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Carbon Nanomaterial from Watermelon Skin Waste for Parallel Plate Capacitor Dielectric Material

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Abstract: Watermelon skin waste, typically underutilized, holds potential as an eco-friendly and efficient carbon nanomaterial for parallel-plate capacitor dielectric filler. The need for efficient and environmentally friendly dielectric materials drives the exploration of alternative resources. This study examines the potential of watermelon rind waste to be converted into promising carbon nanomaterials as dielectric materials in parallel plate capacitors, potentially overcoming challenges in the development of energy storage devices. This study synthesizes carbon nanomaterials from watermelon skin waste and evaluates their role as filler on the capacitance of the parallel-plate capacitor. Carbonization techniques of Two-Steps Low Heating (TSLH) method were employed with characterizations via PSA, XRD, and UV-Vis revealing nanoparticle properties, amorphous patterns, and UV absorption peaks. Capacitance testing using an LCR meter demonstrated significant capacitance enhancement, reaching a maximum capacitance of 63 μF with a five-layer carbon-based dielectric material modification using HCl solution. These findings suggest watermelon skin-derived carbon nanomaterials as a viable eco-friendly alternative for energy storage, supporting sustainability, and waste management.

Keywords: Carbon nanomaterials; Dielectric material; Parallel-plate capacitors; Watermelon skin waste

Introduction

The availability of watermelon plants in Indonesia is very abundant because they are suitable for the climate and can be planted at all altitudes, but will grow and develop well in the lowlands with temperatures of 23-28 °C (Gray & Brady, 2016). Some people only use watermelon flesh and the skin becomes unused waste material. Watermelon skins, as one of the abundant agricultural wastes, are often not utilized optimally and have the potential to become a source of pollution if left to rot or burned. Providing energy in the future is an issue that is of constant concern to all nations because human welfare in modern life is closely related to the amount and quality of energy utilized (Zeng et al., 2024; Nguyen et al., 2023). For Indonesia, which is a developing country, the supply of energy, especially electrical energy, is a very important factor in encouraging development (Tumimomor & Palilingan, 2018; Sambodo et al., 2024; Surya et al., 2021). With the increasing development of electronic and bioelectronic technology, the conversion and storage of electrical energy is recognized as an important part. Carbon materials have opened up new opportunities for efficient energy conversion and storage, especially biofuel cells (BFCs) and supercapacitors (Tawalbeh et al., 2022; Zhang et al., 2025). Carbon and its various allotropes have been the key to this technology, because their chemical and electronic properties have long been

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developed to accelerate this development (Jeerapan & Ma, 2019; Kumar et al., 2025; Wang et al., 2022).

Watermelon skin waste-based carbon nanomaterials have great potential for application in parallel-plate capacitor systems, which are important components in energy storage technology (Tiwari et al., 2022; Orasugh et al., 2024). One of the important parameters in a capacitor is its capacitance, which influences the capacitor's ability to store electrical energy (Zhu et al., 2011; Yusnidah, 2023; Keshyagol et al., 2023). The process of converting watermelon skin wastes into carbon nanomaterials involves carbonization techniques that produce unique carbon nanostructures, such as graphene (Rodoshi Khan et al., 2024; Kang et al., 2020) and carbon nanotubes, which have extraordinary properties in increasing the electrical conductivity and mechanical properties of the material (Al-Saleh, 2015; Liu et al., 2025).

This article aims to explore the potential of watermelon skin-based carbon nanomaterials in increasing the capacitance of parallel-plate capacitors. The method utilized in the carbon nanomaterial preparation is the two-steps low heating (TSLH) technique. In this case, we use the heating process of oven and microwave. By utilizing organic waste effectively, this research is expected to make a significant contribution to the development of more efficient and environmentally friendly energy storage technology.

Method

The materials used in this research were watermelon skin wastes, 0.5 mol HCl, distilled water, pipette, digital scale, aluminum plate, LCR measuring device, scissors, plastic, brush, Pyrex beaker glass, spatula, aluminum foil, filter paper, and tissue. Some of the materials can be observed in Figure 1. The watermelon skin wastes were cut into pieces and then weighed and dried in the sun for 3 days to remove the water content (Du & Ramirez, 2022). Next, the dried watermelon skin wastes were weighed. After that, they were dried at 100 °C in the oven for 2 hours to further remove the water content. Next, the carbonized watermelon skin wastes were weighed again to see the reduction in water content. After that, they were gradually pounded until smooth using a mortar. The carbon powder was then soaked using 500 ml of distilled water for 2 days. Next, the powder was filtered using filter papers. After filtering, 50 ml of the solution was microwaved at 150 °C for 15 minutes. After being microwaved, the solution became crusts and these crusts were used for the next experiment.

