

Green Synthesis of ZnO Nanoparticles Using *Terminalia catappa* Leaf Extract: Effect of Precursor Ratio on Cluster Size and Optical Band Gap Tuning

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Abstract: Zinc oxide (ZnO) nanoparticles have attracted considerable attention due to their unique optical, electronic, and photocatalytic properties; however, conventional synthesis methods often involve hazardous chemicals and generate environmentally harmful waste. Therefore, this study aimed to synthesize ZnO nanoparticles through a green synthesis approach using aqueous ketapang leaf extract (*Terminalia catappa*) as a natural reducing and stabilizing agent and to evaluate the effects of precursor-to-extract ratio on the optical properties of the synthesized nanoparticles. Qualitative phytochemical screening confirmed the presence of alkaloids, flavonoids, tannins, saponins, and triterpenoids, indicating the extract's potential to facilitate nanoparticle formation. ZnO nanoparticles were synthesized using 0.1 M zinc acetate dihydrate with precursor-to-extract volume ratios of 1:1, 1:2, and 1:3. UV-Vis spectroscopic analysis showed that the optimum synthesis condition was achieved at a precursor-to-extract ratio of 1:2, yielding the highest absorbance value of 0.90 at a maximum absorption wavelength of 372 nm. The optical band gap energy determined from Tauc plot analysis was 3.31 eV under optimum conditions. The structural features and functional groups capping the nanoparticles were verified using Fourier Transform Infrared Spectroscopy (FTIR). Furthermore, the effective optical cluster dimensions were estimated using the quantum confinement model via the Brus equation, indicating calculated sizes within the range of 10.20–14.42 nm. These findings demonstrate that ketapang leaf extract can serve as an effective bioreducing and stabilizing agent for the environmentally friendly synthesis of ZnO nanoparticles with tunable optical properties.

Keywords: Band Gap Energy; Cluster Size; Green Synthesis; Ketapang Leaves (*Terminalia catappa*); ZnO Nanoparticles.

Introduction

Zinc Oxide (ZnO) nanoparticles are one of the most intensively researched group II-VI semiconductor-based functional materials due to their unique physical and chemical characteristics. This material has a wide band gap energy of 3.37 eV and high exciton energy at room temperature[1], [2]. These superior optical and structural properties make ZnO nanoparticles highly applicable in various technological fields, ranging from optoelectronic devices and gas sensors to antimicrobial agents and cosmetics. The performance characteristics of ZnO nanoparticles are highly dependent on their cluster size, morphology, and crystal structure, which are strictly controlled by methods and parameters during the synthesis process[3].

Conventionally, ZnO nanoparticles are synthesized through physical and chemical methods such as sol-gel, hydrothermal, chemical precipitation, and pyrolysis. Although these methods are capable of producing materials with high crystallinity, their application is often constrained by dependence on toxic chemical precursors, harmful organic solvents, and high thermal energy requirements[2]. As an effort to support the principles of green chemistry, the biosynthesis method or green synthesis using plant extracts has developed rapidly as an environmentally friendly, economical, and sustainable alternative. In the green synthesis system, the active biomolecules from plant extracts double as a reducing agent (bioreducer) as well as a capping

agent that controls particle growth without the need for harmful synthetic chemicals[4].

One of the abundant tropical natural resources that has great potential as a nanoparticle-forming agent is the ketapang leaf (*Terminalia catappa*). Qualitatively, ketapang leaves are known to be rich in secondary metabolite compounds such as phenolics, flavonoids, and tannins[5]. These phytochemicals possess active hydroxyl (-OH) groups that serve as electron donors, facilitating the reduction of Zn^{2+} ions into Zn-containing nuclei, which subsequently transform into ZnO nanoparticles through hydrolysis, condensation, and thermal stabilization processes. Nevertheless, the formation and growth of ZnO nanoparticle clusters are strongly influenced by the reaction environment, including precursor-to-extract ratio and pH, which regulate nucleation rate, crystal growth, and nanoparticle stability. Factors such as the volume ratio between plant extracts (as a natural source of ligands) and metal precursors, as well as the acidity level (pH) of the synthesis system, play a crucial role in determining the nucleation rate and growth of crystals[6].

