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Medicinal Plants and Phenolic Compounds

Asma Nisar

Abstract

Medicinal plants were shown to play a significant role in curing many diseases of ancient times. The plant kingdom is truly a goldmine of potential drug compounds. Several earlier reviews and research studies summarized that the products from natural sources have contributed significantly to the discovery of drugs and health benefits for people. Moreover, it is believed that natural products are less deadly than synthetic medicines because of their plant origins. Medicinal plants are significant in the role of curing a variety of diseases and the properties that they possess for curing are related to the existence of phenolic compounds, flavonoids, anthocyanins and other phytochemicals. This chapter covers the effects of phenolic compound on plants and the importance of phenolic compounds for human health for prevention of various oxidative stress associated diseases.

Keywords: Medicinal Plants, Phenolic Compounds, flavonoids, stilbenes, lignans and phenolic acid

1. Introduction

Phenolics are a type of secondary metabolite that can be found almost all over in plants. They are an aromatic molecule with a benzene ring (C₆) and one or more hydroxyl groups that belong to a broad and diversified group. In general, phenolics are classified according to the number of carbon atoms in the molecule. Three different biosynthetic pathways produce phenolics: (i) the shikimate/chorismate or succinylbenzoate pathway, which produces phenylpropanoid derivatives (C₆–C₃); (ii) the acetate/malonate or polyketide pathway, which produces side-chain-elongated phenylpropanoids, including the large group of flavonoids (C₆–C₃–C₆) and some quinones; and (iii) the acetate/mevalonate pathway, which produces the aromatic terpenoids, mostly monoterpenes, by dehydrogenation reactions [1].

The content of a certain phenolic in plant tissue varies depending on the season and stage of growth and development. Trauma, wounding and pathogen infection are only a few of the internal and external variables that alter phenolic production and accumulation. Furthermore, light increases the production of phenolics in chloroplasts and their accumulation in vacuoles. In some plant species, photoinhibition, as well as nutrient stressors such as nitrogen, phosphate, potassium, sulphur, magnesium, boron, and iron deficiency, cause the synthesis of phenylpropanoid chemicals [1].

The distribution of phenolics in plants is not consistent at the tissue, cellular, and subcellular levels. Plant cell walls contain insoluble phenolics, while plant cell vacuoles contain soluble phenolics. Certain polyphenols, such as quercetin, can be found in all plant products, including vegetables, fruit, cereals, tea, wine, fruit juices, infusions, and so on, whereas isoflavones and flavanones are found only in specific foods. Polyphenols are found in most foods in complex combinations. Higher levels of phenolics compounds found in outer layers of plants than inner layers. Plant polyphenol content is influenced by a variety of factors, including ripeness at harvest, environmental factors, processing, and storage. Environmental and edaphic factors, such as soil type, sun exposure, and rainfall, have a significant impact on the polyphenolic content of foods. The quantities and amounts of different polyphenols are greatly influenced by the degree of ripeness. In general, phenolic acid content declines as ripening progresses, although anthocyanin concentrations increase. Many polyphenols, particularly phenolic acids, are directly engaged in plants' responses to many types of stress: they aid in the healing of damaged areas by lignification, have antimicrobial capabilities, and their concentrations may rise following infection. Storage is another element that has a direct impact on the polyphenol content in foods. Polyphenolic content in foods changes during storage, according to studies, due to the simple oxidation of these polyphenols. Oxidation reactions result in the creation of more or less polymerised compounds, which affect food quality, especially colour and organoleptic qualities. Such alterations can be useful, as with black tea, or damaging, as with fruit browning. When wheat flour is stored, it loses a significant amount of phenolic acids. In terms of quality, flour after six months of storage had the same phenolic acids, although their concentrations were 70% lower than when it was fresh. Cold storage, on the other hand, has only a minor impact on the polyphenol content of apples, onions or pears. Cooking has a significant impact on polyphenol concentrations. After boiling for 15 minutes, onions and tomatoes lose between 75 and 80 percent of their initial quercetin content, 65 percent after cooking in a microwave oven, and 30 percent after frying [2].

