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Synthesis of Silver Nanoparticles of Cissus Quandrangularis and It's Virtual Screening Against Gastric Cancer

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Abstract

Gastric cancer, also known as stomach cancer, is the third leading cause of cancer-related deaths globally and remains a major health challenge due to its poor prognosis and high mortality, largely attributed to late-stage diagnosis. In this context, plant-based nanomaterials are gaining momentum for targeted therapeutic applications. Cissus quadrangularis, a medicinal plant native to India from the Vitaceae family, is traditionally used for its diverse healing properties. Its stem, in particular, has demonstrated antimicrobial, antioxidant, antiulcer, and cytoprotective effects, including notable protection of the gastric mucosa and aid in bone fracture recovery. Silver nanoparticles (AgNPs), sized below 100 nm in at least one dimension, have emerged as promising nanomaterials due to their distinctive physical, chemical, and biological properties. In this study, AgNPs were synthesized using an eco-friendly green synthesis approach with Cissus quadrangularis stem extract. The nanoparticles were characterized using X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), and UV-visible spectroscopy to confirm their crystalline nature, functional groups, and optical properties. The resulting bio-fabricated AgNPs can be considered as part of a bio-organic nanocomposite system, where plant-derived organic molecules act as stabilizing and capping agents for the metallic nanoparticles. This hybrid composite framework reflects key characteristics of polymer-based materials, offering improved biocompatibility and functional integration for biomedical applications. The synthesized AgNPs were subjected to virtual screening to assess their potential anticancer activity against gastric cancer, indicating promising therapeutic relevance within the domain of polymer-supported nanomedicine.

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Keywords: Cissus quadrangularis, gastric cancer, molecular docking, silver nanoparticles, stomach cancer

INTRODUCTION

Gastric Cancer

Gastric cancer, also known as stomach cancer, stands as the third leading cause of cancer-related deaths globally, posing a significant public health challenge. Despite advancements in medical research, the prognosis for gastric cancer remains poor, primarily due to late-stage diagnoses [1]. The development of gastric cancer is a multifactorial process influenced by a combination of environmental, lifestyle, and genetic factors. One of the significant environmental factors linked to the development of gastric cancer is chronic Helicobacter pylori

infection, which can cause malignant transformation of gastric epithelial cells and induce inflammation in the stomach lining [2]. Gastric cancer exhibits a heterogeneous histological background, comprising multiple subtypes of adenocarcinomas, each with unique clinical behavior and histological features, such as intestinal-type, diffuse-type, and mixed-type adenocarcinomas. This complexity makes the disease more challenging to comprehend and treat [3]. The global burden of gastric cancer varies geographically, with higher incidence rates observed in countries like South Korea, China, and Japan. This variation is influenced by a complex interaction between genetic factors, dietary preferences, lifestyle choices, and H. pylori infection rates [4].

Recent developments in gastric cancer research focus on personalized treatment plans, early detection, and innovative therapeutic agents. The discovery of biomarkers like PD-L1 and HER2 has led to more targeted therapies [5]. Additionally, liquid biopsies, which detect circulating tumor DNA and other biomarkers in the blood, offer a less invasive and potentially more precise method for diagnosing and monitoring the disease. Advances in understanding the tumor microenvironment, particularly the role of the gut microbiome, are also contributing to new insights into gastric cancer pathogenesis and treatment strategies [6]. The evolving landscape, nanotechnology, especially bio-based nanocomposite systems is gaining attention for its ability to deliver targeted therapies with minimal side effects. Functionalized silver nanoparticles synthesized from plant extracts offer an organic-inorganic hybrid system that mimics polymer-composite behavior and holds promise for future cancer theranostics.

Causes of Gastric Cancer

Gastric cancer, also known as stomach cancer, arises from a complex interplay of genetic, environmental, and behavioral factors. While the precise causes can vary, several key contributors have been identified:Helicobacter pylori Infection: Chronic infection with Helicobacter pylori is a significant risk factor for gastric cancer. This bacterium can cause persistent inflammation in the stomach lining, leading to changes that may increase cancer risk over time. Infections are often acquired in childhood and are more prevalent in regions with poor sanitation and hygiene [7].

Dietary Factors: Diet plays a crucial role in gastric cancer risk. High consumption of processed meats, pickled vegetables, and salt-preserved foods has been linked to an increased risk. Conversely, diets rich in fruits and vegetables, particularly those high in antioxidants, may offer protective effects [8].

Alcohol and Tobacco Use: Excessive alcohol consumption and tobacco smoking are established risk factors for gastric cancer. These substances can irritate and damage the stomach lining, leading to chronic inflammation and increased cancer risk [9].

Genetic Predisposition: Genetic factors also contribute to gastric cancer risk. Individuals with a family history of the disease, especially first-degree relatives, have a higher risk. Specific genetic syndromes, such as Lynch syndrome and hereditary diffuse gastric cancer (HDGC), are associated with an increased risk due to inherited mutations [10].

Recent research in materials science reveals that innovative gastric cancer drug delivery systems now integrate both biodegradable polymer composites and sustainably synthesized nanomaterials for more effective and eco-conscious targeting. These hybrid systems enhance biocompatibility and therapeutic efficiency, offering a sustainable and targeted approach to managing cancer progression.

Understanding these factors is essential for developing effective prevention, diagnostic, and treatment strategies for gastric cancer.

Pathway of Gastric Cancer

The initiation of gastric cancer is characterized by the accumulation of genetic and epigenetic alterations that disrupt normal cellular homeostasis and promote malignant transformation [11-23]. The

transformation is further influenced by the tumour microenvironment, where interactions with immune cells, extracellular matrix components, and oxidative stress conditions play a critical role. In this context, engineered nanocomposites such as plant-mediated silver nanoparticles are being explored for their ability to modulate tumour signalling pathways and selectively target cancer cells. Their composite structure, combining metallic cores with organic surface functional groups, offers a polymer-composite-like platform with dual diagnostic and therapeutic capabilities.

METHODOLOGY

Collection of Plant Sample

Cissus quadrangularis, a plant known for its medicinal properties, was collected from various locations around Chennai during January 2024.

Extraction Process

The collected leaves of *Cissus quadrangularis* were shade-dried to remove moisture content and ground into a fine powder using a stainless-steel grinder. The extraction was performed using the thermal agitation method, where the powdered plant material was mixed with a mid-polar solvent (water) in ratios of 1:9 and 2:8. The mixtures were incubated in a shaker at 37°C for 24 hours. After incubation, the mixtures were filtered, and the extracts were stored in sealed containers for further use.

Synthesis of Silver Nanoparticles

Silver nanoparticles (AgNPs) were synthesized using a green synthesis approach, which is an eco-friendly and cost-effective method. In this process, the plant extract served as both a reducing and stabilizing agent, eliminating the need for toxic chemicals. The synthesis was carried out by adding 50 µL of the plant extract to a 1 mM silver nitrate solution, maintaining the mixture at a 1:9 ratio with distilled water. The reaction was allowed to proceed at room temperature for 24 hours. The formation of AgNPs was monitored by observing a colour change and confirmed using UV-Vis spectroscopy, which typically shows a peak around 430–450 nm due to surface plasmon resonance.

