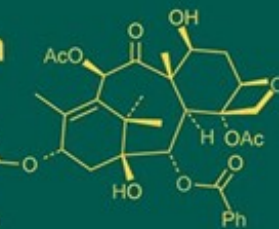
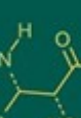
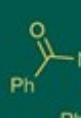
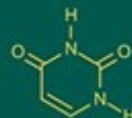


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Biosynthesis and characterization of silver nanoparticles using marigold (*Tagetes Erecta* L.) flower extract

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ABSTRACT

Abstract: An experiment was conducted under the Department of Floriculture and Landscaping, College of Horticulture, Mudigere, during 2025-26 to synthesize and characterize silver nanoparticles (Ag_{NPs}) using flower extract of *Tagetes erecta* L. cv. Dream Yellow through a green synthesis approach. The synthesis and characterization of Ag_{NPs} were carried out at the Centre for Nanotechnology, University of Agricultural Sciences, Raichur. Different ratios of marigold flower extract and 0.001 M silver nitrate ($AgNO_3$) solution were evaluated for nanoparticle synthesis. Significant variation was observed among the ratios for particle size, which ranged from 66.72 to 299.33 nm. The 1:20 ratio produced the smallest particle size (66.72 nm) and was selected for further characterization. The synthesized Ag_{NPs} recorded a particle size of 66.63 nm, polydispersity index of 0.258, zeta potential of -18.7 mV and a characteristic surface plasmon resonance peak at 447 nm. FTIR analysis showed absorption bands at 1022.27, 1352.10, 1602.85 and 2412.95 cm^{-1} , while XRD confirmed the crystalline face-centered cubic structure. SEM revealed predominantly spherical nanoparticles with particle sizes ranging from 39.47 to 70.61 nm. Based on the present study, *T. erecta* L. cv. Dream Yellow flower extract was found suitable for the green synthesis of crystalline silver nanoparticles with desirable physicochemical characteristics.

Keywords: *Tagetes erecta*, Silver nanoparticles, Green synthesis, Flower extract, Characterization

8 9

Introduction

Nanotechnology has gained considerable attention in recent years owing to the unique physicochemical properties of nanomaterials and their applications in diverse fields, including agriculture, environment, pharmacology, medicine, cosmetics and food sciences (Saravanan *et al.*, 2021; Bahrulolum *et al.*, 2021) [1, 2]. Nanotechnology involves the synthesis and application of materials with dimensions ranging from 1-100 nm (Shang *et al.*, 2019) [3]. Noble metal nanoparticles, including gold, silver and platinum, have received considerable attention because of their distinctive physicochemical properties (Pareek *et al.*, 2017) [4]. Silver nanoparticles (Ag_{NPs}) possess antimicrobial, antiviral, antioxidant and anti-inflammatory activities. Their electrical conductivity, optical and photocatalytic properties contribute to their applications in pharmaceutical and electronic industries (Kale *et al.*, 2021; Yaqoob *et al.*, 2020) [5, 6]. In agriculture, Ag_{NPs} have been investigated for crop growth, productivity, protection and postharvest management, including improving the vase life of cut flowers and other horticultural commodities (Kale *et al.*, 2021; Naing *et al.*, 2020) [5, 7]. Various approaches have been employed for the synthesis of silver nanoparticles, including physical, chemical and biological methods (Pareek *et al.*, 2017; Bahrulolum *et al.*, 2021) [1, 4]. Physical and chemical methods have several limitations, including expensive equipment, high energy requirements and low production yield, while the use of hazardous and toxic chemicals can result in environmental concerns (Pareek *et al.*, 2017; Bahrulolum *et al.*, 2021) [4]. Consequently, the need for sustainable, economical and environmentally friendly approaches to nanoparticle synthesis has increased (Saravanan *et al.*, 2021) [2]. Green synthesis provides an alternative biological route for nanoparticle production. Biological synthesis can involve microorganisms and plants, while other biological routes include microbial enzymes, polysaccharides and degradable polymers (Bahrulolum *et al.*, 2021) [1]. Plant-derived biomolecules, including phenolic compounds, flavonoids, tannins, proteins, ketones, aldehydes and carboxylic acids, participate in the reduction of silver ions (Ag^+) to metallic silver (Ag^0) and contribute to the capping and stabilization of the resulting nanoparticles (Vanlalveni *et al.*, 2021) [8]. Green synthesis has advantages over conventional methods, including mild conditions, natural reducing agents, reproducibility, biocompatibility, scalability and versatility (Devi *et al.*, 2024) [9]. Plant-mediated synthesis is simple, cost-effective and a single-step bioreduction approach requiring less energy (Bahrulolum

