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Research Article

Formulation and Characterization of Quercetin–Silver Nitrate Complex Using FTIR Analysis

Vinay Kumar Yadav [1], Vikas Kumar [1,2]*, Amita Verma [3]

[1] Natural Product Drug Discovery Laboratory, Department of Pharmaceutical Sciences, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj, 211007, India.

[2] University Centre for Research and Development, Chandigarh University, Gharuan 140413, Punjab, India.

[3] Bioorganic and Medicinal Chemistry Research Laboratory, Department of Pharmaceutical Sciences, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj, 211007, India.

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For Correspondence:

Vikas Kumar, Natural Product Drug Discovery Laboratory, Department of Pharmaceutical Sciences, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj, 211007, India.

Abstract

Quercetin, a flavonoid with potent antioxidant and therapeutic properties, faces limitations due to poor aqueous solubility and bioavailability. This study reports the formulation of a quercetin–silver nitrate complex via a simple solution complexation method using ethanol as solvent in a 1:1 molar ratio. Quercetin was dissolved in absolute ethanol, followed by dropwise addition of silver nitrate solution under stirring at 30–40°C for 3–4 hours, with light protection to prevent photodegradation. The mixture was aged for 12–24 hours, evaporated to dryness, and purified in a desiccator. FTIR characterization confirmed complex formation through shifts in key bands: phenolic O–H stretching (3200–3500 cm^{-1}) broadened due to hydrogen bonding and Ag^{+} coordination; C=O stretching (~1650 cm^{-1}) shifted, indicating carbonyl oxygen involvement; C–O stretches (1200–1300 cm^{-1}) altered, suggesting phenolic group participation; and new Ag–O vibrations (500–700 cm^{-1}) evidenced metal–ligand bonding, primarily via 3-OH/4-C=O chelation or catechol moiety.

Keywords: Quercetin, Silver Nitrate Complex, FTIR Analysis, Colour Change, Complex Formation.

1.INTRODUCTION

In recent years, there has been increasing interest in combining natural bioactive compounds with metal ions to enhance their pharmacological properties. Phytochemicals such as flavonoids possess multiple hydroxyl and carbonyl groups that can interact with metal ions through coordination bonding. The formation of metal–ligand complexes often improves biological activity, stability, and solubility of the parent compound. Among these phytochemicals, quercetin has attracted significant attention due to its strong antioxidant and therapeutic potential[1,2].

Quercetin

Quercetin is a naturally occurring flavonoid widely distributed in fruits, vegetables, and medicinal plants. Chemically, it is a polyphenolic compound with five hydroxyl (–OH) groups and one carbonyl (C=O) group, which makes it capable of chelating metal ions. Quercetin exhibits various pharmacological activities such as antioxidant, anti-inflammatory, antimicrobial, anticancer, and cardioprotective effects. However, its poor aqueous solubility and low bioavailability limit its clinical applications. Therefore, complexation with metal ions is considered an effective strategy to improve its physicochemical and biological properties[3–5].

Silver Nitrate

Silver nitrate is an inorganic silver salt widely used in pharmaceutical and biomedical applications due to its well-known antimicrobial properties. It readily dissociates in aqueous medium to release silver ions (Ag^{+}), which can interact with functional groups of organic molecules. Silver ions exhibit strong affinity toward oxygen-donor ligands such as hydroxyl and carbonyl groups present in quercetin, enabling the formation of a stable coordination complex[6].

Rationale for Quercetin–Silver Complex Formation

The formulation of a quercetin–silver nitrate complex is based on the principle of coordination chemistry, where quercetin acts as a ligand and silver ion acts as a central metal ion. The hydroxyl groups at positions 3, 5, 7, 3′, and 4′ and the carbonyl group at position 4 of quercetin provide binding sites for silver ions. Complex formation may enhance antimicrobial efficacy due to the synergistic effect of quercetin and silver. Additionally, metal complexation may improve stability, reduce degradation, and modify solubility characteristics of quercetin[7].