The synthesized nanoparticles were characterized using various techniques, including scanning electron microscopy (SEM), transmission electron microscopy (TEM), and Fourier-transform infrared spectroscopy (FTIR), to determine their size, shape, and functional groups. The green synthesis technique not only ensures environmental safety but also results in the development of a bio-inspired nanocomposite system. The interaction between phytochemicals in the plant extract and silver ions leads to the formation of a surface-functionalized nanoparticle, resembling the structure and stability seen in polymer-based composite materials. These nanoparticles can be categorized as organic-inorganic hybrid nanocomposites, where the plant-derived capping agents act similarly to polymeric matrices, enhancing dispersion, stability, and bioactivity.

The method offers a sustainable alternative to traditional chemical synthesis, producing nanoparticles with potential applications in various fields, including medicine, environmental remediation, and polymer composite-based biomedical systems.

Stability of Silver Nanoparticles (AgNPs)

The stability of silver nanoparticles (AgNPs) is critical for their effective application across various fields, including biomedicine, electronics, and catalysis. Several factors influence the stability of AgNPs, such as their size, shape, surface chemistry, and the surrounding environment. Due to van der Waals forces and electrostatic interactions, AgNPs tend to agglomerate, which can compromise their functionality and efficacy. To counteract this tendency, stabilizing agents like polymers, surfactants, or ligands are often employed during synthesis to coat the nanoparticle surface and prevent aggregation. These stabilizing agents create a protective barrier around the AgNPs, inhibiting their agglomeration and ensuring long-term stability. Moreover, controlling synthesis parameters, such as temperature, pH, and reaction time, allows researchers to fine-tune the properties of AgNPs and enhance their stability.

Surface modifications and functionalization techniques further contribute to stabilizing AgNPs by improving their compatibility with specific environments or target applications. Overall, achieving and maintaining the stability of AgNPs is crucial for maximizing their potential in various technological advancements, from advanced drug delivery systems to high-performance electronic devices [24].

RESULTS

Extraction Process

The collected plant source leaves of *Cissus quadrangularis* was shade dried. The plant extract was mixed with mid-polar solvent (water) with the ratio of 1:9 and 2:8. The mixture was kept in incubator shaker for 24 hours. After 24 hours the mixture was filtered and stored in a container.

Synthesis of Silver Nanoparticles

The sample was made up into 1:9 and 2:8 ratio with distilled water. 50µl of AgNPs is added in both mixture and left the mixture undisturbed for 24 hours as shown in figure 1 (Original work)."

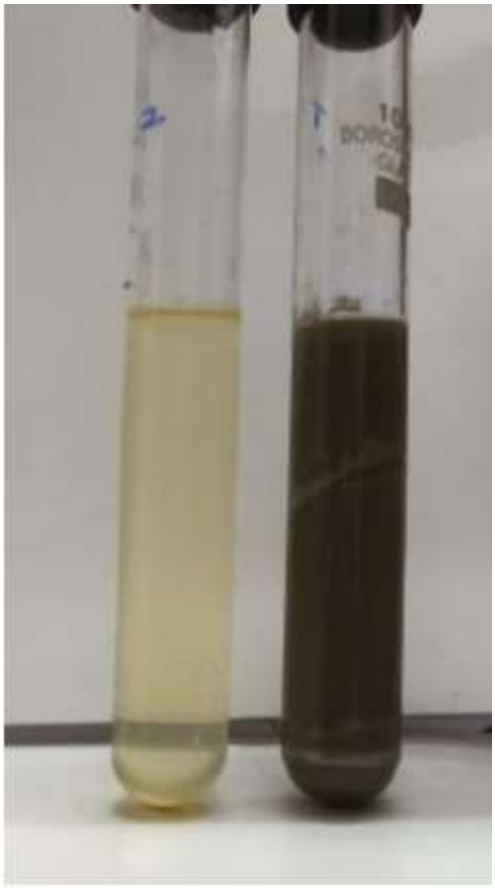


Figure 1. Synthesis of nanoparticles

Stability

The stability of silver nanoparticles (AgNPs) is fundamental for their widespread applications across various industries, including biomedicine, electronics, and catalysis. AgNPs' stability is influenced by multiple factors, including their size, shape, surface chemistry, and the surrounding environment. AgNPs tend to agglomerate due to van der Waals forces and electrostatic interactions, which can compromise their functionality and efficacy. To check the stability of AgNPs, readings were taken at different duration such as 24hours, 48hours, 72hours, 96hours and 120hours. The graph for stability of sample observed in UV visible spectroscopy at different time interval was shown in figure 2, 3 and 4 respectively (Original work)."

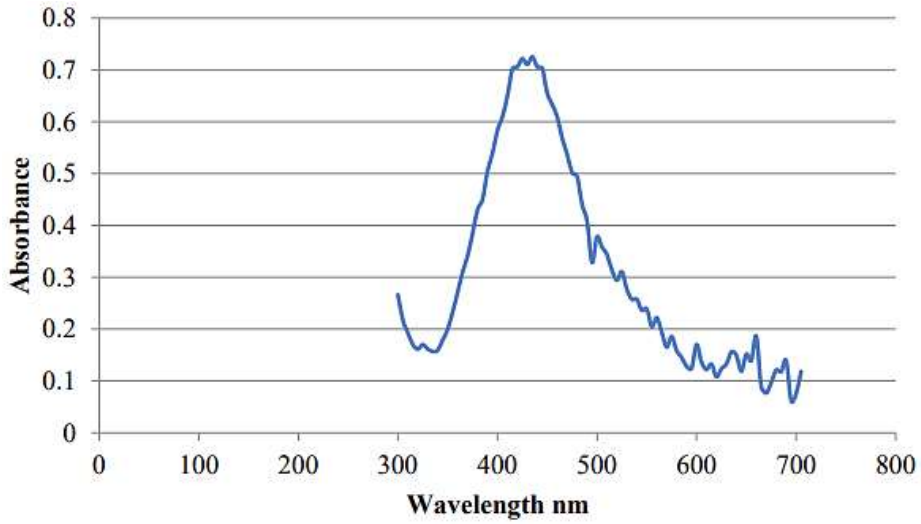


Figure 2. Graph for stability of sample at time interval 24 hours and peak was 435nm

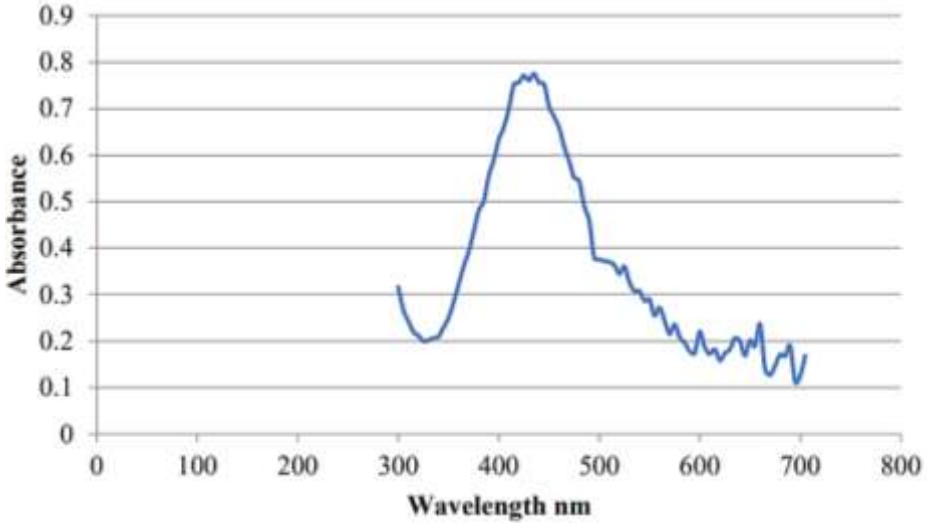


Figure 3. Graph for stability of sample at time interval 72 hours and peak was 435nm

