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# Biosynthesis of Silver Nanoparticles using Aqueous Extract of Waste *Kigelia africana* Flowers and their Photocatalytic Degradation of Dyes from Polluted Water

**Lakshya[1], Amanpreet Kaur[2]*, Utkarsh Tyagi[1], Neha Bhatt[3], Neelaxi Pandey[4], Pankaj Singh Rawat[5] and Man Vir Singh[6]**

[1]School of Biotechnology, IFTM University, Moradabad-244102, Uttar Pradesh, India
[2]Department of Chemistry, School of Sciences, IFTM University, Moradabad-244102, Uttar Pradesh, India
[3]Department of Chemistry, Pt. L.M.S., Rishikesh Campus, SDS University, Tehri Garhwal- 249145, Uttarakhand, India
[4]Department of Zoology, Pt. L.M.S., Rishikesh Campus, SDS University, Tehri Garhwal- 249145, Uttarakhand, India
[5]Department of Physics, Pt. L.M.S., Rishikesh Campus, SDS University, Tehri Garhwal- 249145, Uttarakhand, India
[6]Department of Chemistry, Graphic Era (Deemed to be University), Dehradun, Uttarakhand, India, 248002
*Corresponding author (e-mail: Amanpreet2225@gmail.com, manvir24365@gmail.com)

The present research developed a sustainable, eco-friendly approach to biosynthesizing silver nanoparticles (AgNPs) using the aqueous extract of waste *Kigelia africana* flowers. The floral waste extract served as a natural reducing and stabilizing agent and gave a green alternative to the traditional chemical synthesis pathways. AgNPs formation was established by UV spectroscopy and confirmed by an adsorption peak at 446nm. The FTIR analysis revealed the presence of phytochemicals in stabilizing nanoparticles. The structure and morphology were also studied using SEM and EDX, which revealed the presence of well-dispersed, mostly spherical nanoparticles in the nanoscale range of 40-60nm. While XRD analysis determined the average crystalline size of 30.46nm. The photo-reactive activity of AgNPs produced by biosynthesis was analyzed about 84% degradation at 90-120 min of methyl orange dyes at 90- 120 min of irradiation with visible light. The AgNPs were found to be highly photocatalytic, with great dye removal in a relatively short time under the irradiation light and according to pseudo-first-order kinetics. The nanoparticles were also stable and reusable with several catalytic cycles. The given work shows a promising waste-to-wealth approach based on the use of flowed *Kigelia africana* flowers to produce useful nanomaterials by which sustainable wastewater treatment and environmental remediation could be achieved.

**Keywords**: Dye degradation, floral waste, *Kigelia africana*, wastewater treatment, silver nanoparticles

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Discharge of effluents containing dye by textile, leather, paper, cosmetic, and pharmaceutical industries results in water pollution, which is a significant environmental issue around the globe. Synthetic dyes are non-biodegradable, chemically stable, toxic, and cause severe ecological imbalance, making them dangerous to health. According to Robinson et al. (2001), there is a considerable proportion of over 7 × 10 ^5 Tons of dyes are manufactured annually that are discharged into water bodies without treatment [1]. Gupta and Suhas (2009) also pointed out that most dyes and their degradation wastes are carcinogenic and mutagenic, and thus, remediation measures are much needed. Traditional wastewater treatment methods, such as adsorption, coagulation, flocculation, membrane filtration, and biological processes, have some disadvantages that include incomplete mineralization, secondary waste products, and high cost of operation [2]. Photocatalytic degradation, on the other hand, has been a developed oxidation process that can fully mineralize organic contaminants to environmentally harmless products like $CO_2$ and water. Nanomaterials can also be used to boost photocatalysis considerably because of their excellent surface-to-volume ratio, controllable band gap, and high-quality charge-transfer characteristics [3]. Silver nanoparticles (AgNPs) are among the noble metal nanomaterials that have aroused much interest due to their strong surface plasmon resonance (SPR), high absorption of visible light, and the capacity to produce reactive oxygen species (ROS). It has been demonstrated that AgNPs can be used to increase photocatalytic activity by inhibiting the recombination of electrons and holes [4]. A more recent study by Rani et al. (2025) suggested plasmon-enhanced visible-light-driven degradation of dyes by using

