Pak. J. Bot., 59(2): February 2027.

ARTICLE | DOI: http://dx.doi.org/10.30848/PJB2027-2(12)

BIOSYNTHESIS, CHARACTERIZATION AND ANTI-PHYTOPATHOGENIC ACTIVITY OF SILVER NANOPARTICLES DERIVED FROM *FUMARIA INDICA*

KASHMALA SYED[1], AHMAD ALI[1*], ZAHID ULLAH[1], NAVEED ALAM[2], HASSAN SHER[1], RADEN MAYA FEBRIYANTI[3] AND MUSHTAQ AHMAD[4*]

[1]Department of Botany, University of Swat, Charbagh (19120) Swat, Pakistan
[2]Department of Agriculture Sciences and Forestry, University of Swat, Charbagh (19120) Swat, Pakistan
[3]Department of Pharmaceutical Biology, Universitas Padjadjaran, Sumedang, West Java, Indonesia
[4]Department of Plant Sciences, Quaid-I-Azam University, Islamabad, 45320, Pakistan

*Corresponding author's email: aali_swat@yahoo.com, mushtaq@qau.edu.pk

Abstract

Fumaria indica (Hausskn.) Pugsley is a well-known medicinal herb in the Hindukush region of Pakistan. A comprehensive review of ethnomedicinal studies was conducted to document the traditional uses of *F. indica* for further biological screening, synthesis of nanoparticles and its efficacy against plant pathogenic bacteria. Silver nanoparticles (AgNPs) were synthesized via an ecofriendly green route using plant extract as reducing agent. AgNPs were characterized and confirmed through fourier-transform infrared spectroscopy (FTIR), transmission electron microscopy (TEM), scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDX), and X-ray diffraction (XRD). Results revealed spherical-shaped AgNPs ranging from 20 to 60 nm in size, with crystalline properties and surface functional groups facilitating stability and interactions of the particles. The aqueous leaf extract of *F. indica* exhibited marked antioxidant activity in the DPPH free radical scavenging assay, demonstrating a concentration-dependent response. Radical scavenging activity increased progressively from 41.81% at 62.5 µg/mL to 82.87% at 1000 µg/mL, while the standard ascorbic acid showed 97.62% inhibition. GC-MS analysis revealed chemically diverse composition of nitrogen-containing heterocyclic compounds, oxygenated constituents, aromatic derivatives, fatty acid esters, macrocyclic lactones, nucleoside analogues, and long-chain aliphatic constituents. The identified constituents included 2-cyclohexylpiperidine, octanal, minocycline, flufenoxuron, 1H-pyrrole, 2,3-dihydro-1-methyl, adenosine, 5′-amino-5′-deoxy, piperidine, celecoxib, procyclidine, dicyclomine, octadecanoic acid octadecyl ester, and numerous additional aromatic and aliphatic constituents. The antibacterial efficacy of both AgNPs and plant-extract-coated AgNPs (AgNPs-PE) was evaluated against *Pseudomonas syringae*, *Erwinia carotovora* and *Ralstonia solanacearum* causing bacterial diseases in tomato. Microtiter plate assays demonstrated significant growth inhibition of the experimental phytopathogenic bacteria by AgNPs and AgNPs-PE, indicating their potential as effective antimicrobial agent. These findings will help in understanding of plant disease control using AgNPs and contribute to the production of novel control agents against phytopathogens with reduced side effects compared to chemical pesticides.

Key words: *Fumaria indica*; Silver nanoparticles; Antioxidant activity; GC-MS profiling; Phytopathogenic bacteria; Antibacterial activity

Introduction

Medicinal flora has long been a source of healthcare practices across cultures, offering remedies deeply rooted in local traditions and ecological knowledge (Lulekal *et al*., 2008). In the past few decades, research on traditional uses of medicinal plants has been summarized by many researchers such as (Salmeron-Manzano *et al*., 2020). Additionally, different authors have explored the ethnobotanical aspects of the Hindukush-Himalayas mountains, including (Alam *et al*., 2011; Sher *et al*., 2016; Rahman *et al.,* 2016; Ashfaq *et al*., 2019; Khan *et al*., 2023). All these studies have focused on documentation and exploration of traditional uses of medicinal plants, highlighting the need to transfer this knowledge from the field to industry and the commercial sector (Rahman *et al*., 2022) including formation of ecofriendly nanoparticles. The pharmaceutical industry has increasingly recognized traditional medicine as a valuable source for identifying bioactive agents used in synthetic medicine. However, it is essential to test the most commonly used species (Fabricant & Farnsworth, 2001; Heinrich & Bremner, 2006).

Over time, conventional methods, such as synthetic chemicals and pesticides, have shown limited effectiveness, posing environmental issues and health risks (Arora *et al*., 2022). Resistant cultivars are challenged by climatic changes and pathogen mutations, while phytoextracts act slowly, potentially causing economic loss (Mazhar *et al*., 2021). Therefore, an urgent need exists for an alternative, efficient, safe, and effective approach against such harmful pathogens and plant diseases. Among the different pathogens *Pseudomonas syringae* pv. *tomato*, causing Bacterial speck disease, is a common and damaging disease affecting tomato plants (Zhao *et al*., 2003). This disease can significantly impact both the quality and yield of tomato crops. Initially small dark spots appear on the leaves, which later become necrotic with yellow halos around them. On the same way small, black specks develop on the fruit, often surrounded by a slightly sunken area. Dark lesions can also form on stems and petioles (Fig. 1).

Nanotechnology has revolutionized plant disease management, with green-synthesized nanomaterials proving highly effective, eco-friendly, and successful

Received: 16-06-2026 | Revised: 25-08-2026 | Accepted: 05-09-2026 | Online: 27-09-2026

antibacterial agents to combat plant diseases (Muthuramalingam *et al.,* 2024; Khan, 2023). Secondary metabolites from medicinal and wild plants, known for their antimicrobial properties, exhibit high efficiency against diverse plant pathogens. Nanomaterial applications as nano-foods, nano-fertilizers, and nano-pesticides have been explored in various agricultural studies (Khan, 2023). Specific nanoparticles have been employed against tomato pathogens, including silver nanoparticles against various diseases (Narware *et al*., 2024). Therefore, the current study was designed to synthesize silver nanoparticles from leaf extracts of *F. indica* and explore its application disease management, based on traditional medicinal importance.

The genus *Fumaria* comprises 46 known species worldwide, found across Asia, Europe, and Africa. Specifically, *F. indica* is found in parts of India, Pakistan, Afghanistan, and Central Asia. Belonging to the family Fumariaceae, *F. indica* is an annual herb commonly found as a weed throughout the plains of India and Pakistan (Gupta & Rao, 2012). Locally known as fumitory or papra, this species holds significant importance in traditional medicine, with a history tracing back to Ayurvedic and Unani medicinal practices. The current study was aimed to explore the traditional uses of *F. indica* in the Malakand Division of Pakistan's Hindukush Mountain ranges, for onward evaluating its phytochemicals and silver nanoparticles against phytopathogens. The DPPH (2,2-diphenyl-1-picrylhydrazyl) assay is one of the most widely used methods for evaluating antioxidant activity due to its simplicity, rapidity, and reliability in measuring the free radical scavenging capacity of plant-derived bioactive compounds (Alam *et al*., 2019).

This study was designed with the objectives to explore the traditional ethnobotanical uses of *F. indica,* evaluate its phytochemical constituents, synthesize silver nanoparticles from the plant extract via green route, and to test the efficacy of the synthesized nanoparticles against phytopathogenic bacteria.

Materials and Methods

Study area: The study was conducted in Malakand Division of Pakistan Hindukush mountain ranges in the year 2021-2023. This region has rich biodiversity, diverse cultures and indigenous communities residing in lush green valleys (Fig. 2). Historically the study area was a significant center of Hinduism and Buddhism, but now almost exclusively populated by ethnic Pashtun however the Gujjars, Dalakzak, Kashmiri, Kohistani and Sheikh are also found in minority, sharing strong socio-economic and cultural ties. This region hosted ancient monasteries, important trade networks, and travelers between Central and South Asia (Codrington *et al*., 2017). The study area has numerous high snow-capped peaks, with Tirich-Mir (7,708 m) being the highest point of Pakistan Hindukush Mountain ranges (Rafiq *et al*., 2020). The climate of the region is montane type with pleasant summer and cold winters. The lower parts of the study area have subtropical and scrub vegetation while the upper elevations are inhabited by temperate forests and alpine plans. These forests are home to unique biodiversity and fragile alpine ecosystems which critical for maintaining ecological balance in Pakistan, especially for sustainable water use (Ahmad *et al*., 2020). This area serves as a refuge for many endemic species like Himalayan Ibex, Markhor, Himalayan brown bear, and vulnerable species including common pochard and snow leopard (Aslam *et al*., 2022). Most of the rainfall in the area occur from January to March. The monsoon is short but severe and about 50 rainfalls in this season during July-August (Guo-Yu & Bhakta, 2017).

Methodology

Morphological studies: Morphological Studies were carried out in Plant Taxonomy and Systematics Lab, at the Department of Botany, University of Swat, with the help of available resources like magnifying glass, stereo microscope, ruler, dissecting kit, camera, notebook, pens and reference flora (Ali *et al*., 2024).

Plant collection and documentation of traditional therapeutic uses: Extensive field visits were carried out during flowering season from March to August in the year 2021-2023, in different villages of District Buner, Swat, Shangla, Malakand, Dir lower and Dir upper. Ethnobotanical information was obtained form 54 key informants including herdsmen, farmers, local healers, and school teachers. Most of the informants were male and aged between 19-75 years, for the interview of women, indirect method was used as women were constrained from talking and interaction with strangers. Ethnobotanical data was gathered using semi structured interviews and detailed questionnaires (Lulekal *et al.,* 2008), as well as walk through the wood methods. After recording sociodemographic information from the respondents, they were asked in detail about habitat, collection methods, parts used, availability, harvesting, storage, processing and utilization of *F. indica*. Informants were interviewed in Pashto language by the first author. Individual questionnaire was filled from local Gujjars, farmers, plant collectors, traders and local healers, who were the actual users and have a lot of indigenous knowledge about the plants and their traditional uses.

Statistical analysis

In order to determine the most suitable treatment of *F. indica* for various ailments, a Multi-Criteria Decision Analysis approach was used (Hamidah *et al.,* 2022). This model takes into account several important factors to evaluate each treatment option. In the current study we have considered the following factors for Multi-Criteria Decision approach, i-e Efficacy (E): How effective the plant is in treating a specific ailment, Safety (S): The safety profile or side effects associated with the treatment, Prevalence of Use (P): How commonly the plant is used for this ailment by informants, Cultural Acceptance (C): The traditional and cultural acceptance of using the plant for this treatment, Availability of Alternatives (A): The availability of other effective treatments for the ailment. Economic Impact (V): The cost-effectiveness of using the plant for this particular treatment. Based on these factors composite suitability score Ti for each treatment i by combining these factors was calculated with the given equation:

$$Ti = \alpha Ei + \beta Si + \gamma Pi + \delta Ci - \epsilon Ai + \zeta Vi$$

where, Ti was the Ssuitability score of treatment i for *F. indica*. Ei was efficacy of treatment i.

Si was Safety of treatment i. Pi was Prevalence of use for treatment i. Ci was Cultural acceptance of treatment i. Ai was Availability of alternatives for treatment i. Vi was Economic impact of treatment i. and α, β, γ, δ, ϵ, ζ were the weightage score of each factor based on the its importance (Ersen, 2024).

