Title: Mechanistic Insights into the Pharmacological Actions of Flavonoids: A Comprehensive Review

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Abstract: Flavonoids, a diverse group of polyphenolic chemicals found in plants, have significant attention for their diverse pharmacological actions and therapeutic potential. Their ability to target multiple pathways, modulate oxidative stress, and regulate inflammatory mediators is crucial in preventing and managing chronic diseases like cancer, cardiovascular disorders, diabetes, and neurodegenerative diseases. Flavonoids have multitargeted actions, providing a safer and general therapeutic approach compared to single-targeted synthetic drugs. This review provides a comprehensive understanding of flavonoids' biological effects, focusing on their modulation of key molecular signaling pathways such as nuclear factor kappa-light-chain-enhancer of activated B cells (NF-κB), mitogen-activated protein kinases (MAPK), phosphatidylinositol 3-kinase (PI3 K)/protein kinase B (AKT), nuclear factor erythroid 2-related factor 2 (Nrf2), oxidative stress, inflammation, and apoptosis. Their anticancer potential is supported by their ability to induce apoptosis, modulate autophagy, and influence gene expression, while their anti-inflammatory and antioxidant properties aid in cytoprotection. Certain hydroxylation and glycosylation patterns enhance their biological efficacy based on structure-activity connections. The review demonstrates the various benefits of these substances, including their hepatoprotective, neuroprotective, anticancer, antidiabetic, and cardioprotective properties, based on both experimental and clinical evidence. It discusses the structure–activity relationship (SAR) that supports their bioefficacy as well as issues with metabolism, bioavailability, and therapeutic translation. It also provides a comprehensive understanding of flavonoids as potential agents for chronic disease prevention and management, integrating pharmacological findings with molecular facts. A method was used to identify works published in reputable journals. Every search result came from PubMed, Scopus, Web of Science, ScienceDirect, Google Scholar, etc The terms flavonoids, pharmacological properties, disease, and mechanism of action were utilized. We selected and investigated research papers, review articles, and original studies that were published up until 2025. Future research should focus on improving flavonoids' bioavailability using advanced drug delivery methods like conjugates, liposomes, and nanoparticles, with extensive clinical trials needed for validation. Furthermore, the potential of flavonoids in therapeutic interventions will be enhanced through the use of computational techniques such as molecular docking, network pharmacology, and precision medicine. Future perspectives emphasize the need for advanced drug delivery systems, clinical trials, and molecular docking techniques to enhance their therapeutic efficacy.

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