

Fabrication and Comparative Evaluation of PVA-Ninhydrin and PVA-Nano ZnO-Ninhydrin Composite Films as Colourimetric Sensors for Soil Fertility Assessment

Unnimaya M¹; Mubashira Thasni EP²; Nafeesathul Misriya TK³; Mujeeb Rahman P^{4*}

^{1,2,3}P.G Department of Chemistry, Grace Valley College of Arts& Science, Maravattam, Malappuram, Kerala

^{*4}Department of Chemistry, Government Arts and Science College Calicut, University of Calicut, Kerala, India

*Corresponding Author

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Abstract— The fabrication of a rapid, simple and cost-effective method for soil fertility assessment is crucial for sustainable agricultural practices. Since nitrogen is an essential nutrient for soil fertility, its detection in soil helps to quickly identify the quality and fertility of the soil. In this study, two different composite films comprising polyvinyl alcohol (PVA)–ninhydrin and PVA–nano zinc oxide (ZnO)–ninhydrin were prepared and evaluated for their soil fertility sensing ability. Both films were prepared by the solution-casting method and dried under sunlight. The fabricated films were well characterized and investigated for thermal stability, mechanical properties, and antibacterial activities. The simple and rapid method of soil fertility testing was carried out with different soil samples. Thermogravimetric analysis revealed that ZnO incorporation enhanced the thermal stability of the composite films by delaying thermal degradation and increasing the residual mass. Mechanical studies proved enhanced flexibility and durability of the ZnO-containing film compared to the PVA–ninhydrin film. Similarly, the nano ZnO-containing film exhibited enhanced antibacterial activity, attributed to the intrinsic antimicrobial properties of ZnO nanoparticles.

The soil fertility sensing ability of the films was tested using four different soil samples: chicken manure-amended soil, cow dung-amended soil, black soil, and normal soil. The rate and intensity of colour development followed the order: chicken manure-amended soil > cow dung-amended soil > black soil > normal soil, reflecting their fertility order. The PVA–ninhydrin film exhibited a faster colour response, whereas ZnO incorporation slightly delayed colour formation, suggesting that ZnO influences reactant diffusion and the reaction kinetics within the polymer matrix.

Altogether, both films exhibited excellent potential as simple, portable, and low-cost colourimetric sensors for the rapid qualitative detection of soil fertility. Although the PVA–ninhydrin film provided a faster sensing response, the PVA–nano ZnO–ninhydrin composite film offered superior thermal stability, mechanical robustness, and antibacterial performance, making it a promising candidate for practical agricultural sensing applications.

Keywords— Polyvinyl alcohol; Ninhydrin; Zinc oxide nanoparticles; Colourimetric sensor; Ruhemann's purple; Soil fertility; Nitrogen-containing compounds; Nanocomposite film.

I. INTRODUCTION

Agricultural productivity and sustainable crop production are necessarily related to soil fertility. It determines the availability of essential nutrients required for plant growth and development (Khan et al., 2024). Among the primary macronutrients present in soil, nitrogen is predominantly important as it is a major constituent of amino acids, proteins, nucleic acids, enzymes, and chlorophyll, thereby playing a vital role in plant metabolism, growth, and crop yield. Consequently, rapid and reliable assessment of soil fertility in connection with nitrogen status is essential for efficient nutrient management and sustainable agricultural practices (Ali et al., 2025).

A significant source of soil nitrogen is organic matter such as cow dung, chicken manure, etc. Nitrogen produced through the decomposition of such organic matter makes soil fertile. The nitrogen present in the soil as amino acids can be qualitatively detected and provide information on soil fertility status. Conventional methods for soil fertility assessment, including Kjeldahl analysis, elemental analysis, and spectroscopic techniques, provide accurate results but often require sophisticated instrumentation, extensive sample preparation, skilled personnel, and laboratory-based analysis. These limitations highlight the need for simple, rapid, portable, and cost-effective sensing methods suitable for on-site applications.

The organic molecule ninhydrin (1,2,3-indanetrione hydrate) is one of the most widely used analytical reagents for detecting amino acids and other primary amine-containing compounds. It reacts with free amino groups through oxidative deamination and decarboxylation to produce the characteristic deep purple known as Ruhemann's purple. These characteristics make ninhydrin an attractive reagent for the development of colourimetric sensors for nitrogen-containing compounds. The intensity and rate of colour formation depend on the concentration of reactive amino groups. Due to this, ninhydrin reactions have been extensively employed in analytical chemistry, biochemistry, forensic science, chromatography, and protein analysis (Gelaye, 2024; Stauß et al., 2024).

Conventional ninhydrin assays have portability issues and on-site practical difficulties owing to their liquid nature and complicated laboratory procedures. Hence, developing solid-state colourimetric sensors which are easy to handle, reusable, portable, and suitable for rapid on-site detection has great significance in soil fertility analysis (Jeong et al., 2023; Wang et al., 2020). This can be achieved by immobilizing ninhydrin molecules in a polymer matrix. Among various polymeric materials, polyvinyl alcohol (PVA) has attracted considerable attention owing to its excellent film-forming ability, transparency, flexibility, biocompatibility, non-toxicity, and favorable mechanical properties (Abazari et al., 2025). Furthermore, the abundant hydroxyl groups present in PVA facilitate the immobilization of functional sensing reagents while maintaining their chemical reactivity, making PVA an excellent matrix for colourimetric sensor fabrication (Elgharbawy et al., 2024).

The incorporation of ZnO nanoparticles in a PVA matrix has emerged as an effective approach for enhancing the functional properties of sensing materials (Liang et al., 2024; Jailani et al., 2026; Etemadi et al., 2022). Zinc oxide (ZnO) nanoparticles have characteristic thermal and mechanical properties. They exhibit a large specific surface area, ultraviolet shielding ability, and intrinsic antimicrobial activity. Nanoparticle–polymer interactions may influence molecular diffusion, reagent accessibility, and reaction kinetics within the polymer network, thereby affecting the sensing behavior of immobilized colourimetric reagents (Khaydarov, 2025; Nosheen et al., 2021).

