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Biosynthesis and Mapping of ZnO Nanoparticles Using Celery Leaf Extract as Latent Fingerprint Identification

Sri Adelila Sari*, Luthfi Qori Nabillah, Riri Virzan Putri Br. Siregar, Tiara Ramadhani, Lesa Octavia Br. Sinulaki, Kristin Enjelika Marbun

Department of Chemistry, Faculty of Mathematics & Natural Sciences, State University of Medan, Jalan Willem Iskandar, Pasar V, Percut Sei Tuan, Medan, Indonesia

*Email: sriadelilasari@unimed.ac.id

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Abstract. Latent fingerprint identification is an important aspect in forensic science that helps in revealing criminals. Latent fingerprint visualization methods continue to develop to improve their effectiveness and safety. This study aims to synthesize and map ZnO nanoparticles using celery leaf extract (*Apium graveolens* L.) and test its effectiveness in latent fingerprint identification. Celery leaf extract is used as a reducing agent and stabilizer in the biosynthesis of ZnO nanoparticles. Characterization of ZnO nanoparticles was carried out using FTIR and SEM-EDS. The characterization results showed that ZnO nanoparticles have a good crystal structure and uniform particle size. Application testing on porous and non-porous surfaces showed that ZnO nanoparticles were able to significantly increase the visibility of latent fingerprints compared to conventional methods. On non-porous surfaces, fingerprint visualization showed clearer results compared to porous surfaces. Thus, this study provides an environmentally friendly and effective solution for latent fingerprint identification in forensic applications, as well as expanding the potential use of natural materials in nanoparticle biosynthesis.
Keywords: Latent Fingerprint, Biosynthesis, Nanoparticles, Zinc Oxide, and Celery Leaf Extract

Introduction

The use of nanoparticle technology in various scientific and industrial applications has shown significant growth in the last few decades. One of the prominent applications is in the field of forensics, especially in the identification of latent fingerprints. Latent fingerprints, which are invisible to the naked eye, require special visualization techniques in order to be analyzed. Various methods have been developed to improve the effectiveness and efficiency of latent fingerprint visualization, including the use of nanoparticles (Bhagat, et al., 2020).

Zinc oxide (ZnO) nanoparticles have attracted great attention in forensic research due to their unique physicochemical properties, including small particle size, large surface area, and good photocatalytic properties (Verma, et al., 2022). Various studies have been conducted to synthesize ZnO nanoparticles using environmentally friendly methods, known as "biosynthesis". Biosynthesis involves the use of natural materials as reducing agents and stabilizers in the process of nanoparticle formation (Sari & Nasution, 2021). One interesting approach in ZnO biosynthesis is the use of plant extracts as reducing agents. This approach is not only environmentally friendly but also economical and easily accessible (Thi, et al., 2020). Several studies have successfully used various plant extracts such as dragon fruit peel, orange peel, lime leaves, and green seaweed for the synthesis of ZnO nanoparticles with satisfactory results in visualization of latent fingerprints (Sari & Lubis, 2021).

This study aims to explore the potential of celery leaf extract (*Apium graveolens* L.) in the biosynthesis of ZnO nanoparticles and its application in latent fingerprint identification. Celery leaves were chosen because they are known to have high phenolic and flavonoid compounds, which can act as reducing agents and stabilizers in the formation of nanoparticles (Sasangka & Estuningtyas, 2023). In addition, celery leaves are easily obtained and relatively inexpensive, making them an attractive choice for further research.

Several previous studies have shown success in using leaf extracts from other plants for the biosynthesis of ZnO nanoparticles and their application in forensics. For example, extracts of suji leaves, moringa leaves, and kopasanda leaves have been used to synthesize ZnO nanoparticles which were then applied in the visualization of latent fingerprints with satisfactory results. This method is not only effective but also safer and more environmentally friendly compared to conventional methods that use hazardous chemicals (Rajan, et al., 2023).

In addition, this study will also map the characteristics of the resulting ZnO nanoparticles, including particle size, morphology, and crystal structure, using various characterization techniques such as FTIR and SEM-EDS (Josep & Poornima, 2019). A deep understanding of these characteristics is important to optimize the biosynthesis process and its forensic applications. Thus, this study is expected to provide significant contributions to the development of more environmentally friendly and effective latent fingerprint visualization methods, as well as expanding the application of ZnO nanoparticle biosynthesis using easily accessible natural materials (Sari & Nasution, 2023). The purpose of this study is to explore the effectiveness of using celery leaves as a biosynthesis agent in the development of nanoparticles for latent fingerprint identification. Additionally, this paper aims to highlight how this approach could offer an effective solution for forensic applications, while also expanding the potential use of natural materials in nanoparticle biosynthesis.

Methods

The equipment used in this study included 500 mL, 250 mL, and 100 mL chemical glasses (Phyrex), 2 pieces each; magnetic stirrer; thermometer; analytical balance (Fujitsu); grinder; stand; furnace, 1 piece each; glass funnel (Phyrex), 99 mm and 50 mm, 2 pieces each; filter paper (Whatman No. 1); 50 mm porcelain cups; scissors (Joyco); magnifying glass (Joyco); macro camera on Vivo Y21 phone; black marabou feather duster (Sirchie); FTIR; and SEM-EDS, 1 piece each.

