



**INTERNATIONAL JOURNAL OF
PHARMACEUTICAL SCIENCES**
[ISSN: 0975-4725; CODEN(USA): IJPS00]
Journal Homepage: <https://www.ijpsjournal.com>



Review Article

Systematic Studies on Phytochemistry and Pharmacological Effect of Quercetin: A Bio-Flavonoid

Mohd. Amil Usmani¹, Abul Hasnat¹, Kahkashan Begum¹, Shaista Mahfooz², Akil Ahmad Khan³, Azahar Sajjad^{*3}

¹Department of Chemistry, Gandhi Faiz-e-Aam College, Shahjahanpur, U.P. India

²Department of Tahaffuzi wa Samaji Tib, State Takmeel-ut-Tib College and Hospital, Lucknow, U.P. India

³Department of Botany, Gandhi Faiz-e-Aam College, Shahjahanpur, U.P. India

ARTICLE INFO

Published: 24 May. 2026

Keywords:

Flavonoids, Quercetin,
Biosynthesis and
Pharmacological properties

DOI:

10.5281/zenodo.20366492

ABSTRACT

Quercetin belongs to flavonol class of flavonoid present naturally in many beverages, fruits and vegetables including red wine, tea, many nuts, apples, berries, broccoli, cabbage, cauliflower, and most prominently in onion. It is also found in Ginkgo biloba, an important medicinal plant. Quercetin is a cytotoxic compound and popularly known for its high antioxidant nature. In present day, many popular cosmaceutical and nutraceutical products contain quercetin as major ingredients for health benefits. In the present study, the general properties of flavonoids along with biosynthesis, pharmacological and biological activities of quercetin mainly enlightened with anti-inflammatory, antioxidant, antidiabetic and antimicrobial action are discussed. Furthermore, it has been revealed that quercetin alone as well as chelation with metal ions and polymers, effectively behaves as significant antidiabetic agent and ultimately provide a new clinical remedies and pharmaceutical approach of quercetin.

INTRODUCTION

The diversity and number both of chronic diseases are increasing day by day due to unhealthy and damaging habit change in the lifestyle and in the environment as well. Poor eating habits, intake of food deficient in vitamins, fibres and rich in fat, carbohydrates further magnify the above effects.

Furthermore, increased vogue of processed foods is another factor contributing to this phenomenon. Physician and nutritional experts have been trying hard to overcome the situation by educating the public as well as food producers are taking some corrective measures by offering their products with appropriate concentration of biologically active compounds. There are large numbers of

***Corresponding Author:** Azahar Sajjad

Address: Department of Botany, Gandhi Faiz-e-Aam College, Shahjahanpur, U.P. India

Email ✉: azaharsajjad@gmail.com

Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.



investigations and researches proving the potential of plants as a safer and more natural option with fewer or no side effects in comparison to regular synthetic pharmaceutical products for the treatment and for the cure of many ailments including chronic one. In this regard, plant based bioactive products provide appreciative and laudable solutions for treating many chronic ailments. In the last few decades, improvements in techniques and researches have authenticated the effectiveness of natural products making them more reputable. According to some estimate, massive population of world relies on traditional plant-based medicines for their primary healthcare. About 100,000 plant-derived chemicals have been reported to show interesting biological activity and may be useful in the treatment of human ailments (Sajjad, 2019a; 2019b; Yunusoglu et al., 2025). In plants, large numbers of primary as well as secondary metabolites are produced. Primary metabolites are used up by the plant for their metabolic activities itself while the secondary metabolites are utilized for several other activities either in-situ or ex-situ. About 100,000 secondary metabolites are synthesized by different pathways in various plant species. Secondary metabolites are grouped into three categories such as terpenes (isoprenoids), phenolic compounds (flavonoids) and nitrogen containing (alkaloids, glucosinolates). Phenolic compounds are significantly important and largely spotted by the researchers in the recent years, which are highly diversified with respect to their chemical structures and properties ranges from phenolic acids to tannins, the former is simple while the latter is very complex in nature. These compounds are not essential nutrients but their role as pharmacological active constituents make them super nutrients for the health benefits (Lakhan Pal and Rai, 2007).

Flavonoids mainly present as aglycone, methylated as well as glycosides derivatives are one of the most prominent and highly potent plant originated compounds. Mainly scientific studies on flavonoids are centred disproportionately towards the quercetin because it is the most extensively studied flavonoids due to its availability, easy extraction and detection as well as the pharmacological activities. In present communication efforts have been made to concisely report the significance of potential therapeutic effect of quercetin with especial reference to antidiabetic, antioxidant, antimicrobial and anti-inflammatory Activity (Chen et al., 2023).