In the present study, two different films—PVA–ninhydrin composite films and PVA–nano ZnO–ninhydrin composite films—were fabricated and comparatively evaluated as colourimetric sensing materials for rapid qualitative soil fertility assessment. Nano ZnO nanoparticles were synthesized by the sol–gel method and incorporated in the PVA matrix to obtain the nanocomposite film. The fabricated films were characterized, and their thermal stability, mechanical properties, and antibacterial activity were investigated. The practical applicability as soil fertility testing films was examined using soil samples with different nitrogen levels by monitoring the formation of Ruhemann's purple colour. The findings confirmed the potential of PVA-based ninhydrin films as simple, portable, environmentally friendly, and low-cost colourimetric sensing materials for rapid qualitative soil fertility assessment.

II. EXPERIMENTAL

2.1 Materials

Polyvinyl alcohol (PVA, 95% hydrolysed) was purchased from Qualikems Lifesciences, India. Ninhydrin and ethanol were purchased from Merck, India. Zinc acetate and sodium hydroxide were obtained from Nice Chemicals, India. Distilled water prepared in the laboratory was used throughout the study. All chemicals were analytical grade and used as received without further purification.

2.2 Fabrication of PVA-Ninhydrin Film

A homogeneous PVA solution was prepared by dissolving 6 g of polyvinyl alcohol in 88 mL of distilled water under continuous stirring using a hot plate magnetic stirrer at 80 °C and then cooled to room temperature. In parallel, 1 g of ninhydrin was dissolved in 5 mL of ethanol, and the ninhydrin solution was added dropwise to the previously prepared PVA solution with continuous stirring. The resulting mixture was further stirred for 10 min to ensure the uniform distribution of ninhydrin throughout the polymer matrix. The homogeneous film-forming solution was cast onto clean, levelled polypropylene plates and dried at room temperature. The resulting PVA–ninhydrin composite film was carefully peeled from the plate and stored in a clean, airtight bag for further analysis.

2.3 Synthesis of ZnO Nanoparticles

Nano ZnO particles were synthesized by the sol–gel method by dissolving 0.5521 g of zinc acetate dihydrate in 50 mL of distilled water with continuous stirring to get a clear solution. In parallel, 0.1 M sodium hydroxide solution was prepared by dissolving 0.2 g of sodium hydroxide in 50 mL of distilled water. The previously prepared zinc acetate solution was added dropwise to the sodium hydroxide solution under continuous stirring at room temperature until a homogeneous mixture was obtained. The resulting mixture was kept in a hot-air oven at 90 °C for 1 hr; the precipitate was collected by gravimetric filtration using Whatman No. 40 filter paper and washed repeatedly with distilled water. The recovered ZnO nanoparticles were dried, collected, and stored in an airtight container for subsequent preparation.

2.4 Fabrication of PVA-Nano ZnO-Ninhydrin Composite Film

PVA–nano ZnO–ninhydrin composite film was prepared by dispersing 0.025 g ZnO nanoparticles in 88 mL of distilled water with continuous stirring to obtain a homogeneous dispersion. To this mixture, 6.5 g polyvinyl alcohol was gradually added with continuous stirring at 80 °C for 1 hr, then cooled to room temperature. The ninhydrin solution, prepared by dissolving 0.5 g of ninhydrin in 5 mL of ethanol, was added dropwise to the PVA–nano ZnO mixture with continuous stirring. The resulting mixture was stirred for an additional 10 minutes to obtain a homogeneous film-forming solution. The prepared solution was cast on a clean and dry polypropylene plate and dried at room temperature. The resulting PVA–nano ZnO–ninhydrin composite film was carefully peeled and stored in an airtight bag.

2.5 Characterization

The structural, crystalline, thermal, and surface morphological properties of the fabricated films were characterized using X-ray diffraction (XRD) (Model: Rigaku Miniflex 600 diffractometer), Fourier transform infrared (FTIR) spectroscopy (Model: PerkinElmer Inc. USA), scanning electron microscopy (SEM) (Model: Hitachi SU-6600 FESEM), UV–Visible spectrophotometer (Model: Shimadzu), thermogravimetric analysis (TGA) (Model: TGA/DTA 851e), and a Universal Testing Machine (UTM Model 3345), respectively.

2.6 Antibacterial Activity

The antibacterial activity of the fabricated PVA–ninhydrin and PVA–nano ZnO–ninhydrin composite films was evaluated against the Gram-negative bacterium *Escherichia coli* (ATCC 25922) and the Gram-positive bacterium *Staphylococcus aureus* (ATCC 25923) using the agar diffusion method. Pure cultures of *E. coli* (ATCC 25922) and *S. aureus* (ATCC 25923) were inoculated separately in sterile nutrient broth and incubated at 37 °C for 18–24 hrs to obtain actively growing cultures. Mueller-Hinton Agar (MHA) was prepared and sterilized by autoclaving at 121 °C for 15 minutes, poured into pre-sterilized Petri plates, and allowed to solidify. Each standardized bacterial suspension was uniformly spread over the MHA surface using a sterile cotton swab to obtain a lawn culture. PVA–ninhydrin and PVA–nano ZnO–ninhydrin composite films were cut into equal circular discs and placed on the inoculated agar plates. An uninoculated MHA plate containing the film specimens was maintained as a control. The plates were incubated at 37 °C for 18–24 h under aerobic conditions. Antibacterial activity was assessed by measuring the diameter of the inhibition zone (mm) surrounding each film specimen.

2.7 Soil Fertility Evaluation of Films

The fabricated PVA–ninhydrin and PVA–nano ZnO–ninhydrin composite films were tested for their ability to qualitatively detect the fertility of different soil samples. Four different types of soil samples representing different fertility conditions were selected: normal soil amended with chicken droppings (S1), normal soil amended with cow dung (S2), black soil collected from an area where kitchen waste was regularly discarded (S3), and normal soil (S4). Equal quantities of each soil sample were placed in separate labeled containers. Films of identical dimensions were placed in direct contact with the respective soil samples and kept under identical ambient conditions. Colour development was monitored after 2.5, 4, and 24 hrs, respectively, and photographed at each time interval. The intensity of the characteristic Ruhemann's purple colour was used as a qualitative indicator, and the colour responses of the films were compared to evaluate their suitability for soil fertility assessment.

III. RESULTS AND DISCUSSION

3.1 Physical Appearance and Characteristics of the Fabricated Films

Both films were successfully prepared by the solution-casting method, producing continuous, flexible, and self-supporting films without visible cracks or bubbles. The photographs of the fabricated PVA–ninhydrin and PVA–nano ZnO–ninhydrin composite films are shown in Figure 1, and their physical characteristics are summarized in Table 1.