et al., 2021; Kuppusamy *et al.*, 2016) [1, 10]. Biological synthesis can utilize microorganisms such as bacteria, algae and fungi and plant parts including leaves, stems, roots, bark, seeds and flowers (Pareek *et al.*, 2017; Kuppusamy *et al.*, 2016) [4, 10]. Flower-mediated synthesis uses floral extracts for nanoparticle production. Compared with microorganism-mediated synthesis, it avoids aseptic microbial cultures and downstream separation from microbial broth (Kumar *et al.*, 2020) [11]. Flowers such as *Catharanthus roseus*, *Chrysanthemum indicum*, *Hibiscus rosa-sinensis*, *Jasminum nudiflorum*, *Plumaria alba*, *Salvia hydrangea*, and *Tagetes erecta* have been used for AgNP synthesis (Jamatia *et al.*, 2025; Kumar *et al.*, 2020) [12, 11]. Notably, *T. erecta* flower-derived AgNPs exhibited antibacterial activity against *Escherichia coli* and *Pseudomonas aeruginosa* and antifungal activity against *Candida albicans* (Kumar *et al.*, 2020) [11].

Marigold (*Tagetes erecta* L.), commonly known as African marigold, is an important ornamental flower crop belonging to the family Asteraceae. It is an erect, profusely branched annual herb native to Central and South America, particularly Mexico and is extensively cultivated in several regions, including India. Its large, showy flower heads, ranging from lemon yellow to orange, contribute to its ornamental and commercial importance and its flowers are widely used for religious practices, social events, garland decoration and garden ornamentation in India and Southeast Asia (Bhardwaj *et al.*, 2025) [13]. *T. erecta* is also a source of carotenoid pigments used in the pharmaceutical, food supplement and poultry feed industries, while its essential oil has perfume and insecticidal applications and its phytochemical and allelopathic potential has been explored for nematode management and natural weed control (Sharma *et al.*, 2024) [14]. Its flowers, leaves and roots have been used in traditional medicine and the plant exhibits antioxidant, anti-inflammatory, antimicrobial, hepatoprotective and antidiabetic activities (Singh *et al.*, 2020; Dey *et al.*, 2025) [16, 15].

The flowers contain diverse phytochemicals, including phenolic compounds, flavonoids, carotenoids such as lutein, zeaxanthin and β -carotene, anthocyanins, amino acids, tannins, alkaloids, saponins and sugars (Burlec *et al.*, 2021; Sultana *et al.*, 2025) [17, 18]. The presence of these phytochemicals in marigold flowers provides a basis for their utilization in plant-mediated nanoparticle synthesis. Their reducing and stabilizing properties support the formation and stabilization of AgNPs (Vanlalveni *et al.*, 2021) [8]. Therefore, the present investigation was undertaken to synthesize and characterize silver nanoparticles using marigold (*Tagetes erecta* L.).

Material and Methods

The study entitled “Biosynthesis and Characterization of Silver Nanoparticles Using Marigold (*Tagetes erecta* L.) Flower Extract” was conducted during 2025-26 under the Department of Floriculture and Landscaping, College of Horticulture, Mudigere. Biosynthesis and characterization of silver nanoparticles were carried out at the Centre for Nanotechnology, University of Agricultural Sciences, Raichur.

3.1 Biosynthesis of silver nanoparticles using marigold (*Tagetes erecta* L.) flower extract

Fresh flowers of marigold (*T. erecta* L.) cv. Dream Yellow were collected from a local farmer in Kolhapur, Maharashtra. The experiment comprised eight treatments with three replications in a Completely Randomized Design (CRD). The treatment combinations were marigold flower extract: 0.001 M AgNO₃ at ratios of 1:9, 2:8, 3:7, 4:6, 5:5, 6:4, 1:15 and 1:20. Nanoparticle formation was initially indicated by a dark brown colour and the treatment producing the smallest particle size was selected for further synthesis and characterization.