Changes in the extract-precursor ratio affect the availability of the number of natural stabilizers on the surface of the nanoparticles, while pH variations dramatically alter the surface charge of the biomolecule and modulate the deprotonation rate of the active functional group[7]. This phenomenon will directly shift the optical absorbance, modify the size of the cluster/particle through the quantum confinement effect, and change the optical band gap (E_g)

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of the resulting ZnO. Therefore, systematic investigation of the effects of variations in operating parameters is a key aspect in the engineering of ZnO materials using a green approach [8].

This study aims to perform green synthesis of ZnO nanoparticles using ketapang leaf extract (*Terminalia catappa*) with an emphasis on process parameter control. The phytochemical profile of ketapang leaf extract was first qualitatively tested to confirm the presence of the main bioreducing compounds. While prior literature (2021–2025) has explored plant-mediated synthesis, a critical gap remains in understanding how specific volumetric ratios of *Terminalia catappa* modulate optical band gaps and control cluster growth via quantum confinement effects. To address this, ZnO nanoparticles are synthesized under variations in the ratio of extracts to precursors as well as variations in the pH of the reaction environment. The structural characterization and identification of functional groups interacting with ZnO were analyzed using Fourier Transform Infrared (FTIR) spectroscopy[9]. The optical properties of the material are monitored through the UV-Vis spectrophotometer, where the absorbance data obtained is used specifically to calculate the optical band gap value (E_g) as well as estimate the size of the ZnO nanoparticle cluster at each parameter variation[10].

Research Methods

Preparation of Ketapang Leaf Extract (*Terminalia catappa*)

The procedure for preparing plant extracts refers to the modified method of [11]. A 10-gram powder of ketapang leaves is carefully weighed on an analytical balance and placed in a sterile beaker. Next, up to 100 mL of aqua solvent was added to the beaker. The beaker is tightly sealed using plastic wrap to prevent excessive evaporation. The extraction process is carried out using the infusion method, in which the sample is heated and stirred continuously on a hotplate at 60°C and 1000 rpm for 90 minutes. After the extraction is complete, the mixture is cooled to room temperature and filtered through Whatman No. 1 filter paper. The clear filtrate obtained is stored in a refrigerator at 4°C for use as a bioreducer parent solution in the next stage.

Qualitative Phytochemical Screening of Ketapang Leaf Extract

Qualitative phytochemical screening was carried out on the ketapang leaf filtrate to confirm the presence of secondary metabolites that function as reducing and capping agents. Phenolic compounds and tannins testing was carried out by adding a few drops of 1% iron(III) chloride(FeCl_3) solution to the extract, where the formation of a blackish-green or dark blue color indicated a positive result [5]. Identification of flavonoid compounds is carried out by adding magnesium powder (Mg) and a few drops of concentrated hydrochloric acid (HCl) to the sample; the formation of red or orange color indicates the presence of flavonoids[12].

Green Synthesis of ZnO Nanoparticles

The biosynthesis of ZnO nanoparticles begins with preparing a solution of zinc acetate dihydrate as a precursor with a concentration of 0.1 M[13]. The synthesis process is designed by varying the volume ratio of the 0.1 M zinc acetate solution to the ketapang leaf extract, with a total volume of 60 mL. The volume ratio variations evaluated were 1:1, 1:2, and 1:3, while the volume of Zinc acetate solution was kept fixed [11]. The homogeneous mixture is stirred using a magnetic stirrer at a speed of 1000 rpm at a constant temperature of 60°C for 30 minutes[13]. The colloids synthesized from each variation were monitored using a UV-Vis spectrophotometer in the wavelength range of 200–800 nm to determine the typical maximum absorption spectrum of ZnO nanoparticles. The volume ratio variation that produces the sharpest and highest absorbance peaks is selected to proceed to the pH optimization stage[14].

Structural and Optical Characterization

Structural characterization is carried out to determine the functional groups that interact on the crystal surface and evaluate their crystallinity phases[15]. Crystalline solids were analyzed using FTIR spectroscopy at wavenumbers 4000–400 cm^{-1} to identify the presence of typical Zn-O bonds as well as organic compound residues from plant extracts. The optical properties of the material were evaluated based on UV-Vis absorbance data obtained from the sample prior to calcination[16].