The materials used included 500 grams of celery leaves; 1 L of aquabides; 24 grams of zinc nitrate hexahydrate ($Zn(NO_3)2{\cdot}6H_2O$) (Smart-Lab); 1 box of aluminum foil; 1 box of nitrile gloves (Safeguard); 20 pieces of fingerprint hinge lifter (Sirchie); 1 piece of HI-FI Olcano latent print powder (Sirchie); porous surface media (black cardboard and oil paper); and non-porous surface media (aluminum foil, glass preparation, compact disk), as needed.

Celery leaves were cut into small pieces, then washed thoroughly using aquabides to remove impurities and reduce contamination with other substances. After being washed thoroughly with aquabides, the celery leaves were dried at room temperature for 4 days. Then after that the celery leaves were ground to obtain a smaller particle size. The smaller particle size functions to accelerate the solubility and distribution of celery leaf extract in the solvent. After being ground, 2 grams of celery leaves were taken then 85 mL of aquabides were added in a 100 mL beaker then placed on a hotplate with a magnetic stirrer placed into the beaker containing the solution. Extraction was carried out at a temperature of 70°C for 10 minutes then continued again at a temperature of 80°C for 10 minutes then cooled at room temperature. After the celery leaf extract solution was cold, the celery leaf extract was filtered to obtain the filtrate. The celery leaf filtrate from the filtration was used for the biosynthesis process of ZnO nanoparticles using celery leaf extract (Fitriana, 2018).

The biosynthesis process of ZnO nanoparticles was carried out by adding 4 grams of zinc nitrate hexahydrate ($Zn(NO_3)_2.6H_2O$) into 85 mL of filtrate from celery leaf extract then homogenizing the solution using a magnetic stirrer for 1 hour. The solution was then placed in a water bath for 1 hour at a temperature of 60°C. Furthermore, the solution was stirred again using a magnetic stirrer at a temperature of 150°C to obtain the results of the suspension in a solution of celery leaf extract with zinc nitrate hexahydrate ($Zn(NO_3)_2.6H_2O$). The color change in the solution and the formation of a precipitate indicated that the bioreduction of ZnO salt into nanoparticles had been completed (Nurbayasari & Saridewi, 2017). The next step was to calcinate the nanoparticle solution at a temperature of 350 - 400°C to produce ZnO nanoparticle powder derived from the biosynthesis of celery leaf extract.

Functional groups in the results of ZnO nanoparticle biosynthesis powder using celery leaf extract will be identified using FTIR instrumentation. Furthermore, morphological analysis and the composition of the number of substrate structures in ZnO nanoparticle biosynthesis using celery leaf extract will be determined using SEM-EDS instrumentation (Jacinto, et al., 2021).

Latent fingerprint identification in this study involved 30 students from various departments of Medan State University who were randomly selected. Students whose fingerprints would be identified were directed to wash their hands with soap first and then dry them in the air before touching sweaty parts of their faces such as the forehead, nose, chin and cheeks to help the ZnO nanoparticle biosynthesis powder using celery leaf extract stick to the fingerprints and be visible on the media to be applied (Sari, et al., 2020). Parts of the body that produce sweat such as the face contain amino acids that have functional groups such as $-NH_2$ (amino) and -COOH (carboxyl) which can form bonds with the surface of ZnO nanoparticles. The interaction of these functional groups helps ZnO nanoparticles to adhere better to fingerprint residues, thereby increasing the visibility of latent fingerprints (Sari, et al., 2019).

Students whose fingerprint patterns would be identified would use porous surface media (black cardboard and oil paper) and non-porous surface media (aluminum foil, glass preparation, compact disk). The finger identified is the right thumb by attaching its fingerprint to one of the media then slowly spreading the results of ZnO nanoparticle biosynthesis powder using celery leaf extract on the media then wiping in one direction and carefully using black marabou feather duster (sirchie) until the latent fingerprint trace is visible on the media. Furthermore, the fingerprint trace is photographed with a macro camera on the Vivo Y21 cellphone then the latent fingerprint trace is taken using the finger print hinge lifter (Sirchie).

Results and Discussion

Biosynthesis of ZnO Nanoparticles using Celery Leaf Extract

Two grams of celery leaves that have been ground into powder are stirred by repeating the extraction process twice to support the analyte to diffuse with the solvent from the amount of solute to obtain the extractant phase from celery leaves. The extractant from celery leaves will be used for ZnO biosynthesis nanoparticles (Sari & Hawari, 2022).

Color changes indicate the presence of physio-chemical properties by changing the aquabides solvent during the stirring process of the mixture ($Zn(NO_3)_2.6H_2O$) with celery leaf extract marked as an early indicator for nanoparticle production. The mixing process is carried out at a temperature of 150°C for 10 minutes with a magnetic stirrer producing a brownish black and suspended solution indicating that the bioreduction of nanoparticles has been completed. The remaining impurities such as CO_2 are removed by exposure to heating at a temperature of 350 - 400°C with a calcination process to produce the biosynthesis of ZnO nanoparticles with vanilla-colored celery leaf extract (Samy, et al., 2019).