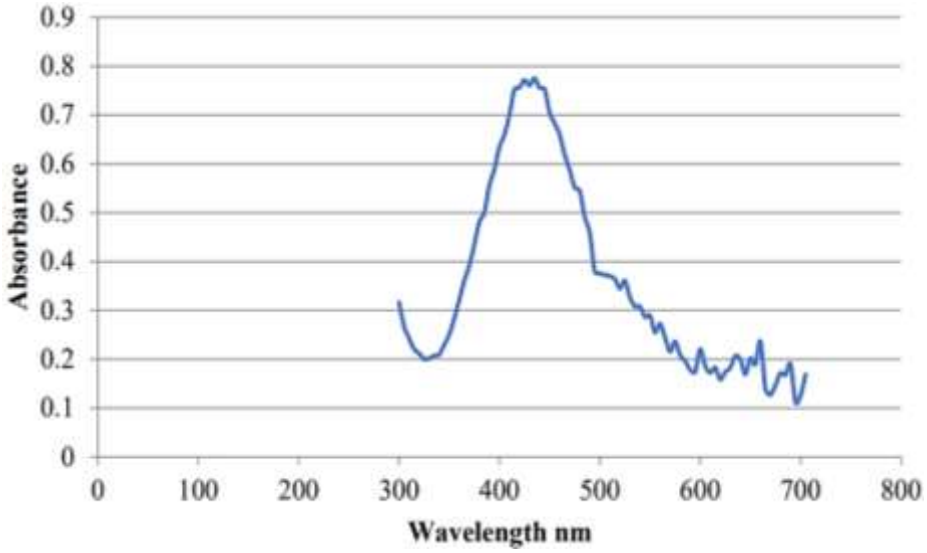


Figure 4. Graph for stability of sample at time interval 120 hours and peak was 435nm

Characterization of UV Spectrophotometer Analysis

An essential tool in analytical chemistry, a UV spectrophotometer measures how much visible and ultraviolet light a substance absorbs. UV spectrophotometry uses the idea that molecules absorb particular light wavelengths because of electronic transitions to allow for the quantitative examination of chemicals based on their absorbance spectra. These devices usually include a light source, a sample holding, a detector, and a monochromator to separate out particular wavelengths. UV spectrophotometers are widely used in many different sectors, including biochemistry, environmental science, and pharmaceuticals. UV spectrophotometry plays a critical role in pharmaceutical analysis by measuring the concentration of active medicinal components in formulations and identifying contaminants. It facilitates the measurement of pollutants and toxins in air, water, and soil samples used in environmental monitoring.

The peak was attained at wavelength of 435 nm Confirms the synthesis of silver nanoparticles, as the characteristic absorption peak for silver nanoparticles falls between 400-420 nm. Therefore, a peak at 435 nm is considered a strong indication of the presence of silver nanoparticles. The graph for characterization of silver nanoparticles using UV spectroscopy is shown in figure 5 (Original work).”

UV-Vis spectroscopy also serves as a critical tool for monitoring the surface plasmon resonance behavior of embedded nanoparticles. The absorption properties not only confirm nanoparticle formation but also provide insights into the dispersion, capping efficiency, and stability of organic-inorganic hybrid systems, such as those derived from plant-mediated nanoparticle synthesis. These hybrid nanostructures behave similarly to polymer composites, offering multifunctional potential in optoelectronics and biomedical fields.

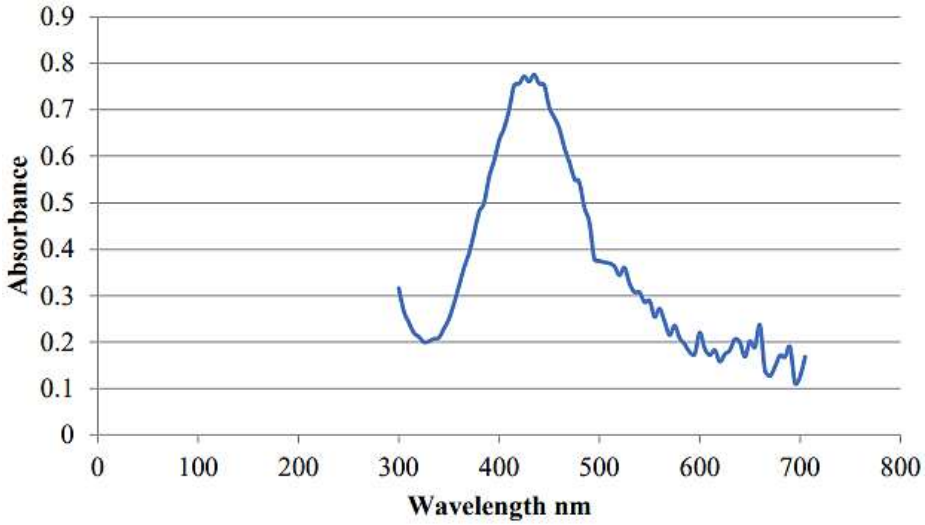


Figure 5. Graph for characterization of silver nanoparticles using UV spectroscopy and peak was 435nm

FT-IR Analysis

FTIR spectroscopy, or Fourier Transform Infrared spectroscopy, is a flexible analytical method that may be used to find chemical bonds and functional groups in a variety of materials. FTIR measures the absorption of infrared light as it interacts with a sample and yields important details on the molecular makeup and structure of various materials. The method is based on the idea that various chemical bonds absorb infrared light at distinctive frequencies, giving each compound a distinct spectral pattern. Forensic analysis, quality control, and research can all benefit from the non-destructive nature of FTIR analysis and its low sample preparation requirements. FTIR is used in the pharmaceutical industry to confirm the identity and purity of a drug's active components. It aids in clarifying the molecular structure of polymers and tracking alterations throughout. FT-IR spectra of silver nanoparticles exhibited

prominent peaks at 2547, 2100 and 1459 cm−1. FT-IR analysis shows the presence of stretching thiol compounds, strong isothiocyanate and medium alkane compounds.

FTIR plays a crucial role in identifying organic functional groups that contribute to the stability and bioactivity of nanocomposites. The presence of such groups in the synthesized silver nanoparticles confirms their composite-like structure, where the organic (plant-based) and inorganic (silver) components work synergistically similar to polymer matrix composites. This hybrid nature enhances not only structural integrity but also the biomedical relevance of the nanoparticles in therapeutic applications.

The result of FTIR analysis with peak wavelength and bond present in it is tabulated in table 1 (Original work)" and the graph was visualized in figure 6 (Original work)."

