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FLAVONOIDS: BIOSYNTHESIS, FUNCTIONAL DIVERSITY, AND THERAPEUTIC POTENTIAL IN PLANTS AND HUMANS

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ABSTRACT:

Flavonoids represent a large and diverse group of polyphenolic compounds produced by plants, where they play essential roles in growth and survival. These compounds are formed through the phenylpropanoid pathway and display considerable structural variation, which contributes to their wide range of functions. In plants, flavonoids are responsible for coloration, protection against various environmental stresses, and defense against pathogens. In addition to their importance in plants, flavonoids have gained attention for their beneficial effects on human health, including antioxidant, anti-inflammatory, cardioprotective, and anticancer activities. This review provides an overview of their biosynthesis, classification, biological functions, and therapeutic potential, while also highlighting limitations such as poor bioavailability and discussing directions for future research.

KEYWORDS:

FLAVONOIDS, FUNCTIONAL DIVERSITY, POLYPHENOLIC COMPOUNDS, THERAPEUTIC.

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1. INTRODUCTION

Flavonoids constitute a broad class of naturally occurring phytochemicals that are widely present throughout the plant kingdom. They are commonly found in fruits, vegetables, seeds, and various medicinal plants, where they contribute to pigmentation, flavor, and protective roles. Structurally, flavonoids are characterized by a three-ring backbone consisting of two aromatic rings linked by a heterocyclic ring.

In recent years, flavonoids have attracted considerable scientific interest due to their diverse functions in plant physiology and their promising implications for human health. Their capacity to modulate multiple biological pathways and interact with various molecular targets has made them important subjects of therapeutic research.

2. BIOSYNTHESIS OF FLAVONOIDS

2.1 ORIGIN AND PATHWAY

Flavonoid synthesis begins with the amino acid phenylalanine, which is directed into the phenylpropanoid pathway. The process starts when phenylalanine is deaminated to produce cinnamic acid, a reaction catalyzed by the enzyme phenylalanine ammonia-lyase (PAL).

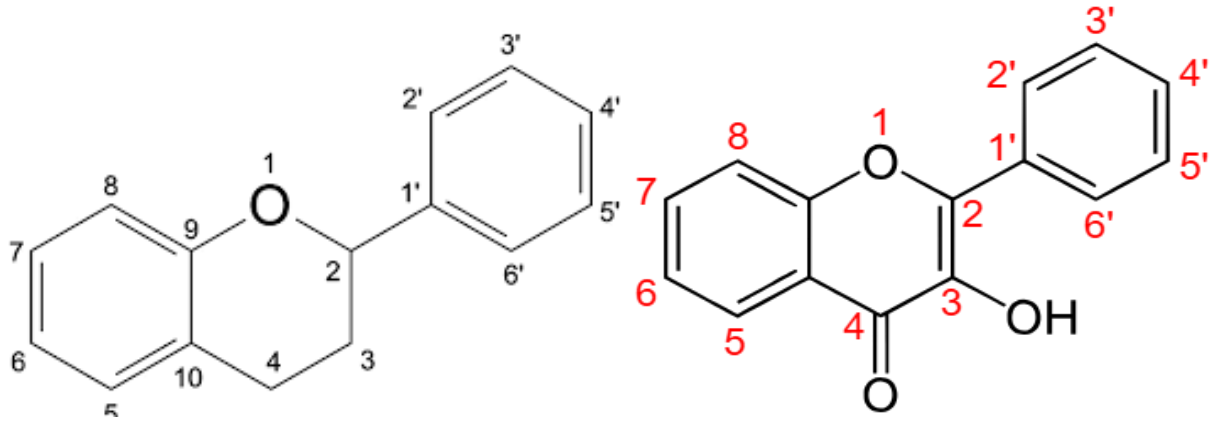
Following this step, a sequence of enzyme-mediated reactions generates several important intermediates that serve as building blocks for various flavonoid subclasses. Among these enzymes, chalcone synthase is particularly significant, as it catalyzes the formation of chalcone, a key precursor from which most flavonoid compounds are derived.

2.2 ENZYMATIC REGULATION

The pathway is controlled by several enzymes, including:

- Chalcone isomerase
- Flavanone hydroxylases
- Dihydroflavonol reductase

Gene expression regulating these enzymes is influenced by environmental stimuli such as light intensity, temperature fluctuations, and biotic stress.



Structure of flavonoids and flavonols

Flavonoids are categorized into multiple subclasses based on variations in their chemical structure.

3. CLASSIFICATION AND STRUCTURAL DIVERSITY

3.1 MAJOR SUBGROUPS

- Flavonols
- Flavones
- Flavanones
- Anthocyanins
- Isoflavones

Each subclass exhibits distinct chemical properties that determine its biological activity.