Nanoparticle Mapping

The stretching vibration forms 9 wave number peaks with different functional groups and types of compounds. At wave number 3392.56 cm^{-1} is a type of hydroxyl compound with O-H functional group. The interaction of CO_2 absorption with water molecules in the solvent in the nanoparticle causes this peak to form. The stretching vibration of two carbon bond chains indicates the C=O functional group in the carbonyl compound type forming waves of 1763.17 cm^{-1} and 1634.49 cm^{-1}. The peak is formed again in the alkane compound type with a wavelength of 1374.03 cm^{-1}. The wave number peak of 1192.28 cm^{-1} forms an ether compound type with C-O-C functional group. Furthermore, at wavelengths of 1097.21 cm^{-1} and 824.66 cm^{-1} forms an aromatic compound type with C=C and C-H functional groups respectively. Then at a wavelength of 657.07 cm^{-1} and 643.80 cm^{-1} formed a type of halogen compound with a C-Cl functional group. The signal that forms the wave number comes from the ZnO compound that interacts with the celery leaf extract biosynthesis mixture using aquabides solvent. So that the results of the FTIR spectrum of ZnO nanoparticles from the biosynthesis that has been carried out are shown in the graph below (Amin & Tengker, 2023).

The FTIR analysis of ZnO nanoparticles biosynthesized using celery leaf extract provides detailed insights into the interaction between the ZnO nanoparticles and various organic compounds present in the extract. The stretching vibrations observed at different wave numbers signify the presence of specific functional groups that interact with the ZnO structure. The peak at 3392.56 cm^{-1}, attributed to the O-H functional group, suggests the presence of hydroxyl compounds. This peak likely arises from the interaction between carbon dioxide (CO_2) absorption and water molecules in the solvent. Such interactions are known to affect the chemical structure of the nanoparticles, especially in biosynthesis processes, where water molecules can stabilize the formed nanoparticles (Khoramian, et al., 2024).

At 1763.17 cm^{-1} and 1634.49 cm^{-1}, the peaks correspond to the stretching vibration of the C=O bond in carbonyl compounds. These peaks indicate the interaction of the carbonyl group with ZnO, likely due to the presence of organic acids or aldehydes in the extract. The carbonyl groups may act as stabilizers in the synthesis process, influencing the morphology and surface characteristics of the nanoparticles (Madi, et al., 2024). The peak at 1374.03 cm^{-1} indicates the presence of alkane compounds, which are typically characterized by the C-H bending vibrations. The formation of this peak suggests the involvement of aliphatic compounds in the biosynthesis process. Alkanes, with their hydrophobic nature, might contribute to the stability of the nanoparticles, preventing agglomeration. At 1192.28 cm^{-1}, the C-O-C stretching vibration signals the presence of ether compounds. Ethers, being polar, can facilitate the dispersion of nanoparticles in aqueous solvents, influencing their stability and solubility. The peak at 1097.21 cm^{-1} further confirms the presence of aromatic compounds with C=C bonds, which could be derived from polyphenolic compounds in the celery extract. The aromatic rings are likely involved in stabilizing the ZnO nanoparticles via π-π interactions, a common feature in nanoparticle surface chemistry. The peaks at 824.66 cm^{-1} and 657.07 cm^{-1} are indicative of halogenated compounds, with the C-H and C-Cl stretching vibrations respectively. The presence of chlorine could be linked to the extract's interaction with chloride ions, which might influence the final structure of the ZnO nanoparticles. The C-Cl bonds can also act as a functional group in the process, contributing to the surface modification of the nanoparticles (Arias et al., 2024).

The interaction of these functional groups with ZnO nanoparticles during the biosynthesis process provides essential information on how organic compounds from the celery leaf extract influence the size, shape, and stability of the nanoparticles. The FTIR spectrum highlights the complex interaction between the natural extract components and the ZnO particles, showcasing a successful green synthesis process that avoids the use of toxic chemicals (Basnet, et al., 2018). The final nanoparticle structure is a result of the coordination between the ZnO and the various functional groups from the plant extract, providing a potential for diverse applications in fields such as catalysis, drug delivery, and environmental remediation (Raha & Ahmaruzzaman, 2022).