Table 1. Result of FT-IR analysis with wavelength and bond present in it.

Wavelength	Bond
2547 cm-1	Weak S-H
2100 cm-1	Strong N=C=S
1459 cm-1	Medium C-H

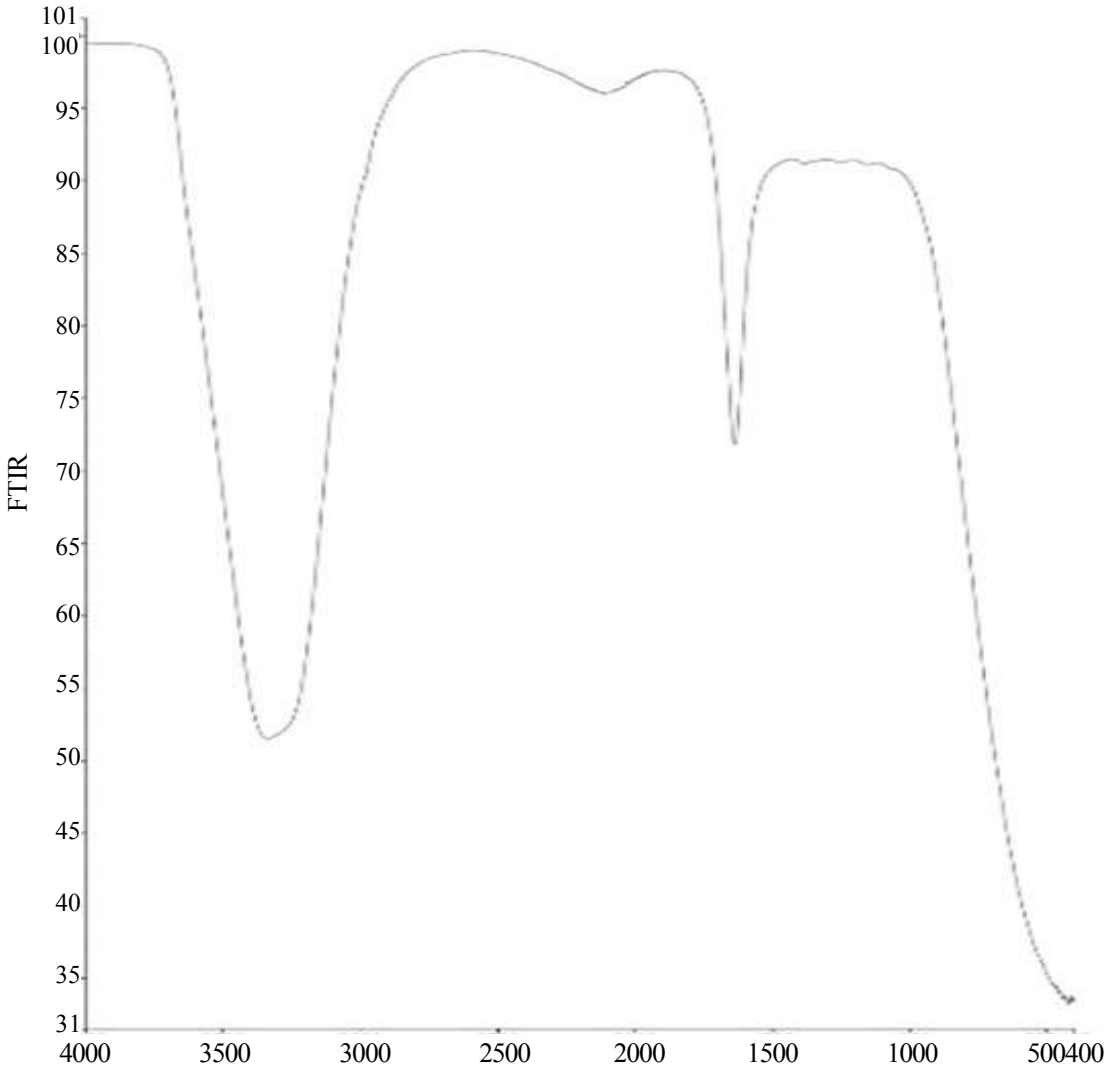


Figure 6. Graph of FT-IR analysis of silver nanoparticles

X-ray Diffraction Analysis

In materials research, X-ray diffraction is a potent method for figuring out a crystalline material's atomic and molecular structure. Diffraction patterns are produced when a crystalline sample is subjected to constructive interference by an X-ray beam. Since these patterns are specific to each crystal structure, X-ray diffraction is a useful technique for identifying and researching previously unidentified materials. The arrangement of atoms within the crystal lattice is represented by peaks at particular angles, or Bragg peaks, that appear in the diffraction pattern created by X-rays. Researchers can infer details about the distances between atoms, the symmetry of the crystal lattice, and the general structure of the material by examining the intensity and location of these peaks. The graph of X-ray diffraction analysis is visualized in figure 7 (Original work).”