The band gap energy of ZnO nanoparticles is calculated based on the absorbance spectral data using E_g The Tauc Plot method through the following equation approach:

$$(\alpha h\nu)^2 = A(h\nu - E_g)$$

Where is the absorption coefficient, $\alpha h\nu$ is the energy of the photon, and A is the structural constant[6]. Plot of the relationship graph between $(\alpha h\nu)^2$ to the energy of the photon ($h\nu$) created, and extrapolation of a straight line on the part of the curve that is linear towards the exponential axis ($y = 0$) yields the value of E_g [26].

The size of the green synthesized ZnO cluster/particle is estimated from UV-Vis optical parameters using the quantum confinement model approach through the Brus equation[17]:

$$\Delta E_g = E_{g,\text{nano}} - E_{g,\text{bulk}} = \frac{h^2}{8r^2} \left(\frac{1}{m_e^*} + \frac{1}{m_h^*} \right) - \frac{1.8h^2}{4\pi\epsilon_r\epsilon_0 r}$$

Where is the $E_{g,\text{nano}}$ value of the experimental band gap is, $E_{g,\text{bulk}}$ pure ZnO band gap on a large scale (3.37 eV), r represents the radius of the nanoparticle cluster m_e^* and m_h^* is the effective mass of the electron and the hole, respectively, and ϵ_r is the dielectric constant of the semiconductor[18].

Results and Discussion

Qualitative Phytochemical Screening of Ketapang Leaf Extract (*Terminalia catappa*)

Qualitative phytochemical screening tests on water extracts of ketapang leaves (*Terminalia catappa*) were carried out as a first step to identify the presence of

secondary metabolite compounds responsible for the process of metal ion reduction and stabilization of nanoparticles. The results of the qualitative testing are presented in Table 1.

Table 1. Qualitative Phytochemical Test Results of Ketapang Leaf Extract (*Terminalia catappa*)

Metabolite Compounds	Reagents/ Indicators	Results	Changes That Occur
Alkaloid	Dragendorff / Wagner / Meyer	+	Orange/brown hite precipitation
Flavonoid	Mg + HCl pekat	+	Red-brown color
Tanin	FeCl ₃ 1%	+	Blackish green color
Saponin	Uji Pengocokan	+	Stable foam formed
Steroid	Libermann-Burchard	-	Red color (negative)
Triterpenoid	Libermann-Burchard	+	Red-brown color

Based on experimental data, ketapang leaf extract showed strong positive results on the content of alkaloids, flavonoids, tannins, saponins, and triterpenoids. These compounds are known to be abundant in tropical plant biomass and contain active electron donor function groups [4]. Hydroxyl (-OH) groups bound to the aromatic ring structure of flavonoids and phenolics/tannins undergo deprotonation during mixing with metal precursors. This phenomenon facilitates the transfer of electrons to ions, Zn^{2+} reducing them to pure atomic species Zn^0 [3]. Furthermore, the macromolecular structure of saponins and alkaloids envelops the nucleus of the newly growing solid phase, thereby limiting overgrowth through steric hindrance and preventing particle agglomeration.

Qualitative phytochemical screening test on water extract of ketapang leaves (*Terminalia catappa*) is a fundamental stage to map the presence of secondary metabolite compounds that play an active role during the biosynthesis process of materials [19]. Based on the results of experimental tests, data were obtained that ketapang leaf filtrate contained alkaloid compounds which were specifically proven through the formation of orange deposits in the Dragendorff test, brown deposits in the Wagner test, and white deposits in the Meyer test [20]. The existence of the polyphenol compound group is also strongly confirmed, where the addition of magnesium metal reagents and concentrated hydrochloric acid produces a reddish-brown transition that indicates a positive result of flavonoids, while the addition of 1% iron(III) chloride solution triggers the formation of a blackish-green color which is an absolute indicator of the presence of tannin compounds [21]. In addition, qualitative testing by the mechanical shuffling method produced a stable solid foam layer more than one centimeter high, indicating an abundant saponin content [12]. Lipid phase testing using the Libermann-Burchard reaction showed negative results for the steroid compound class because it did not produce purple, blue, or green but remained red, and gave strong positive results for triterpenoid compounds through the appearance of a distinctive reddish-brown color [5].