2. Phenolics in plant defence

Phenolics perform a dual function in the plant's environment, repelling and attracting various organisms. They act as inhibitors, natural animal toxicants, and pesticides against invading organisms, such as herbivores, phytophagous insects, nematodes, fungal and bacterial pathogens. On the plant surface, simple phenolic acids, complex tannins, and phenolic resins deter birds by interfering with the gut microflora and impairing their digestive ability. Low-molecular-weight phenylpropanol derivatives attract symbiotic microbes, pollinators, and animals that disperse fruit [3].

Phenolics have long been recognised in animals as phytoestrogens and as allelochemicals for competitive weeds and plants. Allelochemicals that are widely effective include volatile terpenoids, toxic water-soluble hydroquinones, hydroxybenzoates, hydroxycinnamates, and 5-hydroxynaphthoquinones. Numerous simple and complex phenolic compounds accumulate in plant tissues and function as phytoalexins, phytoanticipins, and nematocides against soil-borne pathogens and phytophagous insects. Thus, phenolic compounds have been proposed as useful alternatives to chemical control of agricultural crop pathogens for some time. The majority of polyphenols have been shown to have a negative effect on microbes. Plants accumulate phytoalexins

in response to pathogen attacks, such as hydroxycoumarins and hydroxycinnamate conjugates. The synthesis, release, and accumulation of phenolic compounds—in particular, salicylic acid are critical for a variety of plant defence strategies against microbial invaders. Phenolics are synthesised when plant pattern recognition receptors recognise potential pathogens via conserved pathogen-associated molecular patterns (PAMPs), resulting in PAMP-triggered immunity. As a result, the pathogen's progress is slowed significantly before it takes complete control of the plant [1].

3. Classification of phenolic compounds

Polyphenols are classified according to the number of phenol rings they contain and the structural elements that connect these rings. The major classes of polyphenols are phenolic acids, flavonoids, stilbenes, and lignans. **Figure 1** depicts the various polyphenol groups and their chemical structures and **Figure 2** shows the structure of polyphenols.

3.1 Phenolic acids

Phenolic acids, alternatively referred to as phenol carboxylic acids, are aromatic acids composed of a phenolic ring and a carboxyl functional group. As a result, these compounds contain an aromatic ring, a hydroxyl group, and a carboxyl group. Salicylic acid is one of the most basic phenolic acids. Additionally, hydroxycinnamic and hydroxybenzoic acids are important naturally occurring phenolic acids. Hydroxycinnamic acids are derived from molecules of non-phenolic cinnamic acid, whereas hydroxybenzoic acids are derived from molecules of non-phenolic benzoic acid.

Figure 1.
The different groups of polyphenols.

Figure 2.
Structure of polyphenols.

Naturally occurring phenolic acids are found in a variety of horse grams, dried fruits, the mushroom species Basidiomycetes, and human urine. Phenolic acids include protocatechuic acid (PCA), vanillic acid, p-hydroxybenzoic acid (PHBA), caffeic acid, ferulic acid, sinapinic acid, p-coumaric acid and syringic acid.

Phenolic compounds are phytochemicals found in cereals that are beneficial to health. Despite their antioxidant properties, phenolic compounds continue to garner considerable attention. The phenolic acids and flavonoids are the two most abundant types of phenolic compounds found in whole grains. In cereals, phenolic acids are the most abundant. The gut microbiota is widely accepted as a factor in the biotransformation of phytochemicals, including phenolic acids, resulting in the formation of food-derived metabolites that are excreted in the urine. Phenolic acids are easily absorbed through the intestinal tract's walls, which is beneficial for human health because they act as antioxidants, preventing cellular damage caused by free radical oxidation reactions. If humans consume them on a regular basis, they may also help to maintain anti-inflammatory conditions in the body [4].

3.2 Lignans

Lignans are bioactive, non-caloric, non-nutrient phenolic plant compounds found in abundance in flax and sesame seeds and lesser amounts in grains, other seeds, fruits, and vegetables. Enterolignans (occasionally referred to as mammalian lignans) are metabolites of food lignans produced by intestinal bacteria in humans. They have been identified in urine and plasma from humans. Their insignificant estrogenic and other biochemical properties suggest that they may have nutritional value in preventing cardiovascular and other chronic diseases [5].