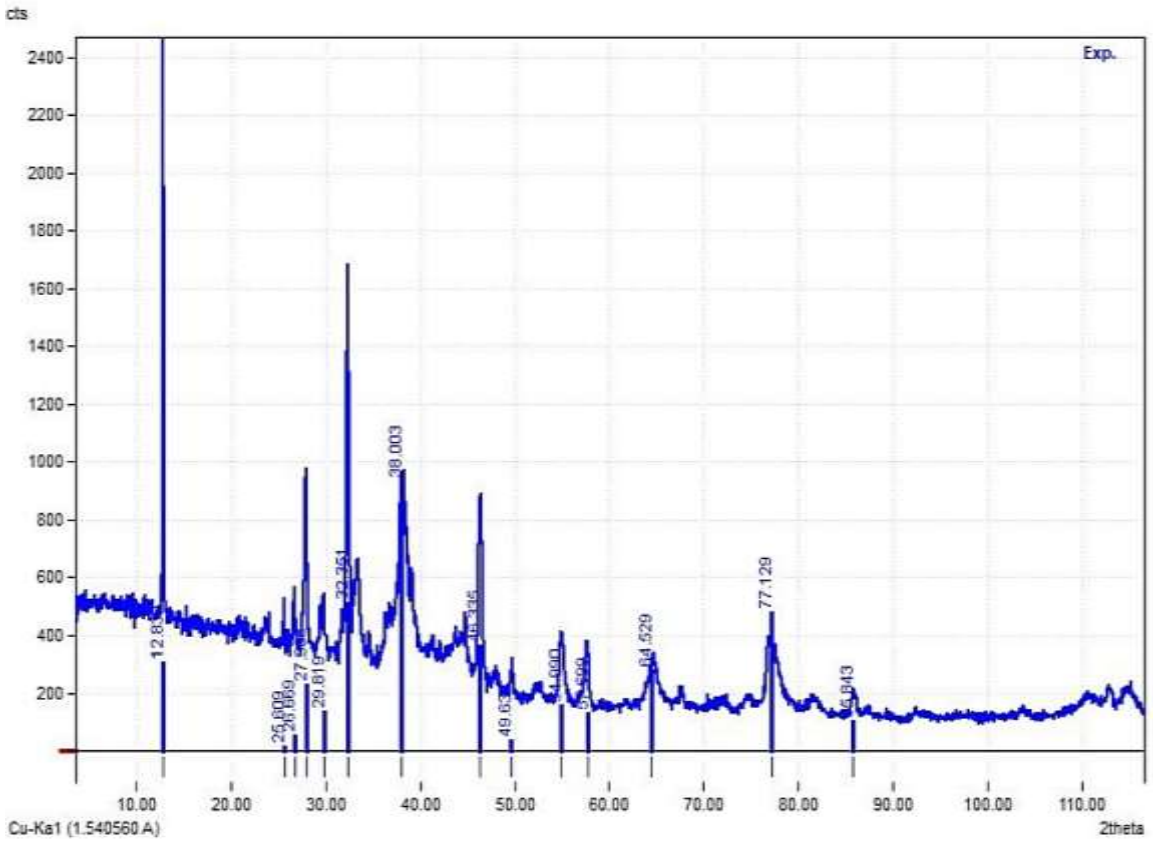


Figure 7. The graph of peak from X-ray diffraction

VIRTUAL SCREENING

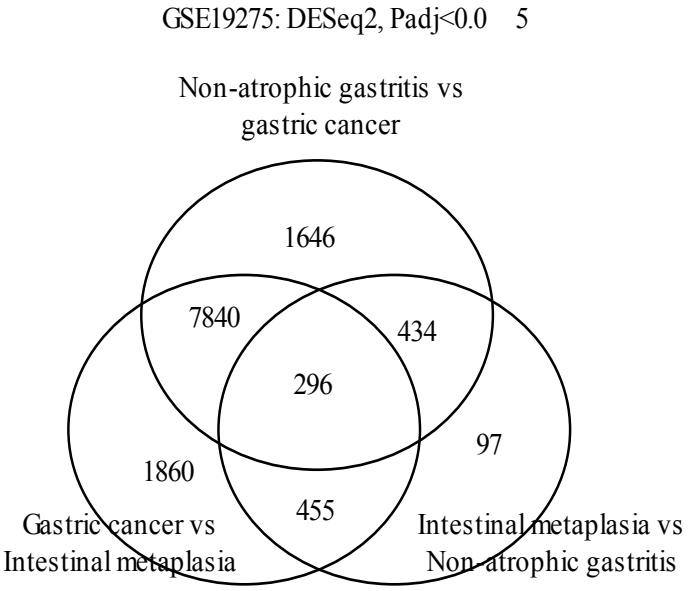
Protein Selection

Gene expression data retrieval: Gene expression data were retrieved from Gene Expression Omnibus (GEO) database with accession number of: GSE191275. This data consists of expression data from gastric tissues with non-atrophic gastritis, intestinal metaplasia and gastric cancer. The expression data consist of 30 samples collected from different patients with non-atrophic gastritis, intestinal metaplasia, and gastric cancer. Each contains 10 samples and were segregated into groups for further analysis. Identification and analysis of differently expressed gene using GEO2R tool: Benjamini and Hochberg method is employed for the adjustment of P-values, with cut-off of 0.05. over 500 defective genes were obtained and used for STRING analysis. Venn diagram and boxplot diagram for the accession number GSE191275 were visualized in figures 8–10 [25],[26],[27].”

String analysis for protein-protein interaction: The list of defective gene from the GEO2R tool analysis was made as input in STRING server to find protein-protein interaction among them. The gene

set were converted into suitable proteins. Above 250 different interactions were obtained from STRING analysis, the interaction is visualized below in figure10 and then converted into nodes for cytoscape analysis.

Protein structure retrieval: The three-dimensional structure pf four defective gene from MCC, degree, closeness and betweenness algorithm were obtained from Protein data. The gene network interaction for the respective algorithms along with their rank table were visualized in figure 11 (MCC network) [27].", 12, 13, and 14 respectively and tabulated below in table 2, 3, 4 and 5.