The presence of functional groups in the various secondary metabolite compounds identified in the ketapang leaf extract plays a vital role in determining the success of the reduction and stabilisation phases during the green synthesis of ZnO nanoparticles. Flavonoid compounds and tannins belonging to the polyphenol macromolecular group act as the main bioreducing agents because they have an abundance of hydroxyl group (-OH) bound to the structure of their aromatic rings. When plant extracts are mixed with a solution of zinc acetate precursor dihydrate at a warm temperature of 60°C, the reaction environment triggers the deprotonation of those hydroxyl groups into highly electron-rich phenoxide ions. These active phenoxide ions immediately donate their free electrons to metal cations. Zn^{2+} , converting into pure atomic clusters, Zn^0 along with the oxidation of polyphenol compounds into quinone or ketone forms. Furthermore, Zn^0 the atoms undergo rapid hydrolysis reactions and secondary thermal transformations by binding dissolved oxygen from the aquabide medium to form a nanometer-scale solid oxide phase of Zinc Oxide (ZnO).

Green Synthesis and Parameter Optimization Using UV-Vis Spectrophotometry

Effect of Comparison Ratio of Precursors and Bioreducers

The initial characterization of ZnO nanoparticle formation was instrumentally monitored through optical absorbance shifts in the wavelength range of 200–800 nm. Absorbance spectra were used to determine the optimal volume ratio between 0.1 M zinc acetate dihydrate and ketapang leaf extract (Table 2).

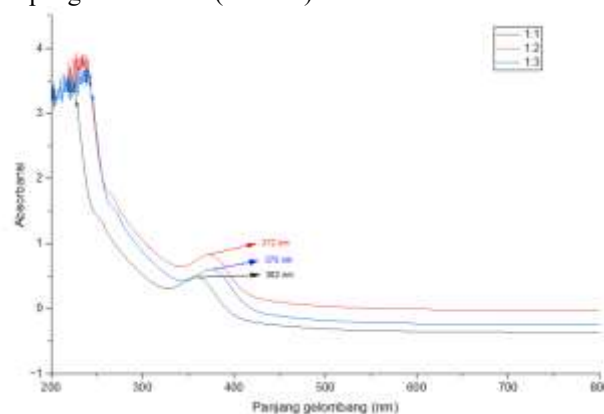


Figure 1. UV-Vis Absorption Spectra of ZnO Nanoparticles Synthesized at Different Precursor-to-Extract Ratios

The increase in the ratio from 1:1 to 1:2 led to a significant increase in absorbance from 0.48 to 0.83. This indicates that the addition of the volume of the extract increases the density of phytochemicals in the system, thereby converting more zinc ions into ZnO nanoparticle phases [22]. However, at a ratio of 1:3, the intensity of absorbance decreases to 0.61, accompanied by a redshift to a wavelength of 375 nm. This decrease in absorbance is due to the saturation condition of the natural ligands of the extract; Excessive volume of extracts reduces the effective concentration of precursor ions Zn^{2+} , thereby limiting the production yield of new clusters and triggering larger

particle growth due to secondary[2]. Therefore, a 1:2 ratio is established as the optimal composition.

Calculation of Band Gap Energy and Cluster Size

Calculation of Ribbon Gap Energy (E_g)

The optical band gap energy of ZnO nanoparticles was determined using the Tauc Plot method for direct-transition semiconductors. The relationship between the absorption coefficient and photon energy is expressed as:

$$\alpha h\nu = A(h\nu - E_g)^{1/2} \Rightarrow (\alpha h\nu)^2 = A(h\nu - E_g)$$
where α is the absorption coefficient, $h\nu$ is the photon energy, A is a proportionality constant, and E_g is the optical band gap energy.

The photon energy was calculated using:

$$h\nu = \frac{1240}{\lambda}$$

The band gap energy was obtained by extrapolating the linear portion of the Tauc Plot curve to the energy axis.