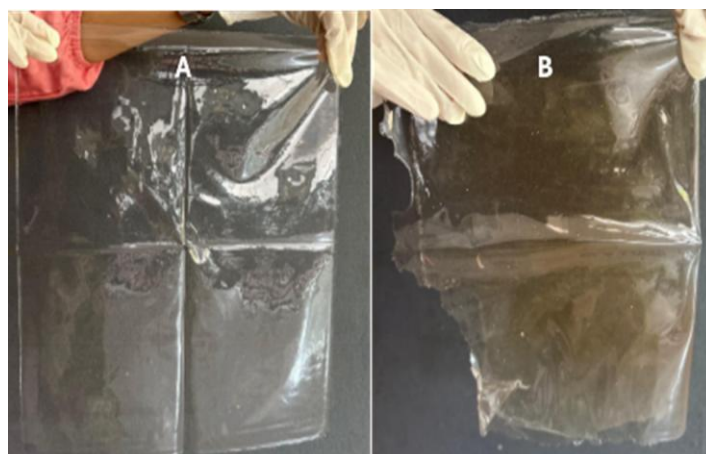


FIGURE 1: Images of fabricated (A) PVA–ninhydrin and (B) PVA–nano ZnO–ninhydrin composite films

TABLE 1

PHYSICAL CHARACTERISTICS OF FABRICATED FILMS

Property	PVA–Ninhydrin film	PVA–Nano ZnO–Ninhydrin composite film
Transparency	High; transparent	Slightly translucent
Colour	Colorless	Pale yellow
Surface	Smooth & homogeneous	Smooth with slight surface irregularity
Edge quality	Well-defined	Slightly irregular
Flexibility	Flexible	Flexible
Visual defects	None observed	None observed

The PVA–ninhydrin film exhibited a transparent, smooth, and homogeneous appearance with well-defined edges, indicating uniform incorporation of ninhydrin within the PVA matrix. Whereas the PVA–nano ZnO–ninhydrin composite film appeared slightly translucent with a pale yellow colour and comparatively rougher edges. The reduced transparency is attributed to light scattering by the incorporated ZnO nanoparticles. Despite these differences, the composite film maintained good flexibility and structural integrity, indicating successful incorporation of ZnO nanoparticles without disrupting the continuity of the polymer matrix.

3.2 Fourier Transform Infrared (FTIR) Spectroscopy

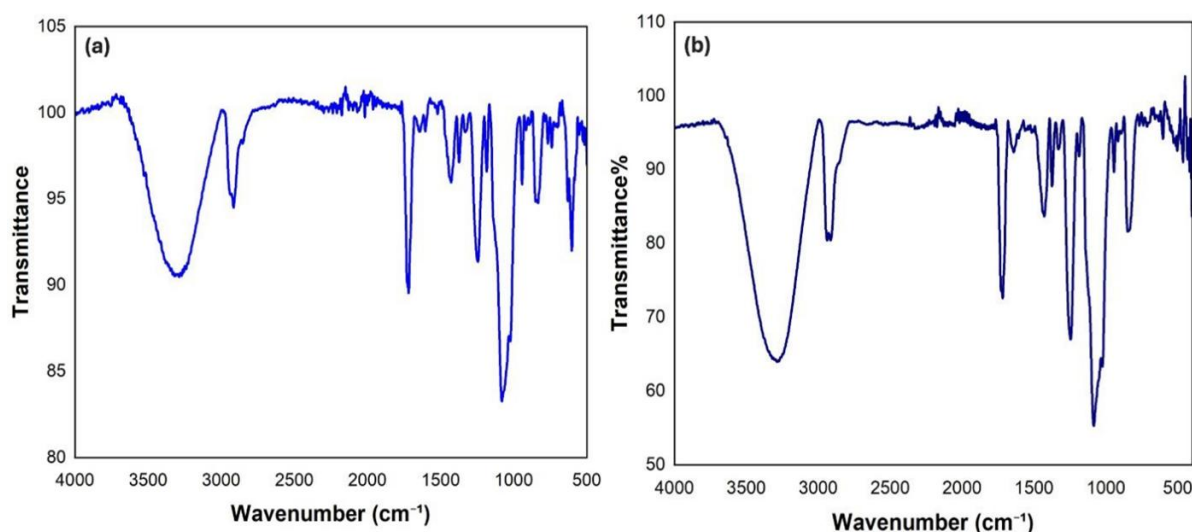


FIGURE 2: FTIR Spectrum of PVA-Ninhydrin (a) and PVA-Nano ZnO-Ninhydrin (b) Composite films

The FTIR spectra of the films are exhibited in Figure 2. The FTIR spectrum of the PVA–ninhydrin film (Figure 2a) exhibited a broad absorption band at 3288 cm^{-1} , corresponding to the O–H stretching vibration of hydroxyl groups in PVA, indicating extensive intermolecular hydrogen bonding within the polymer matrix. The absorption band at 2916 cm^{-1} is assigned to the C–H stretching vibration of the PVA backbone and ninhydrin molecules. A distinct peak at 1719 cm^{-1} corresponds to the C=O stretching vibration of the carbonyl groups of ninhydrin, confirming its successful incorporation into the PVA matrix. The bands at 1428 cm^{-1} , 1246 cm^{-1} , and 1082 cm^{-1} are attributed to CH_2 bending and C–O stretching vibrations characteristic of PVA and ninhydrin. The PVA–nano ZnO–ninhydrin composite film shown in Figure 2b showed similar characteristic absorption bands corresponding to PVA and ninhydrin; the incorporation of ZnO nanoparticles did not alter the fundamental chemical structure of the polymer matrix. The characteristic absorption band observed in the $500\text{--}600\text{ cm}^{-1}$ region is assigned to the Zn–O stretching vibration, confirming the presence of ZnO nanoparticles within the composite film. Minor variations in the intensity and position of the absorption bands are attributed to intermolecular interactions among PVA, ninhydrin, and ZnO nanoparticles (Saini et al., 2025; Shafiee et al., 2021).

3.3 X-ray Diffraction (XRD) Analysis

The X-ray diffraction (XRD) patterns of the fabricated PVA–ninhydrin and PVA–nano ZnO–ninhydrin composite films are presented in Figure 3.