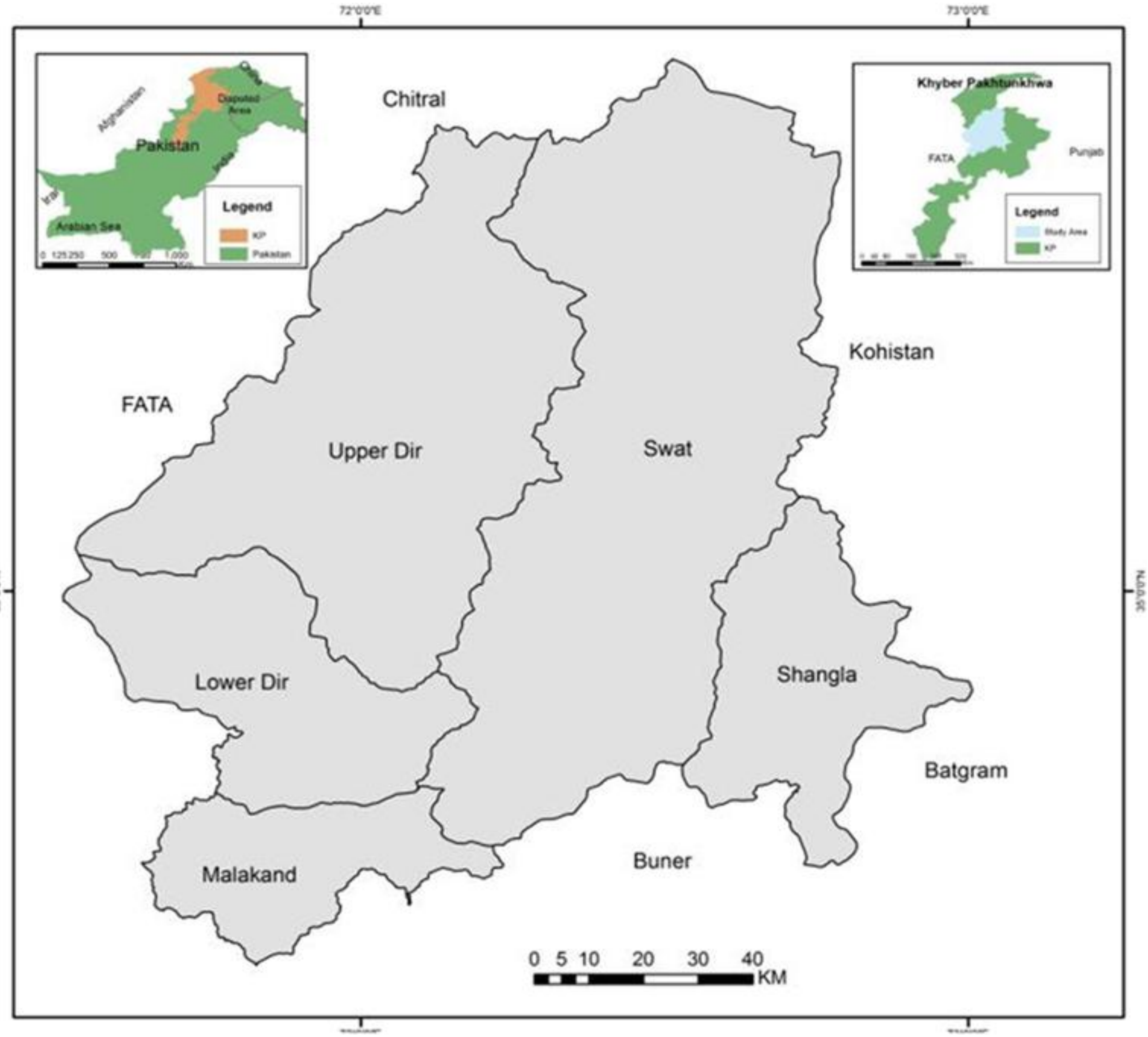

Fig. 2. Map of the study area (Malakand Division, Pakistan).

Biological evaluation and nanoparticles synthesis

Preparation of plant extract: Fresh *F. indica* plants were gathered from the high altitude moist temperate forest of District Swat, Pakistan. After washing the leaves, they were air-dried at room temperature and subsequently ground into a fine powder with the help of a mortar and pestle. To prepare the extract, about 50 g of leaf powder were mixed with 300 milliliters of distilled water in a 500 milliliter Erlenmeyer flask. The mixture was then incubated at 28°C for 24 h. After incubation, the solution was filtered using Whatman filter paper (grade 1, pore size 11 micrometers) to obtain a clear liquid. This liquid was subsequently evaporated to yield the crude extract (Arif *et al*., 2022).

Biosynthesis of silver nanoparticles: In the process of synthesizing silver nanoparticles, we carefully mixed 1.25 milligrams per milliliter (mg/mL) of plant extract with 4 millimolar (mM) silver nitrate at different ratios, ranging from 1:9 to 9:1. A well-established method was followed for this process (Zulfiqar *et al.,* 2024: Arif *et al*., 2022). After mixing, the solution was exposed to sunlight for 15 minutes to see if there were any color changes. Then, we let them sit for an additional 24 h. The solution was analyzed by using special instruments to find the one with the right optical characteristics. Once we found the right solution, the silver nanoparticles were separated by spinning the solutions fast in a centrifuge at 14,000 revolutions per minute (rpm) for 15 minutes. This separated the nanoparticles from the rest of the solution. The leftover liquid was removed and the settled nanoparticles were dissolved in deionized water. This repeated process was repeated for three times to make sure the nanoparticles were pure. After the final round, we removed the supernatants and left the tubes containing the silver nanoparticle pellets open for 24 h at room temperature to let them dry out. Once they were dried, we used different techniques to study the nanoparticles in detail. Finally, to make plant-extract-coated silver nanoparticles (AgNPs-PE), we dipped the dried nanoparticles back into a solution containing 1.25 mg/mL of plant extract and let them dry in the air.

Characterization of silver nanoparticles: Characterization of silver nanoparticles provide a comprehensive overview of their properties and potential applications (Tunc, 2024). The biosynthesized silver nanoparticles were thoroughly examined by the use of Multiskan TM Sky Microplate Spectrophotometer (MAN0018930) to study the silver nanoparticles using UV-visible spectroscopy. This helped us see special peaks related to silver between 300 to 600 nanometers. A Thermo-Nicolet 6700 FTIR Spectrometer from Madison, WI, USA, for Fourier-transform infrared (FTIR) spectroscopy. This machine analyzed the nanoparticles' functional groups to see how they formed. JEOL JEM-101 system was used for transmission electron microscopy (TEM) to take detailed pictures of the nanoparticles, showing their size and shape and selected area electron diffraction (SAED) was followed to understand their crystal structure. For elemental composition analysis, a scanning electron microscope (SEM) JSM5910 was used, equipped with an energy-dispersive X-ray (EDX) system made by JEOL, Japan. This helped us find out what elements were present in the nanoparticles. Lastly, we used JDX-3432, JEOL made in Japan, for X-ray diffraction (XRD) pattern analysis of the nanoparticles. Debye-Scherrer equation was used to figure out the average size of the crystals in the nanoparticles.

DPPH free radicles scavenging activity: The antioxidant activity via DPPH free radicles scavenging activity of *F. indica leaf* extract was determined using the standard protocol of Oyawaluja *et al*., (2024). An amount of 10 mg of dried powder was taken in 4 ml of methanol and then 0.5 ml of methanol solution of DPPH (Fig. 3a). The solution was thoroughly mixed for 15 seconds, through vortex and left still, for 30 minutes. The absorbance gave red color at 517 nm on spectrometer. Using the following formula, the radical scavenging activity was calculated as the percentage of DPPH discoloration:

$$\% \text{ Inhibition} = \frac{\text{Absorbance of control} - \text{Absorbance of sample}}{\text{Absorbance of control}} \text{ x } 100$$

GC-MS analysis of the leaf extract: The leaf extract of *F. indica* was subjected to GS-MS analysis following the methodoly reported in Ahmad *et al*., (2024). Briefly, powdered leaf (30 g) was added to about 250 mL methanol in shaking incubator followed by filtration after 24 h. This was followed by further shaking and filtration after the addition of about 60 mL methanol with the extract. The filtrate / extract was then analyzed using GC-MS (Thermo Scientific-DSQ instrument).

Antibacterial assessment: The growth inhibition potential of green synthesized silver nanoparticles of *Fumaria* plant extract (PE) alone and combination of both (PE+AgNPs) was investigated against bacterial strains including *Pseudomonas syringae*, *Erwinia carotovora* and *Ralstonia solanacearum* (Hossain, 2024; Soheili *et al*., 2023). This was accomplished in an *In vitro* environment by employing microplate assay (96-welled) through variable dilutions viz. (15.62, 31.25, 62.5, 125, 250, 500, 1000 µg / mL and control (water)**.** Bacterial strains were acquired from Crop Disease Research Institute (CRI) at National Agriculture Research Centre (NARC) Islamabad. Micro plate with 96 wells were used in the experiment. The bacterial colonies were produced on nutrient agar, by keeping them in the incubator for 36 h, and then transferred them to a liquid food called nutrient broth and left them overnight in a shaker for determining their respective growth inhibition.

Results

Prior to commencing of fieldwork for the exploration of traditional uses of *F. indica*, the taxonomic diagnostic features of the collected plant speciemens were thoroughly studied under stereomicroscope and consulting flora of Pakistan.

Morphological description of the plant: *Fumaria indica* is a small, delicate, branched herb, 5-25 cm high, featuring a glaucous, glabrous appearance (Fig. 3b). The leaves are 3-10 cm long and 2-5 cm broad, are long-stalked to subsessile and intricately divided into 2-3-pinnatisect or decompound segments, with 3-5 pairs of lateral pinnae and a terminal one. The pinnae are long-petioluled to subsessile, 1-3 cm long and 0.5-2 cm broad, often ternately lobed with deeply and finely lobuled segments up to 5 mm long and 1 mm broad, flat to slightly channelled. The racemes are shortly peduncled to subsessile, leaf-opposed, with 6-12 flowers, and measure 10-20 mm long, with linear, submembranous, whitish bracts as long as or slightly longer than the pedicels. The pedicels are erect, 1.5-2 mm long, with a median ridge and slightly expanded margins, broader below the fruit or at its apex. The flowers, usually white or pale pinkish, are 5-6 mm long, with minute sepals less than 1 mm long and 0.5 mm broad, sometimes obsolete, laciniate-dentate, and whitish. The upper petal features a very short suborbicular spur, about 1.5 mm long, and the fruit is approximately 2 mm in diameter, suborbicular, with a usually rounded apex when mature, slightly keeled margins, and somewhat rugose when dried, containing one seed. The seeds are 1-1.5 mm in diameter and brownish. The leaf lamina has a single-layered epidermis on both sides, with thin-walled, rectangular to oval parenchymatous cells, while the mesophyll consists of thin-walled, oval to polygonal parenchymatous cells with scattered vascular bundles and anomocytic stomata on both surfaces. The stem is quadrangular to pentagonal, with a single-layered epidermis covered with a cuticle, and the cortex is divided into two regions, lacking an endodermis. Closed and bicollateral vascular bundles, either single or in pairs, are arranged at the ridges, each capped with sclerenchyma. In the root, the epidermis may be obliterated or crushed, with a cortex of thin-walled, irregularly shaped parenchymatous cells, and an indistinct endodermis. The secondary phloem is well-developed, consisting of sieve tubes, companion cells, and phloem parenchyma.