Objectives of Formulation

The primary objective of formulating the quercetin–silver nitrate complex is to synthesize a stable and reproducible coordination compound under controlled laboratory conditions. The formulation process generally involves dissolving quercetin in a suitable solvent (such as ethanol or methanol) and reacting it with an aqueous solution of silver nitrate under constant stirring. Parameters such as pH, temperature, molar ratio, and reaction time play crucial roles in determining the efficiency of complex formation. The obtained complex is usually filtered, dried, and stored for further analysis[8].

2. MATERIALS AND METHODS

2.1 Materials

Quercetin was purchased from Sigma-Aldrich. Silver Nitrate was purchased Thermo Electron LLS India Pvt. Ltd. Navi Mumbai and ethanol were used for the synthesis of the quercetin–silver nitrate complex. All other substances used in this study were of analytical purity, and double distilled water was employed.

2.2 Method of Preparation of Quercetin–Silver Nitrate Complex (Using Ethanol as the Solvent)

The quercetin–silver nitrate complex was prepared by a simple solution complexation method using ethanol as the only single solvent. The quercetin- silver complex was prepared in the ratio of 1:1. Accurately weighed quercetin was dissolved in absolute ethanol under constant magnetic stirring at room temperature until a clear yellow solution was obtained. In a separate container, silver nitrate was also dissolved in ethanol with continuous stirring to ensure complete dissolution. The silver nitrate solution was then added dropwise to the quercetin solution under constant stirring to promote complex formation. The reaction mixture was protected from light by covering the container with aluminum foil to prevent photodegradation of silver nitrate and was stirred continuously for 3–4 hours at 30-40 ^{o}C. During this period, a gradual change in the color of the solution from bright yellow to dark yellow or brownish indicated the formation of the quercetin–silver complex through coordination of silver ions with the hydroxyl and carbonyl groups of quercetin.

After completion of the reaction, the resulting solution was allowed to stand for 12- 24 hours to ensure complete interaction between quercetin and silver ions. The solvent (ethanol) was then removed by evaporation at magnetic stirrer at 40-50 C until a semi-solid mass or dry residue was obtained. The obtained product was further dried in a desiccator containing silica gel or anhydrous calcium chloride for 24–48 hours to remove residual solvent and moisture. The dried quercetin–silver nitrate complex was then collected, gently powdered using a mortar and pestle, and stored in an amber-colored glass container to protect it from light and moisture until further characterization[2,7–10].

3 RESULT AND DISCUSSION

3.1 Formation of Quercetin–Silver Nitrate Complex Indicated by Color Change

The formation of the quercetin–silver nitrate complex was indicated by a visible colour change during the reaction. Initially, the ethanolic solution of silver nitrate was colourless. After the addition of quercetin, the solution turned yellow and gradually changed to dark brown upon heating and stirring. This colour change indicates the formation of the quercetin–silver nitrate complex, which was further confirmed by FTIR analysis[11,12].