Effect of Precursor-to-Extract Ratio on Band Gap Energy

The calculated band gap energies of ZnO nanoparticles synthesized at different precursor-to-extract ratios are presented in Table 4.6.

Table 2. Band Gap Energy of ZnO Nanoparticles at Different Precursor-to-Extract Ratios

Ratio	λ_{max} (nm)	E_g (eV)
1:1	362	3.43
1:2	372	3.33
1:3	375	3.31

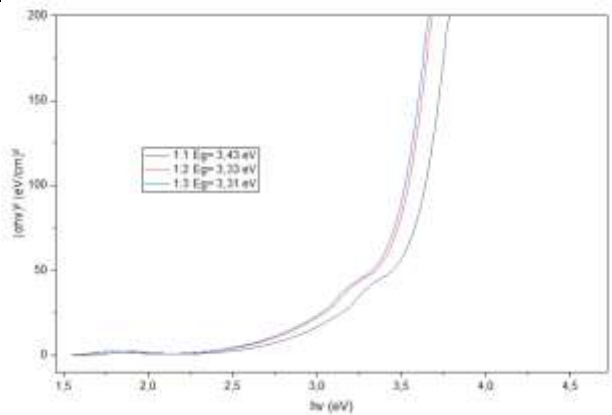


Figure 3. Tauc Plot of ZnO nanoparticles synthesized at different precursor-to-extract ratios

Based on Table 2 and Figure 3, the optical band gap energy decreased from 3.43 eV at a precursor-to-extract ratio of 1:1 to 3.31 eV at a ratio of 1:3. This reduction indicates a red shift of the absorption edge toward lower photon energies. The increased amount of ketapang leaf extract provided a greater concentration of phytochemical compounds, such as flavonoids, phenolics, and tannins, which acted as reducing and stabilizing agents during nanoparticle formation[23].

The presence of these phytochemicals facilitated the reduction of Zn^{2+} ions and promoted the growth of ZnO crystal nuclei, resulting in improved crystallinity and a decrease in band gap energy. Similar observations have been

reported for green-synthesized ZnO nanoparticles, where increasing the concentration of plant extract contributed to modifications in the electronic structure and optical properties of ZnO[24].

The lowest band gap energy was obtained at a ratio of 1:3 (3.31 eV), indicating stronger interaction between ZnO nanoparticles and the phytochemical compounds present in the extract. The obtained values are within the typical range reported for green-synthesized ZnO nanoparticles [25].

Estimated Cluster/Particle Size (r)

The particle size of ZnO nanoparticles was estimated based on the relationship between optical band gap energy and semiconductor particle dimensions described by the quantum confinement model proposed by Brus [17]. In semiconductor nanoparticles, variations in particle size can influence the electronic structure and consequently alter the optical band gap energy. The energy shift of the nanoparticle band gap relative to bulk ZnO can be expressed using the Brus equation:

$$\Delta E_g = E_{g,nano} - E_{g,bulk} = \frac{h^2}{8r^2} \left(\frac{1}{m_e^*} + \frac{1}{m_h^*} \right) - \frac{1.8e^2}{4\pi\epsilon_r\epsilon_0 r}$$

where (r) is the particle radius, (m_e) and (m_h) are the effective masses of the electron and hole, respectively, (ϵ_r) is the relative dielectric constant, and (ϵ_0) is the vacuum permittivity[17].

For practical estimation of ZnO nanoparticle size from UV–Vis data, an empirical simplification based on the band gap energy shift was employed, as commonly applied to semiconductor nanoparticles [25], [26]. The particle diameter (D) was estimated using:

$$D = 2r = \frac{h}{\sqrt{2m^*\Delta E_g}}$$

where D is the particle diameter, h is Planck's constant, m^* is the effective electron mass of ZnO, and ΔE_g is the difference between the band gap energy of bulk ZnO and ZnO nanoparticles. The physical parameters used in the calculation were adopted from Manoranjitham et al. (2025)[26], including an electron effective mass of $m_e^* = 0.24m_0$, a hole effective mass of $m_h^* = 0.59m_0$, and a relative dielectric constant of $\epsilon_r = 8.5$. Particle size estimation was performed based on the difference between the band gap energy of bulk ZnO ($E_{g,bulk} = 3.37$ eV) and the experimentally obtained band gap energy ($E_{g,nano}$).