Fresh flowers were dried at 30 °C in a dehumidifier, powdered and sieved through a 350 BSS sieve. Five grams of powder were mixed with 100 mL double-distilled water and heated at 60 °C for 15 min with continuous stirring, followed by standing for 24 h at room tem-

perature. The extract was filtered through Whatman No. 1 filter paper and used for nanoparticle synthesis (Suprihatin *et al.*, 2023) [19].

Based on preliminary standardization, the 1:20 extract-to-AgNO₃ ratio, which produced the smallest particle size, was selected for further synthesis and characterization. Accordingly, 5 mL of flower extract was added dropwise to 100 mL of 0.001 M AgNO₃ solution with continuous stirring and heated at 60 °C for 20 min. The reaction mixture was protected from light and incubated under dark conditions for 24 h. The nanoparticle suspension was analysed by UV-Visible spectroscopy at 400-500 nm and subsequently dried at 37 °C in a hot air oven until complete drying.

3.2 Characterization of silver nanoparticles

The synthesized AgNPs were characterized by UV-Visible spectroscopy, Dynamic Light Scattering (DLS), zeta potential, Scanning Electron Microscopy (SEM), Fourier Transform Infrared Spectroscopy (FTIR) and X-ray Diffraction (XRD). Colour change from pale yellow to dark brown was recorded as a preliminary indication of nanoparticle formation (Deepika *et al.*, 2025) [20].

UV-Visible spectroscopy was performed using approximately 2 mL nanoparticle suspension in a quartz cuvette with a 1 cm path length to record the surface plasmon resonance spectrum (Burlec *et al.*, 2022) [21]. Particle size and polydispersity index (PDI) were determined by DLS using a Zetasizer Nano ZS after sonication of the nanoparticle suspension (Deepika *et al.*, 2025) [20]. Zeta potential was determined by Electrophoretic Light Scattering using the same instrument after sonication (Burlec *et al.*, 2022) [21].

For SEM analysis, the dried sample was mounted on a carbon-coated stub and examined to determine nanoparticle size and morphology (Sukhwai *et al.*, 2017) [22]. FTIR analysis was performed over 400-4000 cm⁻¹ to identify functional groups associated with the synthesized AgNPs (Padalia *et al.*, 2015) [23]. XRD analysis was carried out over a 2θ range of 10°-90° to determine the structural characteristics of the synthesized nanoparticles (Tyagi *et al.*, 2021) [24].

Results and Discussion

4.1 Synthesis and characterization of silver nanoparticles using marigold (*Tagetes erecta* L.) flower extract

4.1.1 Optimization of flower extract to silver nitrate ratio based on particle size

Silver nanoparticles synthesized using different flower extract to silver nitrate ratios showed considerable variation in particle size (Table 1). The mean particle size ranged from 66.72 to 299.33 nm. The 1:20 ratio produced the smallest mean particle size of 66.72 nm, whereas the 3:7 ratio recorded the largest particle size of 299.33 nm. The smaller particle size at 1:20 may be attributed to the optimum proportion of phytochemicals and silver ions, facilitating efficient reduction and stabilization of the nanoparticles. Hence, the 1:20 ratio was selected for further synthesis and characterization. Based on these results, the 1:20 extract-to-AgNO₃ ratio was selected for further synthesis and characterization. Burlec *et al.* (2022) [21] evaluated different extract-to-silver nitrate ratios using *T. erecta* flower extract and selected the 1:9 ratio, which showed a characteristic absorption peak at 410 nm.