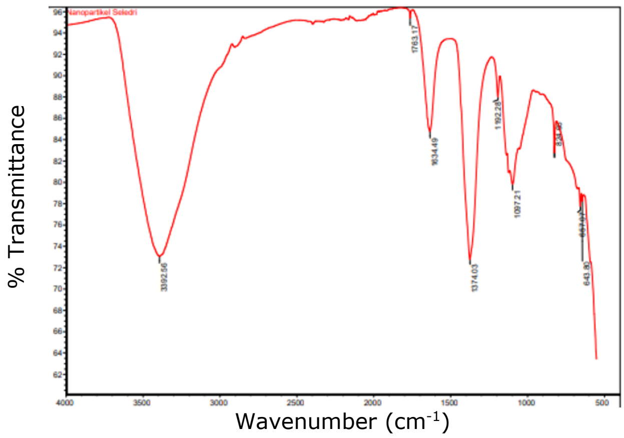


Figure 1. FT-IR spectrum of ZnO nanoparticles

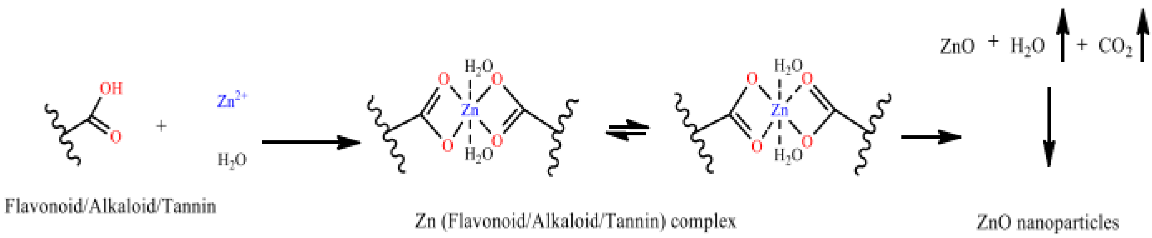


Figure 2. Synthesis Reaction Mechanism of Celery Leaf Extract with ZnO Nanoparticles

Secondary metabolite compounds of celery leaf extract can reduce and oxidize $ZnO2^{+}$ ions. Because the formation of hydrogen atoms changes the hydroxyl group into ketones. Complex zinc compounds containing flavonoids/alkaloids/complex tannins will form molecules when interacting with the free OH group which is reacted with $Zn(NO_3)_2$. The compound has been suspended when the calcination process is complete to form pure ZnO nanoparticles, functional groups in and celery have a role in the process of stability of nanoparticle development, preventing agglomeration and stabilizing compounds during the calcination process (Famia & Muldarisnur, 2019).

The surface morphology of zinc oxide nanoparticles biosynthesized with celery leaf extract at a magnification of 10,000x using SEM instrumentation can be shown in Figure 1. The morphology of ZnO displays a very close nanoparticle surface so that it displays a very smooth and hollow surface. This surface produces agglomeration which causes the nanoparticles to clump together quickly (Yanti et al., 2024). This is due to the strong attractive force between particles so that the size distribution of ZnO nanoparticles biosynthesized with celery leaf extract produces a finer powder with an average diameter of 160.66 nm.

This agglomeration phenomenon, while inherent in many nanoparticle synthesis methods, poses both challenges and opportunities for innovation. The strong attractive forces leading to particle clumping can hinder the uniform dispersion of ZnO nanoparticles in applications such as coatings, catalysts, and biomedical systems. To overcome this limitation, future research could explore strategies to minimize agglomeration. One approach involves modifying the synthesis process by incorporating surfactants or stabilizing agents during the biosynthesis stage. Surfactants can act as steric or electrostatic barriers between nanoparticles, preventing their aggregation and enhancing dispersion. Additionally, controlling reaction parameters such as pH, temperature, and extract concentration could further refine particle size and reduce agglomeration. The hollow and smooth surface of these biosynthesized ZnO nanoparticles presents opportunities for functional optimization (Gaur, et al., 2024). For instance, the hollow structure could be exploited in drug delivery systems, where ZnO nanoparticles can serve as carriers for therapeutic agents. The hollow core allows for the encapsulation of drugs, while the smooth outer surface can facilitate controlled release through surface functionalization. By tailoring the surface chemistry of these nanoparticles with specific ligands or biomolecules, their biocompatibility and targeting capabilities can be significantly enhanced, broadening their potential in nanomedicine (Díez-Pascual, 2022).

Furthermore, the biosynthetic method using celery leaf extract offers a green and sustainable alternative to conventional chemical synthesis methods, aligning with the principles of green chemistry. The bioactive compounds in celery extract, such as flavonoids and phenolics, not only reduce Zn ions to form ZnO nanoparticles but also impart unique surface properties that could influence their functionality. Future studies could investigate the impact of varying the plant extract composition on nanoparticle morphology and properties. For example, utilizing different plant species or combining multiple extracts might yield ZnO nanoparticles with novel structures or enhanced performance characteristics. The average diameter of 160.66 nm, while effective for many applications, can also be optimized based on specific end uses. Smaller nanoparticles generally exhibit higher surface area-to-volume ratios, which are advantageous in catalytic and photocatalytic applications (Basu & Banik, 2024). Conversely, slightly larger nanoparticles with reduced surface energy might be preferred for applications requiring greater stability, such as in coatings or sensors. Researchers could explore post-synthesis treatments like annealing or calcination to adjust particle size and improve crystallinity, thereby tailoring ZnO nanoparticles for targeted applications (Xu, et al., 2018).

Additionally, the hollow structure observed in these nanoparticles could be leveraged for environmental remediation purposes. ZnO is known for its photocatalytic properties, which can be applied to degrade organic pollutants in water or air. The hollow design could increase light penetration and active surface area, enhancing the efficiency of photocatalytic processes. To further innovate, doping ZnO nanoparticles with other elements, such as silver or copper, could improve their photocatalytic and antimicrobial properties, making them more versatile for use in diverse environmental and biomedical contexts.

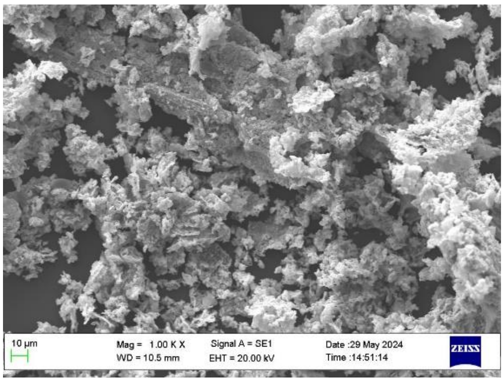


Figure 3. Morphology of ZnO nanoparticles based on the results of SEM testing

The results of the diameter measurements of the nanoparticles are shown in the histogram below.