Monolignols, which are derived from hydroxycinnamic acids (p-coumaric, sinapic and ferulic acids), are either dimerized to form lignans or polymerised to form larger lignin structures in the cell wall. These structurally diverse compounds play a role in plant defence (as antioxidants, phytoalexins, biocides and others), protecting plants from diseases and pests and possibly assisting in plant growth control. Lignans and lignins are two distinct compounds that should not be confused. Lignans are stereospecific dimers of these cinnamic alcohols (monolignols) bonded at carbon 8 (C8- C8) [6].

Lignans (monolignol dimers) are found in plants either free or bound to sugars. There are numerous diglucosides of pinoresinol, secoisolariciresinol, and syringaresinol. 9–12 Sesame seeds contain sesaminol triglucoside and sesaminol diglucoside. Secoisolariciresinol occurs in flax as a diglucoside and is a component of an ester-linked complex or oligomer that also contains 3-hydroxyl-3-methylglutaric acid, a number of cinnamic acid glycosides (most commonly ferulic or p-coumaric acid), and the flavonoid herbacetin [7].

Lariciresinol, pinoresinol, matairesinol and secoisolariciresinol are the most abundant plant lignans found in foods. Numerous other lignans are found in a variety of foods, including medioresinol (found in sesame seeds, lemons and rye), syringaresinol (found in grains), sesamin, and sesamolin, a lignan precursor (in sesame seeds) [8]. Additionally, arctigenin, cyclolariciresinol (isolariciresinol), 7'-hydroxymatairesinol, b and 7-hydroxysecoisolariciresinol are found in foods but are rarely quantified. (Some cyclolariciresinol occurs naturally, while some are formed during the extraction and analysis of lariciresinol under acidic conditions). Lignans have no known nutritional value. While lignans are not classified as dietary fibres, they do share some chemical properties with lignin, an insoluble fibre [9].

Lignins are large plant polymers composed of the hydroxycinnamic alcohols, p-coumaryl, coniferyl, and sinapyl. They are racemic (non-stereospecific) polymers that contain monolignol units at C8 and four additional sites (C5-C5, C5-C8, C5-O-C4, C8-O-C4). Lignins are found in all higher plants' vessels and secondary tissues. They are found in a wide variety of foods, but are especially prevalent in cereal brans. Lignins are considered to be a type of insoluble dietary fibre from a nutritional standpoint. Lignins are necessary for plants because they strengthen the cell walls, aid in water transport, prevent the degradation of polysaccharides found in the cell walls, aid in the resistance of plants to pathogens and other threats, and provide texture in edible plants. Foods contain a small amount of lignan, typically less than 2 mg/100 g. The exceptions are flaxseed²⁷ (335 mg/100 g) and sesame seeds (373 mg/100 g), which contain a hundred times the amount of lignan found in other foods. They are found in a wide variety of plant families, though the types and amounts vary considerably between them. Whole grains (particularly the bran layer) and seeds (in the seed coat) contain lignans. Several grains, including barley, flax, buckwheat, millet, rye, sesame seeds, oats, and wheat, contain a significant amount of lignans. Additionally, nuts and legumes are good sources. Although in smaller quantities than in grains, lignans are also found in fruits and vegetables such as asparagus, kiwi fruit, grapes, lemons, pineapple, oranges, and wine, as well as in coffee and tea [8].

In comparison to plants, animal foods contain almost no lignans. The enterolignans enterodiols and enterolactone are occasionally found in animal foods (milk products) as a byproduct of intestinal bacterial metabolism in the animals' guts, but these are exceptions. Little research has been conducted on the effects of storage and processing on lignans in the majority of foods, although it is known that the lignan content of flaxseed and sesame seed processing does not appear to change significantly [10].