Table 1. Mean particle size of silver nanoparticles synthesized using different flower extract to silver nitrate ratios

Treatments	Particle size (nm)
T ₁ - Marigold extract (1): 0.001M AgNO ₃ (9)	176.73
T ₂ - Marigold extract (2): 0.001M AgNO ₃ (8)	207.10
T ₃ - Marigold extract (3): 0.001M AgNO ₃ (7)	299.33
T ₄ - Marigold extract (4): 0.001M AgNO ₃ (6)	138.53
T ₅ - Marigold extract (5): 0.001M AgNO ₃ (5)	167.23

(continued on next page)

Treatments	Particle size (nm)
T ₆ - Marigold extract (6): 0.001M AgNO ₃ (4)	153.46
T ₇ - Marigold extract (1): 0.001M AgNO ₃ (15)	86.25
T ₈ - Marigold extract (1): 0.001M AgNO ₃ (20)	66.72
Mean	161.92
S.E.m±	0.38
C.D. @ 1%	1.57

4.1.2 Colour change of the synthesized silver nanoparticles

A gradual colour change from pale yellow to dark brown was observed during synthesis, with increasing colour intensity as the reaction progressed. This colour change indicated AgNP formation and is associated with surface plasmon resonance (SPR) resulting from the interaction of light with the nanoparticles. Maji *et al.* (2020) [25] observed a deep brown colour using *T. erecta* leaf extract, while Burlec *et al.* (2022) [21] reported a yellow to brown colour change using *T. erecta* flower extract. Deepika *et al.* (2025) [20] observed a reddish-brown colour during AgNP synthesis using marigold flower extract.

4.1.3 UV-Visible spectroscopy

The synthesized AgNPs exhibited a distinct absorption peak at 447 nm (Fig. 1), confirming nanoparticle formation. The observed peak represents the characteristic SPR absorption of silver nanoparticles. Bharathi *et al.* (2017) [26] reported an absorption peak at 420 nm using *Nerium oleander* flower extract, while Cheng *et al.* (2020) [27] recorded peaks at 448, 440 and 428 nm using *Cosmos indica*, *Cosmos bipinnata* and *Lantana camara* flower extracts, respectively. Aravind *et al.* (2021) [28] reported a peak at 440 nm using jasmine flower extract, whereas Burlec *et al.* (2022) [21] observed peaks at 410 and 420 nm using *T. erecta* flower extract.

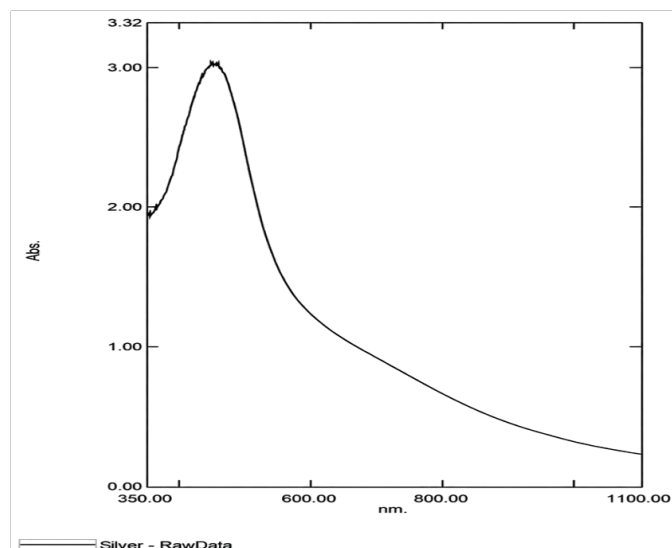


Figure 1. UV-Visible absorption spectrum of silver nanoparticles synthesized using *Tagetes erecta* L. flower extract

4.1.4 Particle size and polydispersity index

Dynamic Light Scattering analysis recorded an average particle size of 66.63 nm with a PDI of 0.258 (Fig. 2), indicating a relatively uniform particle size distribution. Maji *et al.* (2020) [25] reported an average size of 23.2 nm using *T. erecta* leaf extract, while Olfati *et al.* (2021) [29] obtained an average crystallite size of 25.88 nm using *T. erecta* flower extract. In contrast, Burlec *et al.* (2022) [21] reported particle sizes of 104 and 123 nm using *T. erecta* flower extract. Zhangabay *et al.* (2023) [30] recorded a particle size of 80 nm with a PDI of 0.26, comparable to the present observations.