Traditional therapeutic uses: *Fumaria indica* was widely used for the treatment of various ailments, which are briefly describes as follows.

Anti-ulcer properties: *F. indica* was used to cure stomach problems by the local populations, like its role as digestive and carminative, to treat stomach ulcer and gas troubles. *F. indica* has been used to treat ulcers due to its potential to reduce gastric acidity and protect the stomach lining. The dried powdered of the whole plant were taken before breakfast, was consider as cholagogue to cure stomach problems. The plant may contain alkaloids and other compounds that may help in reducing ulcer formation and promoting healing.

Gastric benefits: *F. indica* was known for its positive effects on the digestive system. It can help alleviate various gastric issues such as indigestion, bloating, and gas. The shoot of plants in dried form is used to prepare herbal tea for relive abdominal pain The active compounds in *F. indica* may stimulate the secretion of digestive enzymes, aiding in better digestion.

Fig. 1. Bacterial speck disease on tomato fruit and foliage, caused by *Pseudomonas syringae* pv. *tomato.*

Fig. 3a. (A) Plant material; (B) Plant Extract + Methanol + DPPH (C) Triplet samples of extract; (D) Samples of AgNPs + Plant extract, Plant extract and AgNPs.

Fig. 3b. *F. indica* a small, delicate, branched herb with pinkish flowers.

Appetizer: *F. indica* was widely used to stimulate appetite. Some of the respondents reported the use of green twigs as appetizer. Green twigs of the plant were taken orally and were considered as appetizer and to relive gastrointestinal disorder. It was also beneficial for individuals experiencing loss of appetite due to illness or other conditions. The plant's properties were helpfull in enhancein the taste and to increase the desire to eat.

Laxative: *F. indica* was reported to have mild laxative properties, which can help relieve constipation. It was considered beneficial in promoting bowel movements and maintaining regularity, making it useful for those with digestive issues related to infrequent bowel movements.

Carminative*:* *F. indica* was considered as carminative, according to the perception it helps in reducing the formation of gas in the gastrointestinal tract. This property was considered beneficial in alleviating symptoms of bloating, gas, and discomfort associated with indigestion. As per locals, it facilitates the expulsion of gas and helps in soothing the digestive tract.

Anti-colic: *F. indica* was used to relive colic, particularly in infants and children. According to the local perception colic involves severe cases, often fluctuating pain in the abdomen caused by intestinal gas or obstruction. F. indica anti-colic properties were considered helpful in soothing the intestinal muscles and reducing the pain and discomfort associated with colic. A cold syrup of the plant was used to cure constipation and dyspepsia in children. F. indica leaves extract were mixed with Cassia fistula fruit and a decoction has been prepared for the treatment colic pain in children up to 5 years ages and infants. It was reported that the frequency, length of crying and the occurrence of waking up due to colic pain decrease with this formulation.

Antipyretic, antiperiodic and febrifuge: The local herbalist was recommended *F. indica* for treatment of fevers. As per local herbalist, it was useful in treating conditions associated with elevated body temperatures, providing relief from fever symptoms. Dried plant was cursed in to powdered and was taken orally with a glass of water as antipyretic and febrifuge to treat fever. *F. indica* alone or combined with *Tinospra cardifolia*, *Emblica officinalis* or *Zingiber officinale* were used for the treatment of fever. *F. indica* was used to prevent the recurrence of diseases such as malaria and other periodic fevers. As per local's sources, it was helped in breaking the cycle of fever and chills that characterize such diseases.

Antiemetic: *F. indica* was consider helpful in preventing nausea and vomiting. It was used due to its beneficial effect for individuals suffering from these symptoms due to various conditions, including motion sickness, gastrointestinal disturbances, and during pregnancy.

Blood purifier*:* *F. indica* was used for blood-purifying properties. It was considered helpful in detoxifying the blood, removing toxins and impurities. This detoxification process was considered beneficial for overall health and was thought to prevent various ailments associated with impure blood.

Liver disorders: This plant was reported effective in treating liver disorders. It was considered to supports liver function by promoting bile secretion and improving digestion. *F. indica* was reported to be helpful in conditions such as jaundice, hepatitis, and general liver dysfunction, aiding in the regeneration and repair of liver tissues.

Cure for skin disorders: *F. indica* was used to treat various skin disorders due to its detoxifying and anti-inflammatory properties. As per local perception, the plant was useful in conditions such as psoriasis, acne, syphilis, skin allergies and eruptions caused by fungi and bacteria. It was thought that by purifying the blood and improving liver function, it addresses the root causes of many skin issues, leading to clearer and healthier skin. It was also applied externally in leucoderma and as a fomentation for swollen joints.

Urinary disorders: *F. indica* was consider beneficial in treatment of various urinary disorders. According to locals, it helps in conditions such as urinary tract infections (UTIs), difficulty in urination, and inflammation of the urinary tract. As per their view, plant's diuretic properties promote the production and flow of urine, which helps in flushing out toxins and bacteria from the urinary system. The dried leaves were crushed in to powder and were taken orally with glass of wated to treat urinary tract infections.

Removal of kidney stones: *F. indica* was used for the removal of kidney stones. According to local sources the plant's diuretic and anti-inflammatory properties facilitate the breakdown and expulsion of kidney stones. It was considered helpful in reducing the pain and discomfort associated with kidney stones and prevents the formation of new stones by promoting proper urine flow and reducing the concentration of stone-forming substances in the urine. The dried leaves were crushed in to powder and were taken orally with glass of wated to relive kidney pain and remove kidney stones.

Anodyne: *F. indica,* was believed to have anodyne effects, and can help to alleviate various types of pain, including muscle pain, and joint pain. A syrup was been prepared of fresh leaves extracts and mixed with honey, and was taken orally to cure aches and pains in the body.

Anti-Jaundice: The aerial parts of *F. indica* were infused in water to create a medicinal preparation. This infusion was taken to cure jaundice. According to local beliefs, plant's properties support liver function, helping to clear bilirubin from the blood more efficiently, which can reduce jaundice symptoms. In some traditional treatment's, *F. indica* was used in combination with the dried powder of root bark of *Berberis lyceum*. This remedy was particularly used for the treatment of prolonged jaundice. *Berberis lyceum*, known for its hepatoprotective and anti-inflammatory properties, complements the effects of *F. indica*, was believed to have efficacy in treating liver disorders. A decoction of dried arial parts of *F. indica* and *Berberis lyceum* root bark was prepared by boiling them in water. This decoction was then kept in a cold place before consumption. The cooling process might help in preserving the active compounds and enhancing the therapeutic effects.

Antidiabetic: An herbal mixture of *Tylophora hirsuta* leaves *Trigonella foenum-graceum* seeds and aerial parts of *F. indica* was prepared locally to control sugar level in the body. This mixture was popular for its significant effect in reducing blood glucose levels in diabetics. It was considered that this mixture was enhancing overall metabolism and support liver function, which was crucial in regulating glucose levels.

Local vegetables "sag": *F. indica,* combined with *Medicago polymorpha, Rumex dentatus,* and *Trifolium repens*, was used to prepare a nutritious and delicious local vegetable dish known as "sag." To make this dish, the aerial parts of these plants were boiled in water, mixing a desirable amount of salt only. This dish was to be served hot or even cold with bread or boiled rice, providing a meal rich in carbohydrates, minerals, and antioxidants. The plants used in this sag were consider to have numerous health benefits, including detoxifying properties, improved digestion, and enhanced liver health. This traditional preparation was not only the source of cheap food but was also important source of cultural and symbolic food.

Statistical analysis

Following are the scores for each ailment based on Multi-Criteria Decision Analysis approach. Detail breakdown for each of the 17 traditional uses of *F. indica* are described as follows

Anti-ulcer Properties =0.8+0.9+0.7+0.8−0.6+0.7=3.3.

Gastric Benefits=0.7+0.8+0.6+0.9−0.5+0.8=3.3.

Appetizer =0.6+0.7+0.5+0.8−0.4+0.9=3.1.

Laxative=0.5+0.9+0.3+0.7−0.6+0.6=2.4.

Carminative=0.8+0.8+0.4+0.9−0.7+0.7=2.9.

Anti-colic=0.7+0.9+0.4+0.9−0.7+0.8=3.0.

Antipyretic, antiperiodic and febrifuge=0.8 + 0.9 + 0.9 + 0.8 - 0.5 + 0.6 = 3.5

Antiemetic=0.5+0.8+0.3+0.7−0.6+0.6=2.3.

Blood Purifier=0.6+0.8+0.5+0.9−0.5+0.7=3.0.

Liver Disorders=0.7+0.8+0.5+0.9−0.6+0.8=3.1

Cure for Skin Disorders=0.6+0.8+0.4+0.9−0.7+0.7=2.7.

Urinary Disorders=0.6+0.9+0.4+0.8−0.6+0.7=2.8.

Removal of Kidney Stones=0.7+0.8+0.4+0.8−0.7+0.7=2.7.

Anodyne=0.5+0.7+0.3+0.7−0.6+0.6=2.2.

Anti-Jaundice=0.6+0.8+0.5+0.8−0.6+0.7=2.8.

Antidiabetic and to Control sugar level=0.7+0.8+0.4+0.9−0.7+0.8=2.9.

Local vegetables "sag"=0.4+0.8+0.3+0.7−0.7+0.6=2.1.

Results indicate (Fig. 4) that the most popular usus of *F. indica* were antipyretic, antiperiodic and febrifuge followed by anti-ulcer, anti-gastric and its beneficial impacts in liver disorders.

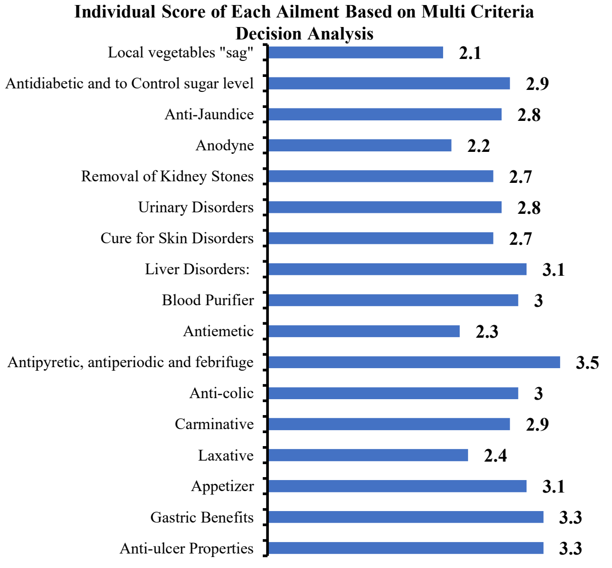

Fig. 4. Overall suitability of *F. indica* for specific use based on the recorded data.

Formation of silver nano particles: Upon adding the plant extract and silver nitrate in various concentrations, the reaction mixtures exhibited a dark brown coloration upon exposure to direct sunlight. This is a typical indicator of silver nanoparticle synthesis in aqueous form (Fig. 5).

