Potential of plant flavonoids in pharmaceutics and nutraceutics

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INTRODUCTION

The word flavonoid is a Latin derivative of flavus which means ‘yellow’ owing to the colour of these compounds in nature. Flavonoids are phenolic compounds that are commonly found in almost all plant species. They have been referred to as ‘phytochemicals’, because they impart color and biological activities to plants. Flavonoids are known to be potent metal chelators and antioxidants. This makes them potential candidates for drug production. They are widely used in medicine and pharmacy, mainly as nutraceuticals for health and disease prevention [1]. Flavonoids present in black and green tea are employed for treatment of cardiovascular diseases [2]. Flavonoids belong to a group of secondary metabolites that are pharmacologically active compounds with roles in plant defence mechanisms [3]. One of the important properties of flavonoids is their low solubility in water which makes them good potential candidates for drug production. For example, aglycones are less soluble in water, so after consumption they remain in the intestine for less amount of time and have low rate of absorption, thus protecting human body from toxic effects of eating flavonoid rich food [4]. Flavonoids also increase bile discharge, reduce blood cholesterol and lipid levels; and exhibit antimicrobial role against few strains of microorganisms, for example, Staphylococcus aureus [5]. In general, secondary metabolites present in plants are utilized for developmental processes such as photosynthesis etc. These secondary metabolites resulting from phenylalanine and acetyl CoA have roles in plant reproduction, development, and survival [6]. Biosynthesis of flavonoids and their derivatives are involved in inhibition of LDL oxidation by determining human health and play a significant role in minimizing effects of various diseases [1]. There are approximately 4000 varieties of the flavonoid compound group that have been identified. Flavonoids are known to be potent metal chelators and antioxidants. This makes them potential candidates for drug production. For example, aglycones are less soluble in water, so after consumption they remain in the intestine for less amount of time and have low rate of absorption, thus protecting human body from toxic effects of eating flavonoid rich food [4]. Flavonoids also increase bile discharge, reduce blood cholesterol and lipid levels; and exhibit antimicrobial role against few strains of microorganisms, for example, Staphylococcus aureus [5]. In general, secondary metabolites present in plants are utilized for developmental processes such as photosynthesis etc. These secondary metabolites resulting from phenylalanine and acetyl CoA have roles in plant reproduction, development, and survival [6]. Biosynthesis of flavonoids and their derivatives are involved in inhibition of LDL oxidation by determining human health and play a significant role in minimizing effects of various diseases [1].

Table 1: Table is showing different flavonoids present in different plants and their drug action.

<table>
<thead>
<tr>
<th>Flavonoids</th>
<th>Plants</th>
<th>Action</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apigenin</td>
<td>Matricaria recutica</td>
<td>Relaxant</td>
<td>[52]</td>
</tr>
<tr>
<td>Kaempferol and quercetin</td>
<td>Tilia sp</td>
<td>Tranquiliser</td>
<td>[54]</td>
</tr>
<tr>
<td>Quercetin</td>
<td>Calluna vulgaris</td>
<td>Nerve smoothening</td>
<td>[55]</td>
</tr>
<tr>
<td>Wogonin, Baicalein, and Baicalin</td>
<td>Scutellaria baicalensis</td>
<td>Hyperlipidaemia, Inflammatory diseases, Allergies, and Arteriosclerosis</td>
<td>[42]</td>
</tr>
<tr>
<td>Geraniol</td>
<td>Daucus carota</td>
<td>Anti-cancerous</td>
<td>[79]</td>
</tr>
<tr>
<td>Hydroxytyrosol</td>
<td>Olea europaea</td>
<td>Prevention of atherosclerosis</td>
<td>[80]</td>
</tr>
<tr>
<td>Rutin</td>
<td>Fagopyrum esculentum</td>
<td>Cardiovascular diseases, Prevent edema, anti-inflammatory property</td>
<td>[81]</td>
</tr>
<tr>
<td>Resveratrol</td>
<td>Vitis vinifera</td>
<td>Anti-diabetic, anti-oxidant, anti-cancerous</td>
<td>[82]</td>
</tr>
</tbody>
</table>