Since variations in band gap energy are associated with changes in semiconductor particle dimensions, the calculated particle sizes were used to evaluate the effects of precursor-to-extract ratio and pH on the growth behavior of ZnO nanoparticles. The estimated particle sizes obtained in this study were within the nanometer range, indicating that ketapang leaf extract effectively acted as a reducing, stabilizing, and crystal-growth-controlling agent during the green synthesis process, resulting in relatively small and homogeneous ZnO nanoparticles [25].

Table 4. Estimated Particle Size of ZnO Nanoparticles at Different Precursor-to-Extract Ratios

Ratio	λ_{max} (nm)	E_g (eV)	Particle Size (nm)
1:1	362	3.43	10.20
1:2	372	3.33	12.49
1:3	375	3.31	14.42

The estimated particle size of ZnO nanoparticles synthesized at different precursor-to-extract ratios ranged from 10.20 to 12.49 nm (Table 4). Increasing the ratio from 1:1 to 1:2 increased particle size from 10.20 to 12.49 nm, indicating enhanced crystal growth during nanoparticle formation. This phenomenon suggests that the available phytochemical compounds were not yet sufficient to effectively suppress crystal growth. At the 1:3 ratio, the estimated size increased further to 14.42 nm. This observed trend suggests that an increasing volume of plant extract provides an excess of reactive species that accelerates the nucleation and growth rate of the clusters, leading to larger optical domain sizes [27], [28].

Although the smallest estimated size was observed at the 1:1 and 1:3 ratios, the optimum synthesis condition was obtained at the 1:2 ratio due to its highest absorbance intensity in the UV-Vis spectrum. This result indicates a more effective formation of ZnO nanoparticles with a high production yield and was therefore selected for subsequent optimization studies.

The optical band gap energy and particle size showed a general inverse relationship, with lower band gap energies corresponding to larger particle sizes. However, the redshift observed in this study cannot be explained solely by particle-size effects. Crystal defects, oxygen vacancies, zinc interstitials, and interactions between ZnO surfaces and phytochemical compounds from the ketapang leaf extract may also contribute to the reduction of band gap energy [29].

Fourier Transform Infrared Spectroscopy (FTIR) Analysis of ZnO Nanoparticles

Following the optical characterization using UV-Vis spectroscopy, further analysis was conducted using Fourier Transform Infrared Spectroscopy (FTIR) to investigate the chemical functional groups associated with the synthesized ZnO nanoparticles. FTIR characterization provides valuable information regarding the interaction between ZnO nanoparticles and phytochemical constituents originating from the ketapang leaf extract (*Terminalia catappa*) [30]. In green synthesis systems, plant-derived biomolecules not only participate in the reduction of metal ions but also act as stabilizing and capping agents that influence nanoparticle growth and stability [31]. Therefore, FTIR analysis is essential for identifying the functional groups involved in the synthesis process and confirming the formation of Zn-O bonds, a characteristic feature of ZnO nanoparticles. The FTIR spectrum of the synthesized ZnO nanoparticles is presented in Figure 5, while the assignment of the major absorption bands is summarized in Table 6.

Fourier Transform Infrared Spectroscopy (FTIR) analysis was performed to identify the functional groups involved in the green synthesis of ZnO nanoparticles using the ketapang leaf extract (*Terminalia catappa*) [32]. As shown in Figure 8, several characteristic absorption bands were observed, indicating the presence of phytochemical compounds from the extract as well as the Zn-O bond characteristic of ZnO nanoparticles. The assignments of the major absorption bands are summarized in Table 5.

A broad absorption band at 3456 cm^{-1} was assigned to O-H stretching vibrations of phenolic compounds, flavonoids, and tannins, indicating that phytochemical

constituents remained adsorbed on the nanoparticle surface after synthesis. The absorption peak at 1636 cm^{-1} corresponds to C=O stretching and H-O-H bending vibrations, while the bands at 1470 and 1094 cm^{-1} are attributed to C-H bending and C-O stretching vibrations, respectively [33]. These functional groups are commonly associated with polyphenols and other secondary metabolites that can act as reducing and capping agents during nanoparticle formation [27], [34].