Flavonoids

Flavonoid structurally consists of 15-carbon atoms in its structure in which two phenyl rings (ring A and ring B) linked with ring C having oxygen as a hetero atom. The general structure of flavonoid is depicted in figure 1.

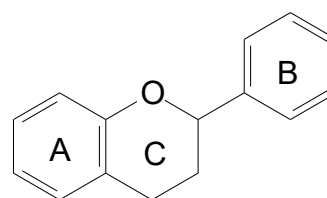


Figure 1: Basic structure of flavonoid

The nature and characteristics of flavonoids which make them the largest and most diversified group of phytochemicals depends on various factors including number of hydroxyl group present in the structure, their degree of hydroxylation, methyl group attached to the aromatic ring B, the nature of carbon atom present in ring C (Ahmed et al., 2016; Kumar and Pandey, 2013; Hasnat et al., 2023). Biosynthesis of flavonoids is given in figure 2.

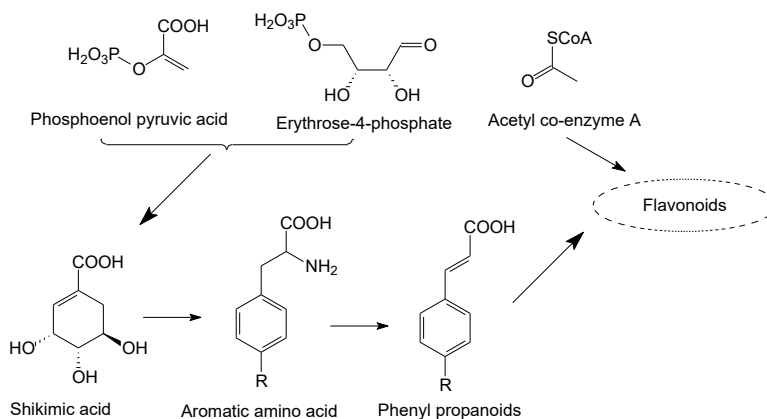


Figure 2: Biosynthesis pathway for flavonoids

Flavonoids are classified mainly into the six subclasses (Figure 3) based on the degree of unsaturation and oxidation of heterocyclic ring (Chen et al., 2023, Hasnat et al., 2023).

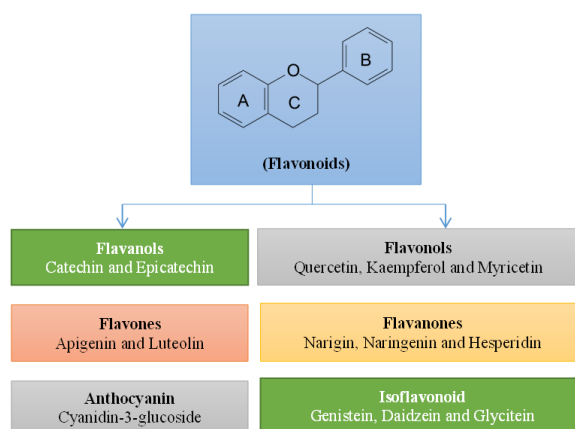


Figure 3: Classification of Flavonoids

QUERCETIN

Mainly studies on flavonoids are prejudice to focus on quercetin because it is the most widely distributed and extensively studied flavonoid due to its availability, easy extraction and detection as well as the pharmacologically most active compound among the flavonoids. (Alrawaiq and Abdullah, 2014; [Barazesh](#) et al., 2026)). Its powerful antioxidant and anti-inflammatory activities are well documented and are thought to play a critical role in treating and protecting many chronic diseases including diabetes, cancer, neurodegenerative and cardiovascular diseases

(Eid and Haddad 2017). The quercetin occurs naturally and abundantly in many vegetables including onion, broccoli, cabbage, in many fruits such as apples, pears, berries etc. and in many beverages such as tea. Quercetin has been the subject of much research in the last few decades. The name quercetin derives from the Latin word quercetum, which means Quercus (oak) (Yunusoglu, 2022; Yunusoglu et al., 2025). Some possible activities of quercetin are given in figure 4.