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biosynthesized AgNPs, and this recommended their application in treating wastewater. Conventional techniques to produce AgNP through the use of toxic reducing agents, large amounts of energy, and dangerous by-products raise concerns with regard to environmental and safety issues. To address these shortcomings, biological resource-based green synthesis methods have become a prominent trend [5]. Gupta et al., (2025) have indicated that plant-mediated synthesis of nanoparticles has a future, particularly as a result of polyphenols, flavonoids, terpenoids, and proteins as natural reducing or stabilizing agents. Extensive analyses carried out by Anandalakshmi et al. (2016) also validated the green synthesis as being sustainable, scalable, and environmentally friendly. Increasingly, research has examined the use of agricultural and plant waste to generate nanoparticles, which aligns with the notion of a circular economy and waste-to-wealth [6, 7]. Banerjee et al. (2014) have shown that AgNPs produced from plant biomass waste were effective in the photocatalytic degradation of dyes. More recently, Sathishkumar et al. (2023) have documented that waste biomass-assisted green synthesis can reduce production costs and improve nanoparticle activity due to the abundance of phytochemicals [8]. Patil and Kim (2022) affirmed that the plant-mediated AgNPs have an excellent photocatalytic activity in visible light compared to their chemically prepared counterparts [9, 10]. *Kigelia africana* is a medicinally valuable plant that boasts good phytochemical compositions of flavonoids, phenolics, iridoids, quinones, and saponins. Its antioxidant, antimicrobial, and anti-inflammatory effects were reported by Grace et al. (2002). Nevertheless, the use of waste *K. africana* flowers as nanomaterials and environmental remedies has not been studied much in the context of the pharmacological studies that have been carried out [11]. The recent sustainability oriented researches by Pokhriyal et al., (2023) acknowledges the significance of utilizing the unutilized plant waste as a source of green nanotechnology [12]. In this regard, the current research intends to biosynthesize the silver nanoparticles with aqueous extract of waste *K. africana* flowers and to determine the photocatalytic activity of nanoparticles in the degradation of polluted water organic dyes under visible light irradiation. This project combines the idea of green chemistry, conversion of waste to valuable things, and efficient photocatalytic remediation, and has led to the creation of sustainable and cost-effective wastewater treatment methods.

## EXPERIMENTAL

### Material

Silver nitrate was purchased from Merck (India) and used as the silver precursor without any purification. The model organic pollutants were analytical-grade dyes, methyl orange (MO). All the chemicals were of analytical grade and utilized in their form. The experiments were performed with the use of double-distilled water. The flowers of Waste *K. africana* were collected from the campus of IFTM University, Moradabad, and authenticate from Department of Botany, School of Sciences, IFTM University, Moradabad

### Methods

*Preparation of Aqueous Extract of Waste K. africana Flowers*

The collected waste flowers were left in a lot of tap water, then distilled water, to eliminate dust and impurities. Shade drying of the flowers was done at room temperature over a 10-15-day period, after which the flowers were ground into a coarse powder. The floral material was distilled with 100 mL of distilled water until it became a fine powder, and it was heated at 50-60 ºC within a constant stirring for 30 minutes. The mixture was allowed to cool down to room temperature and filtered on Whatman No. 1 filter paper. The aqueous extract obtained was stored at 4 °C and utilized in the synthesis of nanoparticles within the next week [12, 13].

*Biosynthesis of Silver Nanoparticles*

In the green synthesis of silver nanoparticles, 10 mL of flower extract aqueous was dropped into 90 mL of 1 mM aqueous $AgNO_3$ solution under constant agitation with a magnetic stirrer at room temperature. The incubation of the reaction mixture was done in the dark to prevent photoactivation [14]. The change from pale yellow to dark brown colour was a sign of the appearance of silver nanoparticles as a result of surface plasmon resonance. The reaction was left to run for over 24 h in order to reduce the amount of silver ions. Purification of the synthesized AgNPs was done through centrifugation at 10,000 rpm for 15 minutes. To eliminate free phytochemicals and impurities, the pellet was washed thrice with distilled water. The resulting nanoparticles were dried using a hot air oven at 60 °C and kept in airtight containers to be subjected to further characterization and application research.

*Characterization of Silver Nanoparticles*

The optical properties and formation of AgNPs were verified through the wavelength of 300-700 nm under the UV- Visible spectroscopy. Fourier Transform Infrared (FTIR) spectroscopy was used to identify functional groups that were involved in the reduction and stabilization of AgNPs. X-ray diffraction (XRD) was used to examine the crystalline structure using the Cu K alpha radiation (1.5406 A). Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM) were used to analyze the morphology of the surface and the particle size. Analysis of elemental composition was done through Energy Dispersive X-ray (EDX) analysis [15].

*Photocatalytic Degradation of Dyes*

The biosynthesized AgNPs were tested as a photocatalyst for the model dye pollutant, which was methylene orange (MO) [16]. An already prepared number of AgNPs (e.g., 10mg) was added to 100mL of the dye solution (10 mgL). A suspension in the dark was stirred by a magnetic field to achieve an equilibrium between the adsorption and desorption processes. The light source used to expose the reaction mixture was a xenon lamp or an LED light source. Aliquots were removed at time intervals, and the nanoparticles were centrifuged and UV-visible analyses performed to measure the reduction in the dye concentration. The percentage of degradation was determined by means of the equation:

$$\text{Degradation (\%)} = (\frac{C_0 - C_t}{C_0}) \times 100$$

Where $C_0$ is the initial dye concentration and $C_t$ Is the dye concentration at time? $t$.