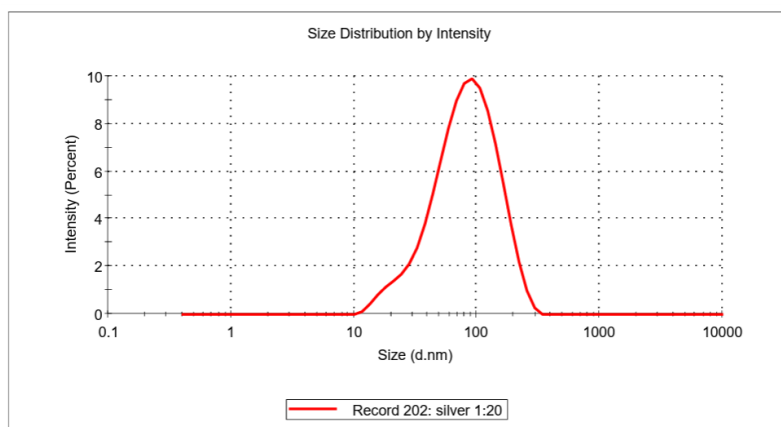


Figure 2. Particle size distribution of silver nanoparticles synthesized using *Tagetes erecta* L. flower extract

4.1.5 Zeta potential

The synthesized AgNPs showed a zeta potential of -18.7 mV, indicating a negatively charged surface and good stability. This negative charge may be attributed to phytochemicals adsorbed onto the nanoparticle surface, where they act as capping and stabilizing agents. Padalia *et al.* (2015) [23] reported a zeta potential of -27.63 mV for *T. erecta* flower-derived AgNPs, while El-Kemary *et al.* (2016) and Sukhwal *et al.* (2017) [22] reported -27 and -14.2 mV using *Calendula officinalis* and *Tagetes patula* extracts, respectively. Elemike *et al.* (2018) recorded values ranging from -14.1 to -15.9 mV for French marigold leaf and flower extracts.

4.1.6 Scanning electron microscopy

SEM analysis revealed predominantly spherical AgNPs, with particle sizes ranging from 39.47 to 70.61 nm (Fig. 3). Cheng *et al.* (2020) [27] reported spherical AgNPs with sizes of 28.7-45.5, 33.5-44.4 and 21.1-30.2 nm using *Cosmos indica*, *Cosmos bipinnata* and *Lantana camara* flower extracts, respectively. Erenler *et al.* (2021) [31], Katta *et al.* (2021) [32] and Ravunni *et al.* (2025) [33] also reported predominantly spherical AgNPs, with Ravunni *et al.* (2025) [33] recording sizes of 33-60 nm with an average of 46.5 nm.

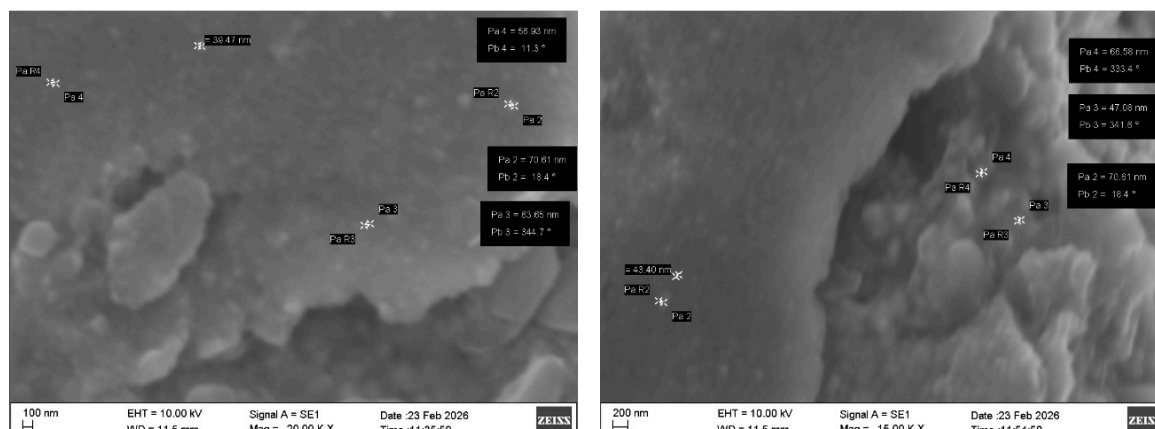


Figure 3. SEM micrograph of silver nanoparticles synthesized using *Tagetes erecta* L. flower