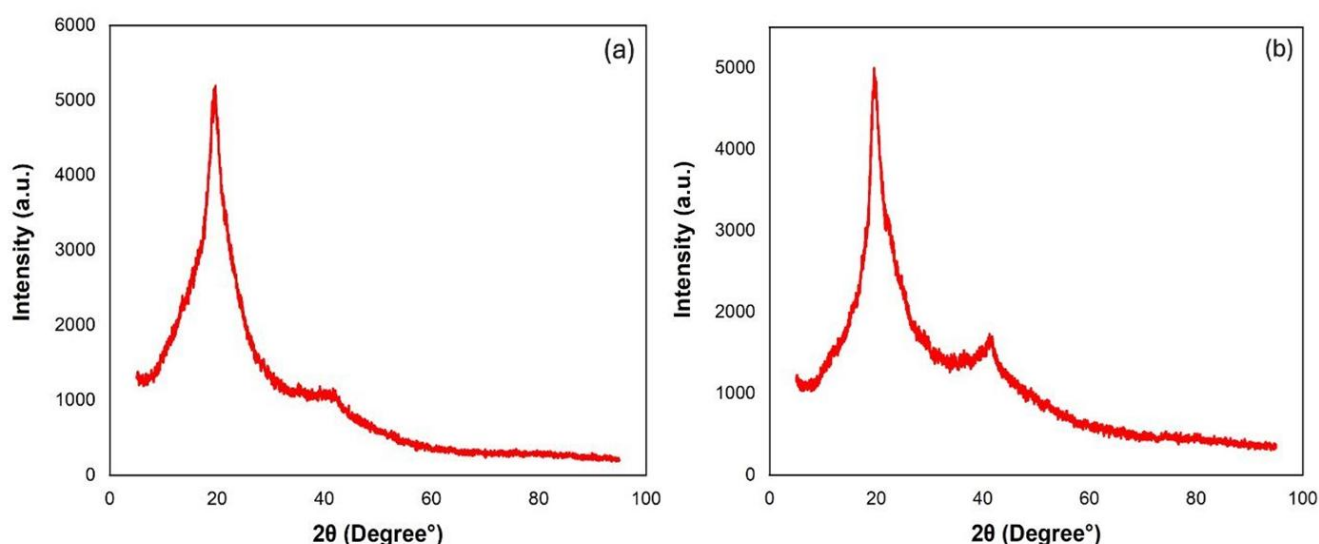


FIGURE 3: X-ray diffraction pattern of PVA-Ninhydrin (a) and PVA-Nano ZnO-Ninhydrin (b) Composite film

The XRD pattern of the PVA–ninhydrin film (Figure 3a) exhibited a broad diffraction peak at $2\theta = 19.72^\circ$, characteristic of the semicrystalline nature of polyvinyl alcohol, which is typical of PVA due to the partial ordering of polymer chains through intermolecular hydrogen bonding. The XRD pattern of the PVA–ninhydrin film did not show any other diffraction peaks, suggesting that ninhydrin is well incorporated within the PVA matrix without forming separate crystalline domains. The XRD pattern of the PVA–nano ZnO–ninhydrin composite film (Figure 3b) also exhibited the characteristic broad diffraction peak of PVA at $2\theta = 19.5^\circ$, indicating that the semicrystalline nature of the polymer matrix is retained after ZnO incorporation. In addition to this distinct diffraction peak, a few other characteristic peaks were observed at $2\theta = 34.4^\circ$, 36.2° , 47.5° , 56.6° , and 62.8° , corresponding to the different crystallographic planes of hexagonal wurtzite ZnO particles (Lopez-Miranda et al., 2023). The appearance of these characteristic peaks confirmed the successful incorporation of crystalline ZnO nanoparticles into the polymer matrix while preserving their crystalline structure.

3.4 UV-Visible Spectra

The UV–Visible transmittance spectra of the fabricated PVA–ninhydrin and PVA–nano ZnO–ninhydrin composite films are depicted in Figure 4.

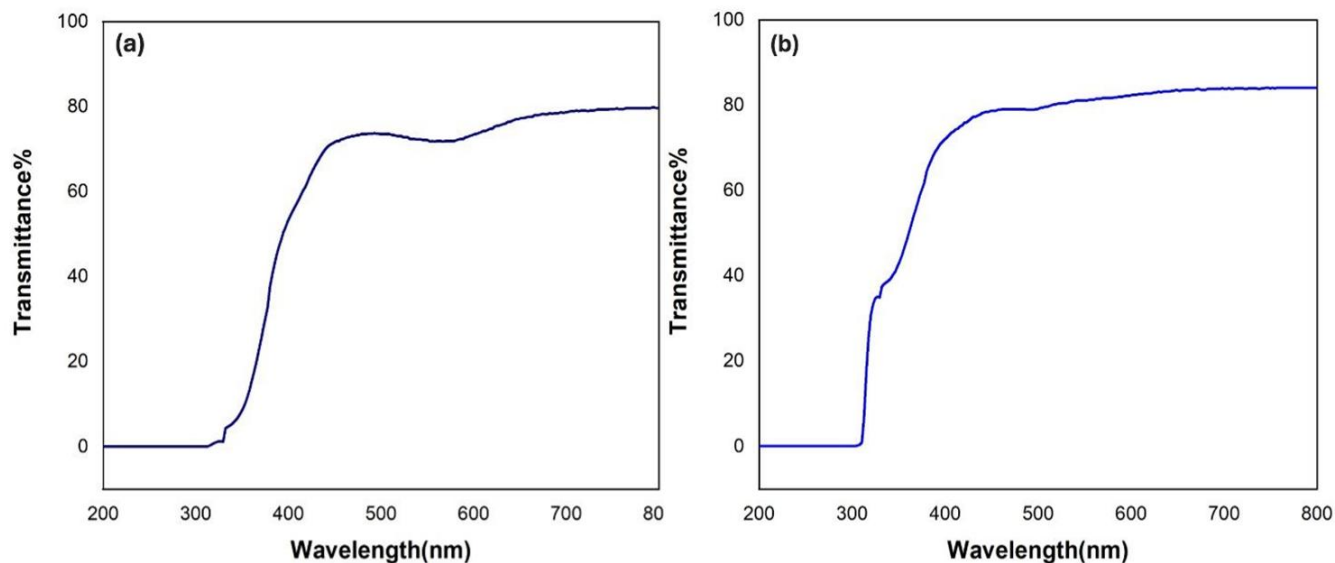


FIGURE 4: UV-Visible transmittance Spectra of PVA-Ninhydrin (a) and PVA-Nano ZnO-Ninhydrin (b) Composite films

As shown in Figure 4, the PVA–ninhydrin film (Figure 4a) exhibited negligible transmittance in the ultraviolet region below 320 nm, indicating strong absorption of UV radiation. The transmittance increases progressively with increasing wavelength, reaching approximately 80% in the visible region, indicating its good optical transparency. The spectrum of the PVA–nano ZnO–ninhydrin film (Figure 4b) displayed a pronounced absorption edge in the 320–350 nm region, which is attributed to the intrinsic UV absorption of ZnO nanoparticles. Beyond the UV region, the transmittance increases rapidly and reaches approximately 85% at 800 nm, indicating that the incorporation of ZnO nanoparticles does not adversely affect the visible-light transparency of the polymer film. The retention of high visible-light transmittance in both films is advantageous for colourimetric sensing, as it enables clear visual observation of colour changes during the detection of nitrogen-containing compounds (Amin et al., 2020).

