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Synthesis and characterization of optical properties of barium titanate ($BaTiO_3$) with the addition of moringa, banana, matoa, and ketapang leaves extracts

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ABSTRACT

Environmentally friendly synthesis of barium titanate ($BaTiO_3$) nanoparticles was conducted using natural leaf extracts of *Moringa oleifera*, *Musa spp.*, *Pometia pinnata*, and *Terminalia catappa* as green dopants via the sol-gel method. This study aims to evaluate the influence of different leaf extracts on the optical properties of $BaTiO_3$ characterized by UV-Vis spectroscopy. Each sample exhibited distinct absorption spectra, reflecting variations in phytochemical composition among the extracts. The results showed that *Terminalia catappa* and *Pometia pinnata* extracts produced the highest band gap values, 3.36 eV and 3.35 eV respectively, indicating optical activity in the ultraviolet region. *Musa spp.* extract resulted in a band gap of 2.81 eV, while *Moringa oleifera* extract yielded the lowest value of 2.59 eV. These differences suggest that the type of plant extract significantly affects the optical characteristics of the synthesized $BaTiO_3$. This research highlights the potential use of local biomass in the development of functional $BaTiO_3$-based materials through green synthesis approaches.

Keywords: Band gap; $BaTiO_3$; green synthesis; leaf extract; UV-Vis spectroscopy

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INTRODUCTION

In the modern era, the development of science and technology relies heavily on human ability to engineer materials on a smaller scale, especially at the nanometer level (1 – 100 nm). Within this size range, all properties (chemical, physical, and biological) change fundamentally in both individual atoms/molecules and their masses. New applications of nanoparticles and nanomaterials are growing rapidly in various fields due to their completely new or improved properties based on their size, distribution and morphology. This phenomenon is caused by high surface effects and quantum effects, which result in drastic changes in the conductivity, reactivity, stability and optical properties of the material [1].

One of the inorganic nanoparticles that is widely researched is barium titanate ($BaTiO_3$). Barium titanate ($BaTiO_3$) is an inorganic ceramic material based on a perovskite structure (ABO_3) which has ferroelectric properties at room temperature. This distinctive structure allows the titanium (Ti^{4+}) ion to shift slightly from its symmetrical position in the crystal lattice, generating a spontaneous dipole moment that can be manipulated by an external electric field. In addition, this material also shows good thermal and optical stability, and has a high dielectric constant that can be adapted to the synthesis method and processing conditions [2]. However, conventional $BaTiO_3$ synthesis processes often involve hazardous chemicals and extreme conditions that are not environmentally friendly.

As a solution to this challenge, a green synthesis approach has been developed which utilizes plant extracts as reducing and stabilizing agents in the formation of nanoparticles. This method is considered more economical, safe and environmentally friendly. Leaf extracts contain phytochemical compounds such as flavonoids, polyphenols, tannins and alkaloids which are able to reduce metal ions to nanoforms and at the same time prevent particle agglomeration [3, 4].

In the context of Indonesia which is rich in biodiversity, the use of local plants for nanoparticle synthesis has great potential. Several plants such as Moringa oleifera leaves, banana leaves (*Musa spp.*), matoa leaves (*Pometia pinnata*) and ketapang leaves (*Terminalia catappa*) are known to contain various bioactive compounds. Differences in the composition of these compounds are expected to influence the size, shape and optical properties of the resulting nanoparticles.

To determine the optical characteristics of the synthesized nanoparticles, the UV-Vis (Ultraviolet-Visible Spectroscopy) characterization technique was used. This technique is able to identify typical absorption peaks of nanoparticles, and is used to calculate band gap energy which is closely related to particle size and electronic structure [5].

This research aims to analyze the UV-Vis spectrum characteristics of $BaTiO_3$ nanoparticles synthesized using extracts of Moringa leaves, banana leaves, matoa leaves and Ketapang leaves. By comparing the optical characterization results of each extract, it is hoped that the influence of the phytochemical composition on the performance and quality of $BaTiO_3$ nanoparticles produced in a green way can be determined.