They have been reported beneficial for human health and play a significant role in minimizing effects of various diseases [1]. There are approximately 4000 varieties of the flavonoid compound group that have been identified. Flavonoids are known to be potent metal chelators and antioxidants. This makes them potential candidates for drug production. For example, aglycones are less soluble in water, so after consumption they remain in the intestine for less amount of time and have low rate of absorption, thus protecting human body from toxic effects of eating flavonoid rich food [4]. Flavonoids also increase bile discharge, reduce blood cholesterol and lipid levels; and exhibit antimicrobial role against few strains of microorganisms, for example, Staphylococcus aureus [5]. In general, secondary metabolites present in plants are utilized for developmental processes such as photosynthesis etc. These secondary metabolites resulting from phenylalanine and acetyl CoA have roles in plant reproduction, development, and survival [6]. Biosynthesis of flavonoids and their derivatives are involved in inhibition of LDL oxidation by determining human health and play a significant role in minimizing effects of various diseases [1].

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(Figure 1) starts with production of naringenin chalcone, by condensation of three malonyl-CoA molecules and one p-coumaroyl-CoA molecule in the presence of chalcone synthase (CHS) [7].

Subsequently, the naringenin chalcone is modified to its isomer naringenin flavanone stereospecifically by the action of chalcone isomerase (also known as chalcone-flavanone isomerase, CHI). Further, the hydroxylation of the naringenin flavanone B ring by flavonoid 3′-hydroxylase (F3′H) or flavonoid 3′,5′-hydroxylase (F3′,5′H) leads to synthesis of eriodictyol or pentahydroxyflavanone, respectively [8]. The synthesis of corresponding dihydroflavonols from three (2S)-flavanones is mediated by the catalyst flavanone 3β-hydroxylase (F3H, also known as FHT). Additionally, dihydrokaempferol, produced from naringenin flavanone directly by enzymatic oxidation, is also the potential substrate for F3′H and F3′,5′H, to produce the corresponding dihydroflavonols, dihydroquercetin. FLS1 catalyses dihydrokaempferol and produces kaempferol (flavonol) while dihydroquercetin catalysed by dihydroflavonol reductase (DFR) to produce leucocyanidin which leads to the formation of proanthocyanidins or it may convert into cyanidin by anthocyanidin synthase (ANS) and forms anthocyanins [9]. Plant natural products have been used by humans as herbal medicine since ancient times. Among numerous plant natural products, flavonoids are phytochemicals used in medicines (Figure 2).

Flavonoids as potential nutraceuticals

Flavonoids possess innumerable beneficial therapeutic properties. Hence, the concept of utilizing flavonoids as nutraceuticals is gradually emerging and gaining considerable interest. The term nutraceutical, which was coined by Stephen DeFelice, is a combination of two words, ‘nutrition’ and ‘pharmaceutical’. DeFelice described nutraceuticals as ‘a food or part of a food that provides medical or health benefits, including the prevention and/or treatment of a disease’ [14]. Nutraceuticals may include dietary supplements, herbal extracts, processed food products such as beverages, cereals etc. Today, nutraceuticals are also called functional foods or nutritional supplements. Flavonoids, being ubiquitous in plants and food products of plant origin, constitute a major portion of nutraceuticals. Foods and beverages including berries, beans, nuts, grapes, red wine etc. are a rich source of flavonoids and are consumed worldwide. The several therapeutic and disease prevention properties of flavonoids which can make them an interesting candidate to be used as nutraceuticals have been described in the following sections.