Total: 19134

Figure 8. Venn diagram from GEO2R analysis of accession number GSE191275

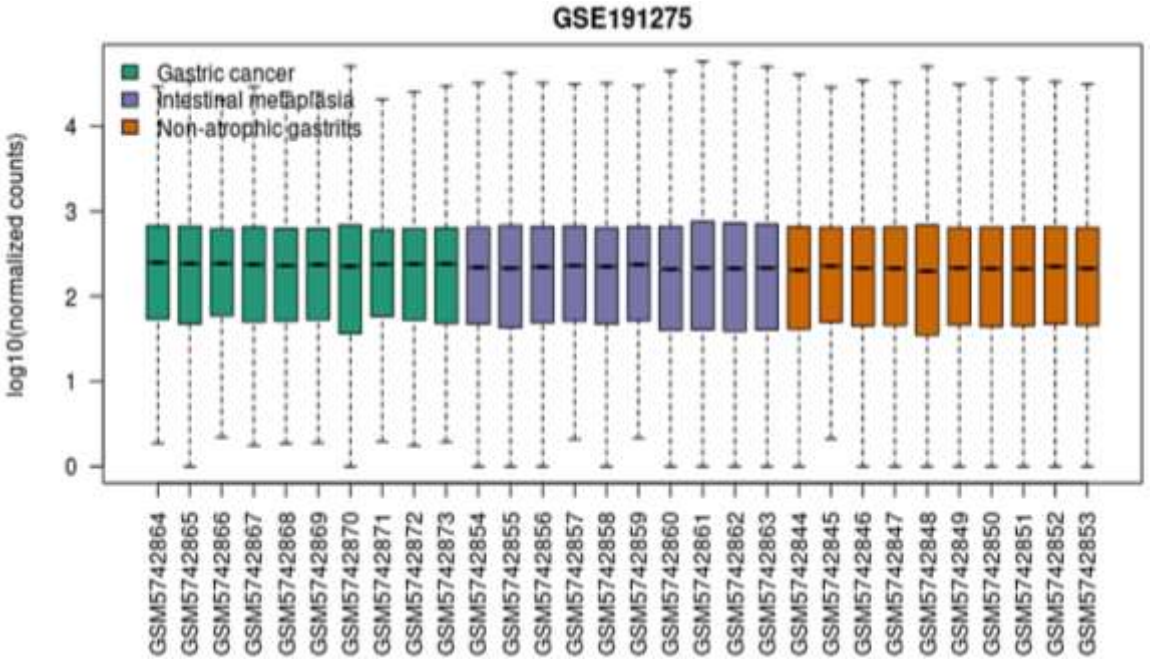


Figure 9. Box plot diagram of GEO2R analysis of accession number GSE191275

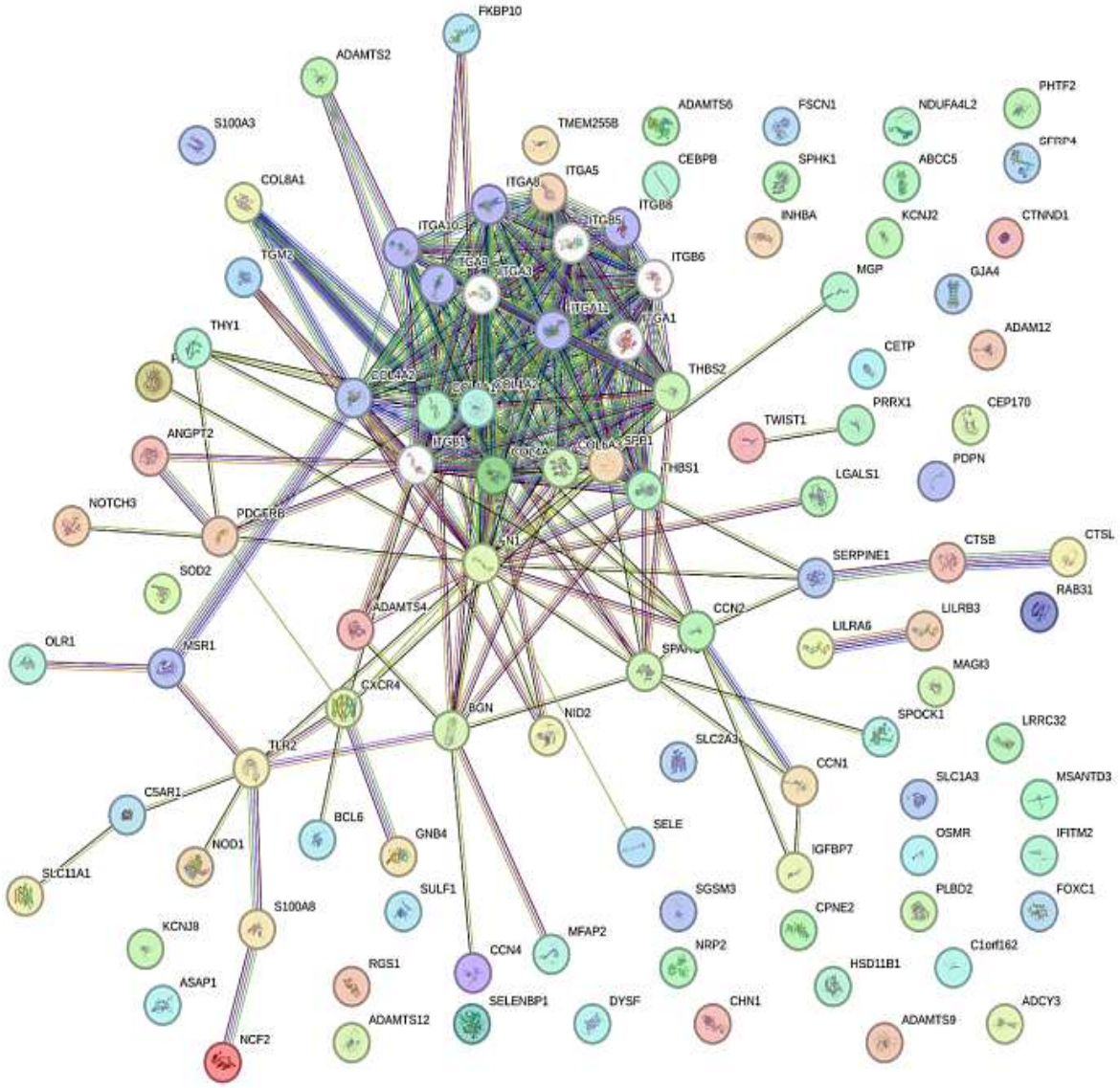


Figure 10. Protein-Protein interaction from STRING analysis

Local Method

Maximum clique centrality (MCC)

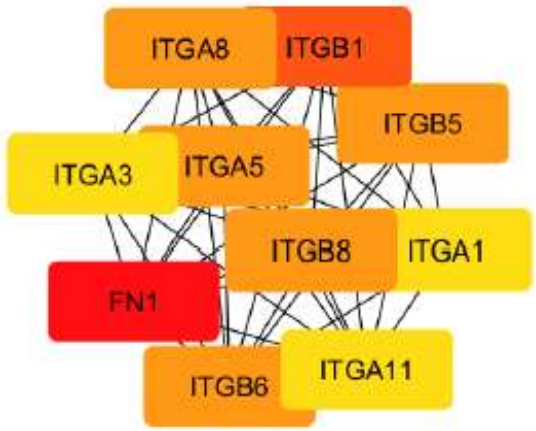


Figure 11. Gene network from MCC algorithm [27].

Table 2. Gene ranking from MCC algorithm [27].

Rank	Name
1	FN1
2	ITGB1
3	ITGB8
3	ITGA8
3	ITGB6
3	ITGB5
3	ITGA5
8	ITGA3
8	ITGA1
8	ITGA11

Degree (Deg)

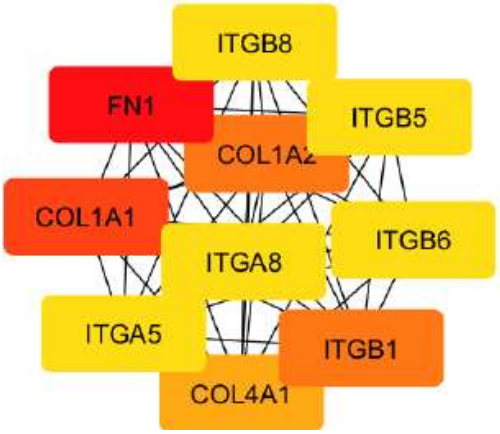


Figure 12. Gene network from Deg algorithm [27].

Table 3. Gene ranking from Deg algorithm [27].

Rank	Name
1	FN1
2	COL1A1
3	COL1A2
3	ITGB1
5	COL4A1
6	ITGB8
6	ITGA8
6	ITGB6
6	ITGB5
6	ITGA5

Global Method

Closeness (Clo)

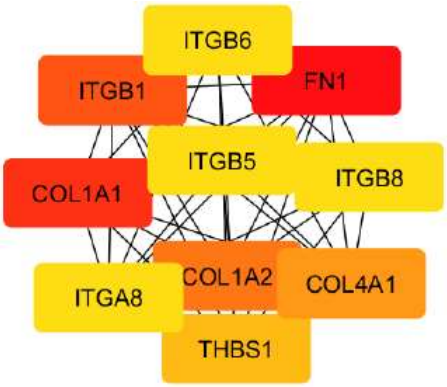


Figure 13. Gene network from Clo algorithm [27].

Table 4. Gene ranking from Clo algorithm [27].

Rank	Name
1	FN1
2	TLR2
3	BGN
4	COL1A1
5	CXCR4
6	ITGB1
7	COL1A2
8	SERPINE1
9	SPARC
10	CCN2

Betweenness

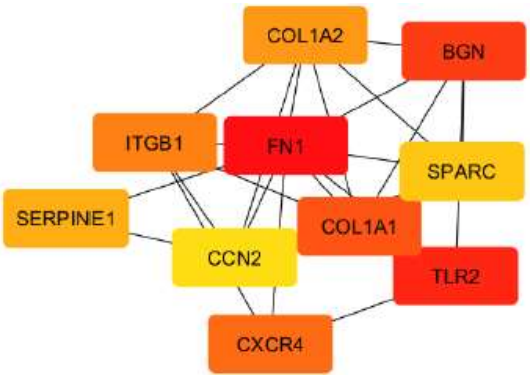


Figure 14. Gene network from Betweenness algorithm [27].

Table 5. Gene ranking from Betweenness algorithm [27].

