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The Chemical Structure and Clinical Significance of Phenolic Compounds

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ABSTRACT: The biological activities and clinical significance of phenolic compounds are heavily dependent on their chemical structure. The great variety of phenolics, flavonoids in particular, accounts for the myriad ways they benefit health, such as through their antioxidant, anti-inflammatory, and antibacterial effects. However, more research is necessary to fill the knowledge gaps related to the action mechanisms, bioavailability, and synergistic effects of these compounds with the mounting interest in phenolic compounds from a practical standpoint; acquiring an appreciation for structure-activity relationships and clinical applications will be imperative in fully realizing them to promote human health. Phenolic compounds form a significant group of phytochemicals known for their antioxidative properties and potential health advantages; they are majorly obtained from plant sources like fruits, vegetables, herbs, and spices. This review paper presents an up-to-date summary relating to different plant-extracted phenolic compounds: sources, types—emphasizing health effects—and identified knowledge lacunae that should receive future probe.

INTRODUCTION

Phenolic compounds are a heterogeneous group of chemical compounds characterized by the presence of one aromatic ring with one or more hydroxyl groups. They are widely known for their important biological activities: antioxidant, anti-inflammatory, antibacterial, and anticancer activities. This review paper synthesizes up-to-date research findings related to the chemical structure and clinical importance of phenolic compounds with a special focus on polyphenols and flavonoids. Phenolic compounds constitute a very large group of phytochemicals that are well known for their antioxidant properties: fruits phenolic compounds and antioxidant activity and potential health benefits. The major sources of these bioactive molecules are plants; consumption (or use) of plants like in fruits, vegetables, herbs etc. This review paper synthesizes newly released research work concerning different plant-derived phenolic compounds from varied plant sources and highlighting issues related to health implications, types, resources (sources), as well as gaps where enough exploration is needed but with no duplication being done in any way.

CHEMICAL STRUCTURE OF PHENOLIC COMPOUNDS

The biological activity of phenolic compounds is based on their chemical structure. As stated by Abotaleb et al. (2020), phenolics are one of the largest groups of active plant substances, with aromatic rings and hydroxyl groups as their primary characteristics. The diversity in structure among phenolics, especially flavonoids, has led to a large number of biological activities. According to Jucá et al. (2018), variation in the chemical structure of flavonoids results in different biological effects and that the knowledge about these structural differences is very important for therapeutic applications. Also, the basic arrangements significantly determine the properties of these compounds. For example, in figure1, the presence or absence of some functional groups like ketonic oxygen and the numbers of hydroxyl groupings play a significant role in determining antioxidant activity as phenolic compounds Modification of bioactivity occurs further with the degree of branching, methoxylation, and substituent groups, which indicates that structural features are important in evaluating the potential health benefits of these compounds (Mitra et al., 2010).

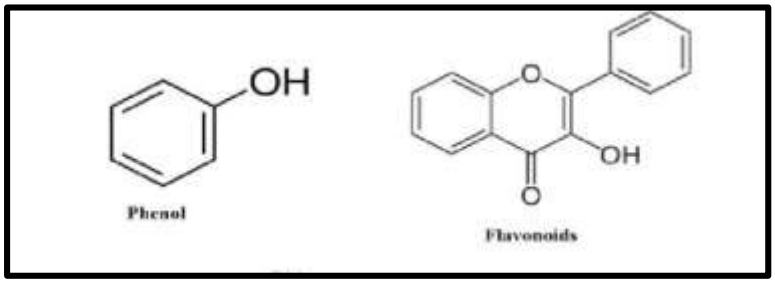

Figure 1. General structure of phenol and flavonoids (Mitra et al., 2010)

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TYPES OF PHENOLIC COMPOUNDS

Phenolic compounds are of several classes: simple phenolic acids, flavonoids, and polyphenols. Brewer (2011) found gallic, protocatechuic, caffeic, and rosmarinic acids to be important compounds that are widespread in plant sources. The presence of some phenols is known to have a pronounced antioxidant action that can be very effective in the fight against oxidative stress in biological systems.

Besides, proanthocyanidins and resveratrol are noted phenolic compounds. An important factor to consider is that they have antioxidant properties. The presence of these compounds in various plant sources indicates that consumption of a wide variety of diets can increase the intake of these beneficial compounds (Brewer, 2011).

In addition, noted phenolic compounds with powerful antioxidant properties include proanthocyanidins and resveratrol. The presence of these compounds in many plant sources further supports the consumption of a wide variety of diets to help increase intake of these beneficial compounds (Brewer, 2011).

SOURCES OF PHENOLIC COMPOUNDS

Phenolic compounds are acknowledged as important antioxidants sourced from fruits and vegetables. Berries are highlighted by Altemimi et al. (2017) to be rich in phenolic acids and flavonoids; these include strawberries, raspberries, blackberries, blueberries, and cranberries. The contribution of these compounds to the overall antioxidant potential of such fruits is often reflected in the purported health-related benefits that accrue from the consumption of such fruits with high antioxidant capacity, which reportedly helps mitigate chronic diseases.

Other plant sources include whole grains, legumes, and specific herbs and spices. For example, p-coumaric acid is a hydroxycinnamic acid that has been observed in its dietary sources to include several grains and vegetables (Devi et al., 2014). The role of endophytes in plants as well as sources of bioactive compounds was emphasized by Gouda et al. (2016) plants a treasure-trove phenolic acids have medicinal importance.