3.3 Stilbene

Compounds of Stilbene in Plants While phenolic compounds are critical mediators of plants' adaptation and survival responses to acute and chronic stress, polyphenols also regulate cell growth, differentiation, pollen fertility, and nodulation, and thus appear to be essential for plant health. For instance, stilbenes are naturally occurring phenolic defence compounds found in a variety of plant species that

exhibit antimicrobial and antioxidant activity against phytopathogens and ozone or ultraviolet stress Stilbene compounds are found in a wide variety of plant species, including wine grapes, peanuts, sorghum, and a variety of tree species [11]. Additionally, commercial sources of stilbenes include a number of plants cultivated in Asia as folk medicines, including *Polygonum cuspidatum*, *Rheum undulatum*, *Rhodomirtus tomentosa*, *Melaleuca leucadendron*, and *Euphorbia lagascae*, whereas pterostilbene is found primarily in bilberries, blueberries, and some other berries. Grape pomaces, winemaking residues, and other grape juice solids contain high levels of polyphenols and are also an excellent source of a variety of stilbene compounds, not just resveratrol. Conifer tree bark waste contains significant amounts of stilbene compounds such as piceatannol, pinosylvin, and trans-resveratrol (t-Res). As a result, this massive amount of industrial byproducts represents an extremely attractive and affordable source of stilbenes with commercial applications. Genetic tools are a very promising method for producing specific stilbenes such as pterostilbene in plants via coexpression of stilbene synthase and O-methyltransferase. These stilbenes may be particularly well suited for pharmacological applications. The enzyme stilbene synthase (STS) is required for the biosynthesis of stilbenic compounds. STS appears to have evolved independently from chalcone synthases (CHSs) in stilbene-producing plants. Interestingly, different STS genes express differently in different tissues and developmental stages. Thus, it has been reported that STS genes were expressed at a lower level in young grape leaves than in mature leaves, whereas the transcript levels of eight STS genes increased dramatically in the berry skins of Cabernet Sauvignon and Norton grape cultivars following veraison, peaking at harvest. Although pine trees' heartwood contains a high concentration of pinosylvin, young seedlings accumulate significant amounts of the compound in response to stress induction (fungal or UV light) [12].

3.4 Flavonoids

Flavonoids are a large class of polyphenolic compounds with a benzo—pyrone structure that is abundant in plants. They are produced through the phenylpropanoid pathway. According to available data, secondary phenolic metabolites, including flavonoids, are responsible for a variety of pharmacological activities [13].

In plants, animals, and bacteria, flavonoids perform a variety of biological functions. Flavonoids have long been known to be synthesised in specific locations in plants and are responsible for the colour and aroma of flowers, as well as the ability of fruits to attract pollinators and thus aid in seed and spore germination, as well as the growth and development of seedlings. Flavonoids protect plants from biotic and abiotic stresses and act as one-of-a-kind UV filters. They also act as signal molecules, allelopathic compounds, phytoalexins, detoxifying agents, and antimicrobial defensive compounds. Flavonoids protect plants from frost and drought and may also play a role in heat acclimatisation and freezing tolerance.

3.4.1 Family of flavonoids

Flavonoids are phytonutrients that belong to the polyphenol class. According to the Global Healing Center, polyphenols have historically been used in Chinese and Ayurvedic medicine and are associated with skin protection, brain function, blood sugar and blood pressure regulation, as well as antioxidant and anti-inflammatory activity.

Flavonoids are classified into several major groups, including flavanols, anthocyanidins, flavones, flavonones, flavonols, and isoflavones. There are additional subgroups within the flavanol subgroup. Each of these subgroups and each flavonoid type has a unique set of actions, benefits, and source foods.