*Kinetic Analysis*

The photocatalytic degradation kinetics were analyzed using the pseudo-first-order model expressed as:

$$\ln (\frac{C_0}{C_t}) = kt$$

where $k$ is the apparent rate constant and $t$ is the irradiation time.

*Statistical Analysis*

All experiments were conducted in triplicate, and results were expressed as mean ± standard deviation. Data analysis was performed using standard statistical methods.

## RESULTS AND DISCUSSION

### UV–Visible Spectral Analysis

The silver nanoparticles were first proved by the fact that the color of the reaction mixture changed to dark brown, in a few hours of incubation, which showed a reduction of $Ag^+$ ions to $Ag^0$ nanoparticles [17]. The formation of nanoparticles was also confirmed using UV-visible spectroscopy, which had a strong surface plasmon resonance (SPR) band with a peak wavelength of around 446 nm, similar to that of silver nanoparticles. Peaks of the SPR became greater as the reaction time progressed, and this also confirmed the progressive formation and stabilization of AgNPs Figure 1. UV-Vis absorption spectrum of silver nanoparticles (AgNPs) produced with *K. africana* flower aqueous extract, which displays the typical surface plasmon resonance peak that is indicative of the formation of nanoparticles.

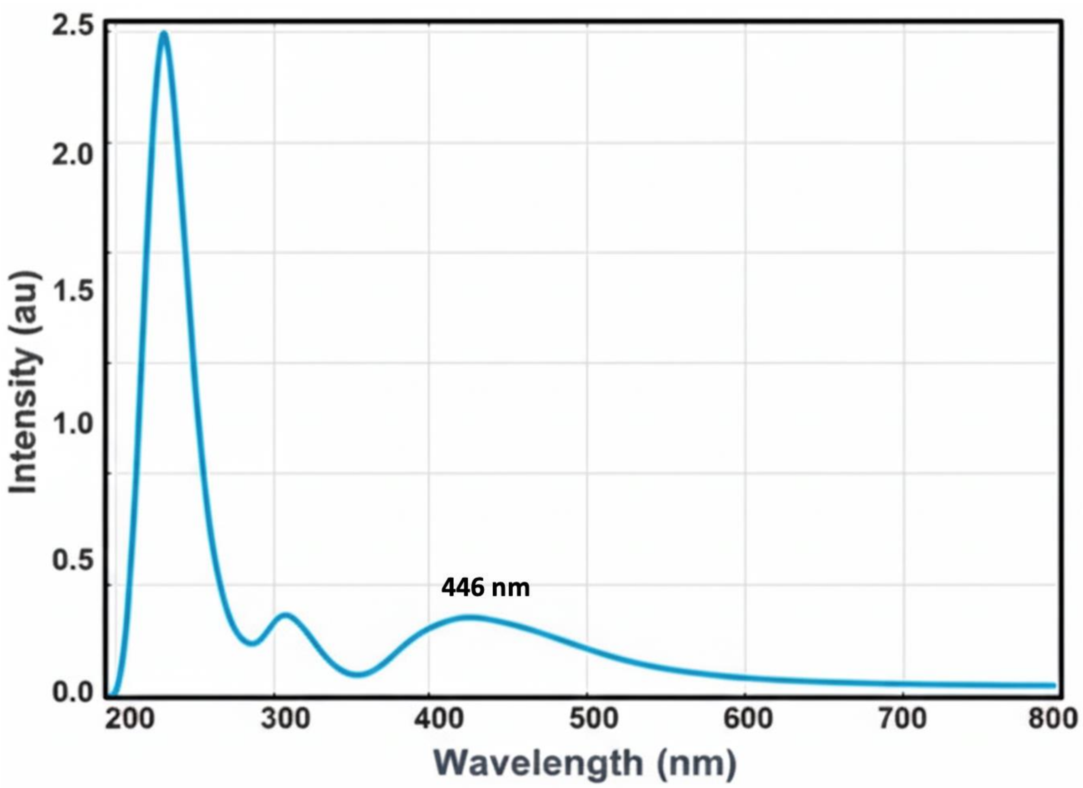


**Figure 1.** UV–Vis absorption spectrum of AgNPs synthesized from *K. africana.*

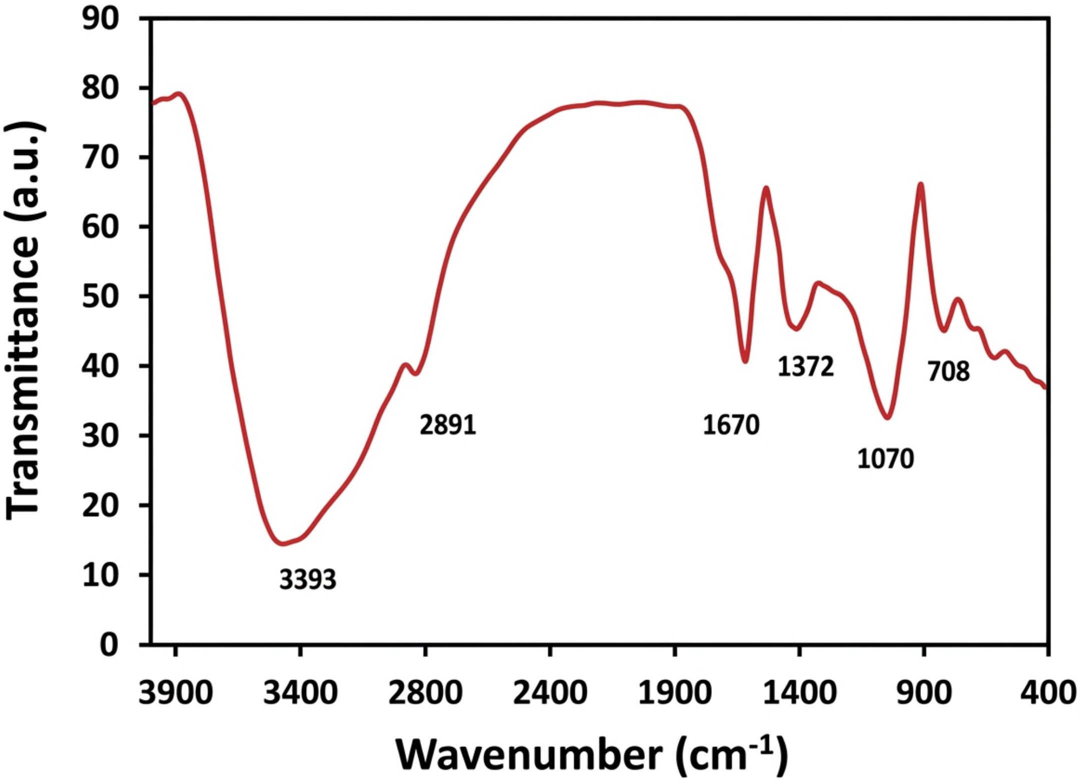


**Figure 2.** FTIR spectra of AgNPs synthesized from *K. africana* flower.

**FTIR Analysis**

The presence of phytochemicals in the synthesis of nanoparticles was revealed in the FTIR spectra of the aqueous extract of *K. africana* flower and the biosynthesized AgNPs. The presence of broad absorption bands at 3393 cm -1 was associated with OH stretching bands of phenolic substances [18]. Peaks at 2891 cm -1 were attributed to CH stretching of aliphatic groups, and those at 1670 cm -1 to C=O stretching of amide or carbonyl groups. The changes and the lowered strength of these peaks in the AgNP spectrum affirmed the presence of flower-derived biomolecules in the reduction and stabilization of these nanoparticles Figure 2. FTIR spectra of silver nanoparticles (AgNPs) made based on *K. africana* flower extract, in which the functional groups that reduce and stabilize nanoparticles are highlighted.