Anti-oxidant properties: Plant flavonoids are a great source of antioxidant substances, equipped for minimizing the risk of cancer, aging and damaging free superoxide radicals. The adverse effects of oxidative processes on organic molecules like carbohydrates, lipids, DNA and proteins in biological systems are reduced by a wide range of substances found in flavonoids. Flavonoids are present in fruits and vegetables as phytonutrients, containing flavones and catechins, which are important sources of antioxidants. Antioxidant activity of flavonoids exhibit double action by scavenging ROS and by inhibiting oxidases. One of the important antioxidants is quercetin, which scavenges highly reactive species such as peroxynitrite and the hydroxyl radicals. Genistein is an isoflavonone, which is also reported as an important antioxidant [15]. The iron chelation activity of quercetin works to reduce oxidative injury induced in the erythrocyte membranes. This injury is induced by a number of oxidizing agents such as phenylhydrazine and acrolein [16]. One of the properties of some flavonoids is chelation with metal ions like copper and iron to reduce free radical development. Different diseases can be prevented by intake of antioxidants that are present in our food in the form of flavonoids in fruits and vegetables. They can help to reduce risk of cancer, liver disorder, heart diseases and diabetes. Interaction of these
biomolecules with antioxidants in food enhances the activation of certain enzymes and inhibition of others [17]. Different plants have antioxidant flavonoids, for example Hibiscus sabdariffa extracts, which have potential to scavenge free radicals by conjugating with glucuronic acid and glutathione with increased uridine diphosphate glucuronosyltransferase (UDPGT) activity and glutathione S-transferase, respectively. Hibiscus sabdariffa infusions are useful in treating cancer because of their action as antioxidants and their enhancing of drug detoxification [18].

**Antimicrobial properties:** Research data indicates that plant flavonoids are the key area for anti-infective investigations, as these natural plant products depict antifungal, antiviral and antibacterial activities. Furthermore, studies have revealed interaction between flavonoids and chemotherapeutics [19]. In several pharmaceuticals, plant parts and their extracts are used to improve human immune system against diseases [20]. The properties of different wine constituents such as quercetin, rutin, vanillic acid, gallic acid and caffeic acid have been examined against pathogenic microorganisms [21]. Additionally, the antimicrobial activity of naringin and quercetin has also been reported [22]. Plants having higher amounts of carotinoids, flavonoids and vitamin C are found to be more effective and useful for improving immune system. Uncaria tormentis, Allium sativum, Echinacea are the plants rich in immunostimulatory molecules. Such plants can further help in production of lymphocyte, macrophages and natural killer cells. They also increase phagocytosis and interferon synthesis [23]. The consequences and effects of medicinal plants and oils extracted from such plants as immune stimulators, particularly the effects at microscopic level, are not well known [24]. Another research finding indicates that oil infusions from medicinal herbs help improve immune system [24]. Plants from different species rich in flavonoid are found exhibiting enhanced antibacterial activity [25]. Numerous flavonoids such as apigenin, galangin, glycosides, flavones, isoflavones, chalcones, flavanones, flavonol, flavonoid ‘myricetin’ inhibited growth of MDR (multi drug resistant) which makes several infections harder to treat. It is a threat to global health and development. A study has depicted the use by flavonoids to investigate that flavonoids which have lipophilic nature may also disturb microbial membranes [27]. Thus, such antimicrobial functions can be correlated to minimizing microbial adhesions, intracellular transport proteins etc. The world is facing a serious problem of antibiotic resistant which makes several infections harder to treat. It is a threat to global health and development. A study has depicted the use by flavonoids to fight antibiotic resistant bacteria. In their study, Xu and Lee report that the flavonoid ‘myricetin’ inhibited growth of MDR (multi drug resistant) bacteria Burkholderia cepacia and the mode of action was reported to be the inhibition of protein synthesis by B. cepacia [28]. Similar results were observed when the effect of flavonoids were studied on the replication and infectivity of human viruses such as herpes simplex virus type 1 (HSV-1), respiratory syncytial virus (RSV) etc. The result of the study concluded that quercetin caused negative effects on the infectivity and replication of these viruses [29].

