols, especially tea catechins [53]. Polyphenols may affect glycemia through different mechanisms, including the inhibition of glucose absorption in the gut or of its uptake by peripheral tissues. The hypoglycemic effects of diacetylated anthocyanins @ 10 mg/kg diet dosage were observed with maltose as a glucose source, but not with sucrose or glucose [54]. This suggests that these effects are due to an inhibition of á-glucosidase in the gut mucosa. It was also observed that catechins at a dose of about 50 mg/kg diet or higher inhibited á-amylase and sucrose in rats. The inhibition of intestinal glycosidases and glucose transporter by polyphenols has been studied [55]. Individual polyphenols such as (+)catechin, (-)epicatechin, (-)epigallocatechin, epicatechingallate, isoflavones from soyabeans, tannic acid, glycyrrhizin from licorice root, chlorogenic acid and saponins also decreased S-Glut-1 mediated intestinal transport of glucose. Saponins additionally delay the transfer of glucose from stomach to the small intestine [56]. Grape polyphenols namely myricetin and resveratrol possess strong ability to ameliorate the biological events responsible for the hyperglycemia [57]. Grape seed polyphenols inhibit high glucose induced cytotoxicity and oxidative stress. Resveratrol inhibited diabetes-induced changes in the kidney (diabetic nephropathy) and significantly reduced renal dysfunction and oxidative stress in diabetic rats. It also decreased insulin secretion and delayed the onset of insulin resistance due to inhibition of K^+ ATP and K^+channel in β cells [58]. Quercetin from onion significantly protected lipid peroxidation and inhibited antioxidant system in diabetics [59]. Ferulic acid (FA), another polyphenol very abundant in vegetables and maize bran lowered blood glucose, followed by a significant increase in plasma insulin [17, 60].

Anti-Aging Effect

Aging is inevitable and multifactorial biological process. It involves accumulation of free radical in the body which leads to oxidative damage of cell and tissue and impairment in repair mechanism [61]. Polyphenols present in medicinal and dietary plants may help in preventing oxidative damage. Anthocyanins (color pigment) have been shown to inhibit lipid peroxidation and the inflammatory mediators cyclo-oxygenase (COX)-1 and (COX)-2, besides possessing potent antioxidant/anti-inflammatory activities [62]. Tea catechins carried strong anti-aging activity and delayed the onset of aging, as per a study[63]. Polyphenols are also beneficial in decreasing the adverse effects of aging on nervous system or brain. The predominant importance of food polyphenols in the protection of the aging brain is the ability of these compounds to cross the blood-brain barrier, which tightly controls the influx in the brain of metabolites and nutrients as well as of drugs. Resveratrol has several biological effects including the activation of sirtuins, a protein that influence the cellular processes such as aging transcription, inflammation and apoptosis[64]. Resveratrol consistently prolongs the life span, as theiraction linked to caloric restriction or partial food deprivation [56]. Seven sirtuins have been identified in mammals, of which Sirtuin (SIRT)-1 is believed to mediate the beneficial effects on health and longevity of both caloric restriction and resveratrol [65]. Resveratrol increased insulin sensitivity, decreased the expression of IGF-1 and increased AMP-activated protein kinase (AMPK) and peroxisome proliferator-activated receptor-c coactivator 1a (PGC-1a) activity[66]. There are experimental evidences that resveratrol extended lifespan in the yeast *Saccharomyces cerevisiae,* the fruit fly *Drosophila melanogaster*, the nematode worm *Caenorhabditis elegans* and seasonal fish *Nothobranchius furzeri* [39]. Quercetin has also been reported to exert preventive effect against aging [67].

Neuro-Degenerative Effect

Neurodegenerative diseases occur due to oxidative stress and damage to brain macromolecules and are becoming an increasing health related burden in old age people. Alzheimer's diseaseis one of the most commonly occurring neurological disorders affecting up to 18 million people worldwide. Because polyphenols are highly antioxidative in nature, their consumption may provide protection in neurological diseases [68]. Polyphenol mainly resveratrol, epigallocatechin gallate and curcumin have immense potential to slowdown cognitive decline. They have shown to produce other important effects including anti-amyloidogenic activity, cell signaling modulation, effects on telomere length and modulation of sirtuin proteins [69]. It was observed that the people drinking three to four glasses of wine per day had 80% decreased incidence of dementia and Alzheimer's disease compared to those who drank less or did not drink at all [70]. Resveratrol, abundantly present in wine scavenges O_2 and OH *in vitro*, and also lipid hydroperoxyl free radicals. Fruits and vegetable juices contain high concentrations of polyphenols and consumption of their juices at least three times per week may play an important role in delaying the onset of Alzheimer's disease [71]. It has been found that apple polyphenol extract has neuroprotective effects against aluminum-induced biotoxicity as aluminum has been implicated in the pathogenesis of Alzheimer's disease [72]. They have the ability to influence and modulate several cellular processes such as signaling, proliferation, apoptosis, redox balance and differentiation [73].

The administration of polyphenols provide protective effects against Parkinson's disease, a neurological disorder characterized by degeneration of paminergic neurons in the *substantia nigra zona compacta* [74]. Nutritional studies have linked the consumption of green tea to the reduced risk of developing Parkinson's disease. In animals, EGCG has been shown to exert a protective role against the neurotoxin MPTP (N-methyl-4- phenyl-1,2,3,6-tetrahydropyridine), an inducer of a Parkinson's like disease, either by competitively inhibiting the uptake of the drug by scavenging MPTP mediated radical formation. EGCG may also protect neurons by activating several signaling pathways, involving MAP kinases which are fundamental for cell survival [75]. The therapeutic role of catechins in Parkinson's disease is also due to their ability to chelate iron. This property contributes to their antioxidant activity by preventing redox-active transition metal from catalyzing free radicals formation. Moreover, the antioxidant function is also related to the induction of the expression of antioxidant and detoxifying enzymes particularly in the brain, which does not have a well-organized antioxidant defense system.[74] Maize bran polyphenol ferulic acid has antioxidant and anti-inflammatory properties and reported to be beneficial in Alzheimer's disease [60].