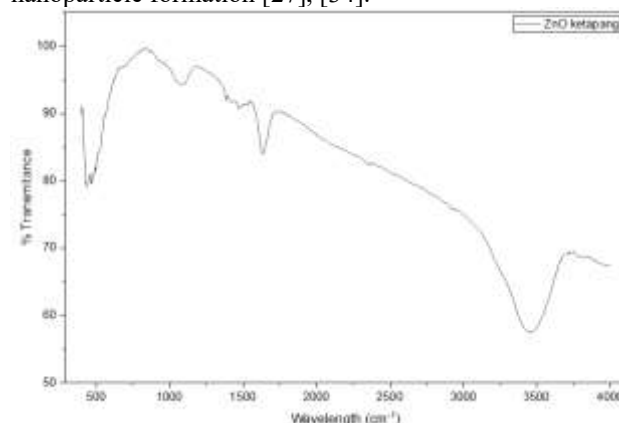


Figure 5. FTIR spectrum of green-synthesized ZnO nanoparticles using ketapang leaf extract (*Terminalia catappa*).

Table 6. Assignment of FTIR absorption bands of ZnO nanoparticles.

Wavenumber (cm^{-1})	Functional Group	Assignment
3456	O-H stretching	Phenolic compounds, flavonoids, tannins
1636	C=O stretching / H-O-H bending	Carbonyl groups and adsorbed water
1470	C-H bending	Aromatic compounds
1094	C-O stretching	Alcohols, ethers, polyphenols
436	Zn-O stretching	Characteristic ZnO bond

The most important absorption band was observed at 436 cm^{-1} , corresponding to the characteristic Zn-O stretching vibration. The appearance of this band confirms the successful formation of ZnO nanoparticles from the zinc acetate precursor, as Zn-O vibrations are typically detected within the range of 400–600 cm^{-1} [28]. The FTIR results are consistent with the UV-Vis analysis and indicate that phytochemical compounds from ketapang leaf extract contributed not only to the reduction of Zn^{2+} ions but also to the stabilization of ZnO nanoparticles through surface capping [35]. Overall, the presence of both organic functional groups and the Zn-O bond confirms the successful green synthesis of ZnO nanoparticles using ketapang leaf extract.

Conclusion

Based on the results obtained in this study, zinc oxide (ZnO) nanoparticles were successfully synthesized through a green synthesis approach using aqueous ketapang leaf

(*Terminalia catappa*) extract as a natural reducing and stabilizing (capping) agent. Qualitative phytochemical screening confirmed the presence of bioactive secondary metabolites, including alkaloids, flavonoids, tannins, saponins, and triterpenoids, which contributed to the reduction of Zn^{2+} ions and the stabilization of the synthesized nanoparticles. The synthesis parameters significantly influenced the optical properties of the ZnO nanoparticles. The optimum synthesis conditions were achieved at a precursor-to-extract ratio of 1:2 resulting in the highest UV–Vis absorbance intensity of 0.90 a.u. at a maximum absorption wavelength (λ_{max}) of 372 nm. Tauc plot analysis revealed an optical band gap energy (E_g) of 3.31 eV, indicating the successful formation of ZnO nanoparticles with favorable optical characteristics. Particle size estimation based on the Brus approach showed that the synthesized ZnO nanoparticles were within the nanometer range, with particle sizes ranging from 10.20 to 14.42 nm. FTIR characterization identified the presence of O–H, C=O, C–H, and C–O functional groups associated with phytochemical compounds from ketapang leaf extract, as well as the characteristic Zn–O stretching vibration at approximately 436 cm^{-1} . These findings demonstrate the viability of using *Terminalia catappa* for designing nanomaterials with tunable band gaps. Future work will expand on these findings by conducting XRD phase analysis and directly evaluating the photocatalytic and antibacterial efficiency of these optimized materials to confirm their practical utility.

Author's Contribution

Y. Qur'aini: Conceptualization, Methodology, Data Collection, and Writing original draft. D. K. Maharani: Supervision, Data Analysis, Validation, and Writing, review, and editing.

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