LITERATURE REVIEW

Barium titanate ($BaTiO_3$) is a lead-free ferroelectric material with a perovskite crystal structure. This material exhibits spontaneous polarization properties that can be reversed by an external electric field, making it ideal for use in various electronic applications [6]. As the Curie temperature approaches, the structure of $BaTiO_3$ undergoes a phase transition from cubic to tetragonal, which significantly affects its dielectric and ferroelectric response [7]. The properties of $BaTiO_3$ are strongly influenced by the morphology and particle size, which can be controlled through synthetic methods such as the sol-gel process, resulting in a very homogeneous material at the nanoscale [8]. Doping with La^{3+} has been shown to lower the transition temperature, reduce the crystallite size, and increase the ferroelectric relaxant properties which are relevant to the development of $BaTiO_3$-based materials [9]. In addition, $BaTiO_3$ thin films synthesized on flexible substrates show excellent ferroelectric stability, making them ideal for further characterization through UV-Vis spectroscopy, which can detect optical interactions and electronic structure modifications [10].

The sol-gel method is a wet chemical synthesis technique that allows precise control over the composition and structure of materials at the nanometer scale. This makes it ideal for producing materials such as BaTiO3 with small crystallite sizes and high homogeneity [11]. This process involves the hydrolysis and condensation of metal precursors to form a gel, which is then dried and calcined. In the synthesis of $BaTiO_3$, it has been shown that rapid heating can increase the dielectric constant and reduce surface roughness [12]. Furthermore, the incorporation of complexing agents and natural porogens, such as tannins, facilitates the development of ideal pore structures for applications in optics, sensors, and biomedicine [13, 14].

UV-Vis spectrophotometry is an optical characterization method used to analyze the interaction of light with materials, especially to detect changes in electronic energy due to chemical bonds or particle aggregation [15]. This technique uses a wavelength of 300 – 800 nm to monitor electronic transitions, making it suitable for observing changes in the optical structure of ferroelectric materials $BaTiO_3$ [16].

RESEARCH METHODS

This research begins with the preparation of the tools and materials used. The glass bottle to be used is washed first then sonicated for 5 minutes using Aquades and 5 minutes using alcohol at a temperature of 40°C. Then dried in the oven at 150°C for 30 minutes to remove any impurities that are still attached.

Next, all the chemicals to make the BT (barium titanate) solution are weighed accurately using a digital scale with an accuracy of up to three digits after the decimal point. With a composition of 1.234 grams of Ba powder, 3 drops of Acetyl Aceton as the solvent, stirred for 2 hours and 2 grams of Ti powder with 5 ml of Ethanol + 5 ml of alcohol as the solvent and stirred for 25 hours. Leave the solution for at least one night at a temperature of 4°C to form a gel or clear solution which will be used for the next process.

Next, leaf extract was made as a natural doping agent. In this study, 4 leaf extracts were used, namely moringa leaves (*Moringa oleifera*), banana leaves (*Musa spp.*), matoa leaves (*Pometia pinnata*) and ketapang leaves (*Terminalia catappa*). Old leaves are washed clean, then dried in the oven at 150°C for 30 minutes. The dried leaves are ground using a blender until they become powder. A total of 5 grams of leaf powder was then dissolved in 100 mL of distilled water and heated at 80°C for approximately 10 minutes while stirring, until the solution was brownish in color. The extract is then filtered and stored in the refrigerator to maintain its stability.

For the doping process, the previously prepared leaf extracts were added to the solution and stirred again for 3 hours using a magnetic stirrer until mixed homogeneously. The final solution was stored in a tightly closed glass bottle and ready for the UV-VIS characterization process.

RESULTS AND DISCUSSION

Synthesis Results of $BaTiO_3$ with Moringa Leaves (*Moringa oleifera*)

UV-Vis absorbance spectrum of barium titanate using a UV-Vis Spectrometer at a resolution of 1 nm with a wavelength range of 300-800 nanometers. Figure 1 shows the UV-Vis absorption of $BaTiO_3$ synthesis with Moringa leaf extract.

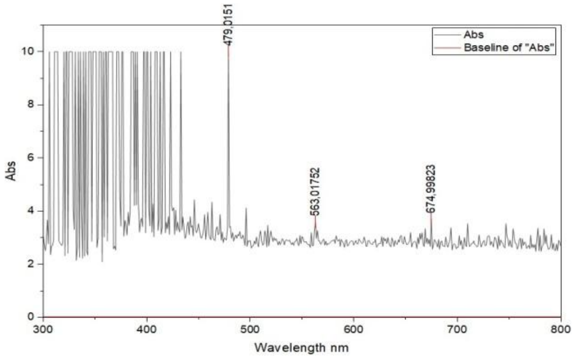

Figure 1. UV-Vis absorbance spectrum of the $BaTiO_3$ compound synthesized using moringa leaf extract.