**X-ray Diffraction (XRD) Analysis**

The XRD patterns of the biosynthesized AgNPs had clear diffraction peaks at 20 values of around 38.1 °, 44.3 °, 64.5 °, and 77.4 o which were related to the (111), (200), (220), and (311) crystallographic planes of face-centered cubic (fcc) silver (JCPDS No. 04-0783). The lack of impurity maxima showed high crystallinity and purity of the obtained nanoparticles. Average crystallite size calculated by the equation of Debye- Scherrer was found to be between 30.46 nm [19] Figure 3. X-ray diffraction (XRD) map of silver nanoparticles (AgNPs) in *K. africana* flower that has been prepared by using flower extract, confirming the crystalline character.

**Morphological and Elemental Analysis**

SEM and TEM images identified that the biosynthesized AgNPs were mostly spherical to quasi-spherical, and they had a relatively uniform size distribution [20]. TEM analysis revealed that the sizes of the particles were 40 to 60 nm, as confirmed by XRD. Minor agglomeration was also found, and it is possible to ascribe it to the presence of biomolecular capping agents on the surface of the nanoparticle. The elemental silver was confirmed by EDX spectra, which showed a large signal at 3 keV and smaller signals at 3. O and 3. O, which is evidence of phytochemical residues, Figure 4. Silver nanoparticles (AgNPs) produced with *K. africana* flower aqueous extract were examined with an energy-dispersive X-ray (EDX) spectrum to identify the composition of the sample, and the elemental composition, as well as the presence of silver as the primary element Figure 5. (A–B). The morphology, size, and distribution of silver nanoparticles (AgNPs) synthesized with the *K. africana* flower aqueous extract are shown in a scanning electron microscopy (SEM) and transmission electron microscopy (TEM) image (A and B, respectively).