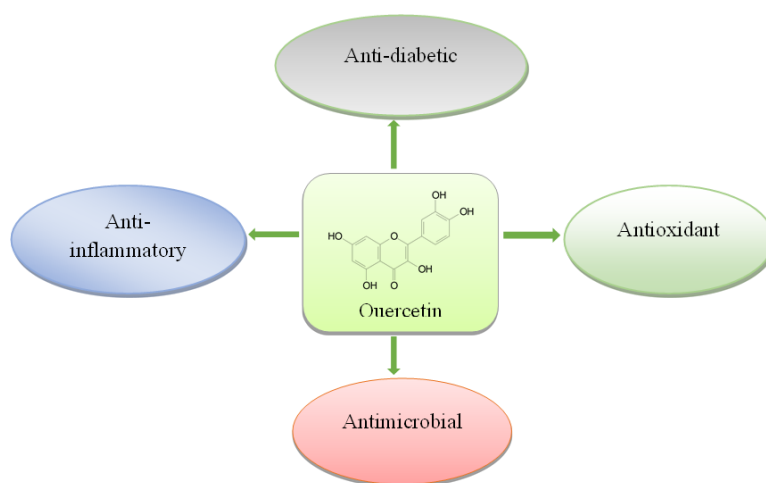


Figure 4: Structure of quercetin along with some pharmacological applications

Chemistry Of Quercetin

Quercetin is a crystalline, yellowish compound, which has less solubility in hot water, insoluble in cold water, however easily soluble in alcoholic solvent and also has bitter taste. Structurally it consists of two benzene rings which are linked by a heterocyclic pyrene ring containing oxygen to form quercetin. Quercetin is 3, 5, 7, 3', 4'-pentahydroxyflavone with chemical formula $C_{15}H_{10}O_7$. The presence of five hydroxyl (-OH) groups at positions 3, 5, 7, 3', and 4', carbonyl group (4-oxo) at the C4 position and a double bond between C2 and C3 and the most importantly, the catechol structure (two adjacent hydroxyl groups) on the B-ring are the key to its diverse biological activities such as anti-inflammatory, anti-cancer, cardiovascular activities, anti-tumor, antiviral, anti-diabetic, anti-hypertensive, and gastroprotective effects including antioxidant and for scavenging free radicals (Lakhanpal and Rai, 2007; Mohammad et al., 2023; Carrillo-Martinez et al., 2024).

Biosynthesis Of Quercetin

Glycolytic and Shikimic acid pathways provide the basic steps for the synthesis of secondary metabolites. Shikimic acid and glycolytic pathways are the initial steps for secondary

metabolite synthesis. Flavonoids synthesis occurs at the intersection of these two pathways. The pathway by which the synthesis of quercetin occurs is known as phenylpropanoid pathway. The generation of p-coumaroyl-CoA is done by shikimic acid pathway while the acetate pathway is responsible for elongation of C2-chain. The noted key enzymes catalysed the different steps of quercetin biosynthesis pathway is listed below:

1. Phenylalanine Ammonia-Lyase (PAL)
2. Cinnamic Acid 4-Hydroxylase (C4H)
3. 4-Coumaric Acid: CoA ligase (4-CL)
4. Chalcone Synthase (CHS)
5. Chalcone Isomerase (CHI)
6. Flavanone -3- β -Hydroxylase (F3H)
7. Flavonol-3'-Hydroxylase (F3'H) and
8. Flavonol Synthase (FLS).

These enzymes are responsible for catalysis of the individual step and successively modify this structure, creating naringenin, dihydrokaempferol, dihydroquercetin, and finally quercetin. The

details of pathway of quercetin biosynthesis are given in figure 5.

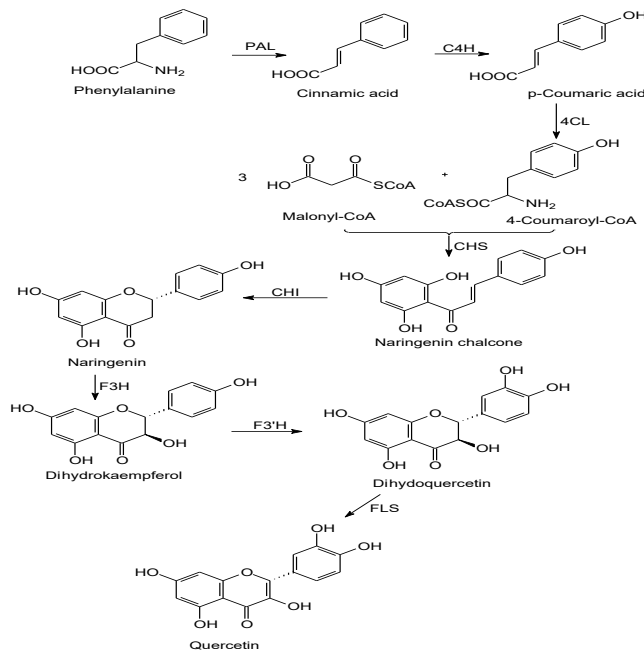


Figure 5: Biosynthetic pathway of quercetin (Chen et al., 2023; Frent et al., 2024)