3.5 Thermogravimetric Analysis

The thermogravimetric (TGA) curves of the fabricated PVA–ninhydrin and PVA–nano ZnO–ninhydrin composite films are presented in Figure 5. Both films exhibited a characteristic multistep thermal degradation profile characteristic of PVA-based polymeric materials (Furhan & Ramesan, 2022).

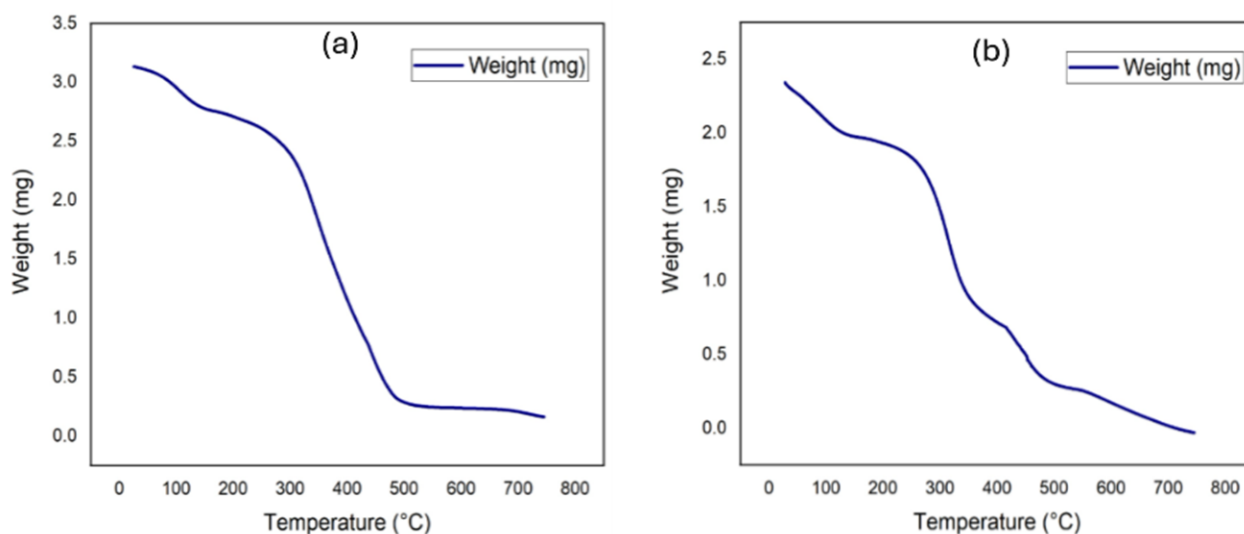


FIGURE 5: Thermogravimetric (TGA) curves of PVA-Ninhydrin composite film (a) and PVA-Nano ZnO-Ninhydrin (b) composite film

As shown in Figure 5a, both films showed an initial weight loss below approximately 150 °C, attributed to the removal of physically adsorbed moisture and residual solvent. In the case of the PVA–ninhydrin composite film, the major degradation occurred between 200 and 470 °C, corresponding to the decomposition of the PVA matrix and incorporated ninhydrin. Above 500 °C, only a slight additional weight loss was observed, indicating the formation of a stable carbonaceous residue. In the PVA–nano ZnO–ninhydrin composite film, the principal decomposition was recorded in the range of 220 to 480 °C. Compared with the PVA–ninhydrin film, the degradation of the PVA–nano ZnO–ninhydrin composite film occurred more gradually, and a higher residual mass was retained at elevated temperatures due to the presence of thermally stable ZnO nanoparticles within the polymer matrix (Duygulu et al., 2024).

The comparison of thermograms indicated that the incorporation of ZnO nanoparticles enhanced the thermal stability of the PVA–ninhydrin film. The improved thermal resistance can be attributed to interactions between ZnO nanoparticles and the PVA matrix, which restricted polymer chain mobility and retarded thermal decomposition. In addition, the inorganic ZnO particles act as thermally stable reinforcing fillers, contributing to the higher residual mass observed after degradation.

3.6 SEM Analysis

The surface morphologies of the fabricated PVA–ninhydrin and PVA–nano ZnO–ninhydrin composite films were investigated by scanning electron microscopy (SEM) and are shown in Figure 6.

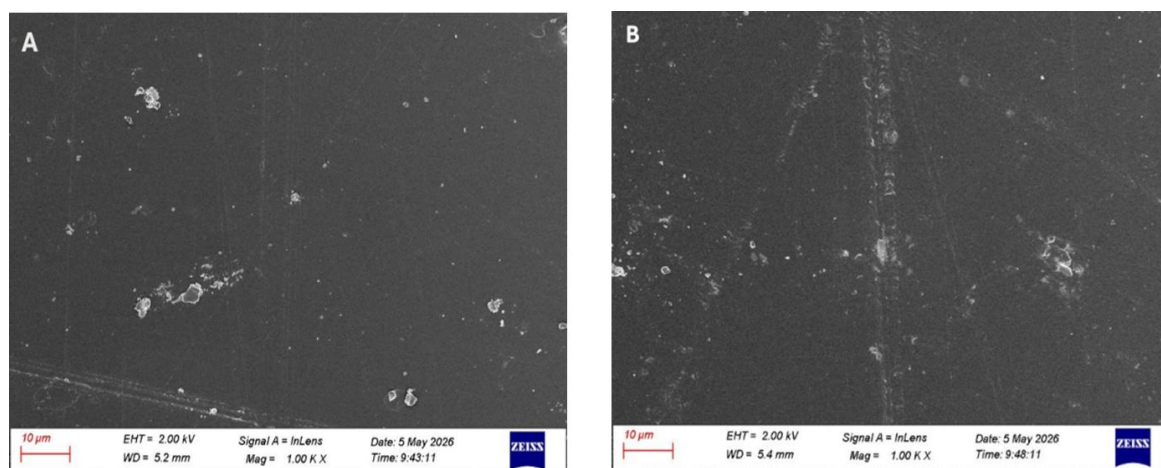


FIGURE 6: SEM micrographs of PVA-Ninhydrin (A) and PVA-NanoZnO-Ninhydrin (B) Composite film