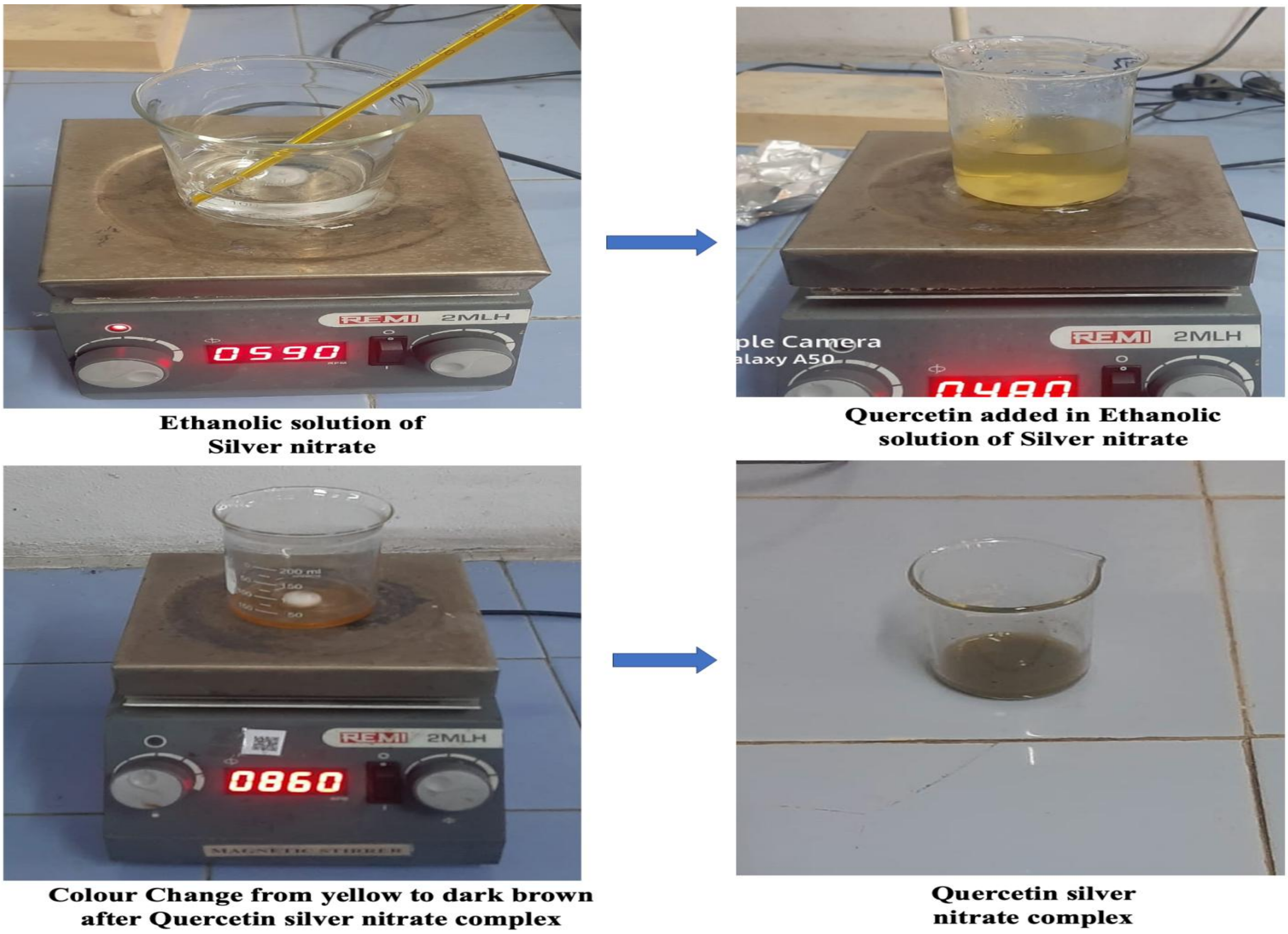

Figure 1. Formation of Quercetin–Silver Nitrate Complex Indicated by Color Change