TABLE 1: MAJOR CLASSES OF FLAVONOIDS AND THEIR NATURAL SOURCES

S.N	Flavonoid Class	Common Compound	Major Plant Source	Biological function in Plants	Therapeutic Potential in Humans
1.	Flavonols	Quercetin	Onion, Apple , Tea	UV protection	Antioxidant, anti-inflammatory
2.	Flavones	Luteolin	Celery, Parsley	Defense against pathogens	Neuroprotective activity
3.	Flavanones	Hesperidin	Citrus fruits	Stress tolerance	Cardioprotective effect
4.	Anthocyanins	Cyanidin	Berries , Grapes	Pigmentation for pollination	Anti-cancer activity
5.	Isoflavones	Genistein	Soybean	Symbiotic signaling	Hormonal balance
6.	Catechins	Epigallocatechin gallate (EGCG)	Green tea	Protection from oxidative stress	Anti-diabetic potential

3.2 STRUCTURE–FUNCTION RELATIONSHIP

Small variations in hydroxylation, glycosylation, and other conjugation modifications can markedly affect the solubility, stability, and biological activity of flavonoids. This diversity in chemical structure largely accounts for the wide range of functions exhibited by different flavonoid compounds.

4. FUNCTIONAL ROLES IN PLANTS

4.1 PROTECTION AGAINST ENVIRONMENTAL STRESS

Flavonoids serve as crucial protective molecules by scavenging reactive oxygen species (ROS) that accumulate under environmental stresses such as drought, high light intensity, and pathogen infection. By donating electrons or hydrogen atoms, these compounds effectively neutralize free radicals, thereby minimizing oxidative damage to cellular components like lipids, proteins, and nucleic acids. In addition to their direct antioxidant role, flavonoids can also modulate stress-responsive signaling pathways, further enhancing the plant's ability to cope with adverse conditions.

4.2 ROLE IN PLANT DEVELOPMENT

These compounds are involved in regulating plant growth

processes, including:

- Root elongation
- Flower coloration
- Pollen viability

They also influence hormone transport, particularly auxin distribution.

4.3 ECOLOGICAL INTERACTIONS

Flavonoids play an important role in mediating plant–environment interactions by aiding in the attraction of pollinators and supporting the establishment of symbiotic associations with microorganisms.

APPROXIMATE FLAVONOID CONTENT IN COMMON DIETARY SOURCES

Food Source	Approximate Flavonoid Content (mg/100g)
Onion	40-50
Blueberry	150-200
Green tea	120-180
Apple	10-15
soybean	80-120
Orange	20-35

5. THERAPEUTIC POTENTIAL IN HUMANS

5.1 ANTIOXIDANT PROPERTIES

Flavonoids are widely recognized for their ability to neutralize free radicals, thereby reducing oxidative damage associated with chronic diseases. This antioxidant activity plays a crucial role in protecting cellular components and supporting overall physiological health.

5.2 ANTI-INFLAMMATORY ACTIVITY

Flavonoids help regulate inflammatory responses by suppressing key signaling pathways and limiting the production of pro-inflammatory mediators. This modulatory effect contributes to the prevention of excessive inflammation and associated tissue damage.

5.3 ANTICANCER EFFECTS

Numerous flavonoids have been shown to inhibit tumor development by promoting programmed cell death (apoptosis) and restricting uncontrolled cell proliferation. They may also interfere with cell cycle progression and signaling pathways involved in cancer progression, thereby contributing to their anticancer potential.

5.4 CARDIOVASCULAR BENEFITS

Regular consumption of flavonoid-rich foods has been linked to better vascular function, lower blood pressure, and a reduced risk of cardiovascular diseases. These benefits are largely attributed to their antioxidant properties and their role in improving endothelial function and circulation.

5.5 NEUROPROTECTIVE ROLE

Recent studies indicate that flavonoids may exert neuroprotective effects by safeguarding neural tissues and enhancing cognitive performance. These benefits are largely linked to their ability to reduce oxidative stress and suppress inflammation within the brain, potentially supporting neuronal function and longevity.

6. BIOAVAILABILITY AND LIMITATIONS

Despite their significant biological potential, flavonoids frequently show low bioavailability, largely due to inefficient absorption and rapid metabolic transformation. Their overall effectiveness is influenced by factors such as molecular size, solubility, and interactions with the gut microbiota.

To address these limitations, recent research has focused on advanced delivery strategies, including nano-based formulations, aimed at improving their stability, absorption, and overall bioefficacy.

7. FUTURE PERSPECTIVES

Further research is required to:

- Elucidate precise molecular mechanisms
- Conduct large-scale clinical trials
- Develop improved delivery systems
- Enhance flavonoid production through genetic engineering

These efforts will be crucial in translating laboratory findings into practical applications.

8. CONCLUSION

Flavonoids constitute a highly versatile class of compounds with vital roles in plant physiology as well as human health. Their wide-ranging biological activities and therapeutic promise position them as valuable candidates for future drug development. Ongoing interdisciplinary research is expected to further elucidate their mechanisms of action and expand their potential applications across various fields.

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