UV-Vis analysis of the spectrum shown shows a number of important peaks at a number of wavelengths, namely at 479.02 nm, 563.02 nm, and 674.99 nm. The first peak at 479.02 nm shows a high level of absorbance, possibly related to the electronic transition of the molecule in the UV-Vis range, indicating that the target compound interacts with light at that wavelength. The second peak detected at 563.02 nm showed a decrease in absorbance compared to the previous peak, but remained significant enough to indicate the presence of other components in the sample, which could be indicated as dyes or compounds with absorbance in the green color range. The last peak at 674.99 nm shows a lower absorbance level, which is usually associated with the red color group.

Synthesis Results of $BaTiO_3$ with Banana Leaves (*Musa spp.*)

The absorbance spectrum in Figure 2 shows the optical characteristics of the Barium Titanate compound synthesized using the sol-gel method based on banana leaf extract. The highest absorbance peak was detected at a wavelength of around 441 nm with an absorbance intensity of more than 10 a.u., which indicates an electronic transition from the valence band to the conduction band, typical for semiconductor materials. This peak indicates that the barium titanate compound formed has a fairly good crystalline structure and is able to absorb light energy in the UV-Vis spectrum range.

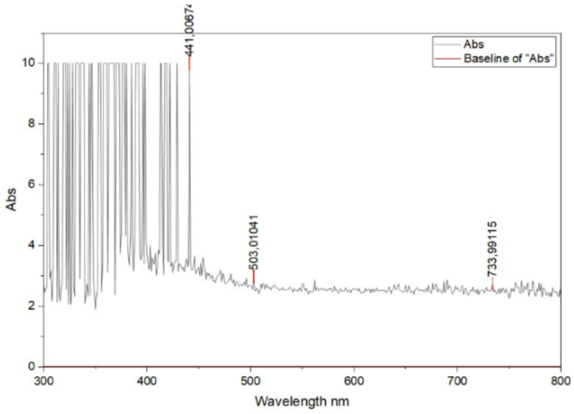

Figure 2. UV-Vis absorbance spectrum of the $BaTiO_3$ compound synthesized using banana leaf extract.

In addition, the spectrum shows a gradual decrease in absorbance after 500 nm, with slight signal interference in the 300 – 450 nm range, possibly caused by the presence of residual organic compounds from banana leaf extract that have not been completely decomposed. The presence of a small absorption at around 733 nm indicates the possible existence of oxygen defects or electron-hole recombination on the material surface.

Synthesis Results of $BaTiO_3$ with Matoa Leaves (*Pometia pinnata*)

Seen in Figure 3, the sample graph shows the results of UV-Vis spectroscopic characterization of the results of the synthesis of BaTiO3 with matoa leaf extract in the wavelength range of 300 – 800 nm. The absorbance curve (Abs) describes the intensity of light absorption by the sample at each wavelength tested.

It can be seen that there is a very significant absorption peak at a wavelength of around 370 nm, with a very high absorbance value, close to 10. This peak is likely the main absorption band of the sample, and can be used to calculate the bandgap energy if necessary.

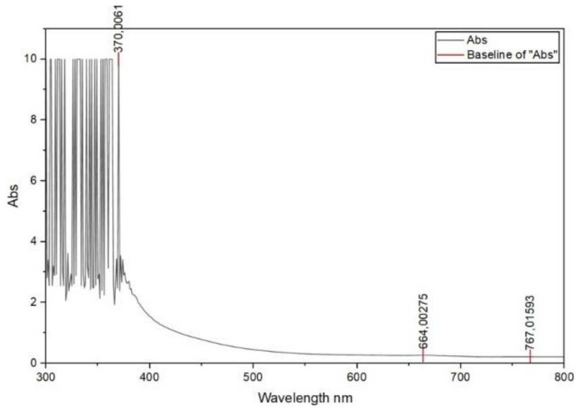

Figure 3. UV-Vis absorbance spectrum of the $BaTiO_3$ compound synthesized using matoa leaf extract.

Apart from that, two other small peaks were also detected at wavelengths of 664 nm and 767 nm, with relatively low absorbance values. These peaks may be related to minor electronic transitions, excitation defects, or the presence of trace compounds or contaminants. The region between 400 – 800 nm shows a sharp decrease in absorbance, indicating that the sample has high transparency in the visible region. This could indicate that the sample has potential applications as an optoelectronic material, such as in solar cells or optical sensors.