3.1 FTIR Spectroscopic Characterization of Quercetin and Quercetin–Silver Nitrate Complex

3.1.A FTIR of Quercetin

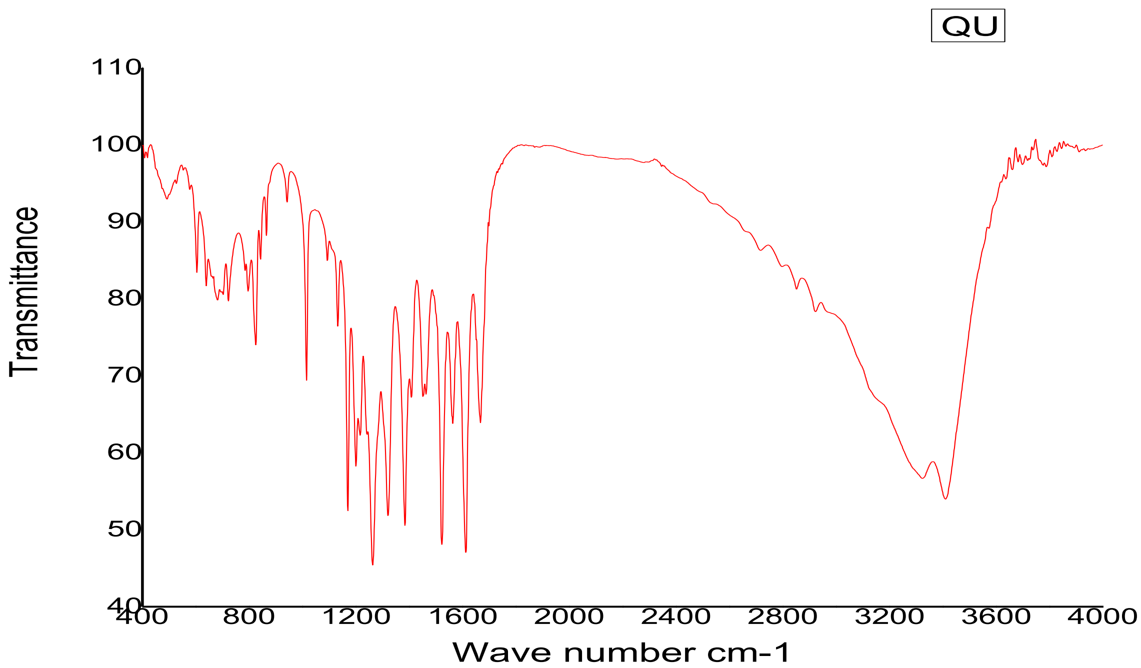

Figure 2. FTIR spectrum of Quercetin

The FTIR spectrum as in figure 2 of quercetin displays a broad, intense absorption band in the region of 3200–3500 cm^{-1}, which is attributed to the stretching vibrations of phenolic –OH groups. The broadening of this peak indicates significant intermolecular hydrogen bonding between the five hydroxyl groups present in the molecule. In the region of 1600–1670 cm^{-1}, a sharp, prominent peak is observed, corresponding to the C=O (carbonyl) stretching of the aryl-ketone group on the C-ring; its slightly lower frequency is due to conjugation with the aromatic system.

The skeletal vibrations of the aromatic C=C rings are clearly identified by multiple sharp peaks between 1450 and 1610 cm^{-1}. Moving into the fingerprint region, the peaks observed around 1310–1380 cm^{-1} denote O-H bending (in-plane), while the strong bands appearing between 1100 and 1260 cm^{-1} are characteristic of C–O–C (ether) stretching and C–OH (phenolic) stretching vibrations. Finally, the peaks below 1000 cm^{-1} represent the C–H out-of-plane bending of the aromatic rings, confirming the specific substitution pattern of the quercetin molecule[13,14].

Table 1: **Major FTIR absorption peaks of quercetin indicating characteristic functional groups.**

S. No	Wave Number cm-1	Assignment	Significance
1	3400 – 3200	O–H Stretching	Phenolic hydroxyl groups with H-bonding
2	1665 – 1610	C=O Stretching	Conjugated carbonyl group (C-ring)
3	1610 – 1450	C=C Stretching	Aromatic ring skeleton
4	1260 – 1160	C–O–C / C–OH	Ether linkages and phenolic C–O stretch
5	930 – 600	C–H bending	Aromatic substitution (out-of-plane)