**Role in cardiovascular diseases:** Studies have reported that flavonoids help declining cholesterol and glucose levels in humans. Flavonoids present in Camellia sinensis (tea plant) are known to prevent cardiovascular diseases. Both green and black tea is a rich source of flavonoids. Sufficient intake of flavonoids is related to reduce effect of coronary heart disease [30]. Tea contains flavonoids which reduce levels of cholesterol in blood, damage caused by oxidative stress, lower blood pressure and inflammation. Many studies suggest that flavonoids of tea also enhance functions of the endothelial [31]. Similarly, bioactive compounds of flavonoids such as non-caloric, non-nutrient secondary metabolites, polyphenolic are found mainly in cocoa, wine, tea, vegetables, nuts and fruits. These flavonoids may reduce LDL cholesterol and regulate anti-inflammatory and antioxidant activities [32]. A good source of quercetin is cranberries, which can help lower the blood pressure [33]. Heart diseases are a major cause of mortality worldwide and polyphenols reduce the possibility of cardiovascular diseases. A study investigated that specific hydroxyl (–OH) groups on the isoflavone structure were critical for inhibition of the phosphodiesterase isoenzymes [34]. This may also explain the therapeutic effects of flavonoids on platelet aggregability and blood pressure.

**Anti-diabetic properties:** Diabetes mellitus (DM) is a chronic metabolic disorder characterized by defective insulin secretion or function, or both. Diabetes mellitus is prevalent worldwide and has been reported in all age groups. It was estimated that its prevalence in all age groups may reach up to 4.4% globally by 2030. There are two types of diabetes Type 1 and Type 2. The Type 1 diabetes is caused by degradation of pancreatic β-cells, which results in lack of insulin in the body. Type 2 diabetes occurs when body becomes resistant to effects of insulin (insulin resistance) or the pancreas loses the ability to produce enough insulin. Diabetes can be cured by natural flavonoids present in plants such as shaminin, diadzein, epicatechin, myricetin, epigallocatechin, hesperidin, naringenin, hesperitin, chrysin, apigenin, genistein, kaempferol, luteolin, quercetin, etc [35].

Flavonoids can restrain catalyse aldose reductase that converts sugars to sugar alcohols and are involved in diabetic intracellularly, for example, neuropathy, cardiac disorder and retinopathy [36]. Another study has proved the role of flavonoids in inhibiting α-glucosidase and α-amylase, the key enzymes involved in carbohydrate digestion [37]. This inhibition leads to suppression of carbohydrate digestion and consequently, the glucose absorption hence imparting hypoglycemic effects. Another mechanism, by which flavonoids are known to help reduce hyperglycemia, is by interrupting absorption of glucose from the intestine. Catechin, a flavan-3-ol, is a known inhibitor of the sodium-dependent glucose transporter, SGLT1 [38].

**Anti-cancer agents:** Consumption of more flavonoid rich foods has been reported to lower the risk of cancer. There are various mechanisms of action reported in this regard including cell cycle arrest, inhibiting proliferation, antioxidation, induction of apoptosis etc. A very recent study conducted on Anthrographis glandulos, discovered rich sources of flavonoids present in the plant. HeLa cells treated with flavonoid extracts from Anthrographis glandulos, exhibited loss in their mitochondrial membrane potential (MMP) and induced apoptosis. This cytotoxic activity of the flavonoid extracts makes them promising candidates for production of anticancer drugs [39].

Flavonoids have the potential to treat cancer at any stage [40], so it is necessary to recognize harmless anticancer constituents from plants as crucial for treatment. Since the herbal infusions are complex mixture, distinctive constituents may have contradicting actions [41], which may decrease the useful effects of plant extracts [42]. Hence, separation of effective components from the plant infusions is essential for producing anticancer medicines. Scutellaria baicalensis infusions have the potential to be utilized as chemoprotective against many types of cancers. These infusions have been reported to cause growth inhibition in several cell lines such as breast cancer, colon cancer, hepatocellular carcinoma, squamous cell carcinoma etc [43]. Another study confirming the bioactive flavonol ‘fisetin’, showed that treatment of human melanoma cells with fisetin caused reduced cell viability by moderating G1 phase arrest [44].