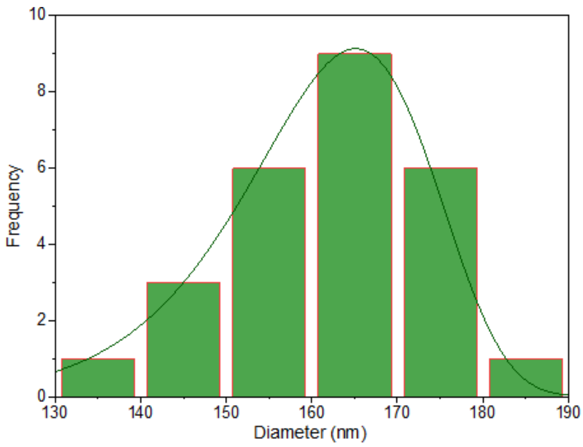


Figure 4. Histogram Diagram of Nanoparticle Size Distribution of Celery Leaf Extract Synthesis with ZnO

The results of the elemental composition of ZnO nanoparticles biosynthesized with celery leaf extract were identified one by one by EDS testing. So that the nanoparticles have elements such as C, O2, S, Cl, K, Ca, Zn, Zr and Nb with a weight of Zn spread as much as 57.90 then successively the composition of the elements formed has an atomic weight of 2.20, 21.86, 1.17, 3.24, 6.12, 2.75, 1.46 and 3.29 with units of percent in each weight up to a total of 100 percent.

The results of the elemental composition of ZnO nanoparticles biosynthesized using celery leaf extract were carefully examined through energy dispersive X-ray spectroscopy (EDS). This technique is essential for identifying the specific elements present in the nanoparticles and provides quantitative information about the atomic distribution of each element. The EDS analysis revealed that the synthesized ZnO nanoparticles contain several elements, including carbon (C), oxygen (O_2), sulphur (S), chlorine (Cl), potassium (K), calcium (Ca), zinc (Zn), zirconium (Zr), and niobium (Nb). Among these, zinc (Zn) was found to be the most abundant element, comprising 57.90% by weight, confirming that zinc oxide is the dominant phase in the nanoparticles.

The remaining elements were detected in varying proportions, with the following atomic compositions: 2.20% C, 21.86% O_2, 1.17% S, 3.24% Cl, 6.12% K, 2.75% Ca, 1.46% Zr, and 3.29% Nb, cumulatively contributing to the full elemental composition (100%). The presence of carbon (C) is likely due to the organic components from the celery leaf extract, which include various phytochemicals such as flavonoids, phenolic compounds, and carbohydrates. These organic compounds play a crucial role in reducing zinc ions to form ZnO nanoparticles during the biosynthesis process. Furthermore, the oxygen (O_2) is primarily attributed to the ZnO lattice itself, as zinc oxide is a compound consisting of zinc and oxygen.

Sulphur (S) could originate from sulphur-containing compounds in the celery leaf extract, which may participate in the reduction and stabilization of the nanoparticles. The detection of chlorine (Cl) might be associated with the residual chlorine ions from the reagents used in the biosynthesis process or could be a result of trace impurities in the extract. Potassium (K) and calcium (Ca) are common elements found in plant-based extracts, as these are essential macronutrients for plant growth and development. Their presence in the nanoparticles suggests that these elements are incorporated into the nanoparticle matrix during the biosynthesis process. The presence of zirconium (Zr) and niobium (Nb) in the composition is relatively unexpected. These elements could potentially be contaminants from the laboratory environment, or they might be trace elements naturally present in the celery leaf extract, though their roles in nanoparticle formation are not fully understood. The incorporation of these elements could also have an impact on the properties of the ZnO nanoparticles, such as their stability, optical behaviour, or catalytic activity. Further investigation into the source and influence of these trace elements would be necessary to understand their potential contribution to the overall properties of the synthesized nanoparticles. The findings from the EDS analysis provide valuable insights into the elemental makeup of the ZnO nanoparticles, highlighting the involvement of both the metal oxide and organic components from the plant extract. This highlights the complex nature of green synthesis processes, where not only the metal precursor but also the phytochemicals in the plant extract significantly contribute to the formation and stabilization of nanoparticles. The biosynthesis of ZnO nanoparticles using celery leaf extract opens up potential applications in various fields, including environmental remediation, catalysis, and biomedical applications. The incorporation of plant-derived elements such as calcium and potassium may also offer additional benefits, such as enhanced biocompatibility and stability of the nanoparticles (Mandal, et al., 2022).

These findings emphasize the need for further studies to explore the detailed roles of each element, especially the trace elements like Zr and Nb, in determining the characteristics and functionality of the ZnO nanoparticles. In addition, optimizing the biosynthesis process through the selection of appropriate plant sources and reaction conditions could improve the efficiency and properties of the nanoparticles, paving the way for their use in practical applications such as sensors, drug delivery systems, and antimicrobial agents.