3.1.B FTIR of Quercetin-Silver nitrate Complex

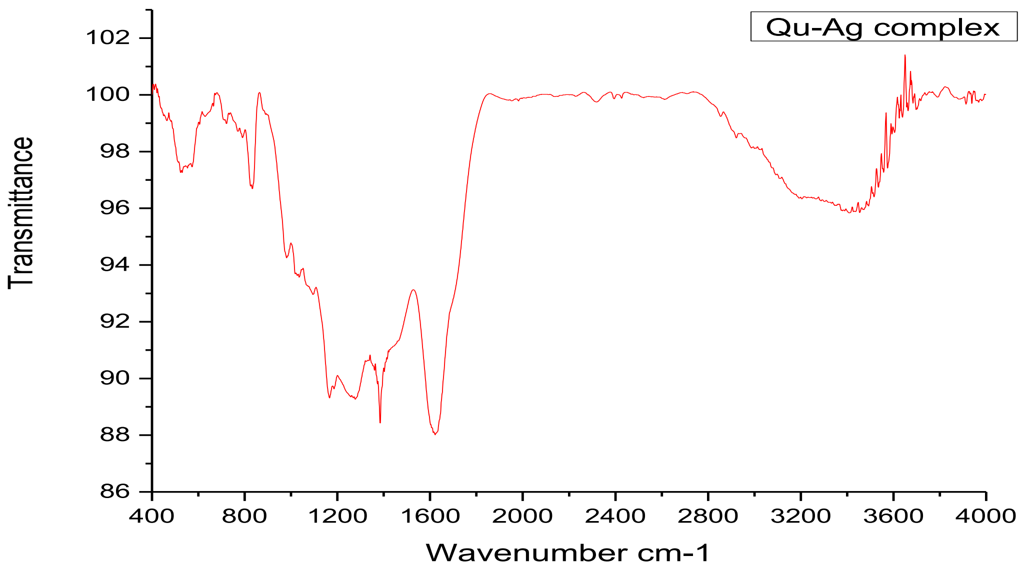

Figure 3. FTIR spectrum of Quercetin–silver nitrate (Qu–Ag) complex

The FTIR spectrum of the quercetin–silver nitrate (Qu–Ag) complex shown in figure 3 confirms the interaction between quercetin functional groups and silver ions through characteristic peak shifts and intensity changes. The broad absorption band observed in the region of 3200–3500 cm^{-1} corresponds to O–H stretching vibrations of phenolic hydroxyl groups, indicating hydrogen bonding and possible involvement of hydroxyl groups in coordination with Ag^{+} ions. A strong band around 1650–1660 cm^{-1} is attributed to C=O stretching of the conjugated carbonyl group (4-oxo group) of quercetin; any shift in this peak compared to pure quercetin suggests coordination through the carbonyl oxygen. Peaks in the range of 1500–1600 cm^{-1} correspond to aromatic C=C stretching vibrations, confirming the flavonoid backbone structure. The bands between 1200–1300 cm^{-1} are assigned to C–O stretching of phenolic and alcoholic groups, and changes in this region further support metal–ligand interaction. Additionally, new or shifted bands in the lower wavenumber region (500–700 cm^{-1}) may be attributed to Ag–O bonding vibrations, confirming complex formation. Overall, the observed peak shifts and band modifications indicate successful chelation of silver ions with quercetin, most likely through the 3-hydroxyl and 4-carbonyl groups or catechol moiety, leading to the formation of a stable Qu–Ag coordination complex[15].

Table 2: **Major FTIR absorption peaks of quercetin–silver nitrate (Qu–Ag) complex indicating characteristic functional groups.**

S.No.	Wave Number cm-1	Assignment	Significance
1	3200–3500	O–H stretching	The broadness suggests extensive hydrogen bonding and the involvement of phenolic groups in Ag^{+} coordination.
2	~1650	C=O (4-oxo group)	A shift here is a "smoking gun" for coordination at the carbonyl oxygen, typically part of the 3-OH/4-C=O chelation site.
3	1500–1600	Aromatic C=C	Confirms the skeletal integrity of the quercetin B and C rings remains intact after complexation.
4	1200–1300	C–O stretching	Changes here point toward the participation of the catechol moiety (3', 4'-OH) or the 5-OH group.
5	500–700	Ag–O vibrations	These low-frequency bands are the most direct evidence of the new metal-oxygen covalent bonds.

4 Conclusion

It was concluded that the formulation and characterization of the quercetin–silver nitrate complex represent an important interdisciplinary approach combining natural product chemistry and coordination chemistry. By understanding the interaction between quercetin and silver ions, improved therapeutic agents with enhanced stability and bioactivity. This study provides a scientific basis for further pharmacological and biomedical investigations of metal–flavonoid complexes. FTIR analysis provides compelling evidence of coordination bonding, with broadening of the phenolic O–H stretch (3200–3500 cm^{-1}), shifts in C=O (~1650 cm^{-1}) and C–O (1200–1300 cm^{-1}) bands, and emergence of new Ag–O vibrations (500–700 cm^{-1}), confirming chelation primarily via the 3-hydroxyl/4-carbonyl site or catechol moiety The observed color progression from yellow to dark brown, alongside controlled reaction parameters 30–40°C, 3–4 hours stirring, light protection, indicates efficient metal–ligand interaction. Future research should explore additional characterizations (e.g., XRD, SEM, UV-Vis) and in vitro/in vivo evaluations of enhanced bioactivity, stability, and toxicity to advance this complex toward pharmaceutical applications.

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Competing Interests: The authors declare that they have no competing financial or non-financial interests related to this work.

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