Prebiotic Effect of Polyphenols

Prebiotics are non-digestible food components which have beneficial effect on intestinal bacteria. Human gut consists of a vast number of microflora that reaches the highest concentrations in the colon (up to 10^{12} cells per g of faeces), the predominant ones being bifidobacteria and enterobacteria. Prebiotic components should have resistance to gastric acidity and mammalian enzymes, be amenable to fermentation by gut microbiota and have stimulating effect on the growth or activity of benefical intestinal bacteria. Inulin and oligofructose (or fructo-oligosaccharides - FOS), galacto-oligosacchardies (GOS) and lactulose were well established prebiotic components. Polyphenols have also recently been characterized as effective prebiotics [76]. Polyphenols travel to the colon, where they undergo extensive bioconversion and metabolism. They have a lower uptake level in gastrointestinal tract and low circulating level in plasma. Polyphenols are then deconjugated by bacterial glycosidases, glucuronidases, and sulfatases and further fermented to a wide range of low-molecular-weight phenolic acids. Gut microbiota play an important role in the health promoting activity of polyphenols through transformation to more active derivatives [77]. The most common dietary polyphenols [(–)epicatechin and (+)-catechin] can be metabolized by fecal bacteria even in the presence of favorable carbon sources such as sucrose and FOS [78], leading to the production of the their metabolites. Itwas found that the administration of extraction juices from apples, rich in polyphenols, increased rat fecal counts of lactobacilli and bifidobacteria [79]. In the intestines of red wine polyphenol-fed rats, the bacteroides, lactobacilli and bifidobacteriaincreased significantly [80]. Consumption of proanthocyanidin rich extract from grape seeds for 2 weeks increases the number of bifiodobacteria [81]. Resveratrol from grapes promoted fecal cell counts of bifidobacteria and lactobacilli in a rat model [82]. These animal studies strongly suggest that polyphenols may act as promoting factors of growth and proliferation or survival for beneficial members of the gut microbiota.

A number of mechanisms may account for the stimulatory effect of phenolic compounds. One of the study suggested that lactic acid bacteria degraded tannic acid to obtain energy and that certain Lactobacilli, such as *Lactobacillus plantarum* degraded the complex esters of gallic acid and glucose containing galloyl groups directly to the glucose molecule [83]. Tannic acid is hydrolyzed to gallic acid and glucose and further decarboxylated to pyrogallol with the help of the enzymes tannase and decarboxylase gallate. Some microorganisms can tolerate and metabolize hydroxycinnamic acid to p-ethylphenols [84]. Phenolic compounds can enhance consumption of nutrients and positively affect the bacterial metabolism, especially in Lactobacilli, during their growth phase. Antioxidant property of flavon-3-ols stimulates the growth of *Lactobacillus hilgardii.* Their chelating activity mainly affects aerobic micro-organisms. Dietary polyphenols may also influence the adhesion and proliferation of probiotic *Lactobacillus rhamnosus* to Caco-2 cells, mainly phloridzin and rutin. This may be due to imitation of acetylated homoserine lactones by catechin and EPCG, that act as regulating factors of biofilm formation involved in bacterial adhesion [85].

Miscellaneous Activities

Dietary polyphenols exert preventive effects in the treatment of asthma, a condition when the airways react by narrowing or obstructing when they become irritated, making it difficult for the air to move in and out. This narrowing or obstruction can cause one or a combination of symptoms such as wheezing, coughing, shortness of breath and chest tightness under asthmatic conditions. Epidemiological evidence shows that polyphenols might protect against obstructive lung disease. Apple pomace consumption has been inversely associated with asthma and positively associated with pulmonary health [86]. Increased consumption of the genistein soy isoflavone was associated with better lung function in asthmatic patients [87]. Intake of polyphenols is also reported as beneficial in osteoporosis. Supplementation of diet with genistein, daidzein or their glycosides for several weeks prevent the loss of bone mineral density and trabecular volume caused by the ovariectomy [88]. Polyphenols also protect skin damages induced from sunlight. Study on animals provide evidence that polyphenols present in tea, when applied orally or topically, ameliorate adverse skin reactions following UV exposure, including skin damage, erythema and lipid peroxidation [89]. Black tea polyphenols are reported to be helpful in mineral absorption in intestine as well as asserts antiviral activity. Theaflavins present in black tea were found to possess anti HIV-1activity by inhibiting the entry of HIV-1 cells into the target cells [44].

Conclusion

Polyphenols are widely distributed in plants such as fruits, vegetables, tea, olive oil, tobacco, cocoa, coffee beans and so on. In this review article we summarize the various health benefits of polyphenols. These polyphenols provide an alternative to conventional medicine toward prevention and management of diseases and related complications either alone or in combination with other therapies. Recent molecular, cellular, and animal studies have begun to reveal detailed mechanisms linking consumption of polyphenols and life-style adjustment with prevention of chronic diseases including cardiovascular disorders, cancer, and diabetes, aging and neuro-degenerative. The bioavailability and effects of polyphenols greatly depend on their metabolism in gut. It was found that they contribute to the maintenance of gut health by the modulation of the gut microbial balance through the stimulation of the growth of beneficial bacteria and the inhibition of pathogen bacteria, exerting prebiotic-like effects.

Although, there have been considerable scientific progress over the past few years but we still need to define missing steps in polyphenol signaling network and elucidate the mechanism based on the complexity of diseases.

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