4.1.7 Fourier transform infrared spectroscopy

FTIR analysis showed absorption bands at 1022.27, 1352.10, 1602.85 and 2412.95 cm^{-1} (Fig. 4). The bands at 1602.85, 1352.10 and 1022.27 cm^{-1} were associated with C=O stretching of carbonyl/amide groups, carboxylate (COO^-) groups and C-O stretching of phenolic compounds, respectively, while the band at 2412.95 cm^{-1} was attrib-

uted to minor organic constituents. Aravind *et al.* (2021) [28] reported bands at 1636, 1371 and 1021 cm^{-1} , corresponding to C=O, hydroxyl and C-O groups, respectively. Cheng *et al.* (2020) [27] recorded bands in the ranges of 1598-1649, 1309-1384 and 1048-1072 cm^{-1} , associated with amide, carboxylate and C-N groups. These functional groups indicate the involvement of phytochemicals in nanoparticle reduction and stabilization.

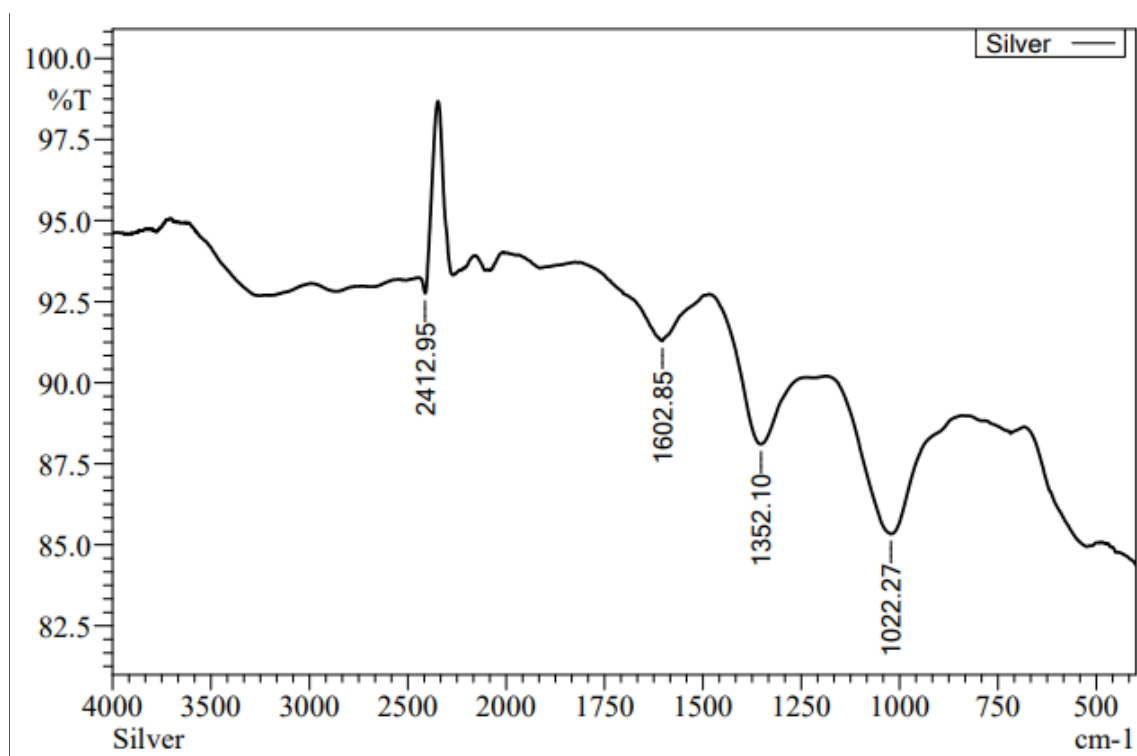


Figure 4. FTIR spectrum of silver nanoparticles synthesized using *Tagetes erecta* L. flower extract