Synthesis Results of BaTiO3 with Ketapang Leaves (*Terminalia catappa*)

The UV-Vis absorbance spectrum of the solution resulting from the synthesis of barium titanate using ketapang (Terminalia catappa) leaf extract is shown in Figure 4. Measurements were carried out in the wavelength range 300 – 800 nm using a resolution of 1 nm.

The graphic results show three main absorption peaks at wavelengths of 368.997 nm, 375.007 nm, and 407.981 nm with very high absorbance values of more than 10 absorbance units (a.u). This shows that the synthesized material has a strong ability to absorb light in the ultraviolet region, which indicates a transition of electrons from the valence band to the conduction band, as generally occurs in semiconductor materials.

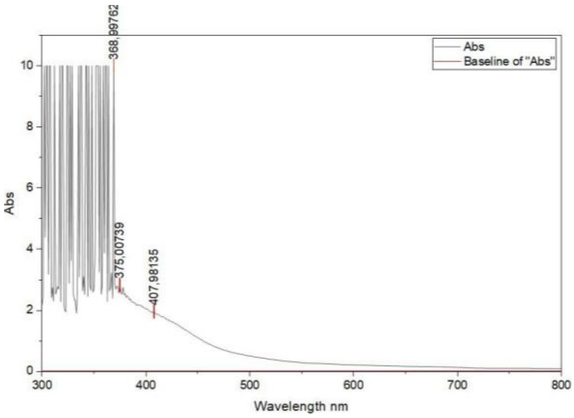

Figure 4. UV-Vis absorbance spectrum of the $BaTiO_3$ compound synthesized using ketapang leaf extract.

Table 1. Band gap energy of the $BaTiO_3$ compound synthesized using green leaf extract.

Sample type	E_{gap} (eV)
$BaTiO_3$ + moringa leaf extract	2.59
$BaTiO_3$ + banana leaf extract	2.81
$BaTiO_3$ + matoa leaf extract	3.35
$BaTiO_3$ + ketapang leaf extract	3.36

After passing a wavelength of 407 nm, the absorbance curve shows a consistent decrease and tends to stabilize towards a wavelength of 800 nm. This decrease in absorbance indicates that the material has a limited optical response outside the UV region. This graph shows that barium titanate synthesized using ketapang leaf extract successfully forms an optically active structure in the UV region.

From the results of the UV-Vis Spectrophotometer Characterization of $BaTiO_3$ with green leaf extract which has been explained, the band gap energy results can be shown in Table 1. Ketapang and matoa leaf extracts produce the largest band gap (± 3.35 – 3.36 eV), indicating optical activity in the UV region making them suitable for applications such as UV sensors or photocatalysts. Banana leaves produce a medium band gap (± 2.81 eV), absorbing light in the violet to blue region. Meanwhile, Moringa leaves have the smallest band gap (± 2.59 eV), allowing wide absorption of visible light and potentially being used in solar cells or photodetectors.

CONCLUSION

This research succeeded in synthesizing and characterizing barium titanate ($BaTiO_3$) material using the sol-gel method with the addition of moringa leaf extract, banana leaves, matoa leaves and ketapang leaves as natural doping agents. The main aim is to observe the influence of the phytochemicals of each extract on the optical properties of the resulting material. The UV-Vis characterization results show that each extract produces different light absorption spectra and band gap values. Ketapang and matoa leaf extracts produced the highest band gaps of around 3.36 eV and 3.35 eV, indicating optical activity in the UV region and potential application in UV sensors or photocatalysts. Banana leaves have a moderate band gap (2.81 eV), while moringa leaves show the lowest band gap (2.59 eV), allowing light absorption in the visible region, making them potential candidates for solar cell or photodetector applications. Thus, the use of leaf extract as a green agent in the synthesis of $BaTiO_3$ is proven not only to be environmentally friendly but also to significantly influence the optical characteristics of the material.