FTIR analysis: Through FTIR analysis, the major functional groups crucial for the synthesis and stabilization of Ag NPs were identified (Fig. 6). The FTIR spectra results exhibit a prominent peak at 2836.76 cm−1, indicating medium C-H stretching of the aldehyde group present in the *F. indica* leaf extract, suggesting the presence of proteins in the green-synthesized Ag NPs. Another strong peak was observed at 2349 cm−1, representing the stretching of O=C=O of carbon dioxide. Additionally, a strong and broad peak at 2874.00 cm−1 corresponds to N-H stretching of amine salts. Furthermore, a deep and robust peak at 1119.67 indicates the presence of groups responsible for nanoparticle synthesis, while a strong C-H bending is observed at peak 869.95. The strong C-I stretching is depicted at peaks 618.42, 671.49, and 570.41. These peaks signify the presence of organic compounds from the leaf extract, which play vital roles in the reduction and stabilization of Ag nanoparticles. Additionally, bioactive functional groups such as phenols adhere from the aqueous leaf extracts to nanoparticles, enhancing their antimicrobial potential.

XRD analysis: The XRD pattern of Ag NPs reveals four distinct peaks, affirming their crystalline nature. The x-axis represents 2θ values, while the y-axis indicates intensities. The crystalline range of AgNPs spans from 10 degrees to 90 degrees at a 2θ diffraction angle. Notably, there are four diffraction peaks observed at approximately 38°, 45°, 65°, and 75° corresponding to the planes of 111, 200, 220, and 311, respectively (Fig. 7). The nanoparticle size was determined to be approximately 30 nm. The presence of sharp peaks unequivocally indicates the formation of Ag NPs within the leaf extract of *F. indica.* The purity of the synthesized AgNPs was confirmed as no other significant peaks were detected in the analysis.

SEM analysis: SEM analysis provided insights about detailed surface morphology and particle size. It's noteworthy that previous research has also underscored SEM and XRD as pivotal techniques for nanoparticle characterization. Specifically, SEM examination revealed particles with a rounded shape and a size range of approximately 30 nm. Similarly, the XRD analysis, depicted in Figure 7, allowed for the measurement of the particle size range. In the current study the majority of particles exhibited a spherical or rounded shape, with only a few irregular cases observed (Fig. 8).

Fig. 5. Showing change of coloration due to AgNPs formation. Flask (1) contain ***F. indica*** leaf extracts. Flask (2) contains mix extracts of AgNo3 and *F. indica* extracts. Flask (3) indicate formation of AgNPs

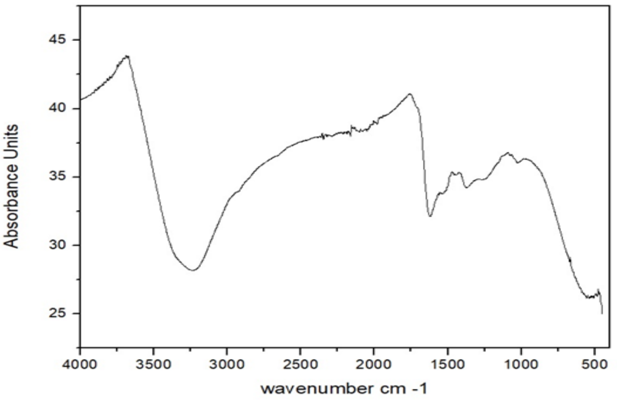

Fig 6. FTIR analysis showing major functional groups of *F. Indica* Silver nanoparticles.

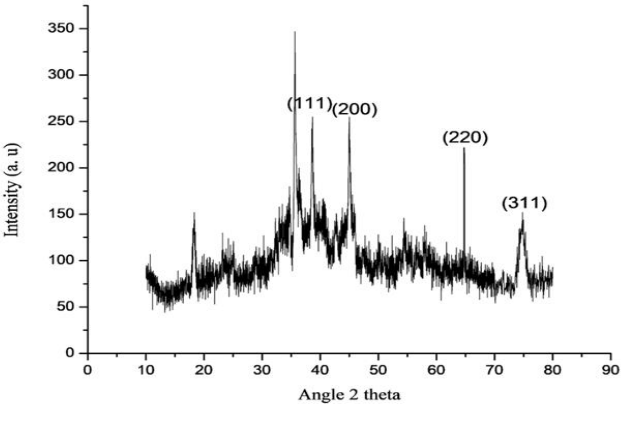

Fig. 7. Ag NPs revealing crystalline nature at four distinct peaks through XRD analysis.

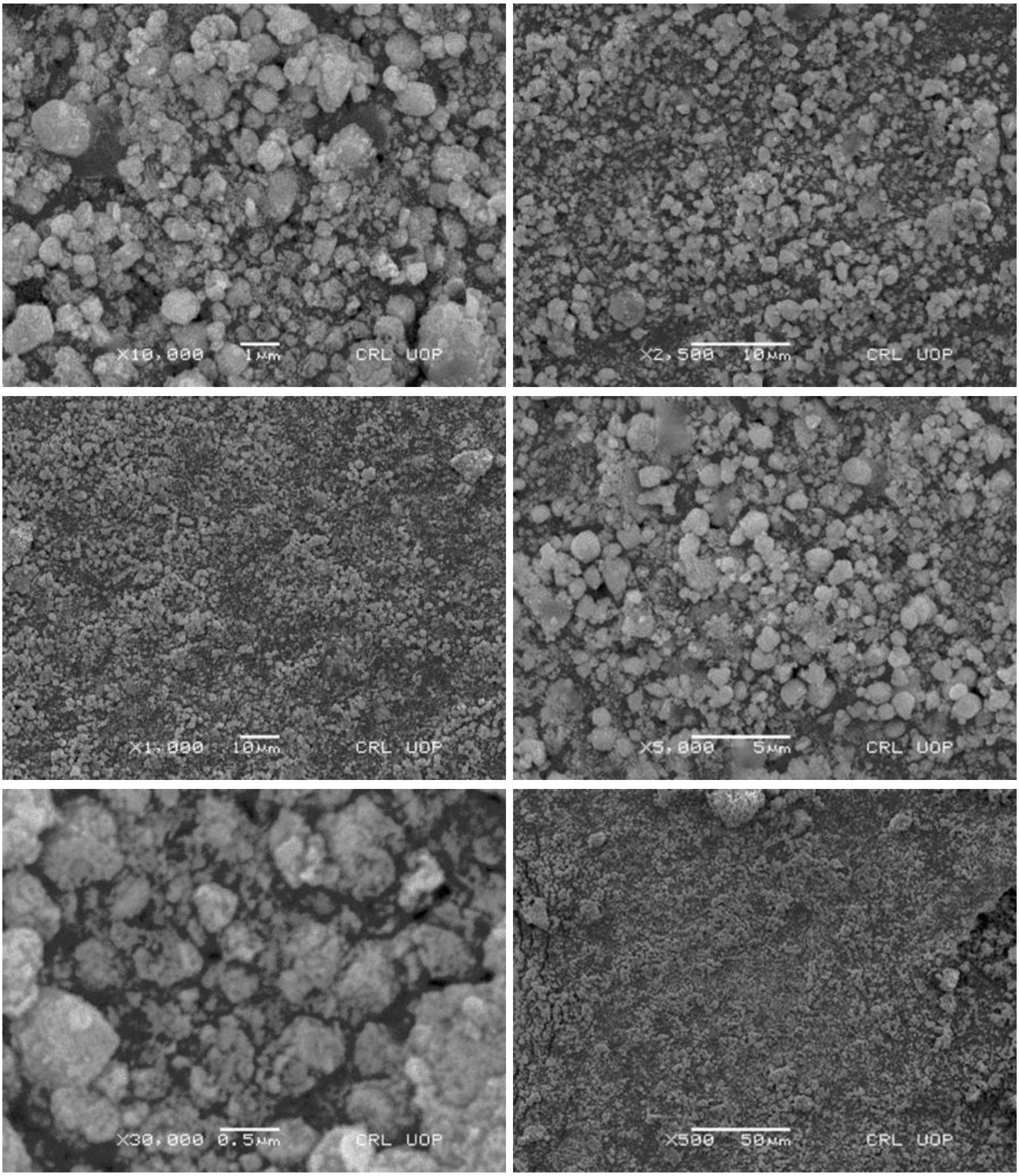

Fig. 8. Scanning electron micrographs depicting shape of silver nanoparticles (AgNPs).

EDX spectra: The elemental composition of the nanoparticles was assessed using EDX Spectra (Fig. 9). The presence of a peak corresponding to silver (Ag) in the leaf extracts of *F. indica* indicated the formation of silver nanoparticles in the EDX spectra. This study validated the presence of silver (Ag) in the leaf extracts of *F. indica*, along with other phytochemicals that serve as capping and stabilizing agents for the synthesized AgNPs.

TEM Analysis: Transmission Electron Microscopy (TEM) images revealed that the green-synthesized silver nanoparticles exhibited aggregation of spherical particles, although these particles were not directly in contact with each other. The nanoparticles ranged in size from 11 to 63 nm, with an average size of 30 nm (Fig. 10).

DPPH free radicles scavenging activity: Different concentrations of methanolic extracts of *F. indica* were used to check out the DPPH antioxidant activity. A standard ascorbic acid was used to explore the comparative DPPH antioxidant assay. The results revealed maximum scavenging capacity for the concentration of 1000 µg/mL (Table 1).

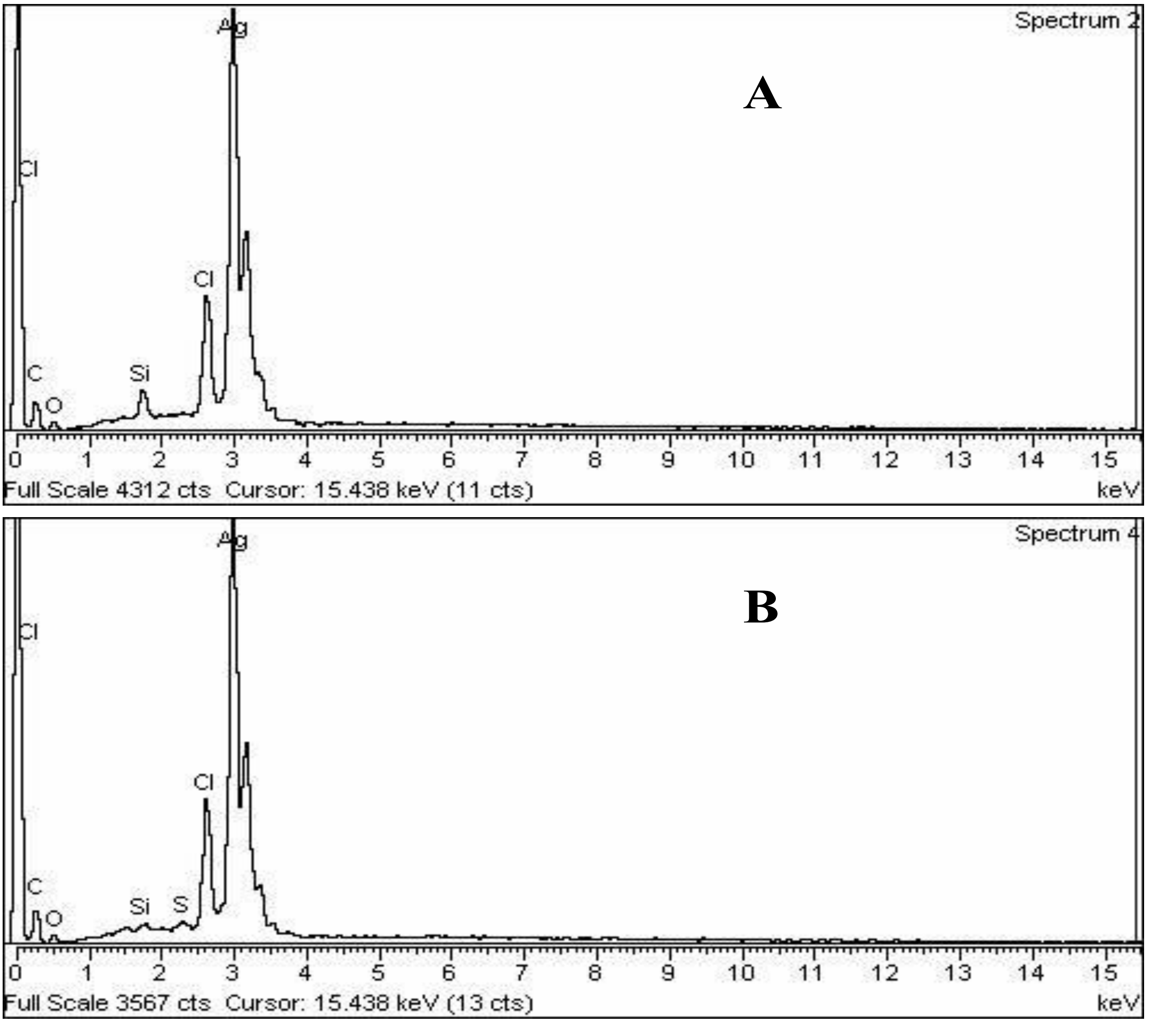

Fig. 9. EDX spectra of the biosynthesized silver nanoparticles (AgNPs).