The powder that has been made into carbon nanomaterials was then characterized using particle size analyzer (PSA) Microtrac Nanotrac Wave II, X-ray diffraction (XRD) Rigaku Miniflex 600, and ultraviolet-visible (UV-Vis) Shimadzu 2450 spectrophotometer. The PSA, XRD, and UV-Vis tests were used to determine the size distribution, crystallinity, and absorption of the carbon nanomaterials produced, respectively. XRD testing was used to determine the crystallinity of a material. In this test, the X-ray source commonly used is Cu-kα with a wavelength (λ) of around 0.15418 Å. The range typically used in XRD testing was from 2° to 80°. Next, add 2 drops of distilled water to dilute the crust. The diluted crusts were applied evenly to two aluminum plates of the same size. These aluminum plates function as electrodes in the parallel-plate capacitor system. The capacitor consisting of two aluminum plates with a layer of carbon nanomaterial was measured using a HoldPeak brand LCR meter to determine the initial capacitance value. The measurement result showed a value of 0.75 μF.

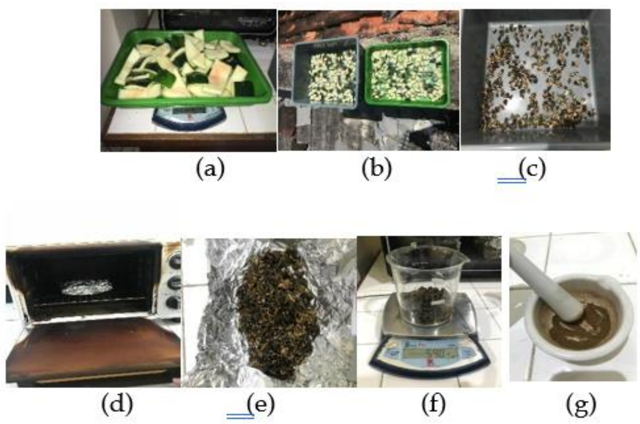

Figure 1. Preparing the carbon nanomaterials from watermelon skin waste, i.e.: weighing the watermelon skin wastes (a); drying the watermelon skin wastes (b); the dried watermelon skin wastes (c); heating the wastes in the oven (d); the wastes after oven heating (e); weighing again the wastes (f); and pounding the wastes into powder (g)

Next, an insulating layer in the form of a tissue paper was added to the surface of the aluminum plate, which has been coated with carbon nanomaterial. This tissue paper had been moistened with 10 drops of hydrochloric acid (HCl) solution as an electrolyte medium to increase the interaction between the carbon nanomaterial layer and the electrodes. After the tissue paper layer was applied, the capacitor system was measured again using an LCR meter to evaluate changes in capacitance values that occurred due to the addition of the layer and the presence of the HCl solution. This procedure was designed to test the capacitance of the parallel-plate capacitor system through modifying the structure of the dielectric layer and its interaction with the electrolyte solution. The capacitance measurement may be observed in Figure 2.

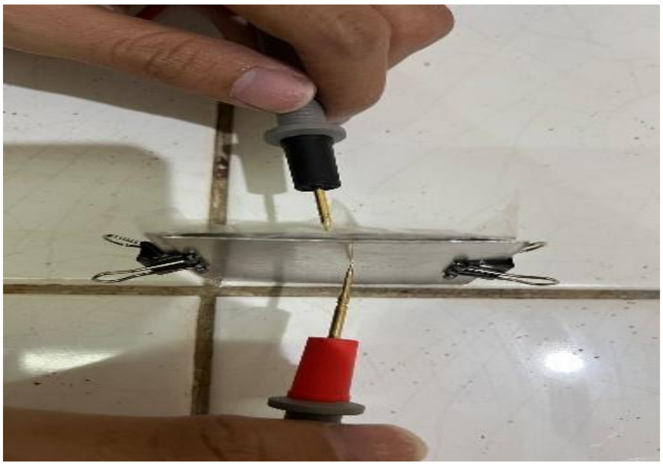

Figure 2. Parallel-plate capacitor capacitance measurement

Results and Discussion

The carbon nanomaterials obtained in this research can be seen in Figure 3. It can be observed in Figure 3 that the carbon nanomaterials produced is blackish in color. Texturally, the carbon nanomaterials produced are in the form of smooth and dense caramel. To determine the characteristics of the carbon nanomaterials produced, various tests are carried out, including using PSA, XRD, and UV-Vis.