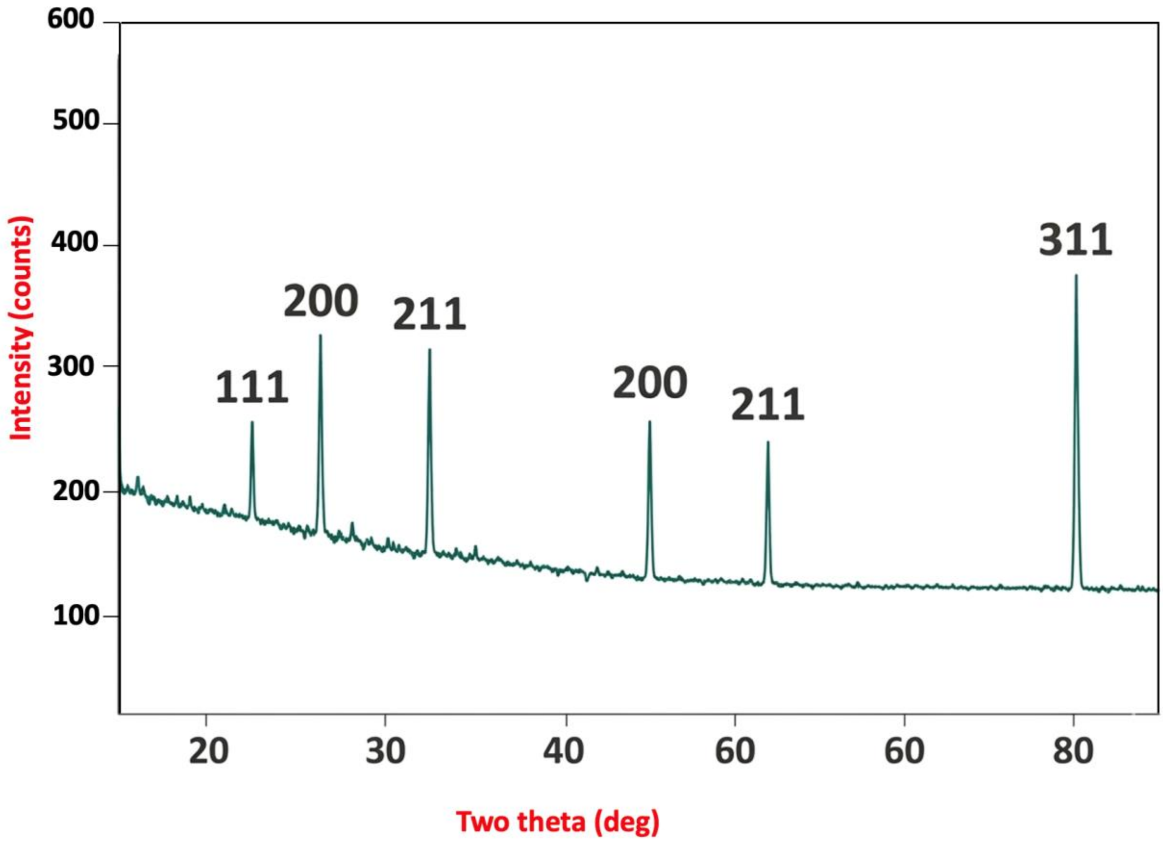


**Figure 3.** X-ray diffraction (XRD) pattern of AgNPs synthesized from *K. africana* flower.

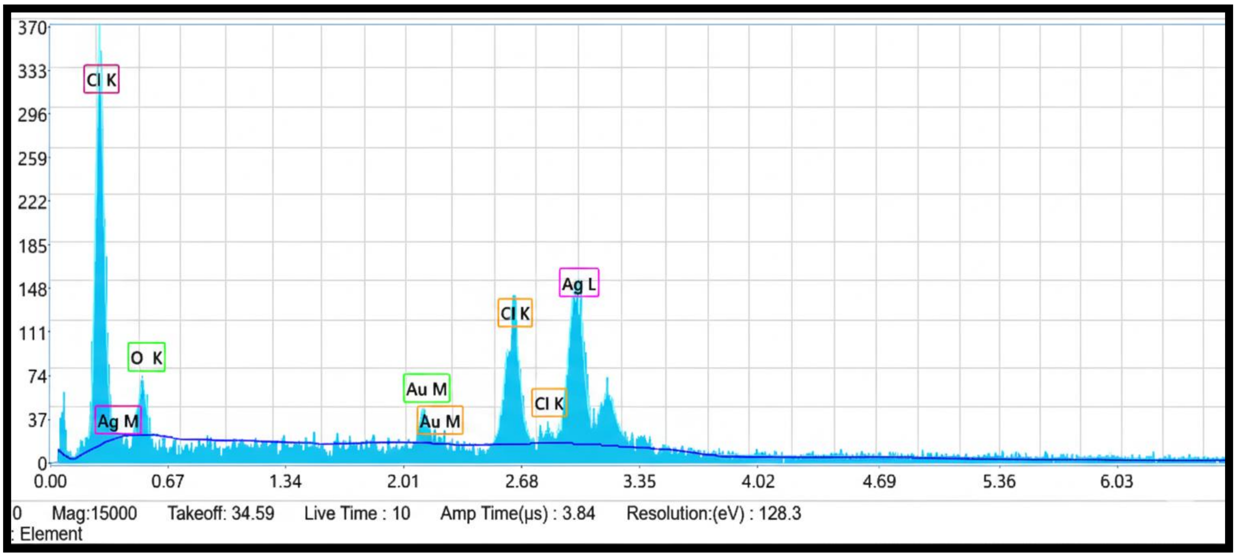


**Figure 4.** Energy-dispersive X-ray (EDX) spectrum of AgNPs synthesized from *K. africana* flower.

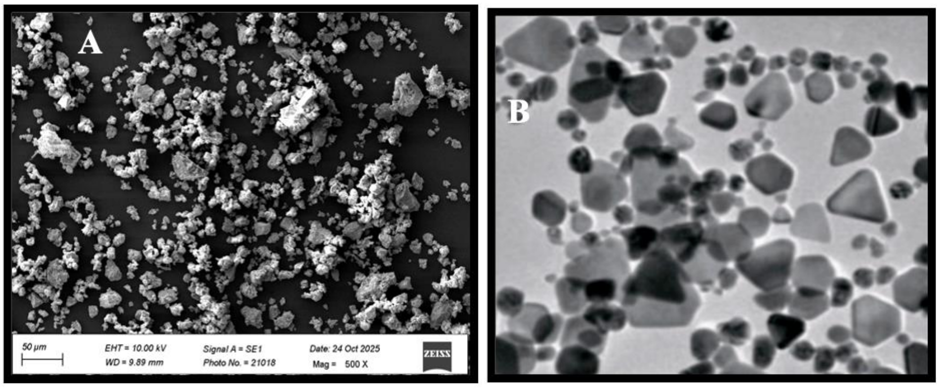


**Figure 5 (A-B).** SEM and TEM images of AgNPs synthesized from *K. africana* flower.

**Photocatalytic Degradation of Dyes**

Methylene blue (MB) was used to test the photocatalytic properties of the biosynthesized AgNPs in the presence of visible light. There was a marked reduction of the characteristic absorption maximum of MB at the wavelength of 664 nm with an increase in the irradiation time, which means that the dye was degraded successfully. About 84 per cent degradation was accomplished in 90 120 min exposure to the visible light. Manipulation experiments in the dark or the presence of a catalyst indicated that there was insignificant degradation, which confirmed that the reaction was photocatalytically activated [21] Figure 6. The degradation of the methyl orange dye based on photocatalysis with the help of silver nanoparticles (AgNPs) synthesized with the use of the *K. africana* flower extract, illustrating the decrease in the dye concentration during the time of irradiation.