Pharmacological Activity And Possible Mechanisms Of Action

Antioxidant Activity

Antioxidants are the compounds highly effective in reducing the reactive oxygen species (ROS) and free radicals and the quercetin is one of them. Increase of ROS and free radicals are the main cause oxidative stress. Various diseases which are chronic in nature such as Alzheimer's disease, Parkinson's disease, cardiovascular disease and cancer are directly related to an imbalance created between the body's natural antioxidant defence systems and harmful free radicals. Antioxidants as supplement significantly reduce the effects of oxidative stress. A direct correlation between quantity of free hydroxyl groups and scavenging property of quercetin has been stated (Shetti et al., 2025). Several studies revealed the antioxidant characteristic of quercetin. A study by using DPPH (2, 2-diphenyl-1-picrylhydrazyl), lipid peroxidation and FRAP (ferric reducing

antioxidant power) assay test was performed which revealed that the methylated form of quercetin showed highest antioxidant activity by inhibiting lipid peroxidation (Aghababaei and Hadidi, 2023). In another study of the similar nature, the effect of quercetin was tested against lipid peroxidation, hydrogen peroxide and reduced glutathione and was found to have the high antioxidant activity. In another study, it has been revealed that increased ROS level and cell damage due to increased oxidative stress was prevented by quercetin. In a similar study, an increased level of antioxidant enzymes were noted when the rats with prostate cancer were treated with quercetin. It was concluded that by controlling antioxidant enzymes and oxidative stress factors, quercetin acts to prevent the progression of a number of cancers, including liver, lung, colon, prostate, cervical, and breast cancers (Aghababaei and Hadidi, 2023; Mohammed et al., 2023; Shao et al., 2023; Vollmannova et al., 2024).

Antimicrobial Activity

Quercetin is known as highly active antimicrobial agent. The antimicrobial activity of quercetin includes antibacterial, antiviral and antifungal activities. Quercetin inhibited the growth of Gram positive as well as Gram negative bacteria. Quercetin is found to be highly active against almost all the types of bacterial strains. An antibacterial study of quercetin was conducted in China and found that quercetin showed significant antibacterial activity in almost all the tested strains. In another study conducted in Saudi Arabia, it was revealed that quercetin exhibit antimicrobial activity against various strains of bacteria and fungi such as *Cryptococcus neoformans* and *Aspergillus niger* respectively (Abd Allah et al., 2015; Mohammed et al., 2023). The mechanisms of action involved in antibacterial activity of quercetin are the inhibition of nucleic acid formation (e.g. in *Escherchia coli*), disruption of plasma membrane (e.g. *Bacillus subtilis*, *Escherchia coli*, *Salmonella typhimurium*); Inhibition of glutamine synthetase (e.g. *Mycobacterium*), inhibition of β -ketoacyl carrier protein synthases (involved in condensation reaction of bacterial fatty acid synthesis) and suppression of the biofilm. The same effect as quercetin is done by fluconazole drug (Shabir et al., 2022; Azeem et al., 2023). All these mechanisms are based on the solubility of quercetin, its interaction with the bacterial cell and also on the number of hydroxyl group which is present in quercetin. It has also been observed that generally gram negative bacteria are most resistant to quercetin than gram positive bacteria and these variation are mainly due differences present in their cell walls (Baquer et al., 2024; Jaisinghani, 2018).