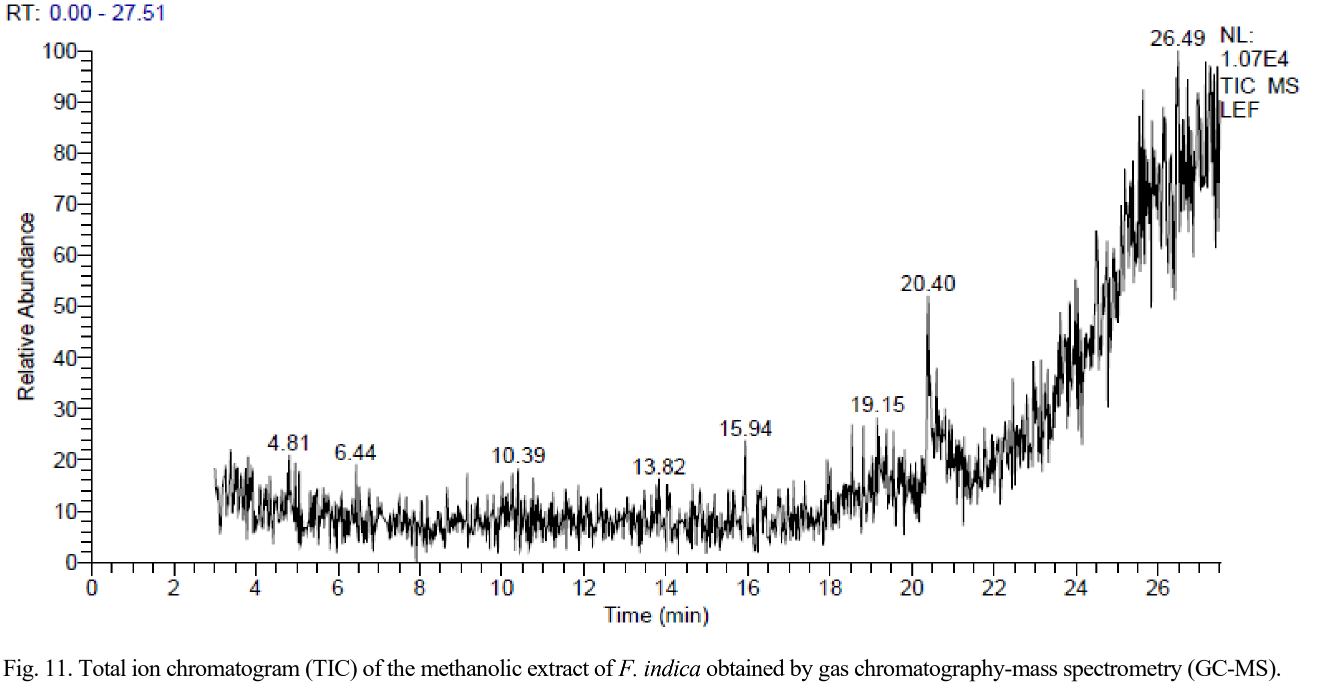

Fig. 11. Total ion chromatogram (TIC) of the methanolic extract of *F. indica* obtained by gas chromatography-mass spectrometry (GC-MS).

Table 2. GC-MS analysis of the methanolic extract of *F. indica* showing details of the tentatively identified phytochemical constituents

S. No.	CAS No.	Qual	Compound	Formula	Molecular weight	Structure	RT	Peak area%
1.	56528-77-9	402	2-Cyclohexylpiperidine	$C_{11}H_{21}N$	167.29	Piperidine ring attached to cyclohexyl group	3.41	3.31
2.	124-13-0	427	Octanal	$C_8H_{16}O$	128.21	$CH_3(CH_2)_6CHO$	4.24	0.87
3.	10118-90-8	681	Minocycline	$C_{23}H_{27}N_3O_7$	457.48	Tetracycline antibiotic skeleton	5.47	1.12
4.	22548-43-2	363	Diborane (6), μ-mercapto-	B_2H_6S	59.73	Diborane bridged by sulfur	5.71	0.99
5.		315	Pyrrolidin-2-carboxylic acid, 1-(2,5-dimethyl-3-furoyl)-	$C_{12}H_{15}NO_4$	237.25	Pyrrolidine linked to dimethylfuran carbonyl	6.06	0.26
6.	10157-76-3	323	Benzenesulfonic acid, 4-methyl-, dodecyl ester	$C_{19}H_{32}O_3S$	340.52	p-Toluenesulfonic acid dodecyl ester	6.42	0.90
7.	1622-61-3	396	Clonazepam	$C_{15}H_{10}ClN_3O_3$	315.71	Benzodiazepine nucleus	6.77	0.20
8.	101463-69-8	470	Flufenoxuron	$C_{21}H_{11}ClF_6N_2O_3$	488.77	Benzoylurea insecticide structure	7.03	0.79
9.	33838-11-8	442	1H-Pyrrole, 2,3-dihydro-1-methyl-	C_5H_9N	83.13	1-Methyl-2,3-dihydro-1H-pyrrole	7.50	0.84
10.	14365-44-7	501	Adenosine, 5'-amino-5'-deoxy-	$C_{10}H_{14}N_6O_3$	266.26	5'-Amino-5'-deoxyadenosine	8.68	0.59
11.	458-88-8	377	Piperidine, 2-propyl-, (S)-	$C_8H_{17}N$	127.23	(S)-2-Propylpiperidine	8.95	1.18
12.	42576-02-3	382	Bifenox	$C_{14}H_9Cl_2NO_5$	342.13	Diphenyl ether herbicide	9.40	0.65
13.	105-95-3	392	Ethylene brassylate	$C_{15}H_{26}O_4$	270.36	Macrocyclic diester (musk compound)	9.76	0.49
14.	71407-30-2	307	N-Retinoylglycine (all-trans)	$C_{22}H_{31}NO_3$	357.49	Retinoid–glycine conjugate	10.05	2.32
15.	169590-42-5	305	Celecoxib	$C_{17}H_{14}F_3N_3O_2S$	381.37	Pyrazole sulfonamide	10.54	0.18
16.	77803-84-0	356	Cyclohexanol, 1R-4-acetamido-2,3-cis-epoxy-	$C_8H_{13}NO_3$	171.19	Epoxy cyclohexanol acetamide	10.82	0.63
17.	529-18-0	302	8-Azabicyclo[3.2.1]oct-2-ene, 8-methyl-	$C_8H_{13}N$	123.20	8-Methyl-8-azabicyclo[3.2.1]oct-2-ene	11.21	0.24
18.	1654-86-0	312	Decanoic acid, decyl ester	$C_{20}H_{40}O_2$	312.53	Decyl decanoate	11.58	0.86
19.	3386-32-1	311	Benzenesulfonic acid, 4-methyl-, octadecyl ester	$C_{25}H_{44}O_3S$	424.69	Octadecyl p-toluenesulfonate	12.07	0.64
20.	77-37-2	365	Procyclidine	$C_{19}H_{29}NO$	287.44	Piperidine alcohol derivative	12.39	0.53
21.	1530-05-8	349	Heptane, 1,1-diphenyl-	$C_{19}H_{24}$	252.39	1,1-Diphenylheptane	13.06	0.82
22.	1204-76-8	334	[2,4,5-Tris(hydroxymethyl)phenyl]methanol	$C_{10}H_{14}O_4$	198.22	Benzene bearing four hydroxymethyl groups	13.49	0.34
23.	822-23-1	332	Acetic acid, octadecyl ester	$C_{20}H_{40}O_2$	312.54	Octadecyl acetate	13.80	1.31
24.	629-70-9	331	1-Hexadecanol, acetate	$C_{18}H_{36}O_2$	284.48	Hexadecyl acetate	14.06	0.84
25.	14113-05-4	373	trans-10-Hydroxy-2-decenoic acid	$C_{10}H_{18}O_3$	186.25	(2E)-10-Hydroxy-2-decenoic acid	14.82	1.52
26.	77-19-0	370	Dicyclomine	$C_{19}H_{35}NO_2$	309.49	Dicyclomine hydrochloride skeleton	15.16	0.46
27.	2778-96-3	303	Octadecanoic acid, octadecyl ester	$C_{36}H_{72}O_2$	536.96	Stearic acid octadecyl ester	15.94	3.00
28.	78490-35-4	262	Diphenylacetylaspartic acid	$C_{18}H_{17}NO_5$	327.33	N-(Diphenylacetyl)aspartic acid	16.32	0.51
29.	2482-37-3	349	Acetamide, N-[2-(acetyloxy)-1-[(acetyloxy)methyl]-3-heptadecenyl]-, [R-[R*,S*-(E)]]-	$C_{24}H_{43}NO_5$	425.60	Acetylated long-chain acetamide	16.78	0.73
30.	18205-60-2	332	Pyrrolidine, 1-(3-cyclohexen-1-ylidenemethyl)-	$C_{11}H_{17}N$	163.26	Pyrrolidine linked to cyclohexene	17.05	0.42
31.	10316-79-7	376	Cyclopentanemethanol, 1-amino-	$C_6H_{13}NO$	115.17	1-Aminocyclopentanemethanol	17.49	0.88

RT = Retention time; CAS No. = Chemical Extracts Service registry number; Qual = NIST library matching quality score; MW = Molecular weight (g/mol); Peak area (%) = Relative percentage of the total chromatographic peak area. Constituents identifications are tentative and were assigned by comparing the obtained mass spectra with those in the National Institute of Standards and Technology (NIST) Mass Spectral Library