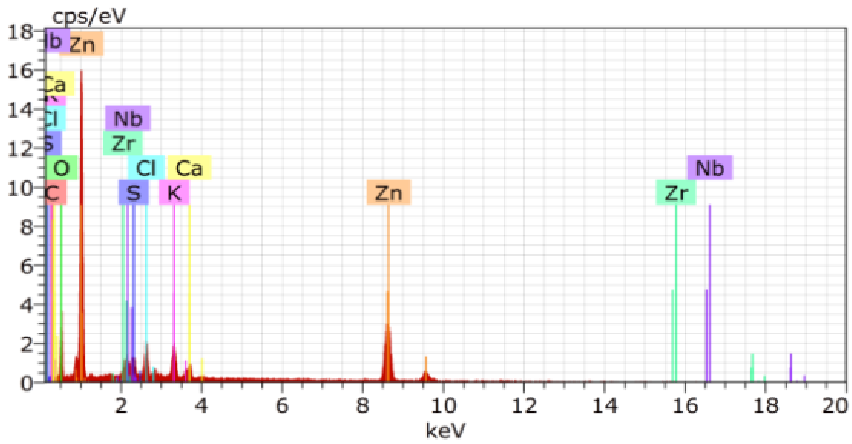
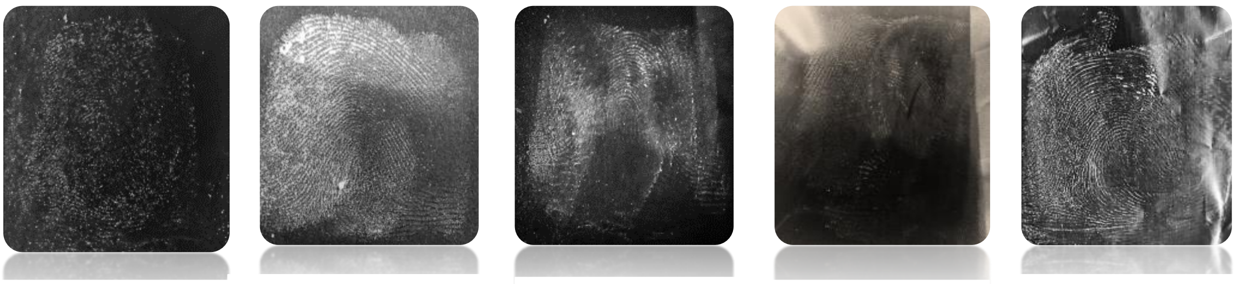


Figure 5. EDS Test Spectrum of ZnO Nanoparticles

Identification of Latent Fingerprints Using ZnO Nanoparticle Biosynthesis Powder

A total of 30 students from Medan State University whose fingerprint samples were taken randomly after following the specified procedure, latent fingerprint prints were obtained and the pattern of scratches formed on the latent fingerprint prints was analyzed. Visualization of latent fingerprints is formed due to the interaction between elements and non-covalent/hydrophobic compounds contained in the powder from the biosynthesis of ZnO nanoparticles using celery leaf extract. Then the residue from the fingerprints contains sebum secretion from organic compounds that are not soluble in water. In addition, the use of powder with smaller particles produces better latent fingerprint prints (Bhagat, et al., 2020).

Figure 6 shows the visualization of latent fingerprints through porous and non-porous media with powder from the biosynthesis of ZnO nanoparticles using celery leaf extract. The size of the nanoparticles formed is effective in identifying latent fingerprints, this is in accordance with previous studies which state that finer and smaller particles will stick better than larger and coarser particles (Taba, et al., 2019). The finer the powder, the better the ability of the attraction between particles to stick to the latent fingerprint, thus increasing the visualization of the latent fingerprint formed. In addition, the results of research in latent fingerprint identification show that the use of media types affects the quality of visualization of the printed (Majani, et al., 2023).



(a) Oil Paper | (b) Cardboard Paper | (c) Glass Preparation | (d) Compact Disk | (e) Aluminum Foil

Figure 6. Visualization of Latent Fingerprint from ZnO Nanoparticle Biosynthesis Powder Using Celery Leaf Extract On Porous and Non-Porous Media

Latent Fingerprint Patterns

Latent fingerprints of 30 students who were randomly sampled were identified by their fingerprint patterns so that Figure 7 shows the results of the percentage of fingerprint patterns from 30 student samples at Medan State University.