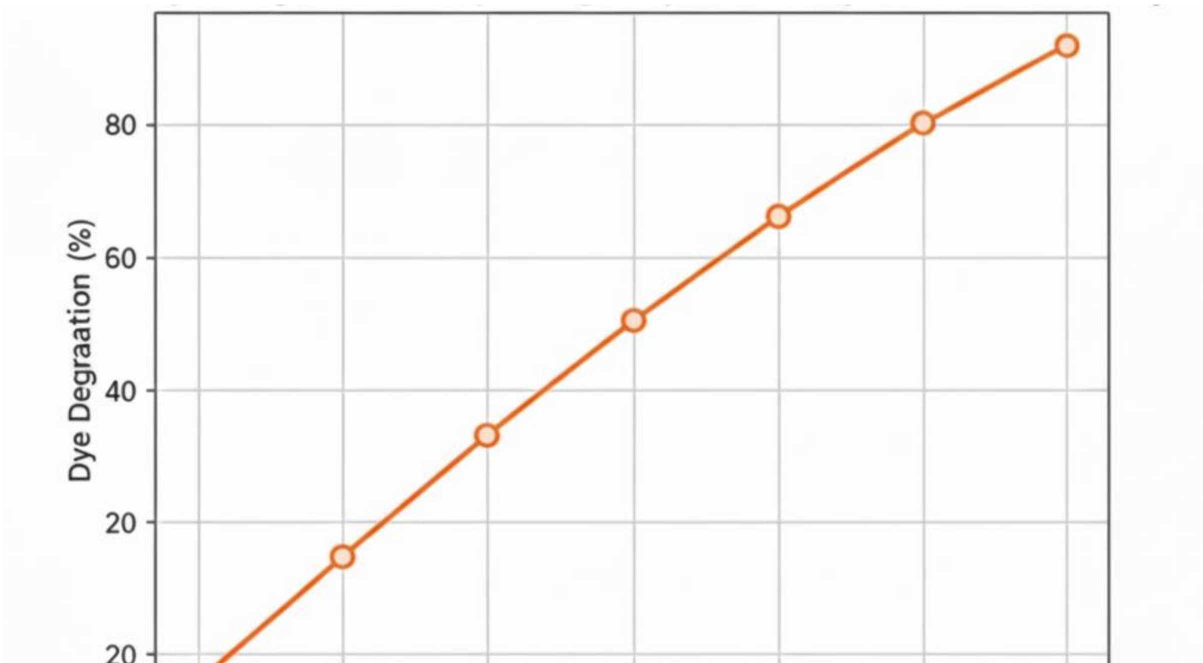


**Figure 6.** Photocatalytic degradation of methylene orange using AgNPs synthesized from *K. africana* flower.

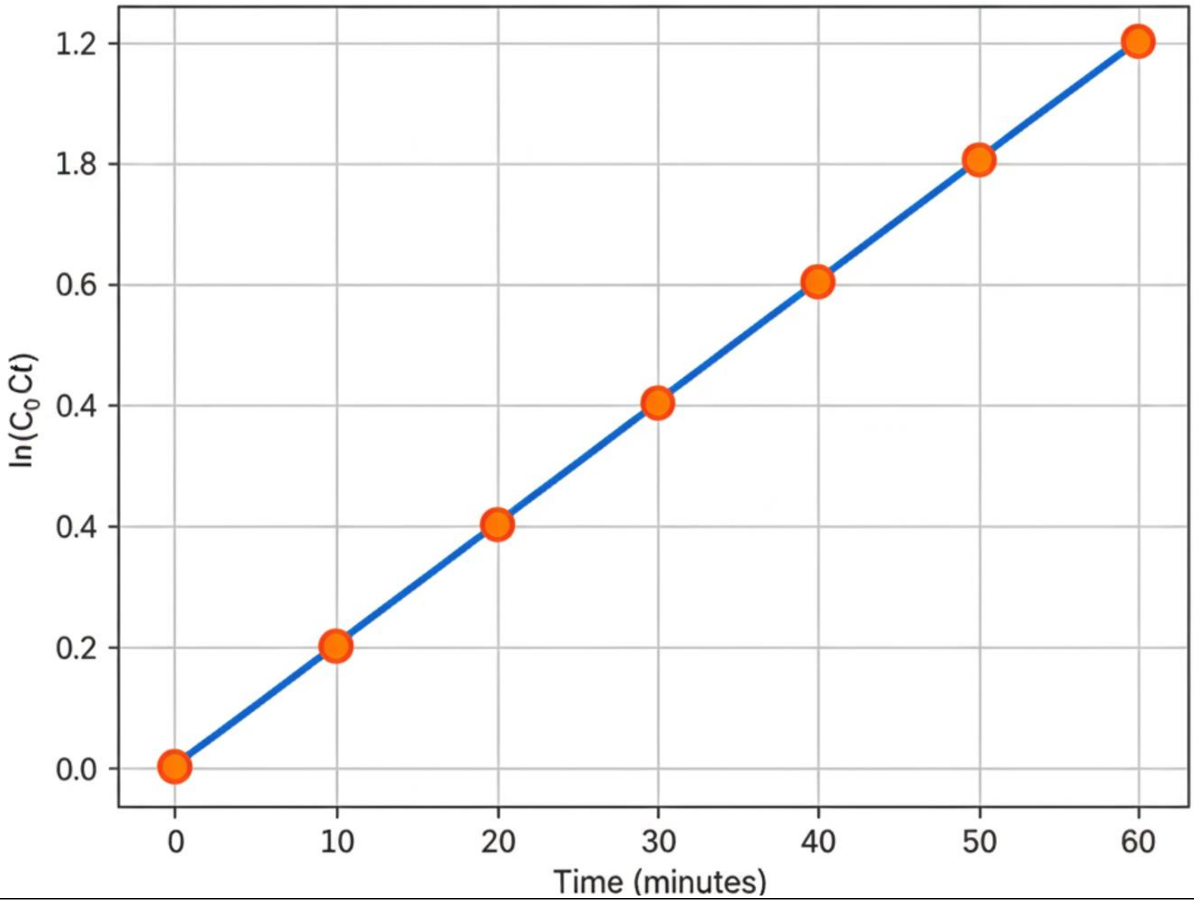


**Figure 7.** Pseudo-first-order kinetic plot of methylene orange using AgNPs synthesized from *K. africana* flower.

**Kinetic Studies**

The degradation kinetics followed a pseudo-first-order reaction model, as evidenced by the linear relationship between $\ln(C_0/C_t)$ and irradiation time [22]. The apparent rate constant (k) was calculated to be approximately 0.018–0.025 $min^{-1}$, demonstrating the high photocatalytic efficiency of the biosynthesized AgNPs **Figure** 7. Pseudo-first-order kinetic plot for the photocatalytic degradation of methyl orange using silver nanoparticles (AgNPs) synthesized from *K. africana* flower extract, indicating the reaction rate and kinetic behavior.

The present study demonstrates a successful green synthesis of silver nanoparticles (AgNPs) using the aqueous extract of waste *K. africana* flowers, followed by their effective application in the photocatalytic degradation of organic dyes under visible light irradiation. The observed color change and the characteristic surface plasmon resonance (SPR) band around 420–430 nm in the UV–visible spectra confirm the reduction of $Ag^+$ ions to metallic $Ag^0$ nanoparticles, consistent with earlier reports on plant-mediated AgNP synthesis. The use of waste floral biomass adds a sustainable dimension to the synthesis process, aligning with recent waste-to-wealth [23].