REFERENCES

1. Ahmed, S., Ahmad, M., Swami, B. L., & Ikram, S. (2016). A review on plants extract mediated synthesis of silver nanoparticles for antimicrobial applications: A green expertise. *Journal of Advanced Research*, **7**(1), 17–28.
2. Wodecka-Duś, B., Dziwoki, T., Wójcik, A., Dziubek, K., Adamus-Włodarczyk, A., Jaskólski, D., & Lenartowicz-Klik, M. (2020). *Mechanochemical Synthesis of $BaTiO_3$ Powders and Evaluation of Their Acrylic Dispersions*. **13**(15), 3275.
3. Singh, J., Dutta, T., Kim, K.-H., Rawat, M., Samddar, P., & Kumar, P. (2018).

'Green' synthesis of metals and their oxide nanoparticles: Applications for environmental remediation. *Journal of Nanobiotechnology*, **16**(84).

4. Sharma, V. K., Yngard, R. A., & Lin, Y. (2009). Silver nanoparticles: Green synthesis and their antimicrobial activities. *Advances in Colloid and Interface Science*, **145**(1–2), 83–96.
5. Manoj, D., & Santhosh, P. (2021). UV–Vis spectroscopic analysis of synthesized ZnO nanoparticles using banana peel extract. *Materials Todasy: Proceedings*, **43**, 2647–2651.
6. Azuma, H., Ogawa, T., Ogata, S., Kobayashi, R., Uranagase, M., Tsuzuki, T., & Wendler, F. (2025). Unique temperature-dependence of polarization switching paths in ferroelectric $BaTiO_3$: A molecular dynamics simulation study. *Acta Materialia*, **296**, 121216.
7. Carroll, E. L., Killeen, J. H., Feteira, A., Dean, J. S., & Sinclair, D. C. (2025). Influence of electrode contact arrangements on polarisation-electric field measurements of ferroelectric ceramics: A case study of $BaTiO_3$. *Journal of Materiomics*, **11**, 100939.
8. Ouyang, J., Xue, Y., Yuan, M., Song, C., Wang, K., Zhao, Y., Cheng, H., Zhu, H., & Liu, C. (2025). Resolving nanograin morphology and sub-grain nanodomains via scanning probe acoustic microscopy in high energy density $BaTiO_3$ ferroelectric films. *Journal of Materiomics*, **11**, 100893.
9. Moutaouaffiq, A., Belhajji, M., Didi Seddik, A., Tahiri, A., Ali, E., Hajji, L., Rjeb, A., Paramasivam, P., Ghoneim, S. S. M., & Abou Sharaf, A. B. (2025). Lanthanum-doped $BaTiO_3$ ceramics: Structural, dielectric, and ferroelectric properties. *Results in Engineering*, **25**, 104466.
10. Liu, X., Wei, C., Sun, T., Zhang, F., Li, H., Liu, L., Peng, Y., Li, H., & Hong, M. (2025). A $BaTiO_3$-based flexible ferroelectric capacitor for non-volatile memories. *Journal of Materiomics*, **11**, 100870.
11. Paalo, M., Yegit, S. S., Moumaneix, L., Kallio, T., & Janes, A. (2025). Synthesis of zirconium carbide via sol-gel method as a precursor for micro- and mesoporous carbide-derived carbon materials. *Carbon Trends*, **19**, 100494.
12. Liu, Y., Li, S., Gallucci, F., & Rebrov, E. V. (2024). Sol-gel synthesis of tetragonal $BaTiO_3$ thin films under fast heating. *Applied Surface Science*, **661**, 160086.
13. Arzani, F. A., Pechina, B., & dos Santos, J. H. Z. (2025). Tannin as a porogenic agent in the synthesis of silica by an acid-catalyzed sol-gel process. *Results in Surfaces and Interfaces*, **20**, 100561.
14. Lincuna, J. R. S., Ueda, K., & Narushima, T. (2025). Citric acid-assisted sol–gel synthesis of highly reactive borate-based bioactive glass powders. *Journal of Non-Crystalline Solids*, **666**, 123637.
15. Guo, Y., Han, Z., Zhang, J., Lu, Y., Li, C., & Liu, G. (2024). Development of a high-speed and ultrasensitive UV/Vis-CM for detecting total triterpenes in traditional Chinese medicine and its application. *Heliyon*, **10**, 32239.
16. Berasarte, I., Bordagaray, A., Garcia-Arrona, R., Ostra, M., & Vidal, M. (2025). Silver nanoparticles for the colorimetric determination of electrolytes by UV–vis spectrophotometry and digital image analysis. *Sensing and Bio-Sensing Research*, **49**, 100831.