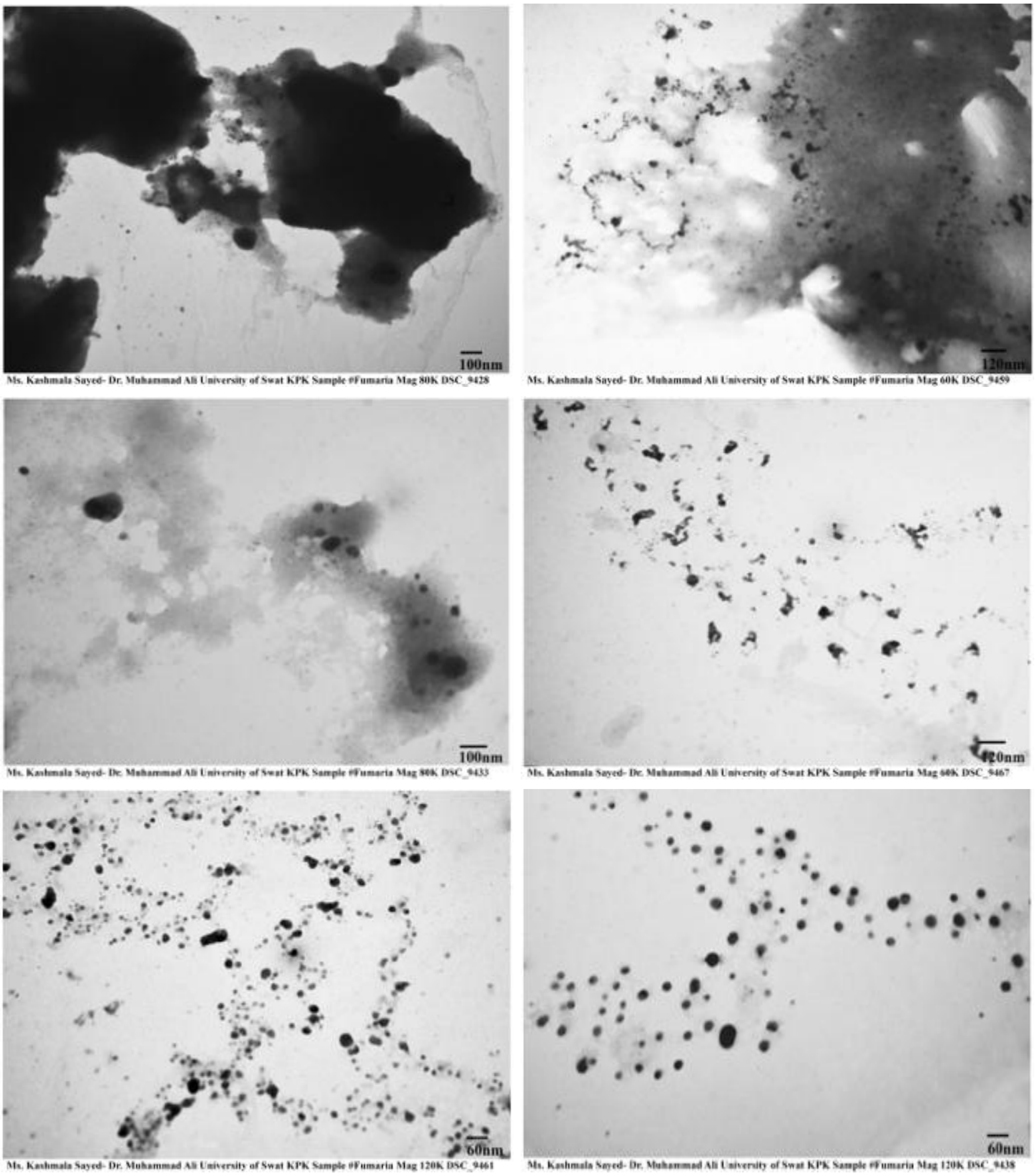

Fig. 10. Transmission electron microscopy (TEM), showing particle size ranging from 11 to 63 nm.

Table 1. DPPH free radicles scavenging activity of aqueous leaf extract of *F. indicia*.

Percent activity	Concentrations
97.62	Control (Ascorbic acid)
41.81	62.5 µg/mL
57.45	125 µg/mL
69.54	250 µg/mL
77.17	500 µg/mL
82.87	1000 µg/mL

GC-MS analysis of the leaf extract: Gas chromatography-mass spectrometry (GC-MS) analysis of *F. indica* revealed a chemically diverse composition of nitrogen-containing heterocyclic compounds, oxygenated constituents, aromatic derivatives, fatty acid esters, macrocyclic lactones, nucleoside analogues, and long-chain aliphatic constituents (Table 2 and Fig. 11). The identified constituents included 2-cyclohexylpiperidine, octanal, minocycline, flufenoxuron, 1H-pyrrole, 2,3-dihydro-1-methyl, adenosine, 5′-amino-5′-deoxy, piperidine, 2-propyl-(S)-, bifenox, ethylene brassylate, N-retinoylglycine (all-trans), celecoxib, procyclidine, diphenylacetylaspartic acid, cyclopentanemethanol, 1-amino, trans-10-hydroxy-2-decenoic acid, dicyclomine, octadecanoic acid octadecyl ester, and numerous additional aromatic and aliphatic constituents. The GC-MS analysis recognized that the sample possesses a chemically varied metabolite profile composed of heterocyclic nitrogen constituents, aromatic compounds, fatty acid esters, oxygenated metabolites, nucleoside derivatives, and long-chain lipid compounds.

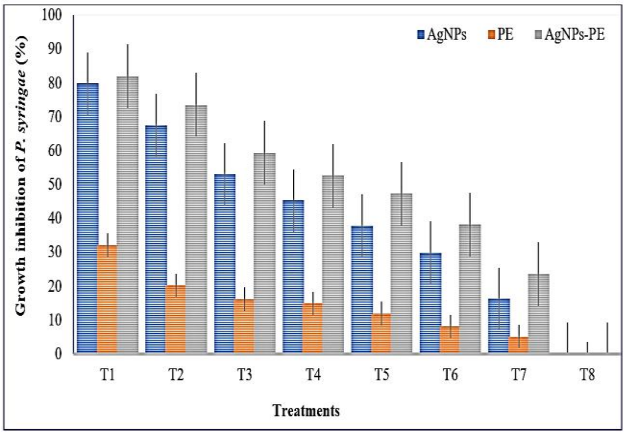

Fig. 12. *In vitro* growth inhibition of *P. syringae* (%) under various concentrations of biosynthesized FI-AgNPs, *Fumaria indica* plant extract and plant extract with coated FI-AgNPs (T1 to T7, 1000, 500, 250, 125, 62.5, 31.25 15.62 µg/mL, respectively); T8, control (water). Error bars are representing standard error of mean (n=3)

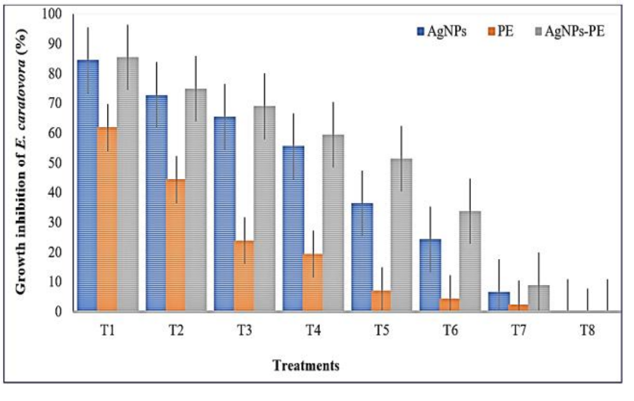

Fig. 13. *In vitro* growth inhibition of *E. carotovora* (%) under various concentrations of biosynthesized FI-AgNPs, plant extract and *Fumaria* plant extract with coated FI-AgNPs (T1 to T7, 1000, 500, 250, 125, 62.5, 31.25 15.62 µg/mL, respectively); T8, control (water). Error bars are representing standard error of mean (n=3).

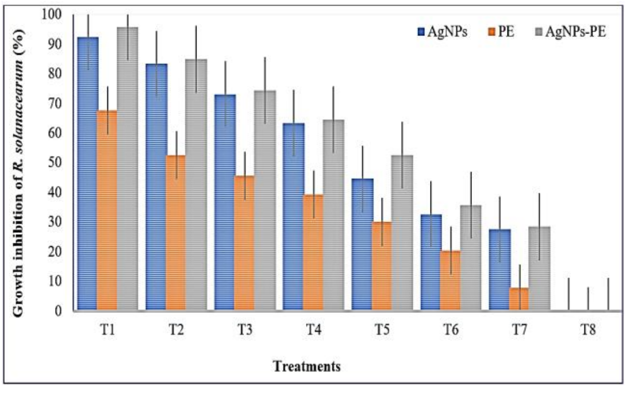

Fig. 14. *In vitro* growth inhibition of *R. solanacearum* (%) under various concentrations of biosynthesized FI-AgNPs, *Fumaria* plant extract and plant extract with coated FI-AgNPs (T1 to T7, 1000, 500, 250, 125, 62.5, 31.25 15.62 µg/mL, respectively); T8, control (water). Error bars are representing standard error of mean (n=3).

Antibacterial efficacy / activities: The results revealed that maximum growth inhibition (81.94%) against *P syringae* was observed for the treatment PE+AgNPs applied @ 1000 µg / mL, while, AgNPs and PE applied at the same rate depicted 79.81% and 32.12% inhibition, respectively (Fig. 12). Likewise, growth inhibition (59.36%) against *P syringae* was observed for the treatment PE+AgNPs applied @ 250 µg / mL, while, AgNPs and PE applied at the same rate revealed 53.00% and 16.12% zone of inhibition, respectively. Subsequently, the growth inhibition (23.58%) against *P syringae* was observed for the treatment PE+AgNPs applied @ 15.62 µg / mL, while, AgNPs and PE applied at the same rate revealed 16.29% and 5.16% zone of inhibition, respectively**.** Similarly, Antibacterial efficacy of the green synthesize silver nanoparticles against *Erwina carotovora* is shown in Fig. 13. It was revealed that maximum growth inhibition (85.47%) against *E carotovora* was observed for the treatment PE+AgNPs applied @ 1000 µg / mL, while, AgNPs and PE applied at the same rate depicted 84.55% and 61.88% zone of inhibition, respectively. Similarly, growth inhibition (75.03%) against *E carotovora* was observed for the treatment PE+AgNPs applied @ 500 µg / mL, while, AgNPs and PE applied at the same rate revealed 72.77% and 44.42% zone of inhibition, respectively. Likewise, growth inhibition (69.04%) against *E carotovora* was observed for the treatment PE+AgNPs applied @ 250 µg / mL, while, AgNPs and PE applied at the same rate revealed 65.56% and 23.96% zone of inhibition, respectively. Further, the maximum growth inhibition (95.8450%) against *R. solanacearum* was observed for the treatment PE+AgNPs applied @ 1000 µg / mL, while, AgNPs and PE applied at the same rate depicted 92.39% and 67.54% inhibition, respectively (Fig. 14). Similarly, growth inhibition (84.84%) against *R. solanacearum* was observed for the treatment PE+AgNPs applied @ 500 µg / mL, while, AgNPs and PE applied at the same rate revealed 83.30% and 52.49% zone of inhibition, respectively. Likewise, growth inhibition (74.36%) against *R. solanacearum* was observed for the treatment PE+AgNPs applied @ 250 µg / mL, while, AgNPs and PE applied at the same rate revealed 73.07% and 45.66% zone of inhibition, respectively. It was revealed that the antibacterial efficacy of the green synthesized silver nanoparticles depicted a strong dose-dependent tendency, with higher concentrations of the synthesized NPs leading to comparatively greater inhibition.