Rank	Name
1	FN1
2	TLR2
3	BGN
4	COL1A1
5	CXCR4

Rank	Name
6	ITGB1
7	COL1A2
8	SERPINE1
9	SPARC
10	CCN2

The defective proteins were Fibronectin (FN1), integrin beta-1(ITGB1), collagen alpha-1(COL1A1) and toll like receptor (TLR2). The role of these mention proteins in gastric cancerwere mention below along with their three-dimensional structure.

- Fibronectin: Fibronectin 1 (FN1) is involved in the occurrence and development of varioustumors and is upregulated in multiple cancer types. FN1 has been demonstrated to promotecell proliferation and migration in gastric cancer cell lines. The three-dimensional structureis visualized in figure 15 [28].”

Figure 15. Three-dimensional image of Fibronectin

Integrin beta-1: This is primarily mediated through their ability to regulate matrix metalloproteinase (MMP) and tissue inhibitor of metalloproteinase (TIMP) expression, thereby facilitating ECM degradation and tumor cell migration. The three-dimensional structure is visualized in figure 16 [28].”

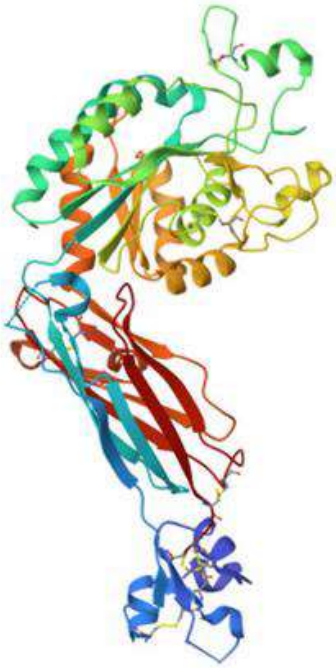


Figure 16. Three-dimensional image of Integrin beta-1

- **Collagen Alpha-1:** over expressed in gastric cancer and potent prognostic factors by showing their associations with an adverse prognosis in gastric cancer patients. In addition, COL1A1 might be a potential biomarker for early gastric cancer diagnosis. The three-dimensional structure is visualized in figure 17 [28].”

Figure 17. Three-dimensional image of Collagen alpha-1

- **Toll like receptor:** up regulation of TLR2 promotes gastric tumorigenesis by directly augmenting gastric epithelial cell proliferation and survival, independent of inflammation. The three-dimensional structure is visualized in figure 18 [28]."

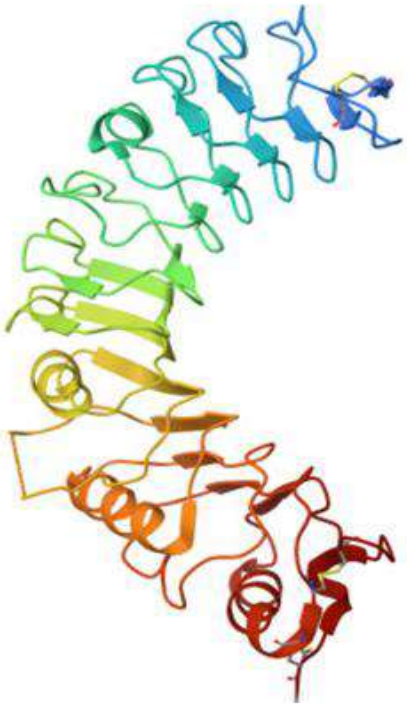


Figure 18. Three-dimensional image of Toll like receptor

Ligand Preparation

Nanomaterial Builder: The silver nanoparticles were designed in nanomaterial modelermodulein CHARMM-GUI server. The silver nanoparticle was constructed as sphere in shape with total radius of 5 Å, material volume of 1191.3 Å3 and system volume of 80,356.1 Å3. The three-dimensional structure is obtained, visualized below in figure 19 (Original work using CHARMM-GUI)."

and minimized for molecular docking process using MOPAC module in Avogadro software.

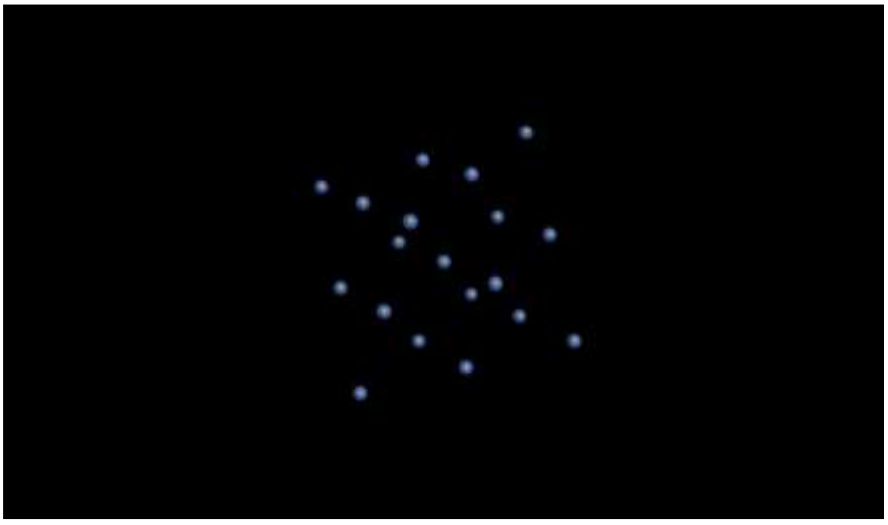


Figure 19. The three-dimensional structure of silver nanoparticles constructed in CHARMM-GUI server

ADMET analysis: The ADMET properties of silver nanoparticle was predicted using Simulationplus ADMET predictor software. As the ligand lacks hydrogen, it is impossible to predict oralbioavailability, lipinski's rule of 5 and metabolism properties. Absorption, distribution, excretionand toxicity properties were predicted. The properties were mentioned below.

Absorption

As the silver nanoparticles are smaller in size, it has lower water solubility with higherskinpermeability as shown in table 6. Gastro-intestinal absorption determines the entry of our drug intothe systemic circulation after oral administration. GI absorption is important for ourcurrent study. Silver nanoparticle has better GI absorption. AgNPs act as neither substratenor inhibitor for P-Glycoproteinwhich is drug efflux protein.

Table 6. Absorption properties of silver nanoparticles (Original analysis using Simulation Plus software)

Compounds	Water solubility	$CaCo_2$ permeability	GI absorption	Skin permeability	P-glycoprotein substrate	P-glycoprotein inhibitor
Ag	0.00	1045.5	2.743	122613	No	No

Distribution

The distribution properties of AgNPs were predicted and tabulated below in table 7 "(Original work)". The results shows AgNPs have higher volume of distribution in steady state which express that it has extensive distribution into tissues. Also, higher blood-brain barrier permeability shows it can penetrate into brain. So, it can also be used to treat nervous disorders. AgNPS have higher fraction unbound which shows that it has shorter half-life.

Table 7. Distribution properties of silver nanoparticles (Original analysis using Simulation Plus software)

Compounds	VDss human	Fraction unbound	BBB permeability	Ratio of blood to plasma	CNS permeability
Ag	2.232	0.011	High	1.098	1.380

Excretion and Toxicity

The excretion and toxicity properties of AgNPs were predicted and tabulated below table 8 "(Original work)". The result shows it act as inhibitor for hERG potassium ion channel and elevated liver toxicity. As the AgNPs act as inhibitor for hERG potassium ion channel, it reduces the risk of drug causing cardiac arrhythmia.