The SEM micrograph of the PVA–ninhydrin film (Figure 6a) exhibited a relatively smooth, compact, and homogeneous surface without noticeable cracks, voids, or structural defects, indicating the formation of a continuous polymer matrix. The absence of distinct particulate features suggests that ninhydrin is uniformly incorporated within the PVA matrix without the formation of visible aggregates. However, the PVA–nano ZnO–ninhydrin composite film (Figure 6b) displayed a comparatively rougher surface with several bright particle-rich regions distributed over the polymer matrix. These bright regions are attributed to ZnO-rich regions due to the higher electron density of ZnO relative to the surrounding polymer. A few localized agglomerates are also observed, which are commonly encountered in nanoparticle-reinforced polymer composites as a result of the high surface energy of nanoparticles. Despite these localized agglomerations, the composite film retains a continuous morphology without apparent cracks or voids. The incorporation of ZnO nanoparticles modifies the surface morphology of the PVA–ninhydrin film by increasing the surface roughness and introducing ZnO-rich domains while preserving the integrity of the polymer matrix. These observations confirm the successful fabrication of the PVA–nano ZnO–ninhydrin composite film and the effective incorporation of ZnO nanoparticles into the polymer matrix (Lopez-Miranda et al., 2023; Amin et al., 2020; Furhan & Ramesan, 2022; Duygulu et al., 2024).

3.7 Mechanical Properties

The tensile properties of the fabricated films were evaluated using a Universal Testing Machine (UTM), and the results are summarized in Table 2. The PVA–nano ZnO–ninhydrin composite film exhibited a higher tensile strength (43.84 MPa) than the PVA–ninhydrin film (24.24 MPa), indicating the reinforcing effect of ZnO nanoparticles on the polymer matrix (Sultan et al., 2024; Shen et al., 2020; Erol et al., 2023; Sirelkhatim et al., 2015). Similarly, the Young's modulus increased from 1.18 MPa to 12.51 MPa, suggesting enhanced stiffness and rigidity following ZnO incorporation. On the other hand, the elongation

at break of the nano ZnO incorporated films decreased from 37.78% to 3.62%, while the maximum displacement decreased from 7.56 mm to 0.72 mm, indicating reduced flexibility of the composite film. The decrease in ductility is attributed to the restriction of polymer chain mobility by the dispersed ZnO nanoparticles.

TABLE 2
MECHANICAL PROPERTIES OF FABRICATED FILMS

Mechanical property	PVA–Ninhydrin film	PVA–Nano ZnO–Ninhydrin composite film
Tensile strength (MPa)	24.24	43.84
Young's modulus (MPa)	1.18	12.51
Elongation at break (%)	37.78	3.62
Maximum displacement (mm)	7.56	0.72

3.8 Antibacterial Properties

The antibacterial activity of the fabricated PVA–ninhydrin and PVA–nano ZnO–ninhydrin composite films was evaluated against Gram-negative *Escherichia coli* (ATCC 25922) and Gram-positive *Staphylococcus aureus* (ATCC 25923) using the agar diffusion method. The inhibition zones are presented in Figure 7, and the corresponding zone diameters are summarized in Table 3.

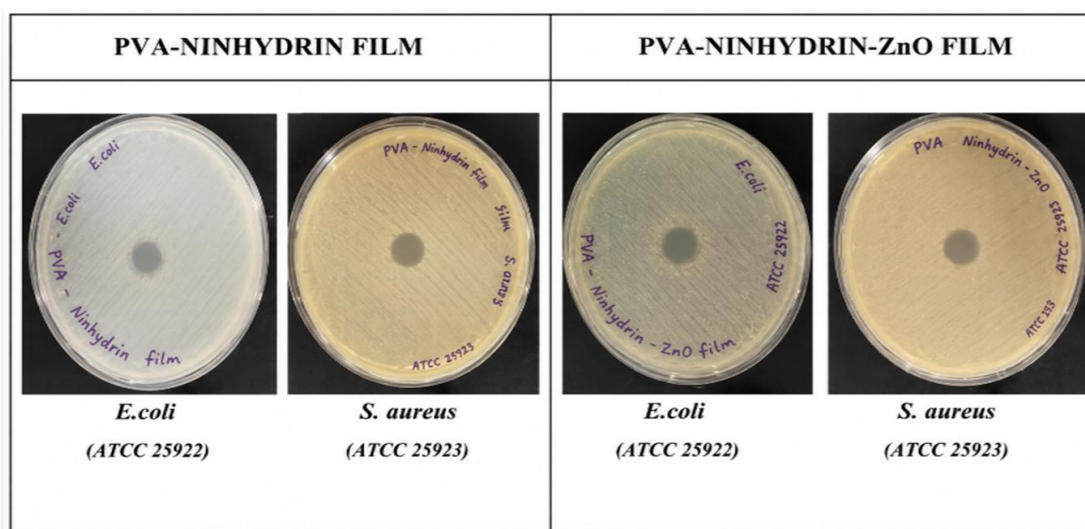


FIGURE 7: Antibacterial activity of the fabricated PVA–Ninhydrin and PVA–Nano ZnO–Ninhydrin composite films against *Escherichia coli* (ATCC 25922) and *Staphylococcus aureus* (ATCC 25923) determined by the agar diffusion method.

TABLE 3
ANTIBACTERIAL ACTIVITY OF THE FABRICATED FILMS

Bacterial strain	PVA–Ninhydrin film (Zone of inhibition, mm)	PVA–Nano ZnO–Ninhydrin composite film (Zone of inhibition, mm)
<i>Escherichia coli</i> (ATCC 25922)	11	12
<i>Staphylococcus aureus</i> (ATCC 25923)	9	12

The PVA–ninhydrin film exhibited inhibition zones of 11 mm against *E. coli* and 9 mm against *S. aureus*, indicating moderate antibacterial activity. While the PVA–nano ZnO–ninhydrin composite film produced inhibition zones of 12 mm against both bacterial strains, demonstrating enhanced antibacterial performance following the incorporation of ZnO nanoparticles. The improved antibacterial activity of the composite film is attributed to the intrinsic antimicrobial properties of ZnO nanoparticles, which are known to inhibit bacterial growth through the generation of reactive oxygen species (ROS), release of Zn²⁺ ions, and

disruption of bacterial cell membranes (Zhao et al., 2018; Abebe et al., 2020; Sudalaimani et al., 2020). The comparable inhibition observed against both Gram-negative and Gram-positive bacteria indicates the antibacterial activity of the fabricated films.