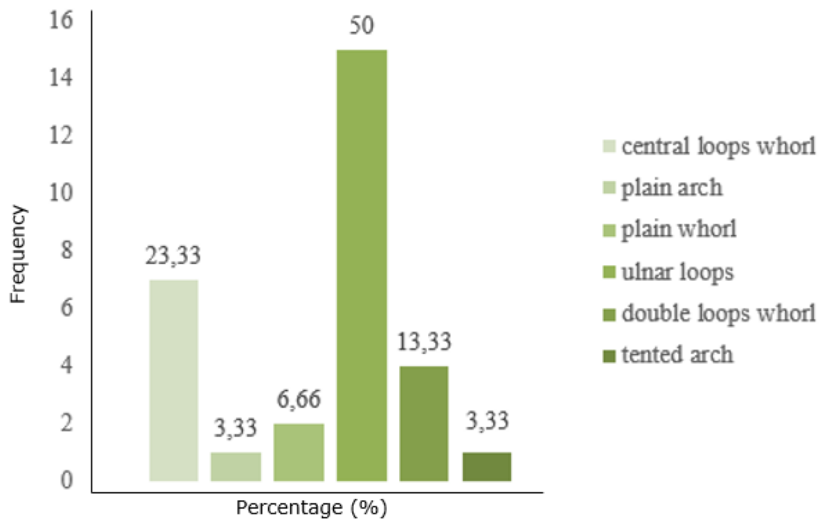


Figure 7. Percentage Diagram of Latent Fingerprints

The ulnar loops pattern has a fingerprint pattern of 60% compared to other fingerprint patterns, this shows that the pattern is quite dominant. The central loops whorl fingerprint pattern contributed 23.33% of the four fingerprint patterns taken from 30 fingerprint samples. Followed by the double loops whorls fingerprint pattern 13.33%, the plain whorls fingerprint pattern only contributed 6.66%, the plain arch and tentes arch patterns each 3.33% This conclusion is consistent with previous research, which found that 11.6% of 120 fingerprint samples had radial loops, 44.1% had ulnar loops, 33.3% had plain whorls, twisted loops, and 0.8% had tented arches.

The analysis of fingerprint patterns in this study revealed that the ulnar loop pattern dominates, representing 60% of the fingerprint patterns compared to other types. This prevalence indicates the ulnar loop is a significant characteristic in the sampled population. The central loops whorl pattern accounts for 23.33%, suggesting its presence is relatively common but less frequent than the ulnar loop. Interestingly, the double loops whorl pattern comprises 13.33%, showing moderate representation, while the plain whorls pattern is less common, contributing only 6.66%. Arch patterns, including both plain and tented types, are the least represented, each making up 3.33% of the observed patterns.

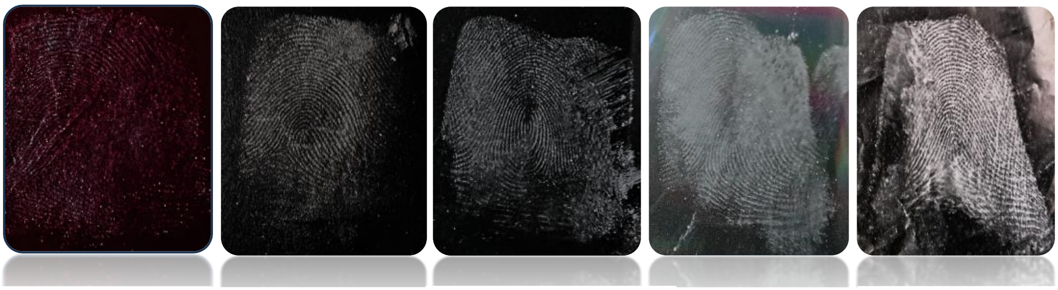
This distribution aligns with earlier studies that highlight the dominance of the ulnar loop pattern in fingerprints. Previous research found that out of 120 samples, 44.1% exhibited ulnar loops, further supporting the prevalence observed in this study. Moreover, variations in the occurrence of other patterns such as radial loops (11.6%) and plain whorls (33.3%) underline the potential influence of genetic, environmental, and demographic factors on fingerprint characteristics.

The predominance of ulnar loop patterns could have implications in forensic science and biometric identification. Since this pattern is highly dominant, it could serve as a critical marker in population-based studies or forensic profiling. The identification and categorization of such patterns are essential in narrowing down suspects or identifying individuals in large databases. Additionally, understanding the variability and frequency of less common patterns, like tented arches and plain whorls, might provide insight into specific subpopulation traits or anomalies (Buzdar, et al., 2024).

This study also opens avenues for innovation in the application of fingerprint patterns. For instance, incorporating fingerprint pattern frequency into biometric algorithms could enhance the accuracy of fingerprint recognition systems. By assigning weight to the prevalence of specific patterns, systems could prioritize more frequent patterns like ulnar loops for quicker identification while reserving additional computational resources for rarer patterns, ensuring comprehensive matching capabilities. Furthermore, the results can contribute to anthropological and genetic studies exploring the heritability and evolutionary aspects of fingerprint patterns. The correlation between certain patterns and genetic traits could deepen our understanding of human development and diversity. For example, studies investigating the link between ulnar loops and certain medical conditions or genetic markers could provide valuable insights into health diagnostics. Lastly, the relatively low frequency of patterns such as tented arches and plain arches highlights a potential area for specialized research. Understanding why these patterns are rare and whether they are influenced by specific genetic or environmental factors could offer deeper knowledge about human variation (Sumalatha, et al., 2024).

Development of Latent Fingerprint Identification

Latent fingerprints were identified using micro-sized ZnO nanoparticle powder and HI-FI Olcano Latent Print Powder using the powder dusting method. Visualization of latent fingerprints identified on porous and non-porous surface media types with HI-FI Olcano Latent Print Powder is shown in Figure 8.