Discussion

Fumaria indica, commonly known as Fumitory, is a plant with a rich history in traditional medicine. It is widely used in various cultures for its diverse therapeutic properties (Gupta & Rao, 2012). The current research investigates the traditional uses of *F. indica* in the Hindukush Mountain communities of the Malakand region in Pakistan and explores its potential for drug discovery. It also examines the application of *F. indica* in the development of silver nanoparticles, which show promising inhibitory effects against plant pathogens. Similar research on other medicinal plants has revealed that traditional knowledge can guide the discovery of valuable sources for silver nanoparticle synthesis, underscoring the rich potential of these plants in modern medicine (Haris & Ahmad, 2024; Jebril *et al.,* 2020) The current findings indicate that *F. indica* has been traditionally used for curing 17 different human ailments. As per local sources the plant was useful as anti-ulcer, anti-gastric, appetizer, laxative, carminative, anti-colic, antipyretic, antiperiodic and febrifuge, antiemetic, its role as blood purifier and to cure liver and skin disorders, to cure urinary diseases and remove kidney stones, its use as anodyne, anti-jaundice, antidiabetic and to control sugar level in the body. Similar studies were conducted by other researchers in different parts of the world which include (Jamshidi-Kia *et al.*, 2018; Salmerón-Manzano *et al.*, 2020).

The study indicated that as per multi-criteria decision analysis approach, locally some of the treatments have more importance than the others like the most popular usus of *F. indica* were antipyretic, antiperiodic and febrifuge followed by anti-ulcer, anti-gastric and its beneficial impacts in liver disorders (Huang *et al.,* 2011; Hamidah *et al.,* 2022). The wide range of traditional uses of *F. indica* makes it a potential candidate for the drug discovery. Its traditional uses provide a basis for exploring its pharmacological potential in modern medicine. The plant's effectiveness in treating various human ailments suggests that it could be utilised to develop drugs for these ailments. Based on traditional uses of medicinal plants many researchers have presented their views, which include drugs were discovered in the past from various plants (Dutfiel, 2010; Wangkheirakpam, 2018). On the same way silver nanoparticles (AgNPs) synthesized using plant extracts are gaining attention due to their potent antimicrobial properties. *Fumaria indica* can be used in the green synthesis of AgNPs, providing an eco-friendly and cost-effective method to control pathogens (Gul *et al.*, 2021). The success of making these nanoparticles depended on how much *F. indica* leaf extract was used compared to the silver nitrate. When a 1:1 ratio was used, nanoparticles with efficient characteristics were obtained. The aqueous extract of the leaves of *F. indica* showed considerable DPPH free radical scavenging activity in a dose dependent manner. The antioxidant activity increased with the concentration of the extract with 41.81% at 62.5 µg/mL and 82.87% at 1000 µg/mL, indicating that it has improved and more radical scavenging capacity as the concentration of extract increased. The antioxidant potential of the extract was found to be high, however, less than the standard ascorbic acid (97.62%) and this may be due to the presence of phenolic and flavonoid compounds. The plants are a good source of antioxidants and can potentially play a role in mitigating the effects of oxidative stress on cells (Oyawaluja *et al*., 2024).

Gas chromatography-mass spectrometry (GC-MS) is one of the most extensively employed analytical techniques for the qualitative characterization of volatile and semi-volatile phytochemicals in therapeutic plants. In the present investigation, GC-MS analysis of *F. indica* showed a chemically diverse metabolite profile comprising of heterocyclic nitrogen-containing constituents, aromatic derivatives, oxygenated metabolites, long-chain fatty acid esters, macrocyclic constituents, and several lipid-derived compounds. The detection of chemically various metabolites suggests that *F. indica* contains several secondary metabolites that may collectively contribute to its reported therapeutic properties. Similar observations have been previously reported where innovative chromatographic techniques, including GC-MS, HPLC, and LC-MS/MS, revealed that *F. indica* possess a complex phytochemical composition dominated by alkaloids together with phenolic constituents and other secondary metabolites (Prokopenko *et al*., 2025; Puri *et al*., 2021). The chromatographic profile obtained in the current study revealed constituents distributed over a wide retention time range (3.41-27.26 min), indicating the existence of metabolites with different molecular weight, polarities, and volatilities. Early eluting constituents mainly consisted of relatively low molecular weight nitrogen comprising heterocyclic molecules and oxygenated constituents, whereas compounds detected at higher retention times were mainly long-chain esters, oxygenated lipids, aromatic derivatives, and relatively fewer volatile compounds. Such chromatographic behavior is normally expected in complex plant matrices because the constituents possessing lower molecular weight and higher volatility elute earlier than greater lipophilic molecules (Zhang *et al*., 2020; Gupta *et al*., 2012). Previous phytochemical investigations have similarly reported that *Fumaria* species comprise diverse classes of primary and secondary metabolites in addition to alkaloids, counting organic acids, lipids, flavonoids, and phenolic compounds, reflecting the remarkable biochemical diversity of this therapeutic genus. Several nitrogen comprising compounds identified in the current GC-MS profile indicate that *Fumaria* remains an important source of nitrogenous secondary metabolites with potential pharmacological activities including antioxidant, antimicrobial, anti-inflammatory, hepatoprotective, antispasmodic, and antinociceptive properties (Yang *et al*., 2024; Prokopenko *et al*., 2025; Frolova *et al*., 2025).

Bacteria like *Pseudomonas syringae* pv. *tomato*, causing bacterial speck disease, is a common and damaging disease affecting tomato plants (Zhao *et al.,* 2003; Kozik, 2002). Chemical pesticides are often used to kill these bacteria, but they have harmful effects and are not environment friendly. Using silver nanoparticles made from plants may be a safer way to control these harmful bacteria. In current study, both the silver nanoparticles alone and those coated with plant extract showed strong antibacterial activity, even at low concentrations. This means they are effective enough at stopping the growth of harmful bacteria in plants. It was noted that the *F. indica* leaf extract significantly inhibited *Pseudomonas syringae* pv. *tomato*, especially at higher concentrations. Overall, the study depicted that using *F. indica* plants in biosynthsizing silver nanoparticles may have great potential to fight harmful bacteria of tomato crop like *Pseudomonas syringae*, *Erwinia carotovora* and *Ralstonia solanacearum* for better growth and yield as previously reported (Alam *et al*., 2019; Santiago *et al*., 2019; Bibi *et al*., 2023; Orfe *et al*., 2026; Mahmoud and El-Zahry 2026).

Conclusion

Fumaria indica is a valuable medicinal plant with numerous therapeutic uses. The green synthesized AgNPs showed significant control of plant pathogen *Pseudomonas syringae pv. Tomato.* The antioxidant potential of the plant extract was recorded as high and near to the standard ascorbic acid. The use of silver nanoparticles in disease management is an innovative dimension to its use, particularly in developing new antimicrobial agents to tackle bacterial and fungal pathogens.

Acknowledgement

The authors acknowledge the help and services provided by the Centralized Resource Lab, Department of Physics, University of Peshawar. We are thankful to the local informants for their generous help during field work, and Mr. Rahman Ali PhD scholar in his help during plant collection.

Author's Contributions: Ahmad Ali & Z. Ullah designed and conceptualized the research work; K. Sayed carried out experimental and field work along with N. Alam; K. Sayed and Z. Ullah and A. Ali wrote the original draft; H. Sher and M. Ahmad helped in data analysis, visualization and writing the revised version; R. M. Febriyanti helped in interpreting some of the results.

Conflict of Interest: The authors declare that they have no competing interest.

References

Ahmad, M., A. Ali, M.A. Ali, M.A. Farah, Z. Ullah, H. Ali, H. Sher, S.M. Eldin, S. Zaman and I. Ali. 2024. GC-MS characterization of *Polygonatum geminiflorum* depicted by antibacterial efficacy of the biosynthesized silver nanoparticles using its leaf extract. *Global NEST J.*, 26(3): 05495. Doi: 10.30955/gnj.005495.

Ahmad, S., M. Israr, S. Liu, H. Hayat, J. Gul, S. Wajid, M. Ashraf, S.U. Baig and A.A. Tahir. 2020. Spatio-temporal trends in snow extent and their linkage to hydro-climatological and topographical factors in the Chitral River Basin (Hindukush, Pakistan). *Geocart. Int.*, 35(7): 711-734. DOI: 10.1080/10106049.2018.1524517.

Alam, N., Z.K. Shinwari, M. Ilyas and Z. Ullah. 2011. Indigenous knowledge of medicinal plants of Chagharzai Valley, District Buner, Pakistan. *Pak. J. Bot.*, 43(2): 773-780.

Alam, T., R.A.A. Khan, K. Ali, A. Ali, H. Sher, Z. Ullah and M. Ali. 2019. Biogenic synthesis of iron oxide nanoparticles via *Skimmia laureola* and their antibacterial efficacy against bacterial wilt pathogen *Ralstonia solanacearum*. *Mater. Sci. Eng. C*, 98: 101-108. DOI: 10.1016/j.msec.2018.12.117.

Ali, N., Z. Ullah, A. Ahmad, Bushra, Z. Abbas and A.A. Khan. 2024. Taxonomic studies of Cyperaceae (sedges) in Swat Pakistan: using a multivariate approach. *Pak. J. Bot*, 56(4): 1517-1531.

Arif, M., R. Ullah, M. Ahmad, A. Ali, Z. Ullah, M. Ali, F.A. Al-Joufi, M. Zahoor and H. Sher. 2022. Green synthesis of silver nanoparticles using *Euphorbia wallichii* leaf extract: Its antibacterial action against citrus canker causal agent and antioxidant potential. *Molecules*, 27(11): 3525. DOI: 10.3390/molecules27113525.

Arora, H., A. Sharma, P. Poczai, S. Sharma, F.F. Haron, A. Gafur and R.Z. Sayyed. 2022. Plant-derived protectants in combating soil-borne fungal infections in tomato and chilli. *J. Fung.*, 8(2): 213. DOI: 10.3390/jof8020213.

Ashfaq, S., M. Ahmad, M. Zafar, S. Sultana, S. Bahadur and N. Abbas. 2019. Medicinal plant biodiversity used among the rural communities of arid regions of northern Punjab, Pakistan. *Ind. J. Tradit. Knowl*., 18(2): 226-241.

Aslam, S., S. Siddiqui, U. Ullah, U. Manzoor, T. Lateef, N. Samreen, P. Nasir, S. Khan, L. Noor and S.A. Ghalib. 2022. Vertebrate wildlife of Pakistan: A review. *Can. J. Pure Appl. Sci.*, 16(2): 5483-5495.

Bibi, Z., M. Ali, M. Abohashrh, I. Ahmad, H. Khan, M. Ali, F. Akbar, N. Ahmad, A. Iqbal, F. Ullah and Z. Ullah. 2023. Biologically synthesized silver nanoparticles efficiently control plant pathogenic bacteria-*Erwinia carotovora* and *Ralstonia solanacearum*. *Inorganics*, 11(7): 309. DOI: 10.3390/inorganics11070309

Codrington, K.D.B. 2017. A geographical introduction to the history of Central Asia. In: *The Turks in the Early Islamic World*. (Ed.): C.E. Bosworth. Routledge, London, pp. 15-57.

Dutfield, G. 2010. Opinion: Why traditional knowledge is important in drug discovery. *Future Med. Chem.*, 2(9): 1405-1409. DOI: 10.4155/fmc.10.210.

Ersen, N. 2024. Assessment of medicinal and aromatic plants' contribution to the country's economy by hybrid multi-criteria decision-making approach: The case of Turkey. *J. Agric. Sci.*, 30(2): 304-316. DOI: 10.15832/ankutbd.1308059.

Fabricant, D.S. and N.R. Farnsworth. 2001. The value of plants used in traditional medicine for drug discovery. *Environ. Health Perspect.*, 109(Suppl. 1): 69-75. DOI: 10.1289/ehp.01109s169.