3.9 Application in Soil Fertility Assessment

The practical applicability of the fabricated PVA–ninhydrin and PVA–nano ZnO–ninhydrin composite films for soil fertility assessment was evaluated by monitoring their colourimetric response toward nitrogen-containing compounds in soils with different fertility levels. The sensing mechanism is based on the reaction of ninhydrin with free amino compounds, producing Ruhemann's purple, the intensity and rate of which serve as qualitative indicators of soil organic nitrogen availability. Four soil samples with different fertility levels—normal agricultural soil, black soil, cow dung-amended soil, and chicken manure-amended soil—were examined using both films. The result of colour development has been summarized in Table 4.

TABLE 4
QUALITATIVE EVALUATION OF SOIL FERTILITY USING THE FABRICATED FILMS

Soil sample	Relative nitrogen content	Colour development rate	Soil fertility
Chicken manure-amended soil	Very high	Fastest (~2.5 h)	Very high
Cow dung-amended soil	High	Fast	High
Black soil	Moderate	Moderate	Moderate
Normal soil	Low	Slowest	Low

The rapid response observed for chicken manure-amended soil is attributed to its higher concentration of readily available organic nitrogen compounds, whereas the delayed response of normal soil reflects its comparatively lower nitrogen availability. Both films successfully differentiated soils based on their relative fertility. The PVA–ninhydrin film exhibited a faster colorimetric response, producing the characteristic Ruhemann's purple more rapidly than the PVA–nano ZnO–ninhydrin composite film. In contrast, the ZnO-containing film displayed a slightly delayed response and developed a brownish-purple colouration, which is attributed to the influence of ZnO nanoparticles on the optical properties of the polymer matrix rather than any alteration of the ninhydrin–amino acid reaction.

The slower response of the PVA–nano ZnO–ninhydrin composite film is likely due to the restricted diffusion of amino compounds through the reinforced polymer network, resulting from interactions between ZnO nanoparticles and PVA chains. Nevertheless, the composite film retained effective sensing capability while offering improved thermal stability, mechanical strength, and antibacterial activity compared with the PVA–ninhydrin film (Vavaiya et al., 2026).

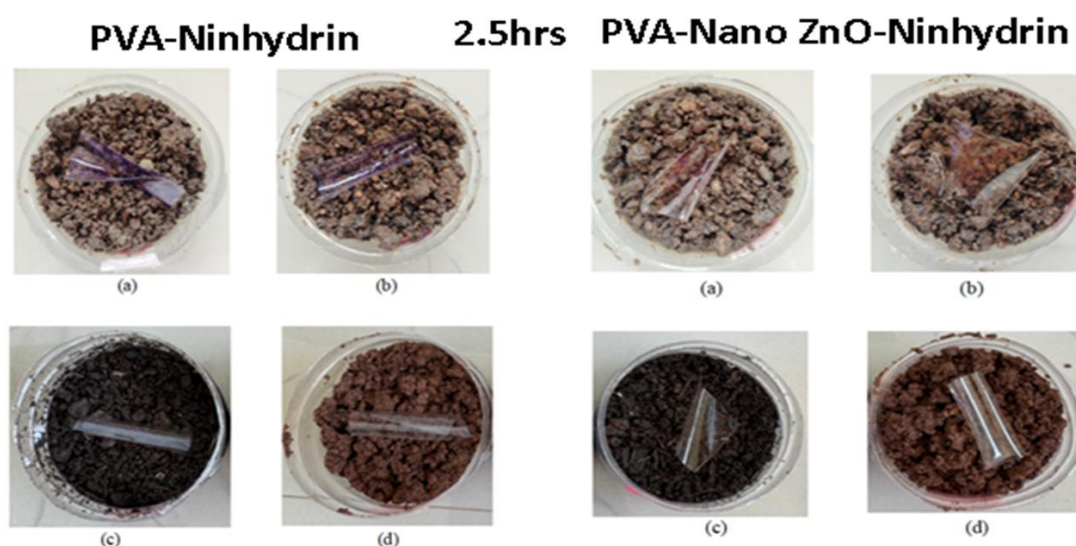


FIGURE 8: Colourimetric response of PVA-Ninhydrin & PVA-Nano ZnO-Ninhydrin Composite film after 2.5 hrs of exposure to different soil samples: chicken manure-amended soil (a), cow dung-amended soil (b), black soil (c) and normal soil (d)

Overall, both fabricated films demonstrated their suitability as qualitative colourimetric sensors for soil fertility assessment. While the PVA–ninhydrin film provided a faster analytical response, the PVA–nano ZnO–ninhydrin composite film offered enhanced physicochemical properties, making it a durable alternative for practical sensing applications.