FTIR analysis revealed the involvement of phenolic, carbonyl, and hydroxyl functional groups in the reduction and stabilization of AgNPs. These functional groups are known to donate electrons and form coordination complexes with silver ions, facilitating nanoparticle formation and preventing aggregation. Similar phytochemical-mediated stabilization mechanisms have been reported by Soomro et al. (2025), who emphasized the critical role of plant-derived biomolecules in controlling nanoparticle size and stability. The slight shifts in FTIR peaks observed after nanoparticle formation further confirm the binding of bioactive compounds to the AgNP surface.

XRD analysis confirmed the face-centered cubic crystalline structure of the biosynthesized AgNPs, with prominent diffraction peaks corresponding to the (111), (200), (220), and (311) planes. The nanoscale crystallite size calculated using the Debye–Scherrer equation is comparable to sizes reported for AgNPs synthesized from other plant wastes. The high crystallinity of the nanoparticles is advantageous for photocatalytic applications, as crystalline materials generally exhibit improved charge carrier mobility and reduced recombination rates.

Morphological studies using SEM and TEM revealed predominantly spherical nanoparticles with uniform size distribution in the range of 10–30 nm. This nanoscale size significantly increases the surface area-to-volume ratio, enhancing the availability of active sites for photocatalytic reactions. Similar morphology-dependent photocatalytic enhancement has been reported by Nguyen et al. (2022), who demonstrated that spherical AgNPs exhibit superior plasmonic activity under visible light.

The biosynthesized AgNPs exhibited excellent photocatalytic degradation efficiency toward methylene blue under visible light irradiation, achieving up to 90% dye removal within a short reaction time. Control experiments confirmed that both light and catalyst are essential for effective degradation, excluding the possibility of photolysis or adsorption-dominated processes. The degradation kinetics followed a pseudo-first-order model, consistent with previous reports on AgNP-mediated photocatalysis [24]. The relatively high rate constant observed in this study can be attributed to the plasmon-induced excitation of electrons on the AgNP surface, leading to efficient generation of reactive oxygen species (ROS).

The photocatalytic mechanism is primarily governed by the surface plasmon resonance effect of AgNPs under visible light irradiation. Upon illumination, excited electrons are transferred to dissolved oxygen molecules, forming superoxide radicals ($\bullet O_2^-$), while holes react with water molecules to generate hydroxyl radicals (•OH) [25]. These highly reactive species attack dye molecules, leading to cleavage of chromophoric bonds and eventual mineralization. This mechanism aligns with ROS-driven degradation pathways.

Reusability and stability studies demonstrated that the biosynthesized AgNPs retained substantial photocatalytic activity over multiple cycles, with only a marginal decrease in efficiency. This stability can be attributed to the strong capping of nanoparticles by phytochemicals present in the *K. africana* flower extract, which prevents aggregation and leaching. Comparable stability trends have been observed in other plant-mediated AgNP systems.

Overall, the findings of this study highlight the dual advantage of utilizing waste *K. africana* flowers for nanoparticle synthesis and achieving efficient visible-light-driven dye degradation. Compared to chemically synthesized AgNPs, the biosynthesized nanoparticles offer enhanced environmental compatibility, cost-effectiveness, and sustainability. The integration of green synthesis, waste valorization, and photocatalytic remediation positions this approach as a promising candidate for practical wastewater treatment applications

## CONCLUSION

In the present study, an environmentally benign and cost-effective approach was successfully developed for the biosynthesis of silver nanoparticles using the aqueous extract of waste *K. africana* flowers. The floral waste extract served as an efficient natural reducing and stabilizing agent, eliminating the need for hazardous chemicals and aligning with green chemistry principles. The formation of well-dispersed, crystalline, and predominantly spherical AgNPs in the nanoscale range was confirmed through comprehensive physicochemical characterization techniques. The biosynthesized AgNPs exhibited excellent photocatalytic performance toward the degradation of organic dye pollutants under visible light irradiation. High degradation efficiency, favorable reaction kinetics, and effective mineralization of dye molecules were achieved, primarily due to the plasmonic properties of AgNPs and the generation of reactive oxygen species. Furthermore, the nanoparticles demonstrated good stability and reusability over multiple catalytic cycles, indicating their potential for practical and repeated use in wastewater treatment applications. This work highlights the effective utilization of waste *K. africana* flowers as a valuable bioresource for the synthesis of functional nanomaterials, thereby promoting a waste-to-wealth strategy and circular economy concept. The integration of green synthesis and photocatalytic remediation offers a sustainable pathway for addressing dye pollution in aquatic environments. Future studies may focus on scale-up feasibility, treatment of real industrial effluents, and comprehensive ecotoxicological assessments to further advance the practical implementation of this green nanotechnology-based water purification approach.

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