Frolova, N., A. Orlova, V. Popova T. Bilova and A. Frolov. 2025. Gas chromatography–mass spectrometry (GC-MS) in the plant metabolomics toolbox: Sample preparation and instrumental analysis. *Biomolecules*, 16(1): 16.

Gul, A., Fozia, A. Shaheen, I. Ahmad, B. Khattak, M. Ahmad, R. Ullah, A. Bari, S.S. Ali, A. Alobaid, M.M. Asmari and H.M. Mahmood. 2021. Green synthesis, characterization, enzyme inhibition, antimicrobial potential, and cytotoxic activity of plant-mediated silver nanoparticles using *Ricinus communis* leaf and root extracts. *Biomolecules*, 11(2): 206. DOI: 10.3390/biom11020206.

Guo-Yu R. and A. Bhakta. 2017. Climate change in the Hindu Kush Himalaya. *Adv. Clim. Change Res.,* 8: 137e140. DOI: 10.1016/j.accre.2017.09.001.

Gupta, P.C. and C.V. Rao. 2012. Morpho-anatomical and physicochemical studies of *Fumaria indica* (Hausskn.) Pugsley. *Asian Pac. J. Trop. Biomed.*, 2(10): 830-834. DOI: 10.1016/S2221-1691(12)60238-X.

Gupta, P.C., N. Sharma and C.V. Rao. 2012. A review on ethnobotany, phytochemistry and pharmacology of Fumaria indica (Fumitory). *Asian Pacific J. Trop. Biomed*., 2(8): 665-669.

Hamidah, M., I.M. Hasmadi, L.S.L. Chua, W.S.Y. Yong, K.H. Lau, I. Faridah-Hanum and H.Z. Pakhriazad. 2022. Development of a protocol for Malaysian important plant areas criterion weights using multi-criteria decision making-analytical hierarchy process (MCDM-AHP). *Glob. Ecol. Conserv.*, 34: e02033.

Haris, Z. and I. Ahmad. 2024. Green synthesis of silver nanoparticles using *Moringa oleifera* and its efficacy against Gram-negative bacteria targeting quorum sensing and biofilms. *J. Umm Al-Qura Univ. Appl. Sci.*, 10(1): 156-167. DOI: 10.1007/s43994-023-00089-8.

Heinrich, M. and P. Bremner. 2006. Ethnobotany and ethnopharmacy—their role for anti-cancer drug development. *Curr. Drug Targets*, 7(3): 239-245. DOI: 10.2174/138945006776054988.

Hossain, T.J. 2024. Methods for screening and evaluation of antimicrobial activity: A review of protocols, advantages, and limitations. *Eur. J. Microbiol. Immunol.*, 14(2): 97-115. DOI: 10.1556/1886.2024.00035.

Huang, I.B., J. Keisler and I. Linkov. 2011. Multi-criteria decision analysis in environmental sciences: Ten years of applications and trends. *Sci. Total Environ.*, 409(19): 3578-3594. DOI: 10.1016/j.scitotenv.2011.06.022.

Jamshidi-Kia, F., Z. Lorigooini and H. Amini-Khoei. 2018. Medicinal plants: Past history and future perspective. *J. Herbmed. Pharmacol.*, 7(1): 1-7. DOI: 10.15171/jhp.2018.01.

Jebril, S., R.K.B. Jenana and C. Dridi. 2020. Green synthesis of silver nanoparticles using *Melia azedarach* leaf extract and their antifungal activities: *In vitro* and *In vivo*. *Mater. Chem. Phys.*, 248: 122898. DOI: 10.1016/j.matchemphys.2020.122898.

Khan, A.H., M. Adil., M.A. Aziz, R. Sõukand and A. Pieroni. 2023. Traditional foraging for ecological transition? Wild food ethnobotany among three ethnic groups in the highlands of the eastern Hindukush, North Pakistan. *J. Ethnobiol. Ethnomed*., 19(1): 9. DOI: 10.1186/s13002-023-00581-9.

Khan, M. 2023. Nanotechnology in plant sciences and agriculture: An overview. In: *Advanced Nanotechnology in Plants: Methods and Applications*. (Ed.): J.-T. Chen. CRC Press, Boca Raton, pp. 1-12. DOI: 10.1201/b23308-1.

Kozik, E.U. 2002. Studies on resistance to bacterial speck (*Pseudomonas syringae* pv. *tomato*) in tomato cv. Ontario 7710. *Plant Breed.*, 121(6): 526-530. DOI: 10.1046/j.1439-0523.2002.00766.x.

Lulekal, E., E. Kelbessa, T. Bekele and H. Yineger. 2008. An ethnobotanical study of medicinal plants in Mana Angetu District, southeastern Ethiopia. *J. Ethnobiol. Ethnomed.*, 4: 10. DOI: 10.1186/1746-4269-4-10.

Mahmoud, A.F., and M.R. El-Zahry. 2026. Antibacterial activity of silver nanoparticles against *Pseudomonas syringae* pv. tomato and their potential in plant disease management. *Physiol. Mol. Plant Pathol*., 145: 103405. Doi:10.1016/j.pmpp.2026.103405.

Mazhar, H.R., M. Atiq, N.A. Rajput, S. Ali, M. Usman, U. Ahmad, A. Nawaz, M.F. Ullah and S. Iqbal. 2021. Determination of antibacterial activity of phytochemicals towards *Xanthomonas citri* pv. *citri* causing citrus canker. *Agric. Sci. J.*, 3(2): 1-12. DOI: 10.56520/asj.v3i2.94.

Muthuramalingam, R., K.A. Barroso, J. Milagres, V. Tedardi, F.F. de Oliveira, V. Takeshita, I. Karmous, R. El-Tanbouly and W. da Silva. 2024. Tiny but mighty: Nanoscale materials in plant disease management. *Plant Dis.*, 108(2): 241-255. DOI: 10.1094/PDIS-05-23-0970-FE.

Narware, J., S.P. Singh, J. Chakma, P. Ranjan, L. Behera, P. Das, N. Manzar and A.S. Kashyap. 2024. Enhancing tomato growth and early blight disease resistance through green-synthesized silver nanoparticles: Insights into plant physiology. *S. Afr. J. Bot.*, 166: 676-689. DOI: 10.1016/ j.sajb.2024.01.059.

Orfei, B., J.F. Pothier, L. Scotti, A. Aceto, C. Moretti, R. Buonaurio and T.H.M. Smits. 2026. Transcriptome analysis of *Pseudomonas syringae* pv. tomato DAPP-PG 215 in response to silver nanoparticles exposure. *Front Microbiol*., 16: 1714857. DOI: 10.3389/fmicb.2025.1714857.

Oyawaluja, B.O., A.A. Oyawaluja, D.E. Akinyimika, O.A. Odukoya and H.A.B. Coker. 2024. Antioxidant profiling, phytochemical investigation and pharmacognostic evaluation of *Nephrolepis biserrata*. *Trop. J. Phytochem. Pharm. Sci.*, 3(2): 208-215. DOI: 10.26538/tjpps/v3i2.8.

Prokopenko, Y., I. Surzhykov, O. Golovchenko, V. Mishchenko and V. Georgiyants. 2025. Fumaria officinalis: Phytochemical complexity and its medicinal significance. *Fitoterapia*, 106780.

Puri, S., D. Sahal and U. Sharma. 2021. A conversation between hyphenated spectroscopic techniques and phytometabolites from medicinal plants. *Anal. Sci. Adv*., 2(11-12): 579-593.

Rafiq, M., S. Nadeem, N. Hassan, M. Hayat, W. Sajjad, S. Zada, W. Sajjad and F. Hasan. 2020. Fungal recovery and characterization from Hindu Kush Mountain range, Tirich Mir glacier, and their potential for biotechnological applications. *J. Basic Microbiol.*, 60(5): 444-457. DOI: 10.1002/jobm.201900608.

Rahman, I.U., F. Ijaz, A. Afzal, Z. Iqbal, N. Ali and S.M. Khan. 2016. Contributions to the phytotherapies of digestive disorders: Traditional knowledge and cultural drivers of Manoor Valley, Northern Pakistan. *J. Ethnopharmacol.*, 192: 30-52. DOI: 10.1016/j.jep.2016.06.049.

Rahman, S.U., Z. Ullah, A. Ali, M.A. Aziz, N. Alam, H. Sher and I. Ali. 2022. Traditional knowledge of medicinal flora among tribal communities of Buner Pakistan. *Phytomed. Plus*, 2(3): 100277.

Salmeron-Manzano, E., J.A. Garrido-Cardenas and F. Manzano-Agugliaro. 2020. Worldwide research trends on medicinal plants. *Int. J. Environ. Res. Public Health.,* 17(10): 3376.

Santiago, T.R., C.C. Bonatto, M. Rossato, C.A.P. Lopes, C.A Lopes, E.S.G. Mizubuti and L.P. Silva. 2019. Green synthesis of silver nanoparticles using tomato leaf extract and their entrapment in chitosan nanoparticles to control bacterial wilt. *J. Sci. Food Agric*., 99: 4248-4259. DOI: 10.1002/jsfa.9656.

Sher, H., R.W. Bussmann, R. Hart and H.J. de Boer. 2016. Traditional use of medicinal plants among Kalasha, Ismaeli and Sunni groups in Chitral District, Khyber Pakhtunkhwa province, Pakistan. *J. Ethnopharmacol.*, 188: 57-69.

Soheili, V., J. Asili, J. Davoodi, S. Soleimanpour, G. Karimi, S.F. Taghizadeh, R. Rezaee and A. Shakeri. 2023. Screening of some Iranian medicinal plants for anti-tuberculosis, antibacterial, and cytotoxic activities. *S. Afr. J. Bot.*, 154: 260-264. DOI: 10.1016/j.sajb.2023.01.036.

Tunc, T. 2024. Synthesis and characterization of silver nanoparticles loaded with carboplatin as a potential antimicrobial and cancer therapy. *Cancer Nanotechnol.*, 15(1): 2. DOI: 10.1186/s12645-023-00243-1.

Wangkheirakpam, S. 2018. Traditional and folk medicine as a target for drug discovery. In: *Natural Products and Drug Discovery: An Integrated Approach*. (Eds.): Mandal, S.C., V. Mandal and T. Konishi. Elsevier, pp. 29-56. DOI: 10.1016/B978-0-08-102081-4.00002-2.

Yang, X., X. Miao, L. Dai, X. Guo, J. Jenis, J. Zhang and X. Shang. 2024. Isolation, biological activity, and synthesis of isoquinoline alkaloids. *Natural Prod. Rep*., 41(11): 1652-1722.

Zhang, R., Q. Guo, E.J. Kennelly, C. Long and X. Chai. 2020. Diverse alkaloids and biological activities of Fumaria (Papaveraceae): An ethnomedicinal group. *Fitoterapia*, 146: 104697.

Zhao, Y., R. Thilmony, C.L. Bender, A. Schaller, S.Y. He and G.A. Howe. 2003. Virulence systems of *Pseudomonas syringae* pv. tomato promote bacterial speck disease in tomato by targeting the jasmonate signaling pathway. *The Plant J.*, 36(4): 485-499. DOI: 10.1046/j.1365-313X.2003.01895.x.

Zulfiqar, Z., R.R.M. Khan, M. Summer, Z. Saeed, M. Pervaiz, S. Rasheed, B. Shehzad, F. Kabir and S. Ishaq. 2024. Plant-mediated green synthesis of silver nanoparticles: Synthesis, characterization, biological applications, and toxicological considerations: A review. *Biocatal. Agric. Biotechnol.*, 57: 103121. DOI: 10.1016/j.bcab.2024.103121.