(a) Oil Paper (b) Cardboard Paper (c) Glass Preparation (d) Compact Disk (e) Aluminum Foil

Figure 8. Visualization of Latent Fingerprints with HI-FI Olcano Latent Print Powder on Porous and Non-Porous Media

The color contrast of latent fingerprints is clearer on porous media identified with HI-FI Olcano Latent Print Powder due to the difference in the gray color of the powder. In contrast, the powder resulting from the biosynthesis of ZnO nanoparticles using vanilla-colored celery leaf extract when applied to non-porous media is much more visible in the fingerprint lines formed. In addition, fingerprints at the end of the groove line or branching point are more clearly visible on ZnO nanopowder due to the nano size of the powder. The smaller the powder size, the higher the surface area, thus providing better interaction with the ridges on the fingerprint and increasing the ability of the powder to adhere to latent fingerprints and thus producing better visualization. This is due to the non-porous surface media which makes sebum quickly absorbed on the Compact Disk and glass slide. One of the factors that makes visualization less effective is due to the slippery surface which makes it difficult to print ridge patterns on fingerprints using the powder dusting method (Vadivel, et al., 2021).

The study demonstrates the effectiveness of HI-FI Olcano Latent Print Powder and biosynthesized ZnO nanoparticles for latent fingerprint visualization on porous and non-porous surfaces, respectively. The observed contrast in color clarity highlights the role of material characteristics and surface types in fingerprint visualization. On porous surfaces, the grey hue of HI-FI Olcano powder enhances contrast, allowing the ridge patterns to be distinguished effectively. Meanwhile, the vanilla-coloured ZnO nano powder, synthesized from celery leaf extract, excels on non-porous surfaces like compact disks and glass slides, offering superior visibility of fingerprint ridges and minutiae.

The key to the ZnO nano powder's success lies in its nano-scale size, which significantly increases its surface area. This larger surface area enables stronger interactions with the ridges and grooves of the fingerprint. As a result, the powder adheres more effectively to sebum and other residues present in the fingerprints, producing sharper and more detailed visualizations. This characteristic is especially valuable on non-porous media, where traditional powders often fail due to the smooth and slippery surfaces that inhibit powder adhesion. This study opens avenues for advancing forensic methods by leveraging nano-engineered materials. The application of ZnO nanopowder demonstrates that the manipulation of particle size and surface chemistry can significantly enhance fingerprint visualization, even on challenging surfaces (Sreedhara et al., 2024). Future research could explore optimizing the biosynthesis process to produce nanopowders with tailored properties, such as controlled particle size, color variations, or enhanced adhesive properties. For example, altering the biosynthesis conditions, like using different plant extracts or solvents, could yield powders with unique characteristics for specific forensic needs. Moreover, this research suggests opportunities to integrate multifunctional nanopowders in forensic science. ZnO nanoparticles have inherent photocatalytic and antimicrobial properties, which could be harnessed for dual-purpose applications. For instance, nanopowders could be designed to visualize fingerprints while simultaneously decontaminating surfaces in crime scenes, ensuring both evidence collection and hygiene (Li, et al., 2024).

The difficulty of visualizing fingerprints on slippery non-porous surfaces, as noted in the study, emphasizes the need for further innovation. One approach could involve functionalizing the surface of ZnO nanoparticles with hydrophobic or oleophilic coatings to enhance adhesion to oily or greasy residues. Additionally, combining nanopowders with advanced application techniques, such as electrostatic spraying or adhesive-based carriers, could improve the consistency of fingerprint deposition and visualization. Beyond forensic science, the findings have potential implications for biometric security and material science. For example, the enhanced visualization of ridge patterns could inform the development of advanced fingerprint recognition technologies. In material science, the study underscores the versatility of biosynthesized nanoparticles for diverse applications, from coating technologies to environmental sensing. This research contributes significantly to the understanding of how material properties influence latent fingerprint visualization on different surface types. By leveraging the unique characteristics of biosynthesized ZnO nanopowder, the study not only enhances forensic techniques but also inspires future innovations in nanotechnology and biometrics. Continued exploration of nanoparticle-based powders will undoubtedly refine visualization methods and broaden their application scope, ensuring forensic science keeps pace with modern challenges (Karnwal, et al., 2024).

Conclusion

Based on the research findings, ZnO nanoparticles were successfully synthesized using celery leaf extract, exhibiting a round morphology with a degraded surface and an average diameter of approximately 160.66 nm. These ZnO nanoparticles demonstrated the capability to visualize latent fingerprints on various porous and non-porous surfaces, producing clear ridge characteristics. However, their effectiveness in certain applications varied depending on the surface type. For porous and non-porous surfaces, HI-FI Olcano Latent Print Powder displayed superior color contrast compared to the ZnO nanopowder, highlighting its effectiveness in enhancing fingerprint visualization. The differing textures and surface interactions between the ZnO nanoparticles and the HI-FI Olcano powder were particularly noticeable on porous media. ZnO nanopowder was found to be less effective on surfaces that were excessively smooth, as the sebum from fingerprints tended to be removed during the powder application process, reducing the clarity of the visualization. In conclusion, while ZnO nanoparticles biosynthesized with celery leaf extract hold promise for forensic applications due to their nanoscale properties and ability to visualize fingerprint ridges, their performance is influenced by surface type and texture. The study emphasizes the importance of selecting appropriate visualization materials tailored to specific surface characteristics and suggests potential areas for improving nanoparticle formulations to enhance their effectiveness in fingerprint detection.

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