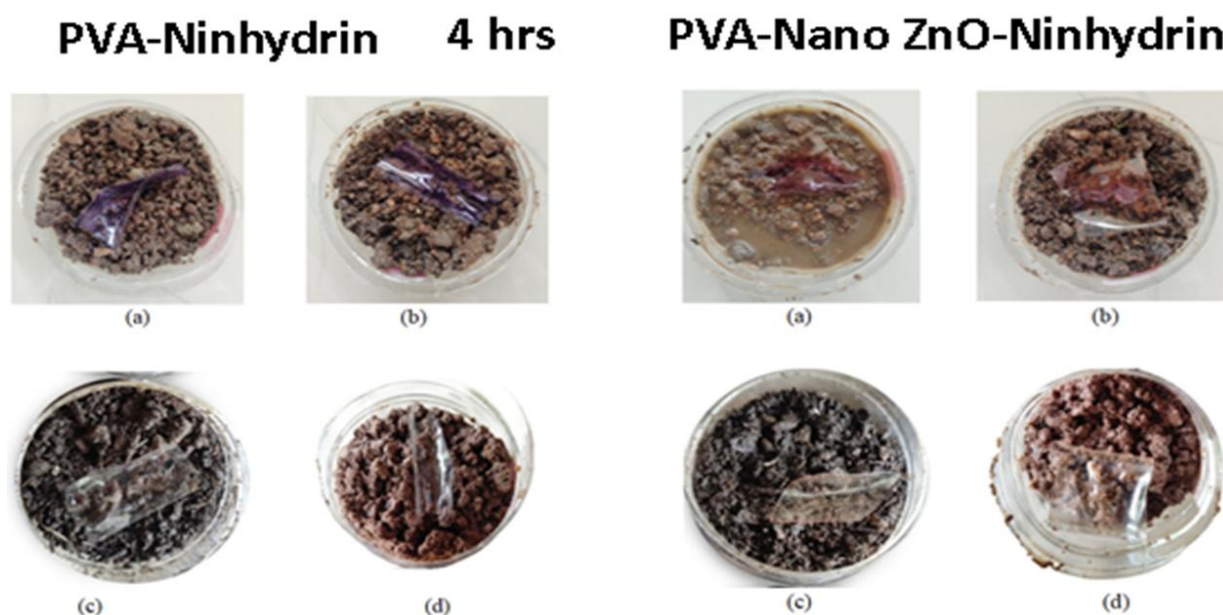


FIGURE 9: Colourimetric response of PVA-Ninhydrin & PVA-Nano ZnO-Ninhydrin Composite film after 4 hrs of exposure to different soil samples: chicken manure-amended soil (a), cow dung-amended soil (b), black soil (c) and normal soil (d)

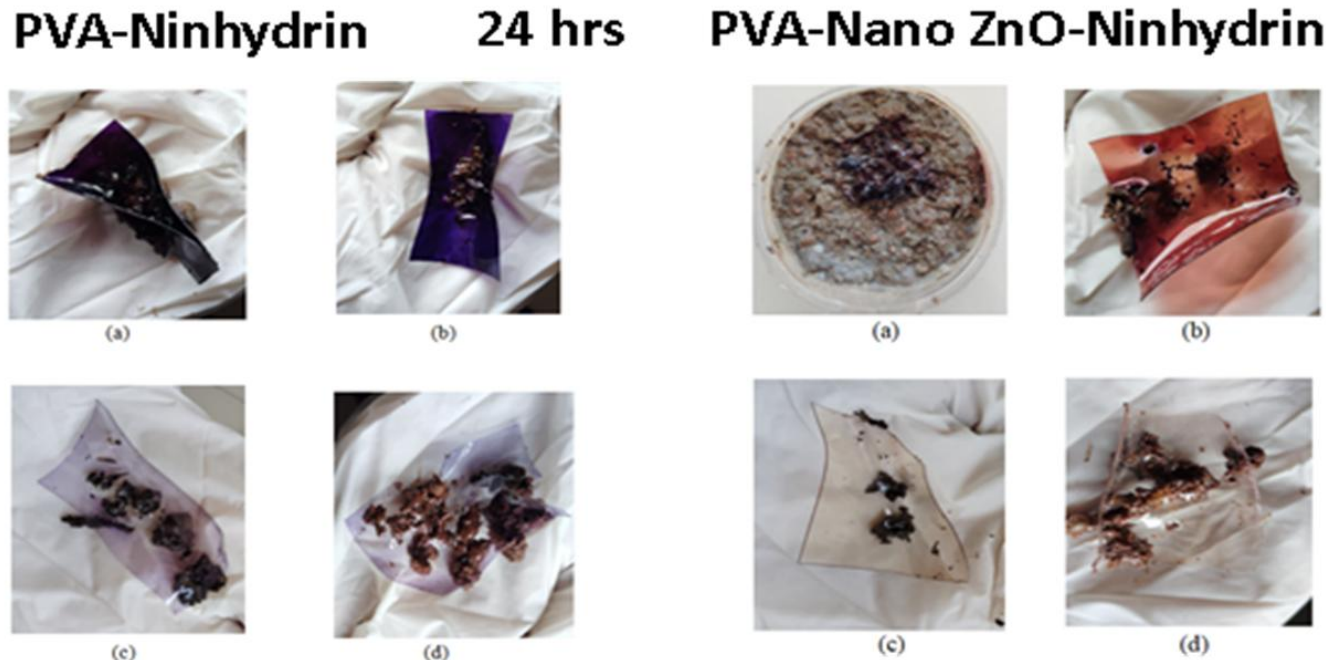


FIGURE 10: Colourimetric response of PVA-Ninhydrin and PVA-Nano ZnO-Ninhydrin Composite film after 24 hrs of exposure to different soil samples: chicken manure-amended soil (a), cow dung-amended soil (b), black soil (c) and normal soil (d)

IV. CONCLUSION

In this study, PVA–ninhydrin and PVA–nano ZnO–ninhydrin composite films were successfully fabricated by the solution-casting method and evaluated as colourimetric sensing materials for qualitative soil fertility assessment. Structural,

morphological, thermal, mechanical, optical, and antibacterial characterizations confirmed the successful incorporation of ZnO nanoparticles into the PVA–ninhydrin matrix. Compared with the PVA–ninhydrin film, the PVA–nano ZnO–ninhydrin composite film exhibited enhanced thermal stability, improved tensile strength and stiffness, and superior antibacterial activity, demonstrating the reinforcing effect of ZnO nanoparticles. Both films effectively detected nitrogen-containing compounds in soils through the ninhydrin colorimetric reaction, with the rate of colour development following the order: chicken manure-amended soil > cow dung-amended soil > black soil > normal soil, consistent with their relative fertility levels. Although the incorporation of ZnO nanoparticles slightly delayed the colorimetric response, the composite film retained excellent sensing capability while offering improved physicochemical properties and durability. Overall, the developed PVA–nano ZnO–ninhydrin composite film represents a simple, low-cost, environmentally friendly, and promising material for qualitative soil fertility assessment, with potential applications in sustainable agriculture and environmental monitoring. Future studies should focus on quantitative evaluation of soil nitrogen, long-term storage stability, and field validation under diverse agricultural conditions.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Unnimaya M: Writing – original draft, Formal analysis, Data curation, Conceptualization. Mubashira Thasni EP: Writing – original draft, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. Nafeesathul Misriya TK: Writing – original draft, Methodology, Formal analysis. Mujeeb Rahman P: Writing – review & editing, Supervision, Project administration, Funding acquisition.

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DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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