Anti-Inflammatory Activity

Many studies suggested the role of quercetin as a powerful and highly potent anti-inflammatory agent. There are presence of many pro-inflammatory cytokines including Interleukin-1 beta (IL-1- β), Interleukin-6 (IL-6) and tumor necrosis factor (TNF- α) which causes inflammation in the body. Quercetin hampers the action of these pro-inflammatory cytokines. TNF- α is a primary pro-inflammatory cytokine produced by macrophages to trigger the systemic inflammation and immune responses. TNF- α as a messenger initiates inflammation, induces apoptosis and promotes fever. Excess of TNF- α is also associated with chronic inflammatory diseases like rheumatoid arthritis (RA) and inflammatory bowel disease (IBD). IL-1- β is a central and highly effective pro-inflammatory cytokine generated by activated monocytes, macrophages, and neutrophils. IL-6 cytokine as pro-inflammatory agent plays a key role by triggering the liver to produce C-reactive protein (CRP) which serves as an inflammatory biomarker in the body. Quercetin also reduces inflammation by inhibiting the synthesis of inflammatory enzymes like cyclooxygenase (COX) and lipooxygenase (LOX), similar to (Nonsteroidal Anti-Inflammatory Drugs (NSAIDs) but without significant side effects (Warren et al., 2009; Xiao et al., 2011; David et al., 2016; Shetti et al., 2025; [Barazesh et al., 2026](#)).

Antidiabetic Activity

Diabetes is a metabolic disorder which results due to disturbances in carbohydrate, lipid and protein metabolism. The reason behind these disturbances is stoppage in insulin secretions or an increase in cellular resistance to insulin. Diabetes is becoming day by day a major health issue throughout the world which is the cause of several complications including keto-acidosis, hyperglycemia and hypoglycemia. Quercetin's action as an



antidiabetic agent is well known. The hypoglycemic properties of quercetin have been shown by various experimental studies in different diabetic animal models. It has been reported that quercetin brings about the regeneration of β -cell in pancreatic islets and probably increase the insulin release in streptozotocin-induced diabetic rats suggesting the place of quercetin in noninsulin dependent diabetes (Bose et al., 2018). The main strategies behind the control of diabetes are to prevent the α -amylase and α -glucosidase enzymes (carbohydrate-hydrolyzing enzymes) originate in digestive tract leading to lower post-meal blood sugar levels which are the main cause of this rise in sugar level. It also decreases hepatic glucose output by inhibiting enzymes like glycogen phosphorylase, promoting glycogen synthesis in liver. In various studies, quercetin has exhibited significant inhibition of both alpha-amylase and alpha-glucosidase activities (Yunusoglu et al., 2025) and further more preventing pancreatic lipid peroxidation may protect the pancreas from cellular damage and accordingly increase the insulin production and secretion (Oboh et al., 2016). In a study expression of two crucial enzymes involved in glucose metabolism such as glucokinase and glucose-6-phosphatase were investigated in three groups of rats: a control group of rats, streptozotocin treated group of rats and a group of rats treated with quercetin. The findings of investigation support the effectiveness of quercetin as nutritional supplement, confirming its positive impact on diabetes. (Hemmati et al., 2018; Aghababaei and Hadidi, 2023). There are many secondary complications such as neuropathy, retinopathy, nephropathy; diabetic cataracts develop in people suffering from diabetes due to accumulation of sorbitol in the body which is mainly due to conversion of glucose into sorbitol by enzyme aldose reductase. Quercetin brings down the rise of sorbitol by inhibiting the action of this enzyme. Quercetin may also bring down the

hyperglycemia-induced oxidative stress which reduces the diabetic complications and may therefore be beneficial in the nutritional management of diabetes (Lakhanpal and Rai, 2007).

CONCLUSION

It has been revealed from the systematic studies that quercetin, a type of dietary polyphenol which is the secondary plant metabolites and has promises to inhibit the remarkable level of several chronic ailments. Furthermore, it has been envisaged from the above study that quercetin has potentials of a valuable natural bioactive substances with possible applications in medication. The quercetin rich diet has remarkable potential to prevent several diseases that will help in the improvement of the overall health status of the current population naturally. It will be essential to assess in the future how quercetin based formulations affect the quality attributes of functional foods. In-vivo studies required to be performed to give a hopeful picture for the future.

ACKNOWLEDGMENTS

We are thankful to the authorities of the G.F. College for providing required facilities and inspiration to carry out this study.

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HOW TO CITE: Mohd. Amil Usmani, Abul Hasnat, Kahkashan Begum, Shaista Mahfooz, Akil Ahmad Khan, Azahar Sajjad*, Systematic Studies on Phytochemistry and Pharmacological Effect of Quercetin: A Bio-Flavonoid, *Int. J. of Pharm. Sci.*, 2026, Vol 4, Issue 5, 6476-6484. <https://doi.org/10.5281/zenodo.20366492>