- a. **Flavones:** Lutein and apigenin are two examples. Celery, parsley, various herbs, and hot peppers are all good sources of flavones. Flavones have been linked to an array of antioxidant properties and a delay in the metabolism of drugs.
- b. **Anthocyanidins:** Malvidin, pelargonidin, peonidin, and cyanidin are examples. Red, purple, and blue berries; pomegranates; plums; red wine; and red and purple grapes are all good sources of anthocyanidins. Anthocyanidins are associated with cardiovascular health, antioxidant activity, and aid in the prevention of obesity and diabetes.
- c. **Flavonones:** Hesperetin, eriodictyol, and naringenin are examples of flavonones. Citrus fruits contain a high concentration of flavonones. They are associated with cardiovascular health, relaxation, and anti-inflammatory and antioxidant activity in general.
- d. **Isoflavones:** Genistein, glycitein, and daidzein are all members of this subgroup. Soybeans and soy products, as well as legumes, contain a high concentration of isoflavones. They are phytoestrogens, which means they are chemicals that mimic the oestrogen hormone. They may be beneficial in reducing the risk of hormonal cancers such as breast, endometrial, and prostate cancer, though current research findings are inconsistent. Isoflavones have been shown in various studies to act as antioxidants and as oxidants, leaving their effect on cancer unclear. Additionally, they are being studied as a possible treatment for menopausal symptoms.
- e. **Flavonols:** Quercetin and kaempferol are members of this widely distributed subgroup of flavonoids. Onions, leeks, Brussels sprouts, kale, broccoli, tea, berries, beans, and apples all contain them. Quercetin is an antihistamine that may help alleviate symptoms of hay fever and hives. Additionally, it is well-known for its anti-inflammatory properties. Kaempferol and other flavonols have been linked to significant anti-inflammatory and antioxidant activity, which may help prevent chronic disease.
- f. **Flavanols:** Flavanols are classified into three types: monomers (more commonly referred to as catechins), dimers, and polymers. Teas, cocoa, grapes, apples, berries, fava beans, and red wine all contain flavanols. Catechins are abundant in green and white teas, while dimers, which have been linked to cholesterol reduction, are found in black tea. Scientists believe catechins may be beneficial in alleviating the symptoms of chronic fatigue syndrome. Additionally, catechins have been linked to cardiovascular and neurological health [14].

4. Phenolic compounds' effects on human health

Epidemiological studies have repeatedly demonstrated an inverse relationship between the risk of chronic human diseases and polyphenol-rich diet consumption.

Polyphenols contain phenolic groups that can accept an electron to form relatively stable phenoxyl radicals, interfering with chain oxidation reactions in cellular components. It is well established that foods and beverages high in polyphenols may enhance plasma antioxidant capacity. This increase in plasma's antioxidative capacity following consumption of polyphenol-rich foods can be explained by the presence of reducing polyphenols and their metabolites, their effects on the concentrations of other reducing agents (polyphenols' sparing effects on other endogenous antioxidants), or their effect on the absorption of pro-oxidative food components. Antioxidant consumption has been linked to decreased levels of oxidative damage to lymphocytic DNA. Similar findings have been made with polyphenol-rich foods and beverages, indicating polyphenols' protective properties. There is mounting evidence that polyphenols, as antioxidants, may protect cell constituents from oxidative damage and thus reduce the risk of developing various degenerative diseases associated with oxidative stress. **Figure 3** shows the different pharmacological functions of polyphenols.

The potential health benefits of dietary phenolics are dependent on their absorption and metabolism, which are determined by their structure, which includes their conjugation with other phenolics, their degree of glycosilation/acylation, their molecular size, and their solubility. These steps occur at various points throughout the small intestine's passage into the circulatory system and subsequent portal vein transport to the liver. Because polyphenol metabolites are rapidly eliminated from plasma, daily consumption of plant products is necessary to maintain adequate metabolite concentrations in the blood. However, it is important to keep in mind that the polyphenols found in the most abundant amounts in the daily diet are not necessarily the ones with the highest bioavailability. For example, hydroxycinnamic acids are found in high concentrations in foods, but their intestinal absorption is reduced by esterification. Additionally, differences in cell wall structures, glycoside distribution within cells, and phenolic compound binding to the food matrix can affect phenolic compound bioavailability. Epidemiological evidence to date indicates that polyphenols perform critical functions such as inhibiting pathogens and decay microorganisms, preventing triglyceride deposition, lowering the incidence of non-communicable diseases such as cardiovascular disease, diabetes, cancer, and stroke, and exerting anti-inflammatory and anti-allergic effects via processes involving reactive