Table 8. Excretion and toxicity properties of silver nanoparticles (Original analysis using Simulation Plus software)

Compounds	Max tolerated dose	hERG inhibitor	Oral rat acute toxicity	Oral rat chronic toxicity	Liver toxicity
Ag	Above 3	Yes	0.105	235.062	Elevated

Molecular Docking

After screening ADMET properties, silver nanoparticles were docked against the four selected proteins using Autodock 4.2 software. As the ligand silver nanoparticle is comparatively smaller in size the binding affinity is possibly positive. The binding affinity of silver nanoparticle against the defective proteins is tabulated below table 9 "(Original work)" and their docking pose is visualized below in images as shown in the figure 20.

Table 9. The binding affinity of silver nanoparticles against different proteins

Protein	Binding affinity
FN1	+3.39
ITGB1	+3.27
COL1A1	+3.59
TLR2	+3.36

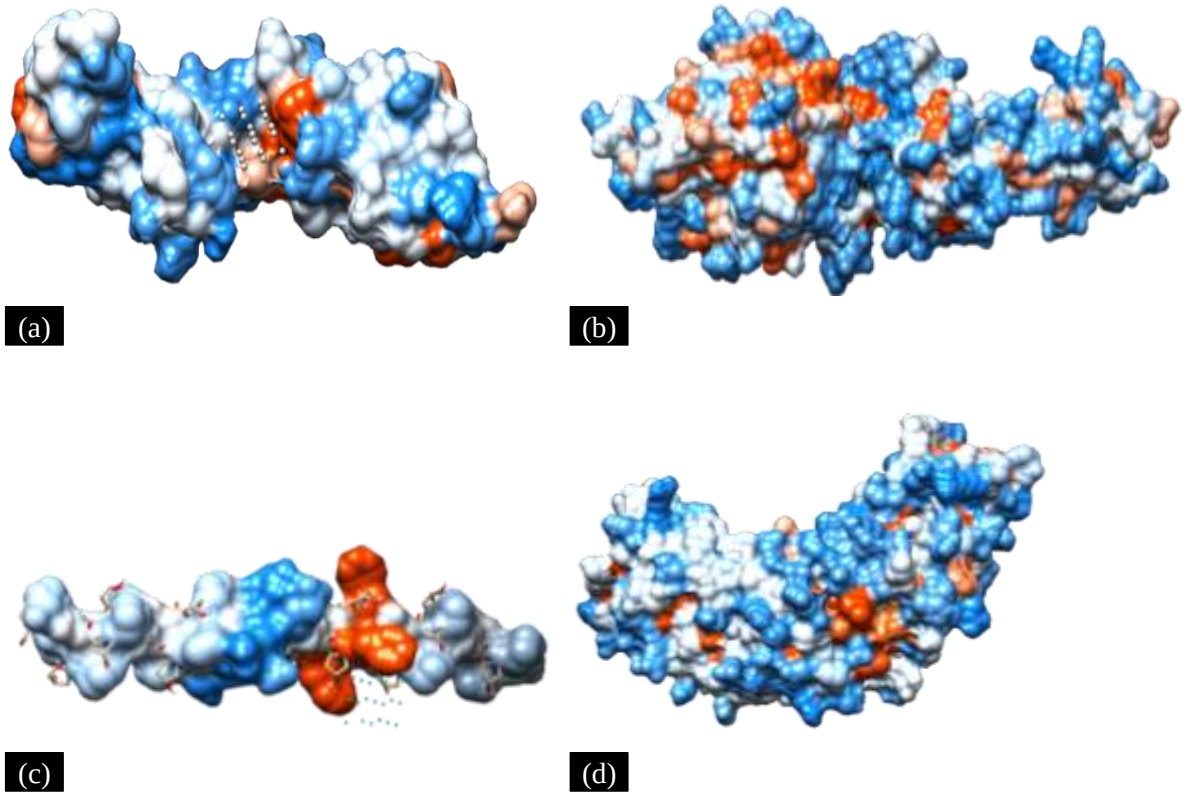


Figure 20. Binding pose of silver nanoparticles against different protein "(Original docking analysis using AutoDock 4.2 software)"

CONCLUSION

Silver nanoparticles (AgNPs) were successfully synthesized using the leaf extract of Cissus quadrangularis and silver nitrate. The synthesis was confirmed by a characteristic surface plasmon resonance (SPR) peak observed at 433 nm in the UV-visible spectrum, indicating the formation of AgNPs.

Characterization of the synthesized AgNPs was performed using various techniques:

UV-Visible Spectroscopy: The SPR peak at 433 nm confirmed the formation of AgNPs.

Fourier Transform Infrared (FTIR) Spectroscopy: FTIR analysis revealed peaks at 2547 cm^{-1}, 2100 cm^{-1}, and 1459 cm^{-1}, indicating the presence of weak S-H, strong N=C=S, and medium C-H bonds, respectively.

X-Ray Diffraction (XRD) Analysis: XRD patterns showed peaks at 38.1°, 44.3°, 64.4°, and 77.4°, corresponding to the (111), (200), (220), and (311) planes, respectively, confirming the crystalline nature of the AgNPs.

The stability of the synthesized AgNPs was assessed using UV-visible spectroscopy over a period of five days, confirming their reliability for potential applications.

To evaluate the anti-gastric cancer potential of the synthesized AgNPs, virtual screening was conducted using various software tools. Defective proteins were selected based on gene expression analysis, and the ligand (AgNPs) was constructed using the CHARMM-GUI server. ADMET properties were predicted using ADMET predictor software. Molecular docking studies revealed binding affinities of +3.39 kcal/mol against FN1 protein, +3.27 kcal/mol against ITGB1 protein, +3.59 kcal/mol against COL1A1, and +3.36 kcal/mol against TLR2 protein, suggesting potential interactions between AgNPs and these proteins.

In vitro studies have demonstrated that AgNPs synthesized from Cissus quadrangularis exhibit significant antimicrobial and antioxidant activities. These properties, along with the observed cytotoxic effects on HepG2 cells, highlight the potential of Cissus quadrangularis-derived AgNPs as promising candidates for biomedical applications.

The resulting nanomaterial can be considered an organic-inorganic hybrid composite, where bioactive phytochemicals from the plant extract form a stabilizing organic shell around the silver core. This structure resembles the function and behavior of polymer composites, where the organic matrix and metallic filler act synergistically to enhance performance. Such hybrid systems open up new directions in bio-inspired polymer composite research, particularly for drug delivery, diagnostics, and tissue engineering applications.

In conclusion, the green synthesis of AgNPs using Cissus quadrangularis extract offers a sustainable and eco-friendly approach to nanoparticle production. The synthesized AgNPs exhibit promising physicochemical characteristics and biological activities, warranting further investigation for their potential use in medical and pharmaceutical applications. Future research could involve exploring polymer-blended nanocomposite systems and conducting detailed in vitro and in vivo cell line studies to validate clinical relevance.

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