BIOLOGICAL ACTIVITIES OF PHENOLIC COMPOUNDS

Phenolic compounds show a wide range of biological activities that are probably related to their chemical structure. Among the most important features are the antioxidant properties of phenolics in EVOO. According to Servili et al. (2013), both hydrophilic and lipophilic phenolic compounds express lignans and secoiridoids contribution in making up the global antioxidant capacity of EVOO. Such structure−activity relationships between chemical structure and biological activity are very important for developing functional foods and nutraceuticals—beyond antioxidant activity, phenolic compounds have a great impact on human health, as evidenced by antibacterial effects, cardioprotection, and immune system enhancement according to research on plant flavonoids and other phenolics (Cosme et al., 2020). Anthocyanins are further examples of phenolic compounds with great potential due chiefly to potent antioxidant and anti-inflammatory activities, as shown for therapeutic applications (Ribas-Agustí et al., 2018). The clinical importance of phenolic compounds is also visible in their application in different industries. Take, for instance, the nutraceutical properties of fruit residues that have a high content of phenolic compounds; they could serve as possible candidates for incorporation into food and pharmaceutical or cosmetic applications (Mogana et al., 2020). From this vantage point, such versatility demonstrates important attention drawn to expanding the useful effect of phenolic compounds on industries as well.

BIOLOGICAL PROPERTIES OF FLAVONOIDS

Antioxidative Properties

Flavonoids do it all as antioxidants, helping to reduce oxidative stress. Their known actions include combating free radicals and normalizing lipid metabolism, thus diminishing the risk of a number of diseases such as cancer and cardiovascular disorders (Panche et al., 2016; Jucá et al., 2018). For example, anthocyanins —which are part of the flavonoid class— show high antioxidant activity and hence have effects that are anti-obesity and protect the brain (Hossain et al., 2016). Moreover, cocoa flavonoids have effects on brain health and cognition by acting as neuroprotectors (Arroyave-Ospina et al., 2021).

Anti-inflammatory Effects

The anti-inflammatory properties of flavonoids have been well described: the mechanisms are related to the inhibition of nuclear factor kappa B signaling and modulation of pro-inflammatory markers (González et al. 2011; Leyva-López et al. 2016). Evidence has supported that flavonoids such as hesperidin, and hesperetin bring about enhancement in cellular defense besides greatly reducing inflammation in vivo (Parhiz et al., 2015). Moreover, flavonoids reduce inflammation by decreasing cytokine expression and secretion, thus showing therapeutic potential in different diseases as well (Smeriglio et al., 2016)

Anticancer and Antimicrobial Activities

Flavonoids are known to portray potential anticancer activity. This property is attributed to their capability to restrain cellular proliferation and alter the functioning of key cellular enzymes (Ullah et al, 2020; Leyva-López et al., 2016). The prospect that they offer in decreasing the risk of different cancers is quite high based on their anti-mutagenic and anti-carcinogenic effects (Kakkar &

Bais, 2014). Besides, antiviral properties are also possessed by flavonoids; this further broadens their applications as therapeutic agents (Ullah et al., 2020).

Protective Effects on Metabolic Disorders

Flavonoids are related to beneficial effects on metabolic disorders, especially. They enhance glucose metabolism and hepatic enzyme activities and have thus proven anti-diabetic effects (Gao et al., 2013; Al-Ishaq et al., 2019). Also, the risk of diseases like cardiovascular situations is reduced with flavonoids due to their antioxidant and anti-inflammatory actions (Pinckard et al., 2019).

Cardiovascular Health

Flavonoids enhance cardiovascular health by stimulating vasodilation and acting as antioxidants— protection is due to the anti-oxidative damage effect against which free radicals play (Nehlig, 2013; Mahmoud et al., 2019). The modulation of different biological pathways through their capabilities makes them highly valuable in the management as well as control — preventable measures for cardiovascular disease (Mahmoud et al., 2019).

KNOWLEDGE GAPS AND FUTURE RESEARCH DIRECTIONS

Even though phenolic compounds have been extensively researched, several gaps exist in the knowledge to date. While the structure-activity relationships of phenolic compounds have been reviewed, further studies need to explain the mechanisms of action of these compounds in details. It would be valuable research to understand how specific structural features impact bioavailability and ensuing health effects as noted by Cosme et al. (2020). In spite of numerous studies on the antioxidant and anti-inflammatory properties of phenolic compounds, there lacks comprehensive clinical trials for their efficacy in human populations. Evidence-based future research ought to give priority to clinical studies, which will prove the health benefits of these compounds and recommend dosages for therapeutic use. Even though phenolic compounds have been studied extensively, not all gaps concerning the bioavailability and metabolism of these compounds in humans have been filled. Moreover, while many studies have been conducted on single compounds, the analysis on synergistic effects between multiple phenolic compounds has not been realized in full in whole food matrices

The health benefits connected with phenolic compounds are known. Antioxidant properties help in the prevention of oxidative damage and the diseases that follow from such damage, including heart disease and cancer (Brewer, 2011). Evidence has shown that people who consume plants that are rich in phenolic compounds have better health outcomes. Equally, studies indicate that dietary intake plays a major role in determining the body's antioxidant status.

Despite such extensive research on phenolic compounds, gaps remain in the bioavailability and metabolism of these compounds in humans. In addition to this, although so many studies have been conducted on individual compounds themselves, a lot of information is still wanting regarding synergistic effects for many phenolic compounds acting together in whole food matrices..

CONCLUSION

In brief, biological activities and clinical significance of phenolic compounds are based on their chemical structure. Because of the vast number of phenolics— flavonoids in particular— they have a wide variety of health benefits. This includes their anti-inflammatory, antioxidant, and antibacterial effects. However, more studies are required to address knowledge gaps: in particular how these compounds work, as well as aspects regarding their bioavailability and synergistic effects. With the increasing interest in phenolic compounds, it is important to study their structure-activity relationships from the standpoint of synthesis and application for practical medicine in promoting human health.

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