Figure 3.
Different pharmacological functions of polyphenols.

oxygen species. These protective effects are partially attributed to phenolic secondary metabolites. Initially, it was believed that the protective effect of dietary phenolics was due to their antioxidant properties, which resulted in a decrease in the body's free radical levels. However, there is emerging evidence that the metabolites of dietary phenolics, which are found in the circulatory system at concentrations ranging from nmol/L to low mmol/L, exert modulatory effects in cells via their selective actions on various components of intracellular signalling cascades critical for cellular functions such as growth, proliferation, and apoptosis. Polyphenols are thought to exert their antioxidant capacity in a variety of ways, depending on the hydroxylation state of their aromatic rings, including (i) radical scavenging, (ii) chelation and stabilisation of divalent cations, and (iii) modulation of endogenous antioxidant enzymes. Phenolic acids, hydrolysable tannins, and flavonoids have anti-carcinogenic and anti-mutagenic properties because they act as antioxidants for DNA, inactivating carcinogens, inhibiting pro-carcinogen activation enzymes, and activating xenobiotic detoxification enzymes. Flavonoids and L-ascorbic acid, in particular, have a synergistic protective effect against oxidative DNA damage in lymphocytes. Chlorogenic and caffeic acids are both antioxidants in vitro and may inhibit the formation of mutagenic and carcinogenic N-nitroso compounds in vitro. Flavonoids, catechins, and their derivatives are being investigated as potential therapeutic agents in studies of degenerative diseases and brain ageing processes, and may act as neuroprotective agents in progressive neurodegenerative disorders such as Parkinson's and Alzheimer's disease. Consumption of flavonoids results in a decrease in LDL oxidation. Resveratrol, also known as trans-3,5,4'-trihydroxystilbene, is the most well-known health-promoting molecule found in grapes and red wine. It has been studied for its effects on genes, as well as the heart, breast, prostate, uterus, and immune system. Additionally, recent research indicates that resveratrol supports healthy nerves and critical brain functions, such as cognitive processes. Tannins, more commonly referred to as tannic acid, have been implicated in experimental animals in reducing feed intake, growth rate, feed efficiency, net metabolizable energy, and protein digestibility. As a result, foods high in tannins, such as betel nuts and herbal teas, are regarded as having a low nutritional value. Numerous studies, however, indicated that the primary effect of tannins was not an inhibition of food consumption or digestion, but rather a decrease in the efficiency of converting absorbed nutrients to new body substances. Tannins' anti-carcinogenic and antimutagenic properties may be related to their antioxidative capacity, which is critical for cellular oxidative damage protection, including lipid peroxidation. Tannins have also been reported to have additional physiological effects, including the acceleration of blood clotting, the reduction of blood pressure, the reduction of serum lipid levels, the induction of liver necrosis, and the modulation of immune responses. Polyphenols (phenolic acid, stilbenes, tannins, isoflavones, and catechins found in green tea) have been shown to inhibit the reproduction and growth of a variety of fungi, yeasts, viruses, and bacteria, including *Salmonella*, *Clostridium*, *Bacillus*, or *Chlamydia pneumoniae*, *Vibrio cholerae*, and enterotoxigenic *E. coli* (ETEC). Because phenolics act as a natural defence mechanism against microbial infections, they can be used in food processing to extend the shelf life of certain foods, such as catfish fillets [4].

5. Conclusion

Phenolic compounds and other bionutrients are abundant in medicinal plants. Phenolic compounds have several biotechnological applications in different industries. Their exploitation is mainly due to their antioxidant, antimicrobial, colouring,

among other properties, specially explored for food preservation, by the food and packing industries, cosmetic and also the textile industry. Polyphenolic extracts are attractive ingredients for cosmetics and pharmacy due to their beneficial biological properties. Numerous studies conducted over the last two–three decades have demonstrated that these Phenolic compounds play a vital role in preventing chronic diseases such as cancer, diabetes, and coronary heart disease, among others. Dietary fibre, antioxidants, anticancer, detoxifying agents, immunity-enhancing agents, and neuropharmacological agents are the major classes of Phenolic compounds with disease-preventive properties. Each of these functional agents are composed of a diverse array of chemicals with varying degrees of potency. There is, however, considerable room for additional systematic research aimed at identifying these Phenolic compounds in medicinal plants and evaluating their potential to protect against a variety of diseases.