**Anti-inflammatory agents:** Flavonoids are present in various plant parts and possess anti-inflammatory properties [45]. Fisetin, luteolin and apigenin are some of the flavonoids reported to have good anti-inflammatory properties. The anti-inflammatory property of fisetin has shown to diminish effects of asthma, a disease caused by airway inflammation [46]. In China and Japan, most of the herbs used in medicines and infusions are obtained from the roots of Scutellaria baicalensis. These roots have several groups of flavonoids for example wogonin, baicalin, and baicalin, that have medicinal properties. Scutellaria baicalensis infusions have been used for hyperlipidemia, inflammatory diseases, allergies, and arteriosclerosis [47].

The Desmodium plant, which is an important member of Papilionaceae (Fabaceae) family, consists of nearly 350 different types of species. It is predominantly spread worldwide in tropical and subtropical areas. Among these, approximately 28 types of species are found in China only [48]. The species of this category have been used to isolate nearly 200 compounds
including steroids, flavonoids, terpenoids, alkaloids, and phenylpropanoids, whereas, the biological activities have been verified in few plants. Alkaloids and flavonoids are considered as chief components which play major role for such activities undertaken by flora of this genus [49]. Besides, in vivo and in vitro experiments undertaken have proved that the Desmodium plant extracts have a wide-range of pharmacological properties. These improve the cardiovascular and cerebrovascular function besides improving immune system, imparting anti-inflammatory, nootropic, antimicrobial, anti-diabetic, antifungal, and cyto-toxic functions [22].

It has also been found that flavonoids impart their anti-inflammatory action on the biosynthesis of protein cytokines that moderate attachment of circulating leukocytes to the location of injury. Few flavonoids are potent inhibitors of synthesis of dominant proinflammatory molecules called ‘prostaglandins’ [50]. Several flavonoids are involved in platelet adhesion, aggregation, and secretion significantly at 1-10 mM concentration [51]. The effects of flavonoid on platelets have been related to the carbon monoxide inhibition of arachidonic acid metabolism [52].

**Neuroprotective activity:** Flavonoids and phenolic compounds have biological activities such as, antidepressant [10], cytotoxic and antitumor [11], antioxidant [12], and anti-inflammatory [13,14] activities. Flowers obtained from Camomile (Matricaria recutita) have been been employed for their nerve-relaxing properties, due to presence of apigenin which belongs to the flavone class [53]. Tannic acid (from oak) commonly known as Feverfew has also been utilized as a prophylactic solution for treatment of headaches [54]. Tilia sp. such as Linden blooms have been employed globally as tranquilizer and it has been demonstrated that kaempferol as well as quercetin flavonoids have some soothing impact [55]. Heather, (Calluna vulgaris) which is extinct now, had been utilized as a nerve soothing agent and was thought to have MAO-A diminishing action, through quercetin being the dynamic part [56]. Evidence suggests that inflammation of the neuron cells and oxidative stress are major causes of decline of the cognitive function. Cocoa flavonoid nutraceuticals can be great in this regard due to their neuroprotective activities. One of such activities is increased cerebral blood flow. Human trials conducted in this regard reported that a 900 mg/day treatment with cocoa for a week increased CBF in grey matter [57]. A meta-analysis of three individual studies with 114,009 participants reported reduction of risk of stroke by 29% in high chocolate consumers compared with consumers who had low intake [58].