4.1.8 X-ray diffraction

The XRD pattern exhibited distinct diffraction peaks at 27.69°, 32.12°, 38.00°, 44.27°, 46.09°, 48.46°, 54.69°, 57.34°, 64.51°, 67.30°, 74.25°, 76.56° and 85.47° (Fig. 5). The prominent peaks at 38.00°, 44.27°, 64.51° and 76.56° corresponded to the (111), (200), (220) and (311) planes of the face-centered cubic (FCC) structure of metallic silver, confirming the crystalline nature of the synthesized AgNPs. Katta *et al.* (2021) [32] reported peaks at 38.11°, 44.27°, 64.42° and 77.47°, while Aravind *et al.* (2021) [28] and Cheng *et al.* (2020) [27] reported corresponding FCC silver peaks at approximately 38, 44, 64 and 77°. Ravunni *et al.* (2025) [33] similarly recorded peaks at 38.1,

44.4, 64.6 and 77.4°, along with minor peaks attributed to organic constituents.

Conclusion

The present investigation demonstrated that *Tagetes erecta* L. cv. Dream Yellow flower extract can be effectively utilized for the green synthesis of silver nanoparticles. The synthesized AgNPs were successfully characterized using UV-Visible spectroscopy, FTIR, XRD, DLS, zeta potential analysis and SEM, confirming their formation, crystalline nature, stability and predominantly spherical morphology. The optimized 1:20 extract-to- AgNO_3 ratio produced AgNPs with a mean particle size of 66.63 nm, supporting the suitability of marigold flower extract for AgNP synthesis.

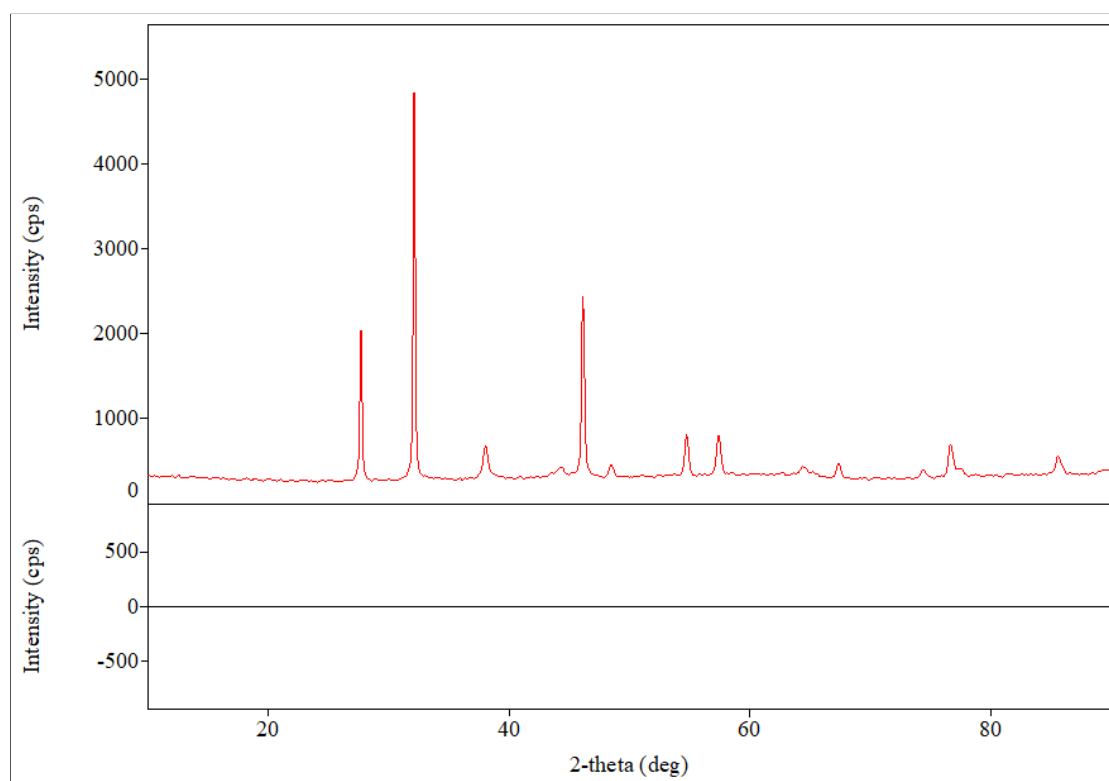


Figure 5. XRD pattern of silver nanoparticles synthesized using *Tagetes erecta* L. flower extract

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