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References

- [1] A. Bhattacharya, P. Sood, and V. Citovsky, "The roles of plant phenolics in defence and communication during Agrobacterium and Rhizobium infection," *Mol. Plant Pathol.*, p. no-no, May 2010.
- [2] K. B. Pandey and S. I. Rizvi, "Plant Polyphenols as Dietary Antioxidants in Human Health and Disease," *Oxid. Med. Cell. Longev.*, vol. 2, no. 5, pp. 270-278, 2009.
- [3] P. A. Ndakidemi and F. D. Dakora, "Legume seed flavonoids and nitrogenous metabolites as signals and protectants in early seedling development," *Funct. Plant Biol.*, vol. 30, no. 7, p. 729, 2003.
- [4] T. Ozcan, A. Akpinar-Bayazit, L. Yilmaz-Ersan, and B. Delikanli, "Phenolics in Human Health," *Int. J. Chem. Eng. Appl.*, vol. 5, no. 5, pp. 393-396, Oct. 2014.
- [5] P. Penttinen *et al.*, "Diet-Derived Polyphenol Metabolite Enterolactone Is a Tissue-Specific Estrogen Receptor Activator," *Endocrinology*, vol. 148, no. 10, pp. 4875-4886, Oct. 2007.
- [6] T. Umezawa, "Diversity in lignan biosynthesis," *Phytochem. Rev.*, vol. 2, no. 3, pp. 371-390, Jan. 2003.
- [7] X. Li, J.-P. Yuan, S.-P. Xu, J.-H. Wang, and X. Liu, "Separation and determination of secoisolariciresinol diglucoside oligomers and their hydrolysates in the flaxseed extract by high-performance liquid chromatography," *J. Chromatogr. A*, vol. 1185, no. 2, pp. 223-232, Mar. 2008.
- [8] J. Peterson, J. Dwyer, H. Adlercreutz, A. Scalbert, P. Jacques, and M. L. McCullough, "Dietary lignans: physiology and potential for cardiovascular disease risk reduction," *Nutr. Rev.*, vol. 68, no. 10, pp. 571-603, Sep. 2010.
- [9] L. B. Davin, M. Jourdes, A. M. Patten, K.-W. Kim, D. G. Vassão, and N. G. Lewis, "Dissection of lignin macromolecular configuration and assembly: Comparison to related biochemical processes in allyl/propenyl phenol and lignan biosynthesis," *Nat. Prod. Rep.*, vol. 25, no. 6, p. 1015, 2008.
- [10] S. W. Lee, M. K. Jeung, M. H. Park, S. Y. Lee, and J. Lee, "Effects of roasting conditions of sesame seeds on the oxidative stability of pressed oil during thermal oxidation," *Food Chem.*, vol. 118, no. 3, pp. 681-685, Feb. 2010.
- [11] C. Parage *et al.*, "Structural, Functional, and Evolutionary Analysis of the Unusually Large Stilbene Synthase Gene Family in Grapevine," *Plant Physiol.*, vol. 160, no. 3, pp. 1407-1419, Nov. 2012.
- [12] M. Reinisalo, A. Kärklund, A. Koskela, K. Kaarniranta, and R. O. Karjalainen, "Polyphenol Stilbenes: Molecular Mechanisms of Defence against Oxidative Stress and Aging-Related Diseases," *Oxid. Med. Cell. Longev.*, vol. 2015, pp. 1-24, 2015.
- [13] S. Kumar and A. K. Pandey, "Chemistry and Biological Activities of Flavonoids: An Overview," *Sci. World J.*, vol. 2013, pp. 1-16, 2013.
- [14] A. N. Panche, A. D. Diwan, and S. R. Chandra, "Flavonoids: an overview," *J. Nutr. Sci.*, vol. 5, p. e47, Dec. 2016.