**Antifungal activity:** Antifungal activities have been reported in flavonoids such as neohesperidin, hesperidin, naringin and some of the derivatives isolated from the citrus plants. These are modified enzymatically and are being studied on four fungi that usually contaminate food. These contaminating fungi are Fusarium semitectum, Aspergillus parasiticus, Penicillium expansum, Aspergillus flavus. Similarly mycelia growth of the Fusarium species is inhibited by plant gene is another method, which is useful in producing flavonoids in plants [60]. Similarly, Eysenhardtia texana has some potential antifungal activity against Candida albicans [61]. Antifungal activity has also been reported in flavonoids extracted from citrus fruits after processing in industries and bergamot peel, which is used to stop the growth of Saccharomyces cervisiae [62]. One of the flavanol commonly present in propolis, a chemical produced by bees, is suggested to be used against moulds [63]. Grapes are rich source of flavonoids and their pomaces are used to stop the growth of Zygosaccharomyces bailii and Zygosaccharomyces rouxii [64] and Chilean grape pomace extract is reported to have antifungal activity against Botryosphaeria dothidea [65]. The growth of common causative agents of diseases in human Candida albicans, can be stopped by extracts from Brazilian grapes which contains flavonoids [66]. A study conducted in this regard exhibited that flavonoids enhanced antifungal action of fluconazole (an antifungal drug) when both were used as a cotreatment [67]. The mode of actions studied for the antifungal activity was induction of apoptosis, ROS accumulation, DNA fragmentation, mitochondrial damage etc.

**Biotechnological approaches towards enhanced production of flavonoids in plants**

Numerous chemicals have been extracted from plants and are being employed for the formulation of drugs. In spite of the enormous developments made in unravelling the flavonoid biosynthetic pathway, the biosynthesis of target flavonoids from plant for drug discovery encounters innumerable deficits. The utilization of plants as bioreactors for the sufficient production of a target flavonoid has been limited due to presence of low amount of a specific metabolite and restrictions to diversify basic chemistry of the compound, which ultimately restricts its application in basic research, development, and in clinical trials [68,69]. Biotechnological approaches such as metabolic engineering and plant cell and tissue culture techniques are the potential targets for higher production of secondary metabolites in plants for drugs production [70].

Metabolic engineering is an emerging technique for enhanced production of a specific secondary metabolite. Several methods are being used for altering the genes, enzymes and proteins involved in synthesis of a metabolite. Similarly competitive pathways can be blocked by antisense genes which result in higher production of desired secondary metabolites [71]. For plants to be engineered for the elevated production of plant secondary metabolites such as flavonoids, information about their biosynthetic pathway is required. Many approaches can be applied such as over-expression of regulatory genes, reducing the competitive pathway, overcoming rate limiting steps etc. Utilizing micro-organisms for over expression of a plant gene is another method, which is useful in conversion of precursors into desired chemicals [72]. Cell and tissue culture represent another approach for the extraction of desired chemical compounds for drugs production. However, there are certain issues associated with plant cell culture which include genetic instabilities, slow and variable culture growth, increased susceptibility to stress and aggregation [73]. The problem has been addressed by the initiation of culture using undifferentiated cambial meristematic cells (CMC), which are multipotent with stem-cell-like properties instead of dedifferentiated cells (DDC) [74]. The utilization CMCs can provide a strong foundation for the future metabolic engineering strategies, and may ultimately enhance flavonoid biosynthesis.

Another novel approach that may evade the limited production of plant flavonoids is the biochemical synthesis in microorganisms [69]. Both yeast and bacteria have been used as model organisms for bioreactor-based flavonoid production [75]. Gut bacteria Escherichia coli and the bread and wine yeast Saccharomyces cerevisiae [76] have been utilized for the biosynthesis of different flavonoids. This has been made possible through the simultaneous co-expression of several downstream enzymatic activities in a flavonone biosynthetic pathway [77].

**CONCLUSION**

Today, a growing demand exists for nutraceuticals globally. They possess superiority over other therapeutic agents because they are natural in origin, safe to consume and are easy to access. But, there are still many challenges ahead of establishing nutraceutical industries. These challenges include the need to accurately test the efficacy and safety of such chemical compounds, identify their exact mode of action, evaluate their bioavailability and study possible interactions with various body organs and systems [78-82]. Research has proven the health benefits of flavonoids against a number of public health concerns such as heart diseases, diabetes, cancer etc. This strongly indicates that flavonoids are worthy of more research as potent nutraceuticals. Therefore, concerns with their use as nutraceuticals should be addressed so that their remarkable array of pharmacological actions can be benefited from.
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