Figure 3. The carbon nanomaterials produced

From Figure 4, the PSA characterization results show that the carbon nanomaterials made from watermelon skin wastes has a particle size of 370 nm, 559 nm, and 1517 nm with volumes of 24.8%, 66.5%, and 8.7%, respectively. There are two curves in Figure 4, i.e.: one (in orange) depicts the cumulative distribution of particles (% passing), and the other (in green) shows the relative distribution (%channel). The orange curve shows that almost all of the carbon nanomaterial particles have sizes below 1000 nm, where the curve reaches a plateau point (approaching 100% passing) at 2000 nm. This indicates that the maximum size of particles in the sample is less than 2000 nm. The green curve shows the intensity distribution of the particle sizes, which indicates the dominant particle size below 1000 nm with small intensity fluctuations. This kind of distribution is generally found in the analysis of nanoparticle materials or dispersed substances (Steinhart, 2004; Khan et al., 2019).

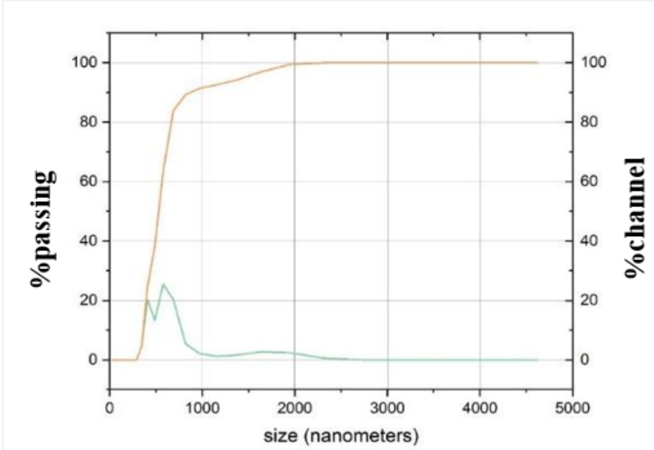

Figure 4. Particle size distribution of the carbon nanomaterials

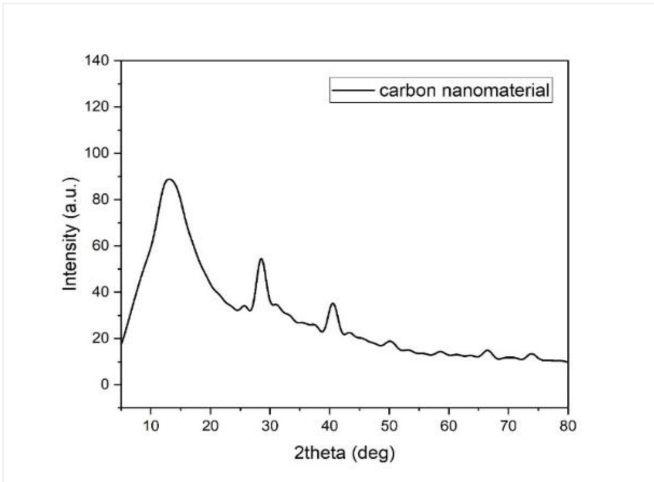

Figure 5. The diffraction pattern of the carbon nanomaterials

The result of the XRD test on the carbon nanomaterial sample consists of the scattering angle (2θ) and intensity (I). Details of this characterization result can be seen in Figure 5. This diffractogram shows that there are several broad peaks detected at various diffraction angles (Bastida & Pardo-Ibañez, 2024). The XRD characterization result shows that the synthesized carbon nanomaterials are amorphous with the highest peak at around 10-15°. The amorphous nature of the carbon nanomaterials is evident from the absence of sharp and distinct peaks in the diffractogram (Budiman et al., 2024; Theodorakopoulos et al., 2024). This means that the distance between atoms in the sample has an irregular pattern and tends to be random. Carbon nanomaterials with diffraction patterns similar to this are often used in energy storage applications, such as supercapacitors, sensors, and catalysts, where the combination of amorphous and crystalline structures provides the desired properties (Mokhena et al., 2024). Partial crystallinity allows for better electrical conductivity, while the amorphous nature helps faster ion diffusion in the electrochemical applications (Puthusseri et al., 2014). Moreover, the diffraction pattern also shows the presence of graphitic domains. This structure allows the material to have high dielectric properties, making it very suitable for energy storage applications. In addition, the use of watermelon skin waste as a basic material strengthens the potential of this material as an environmentally friendly alternative to energy storage devices (Pesode et al., 2023).

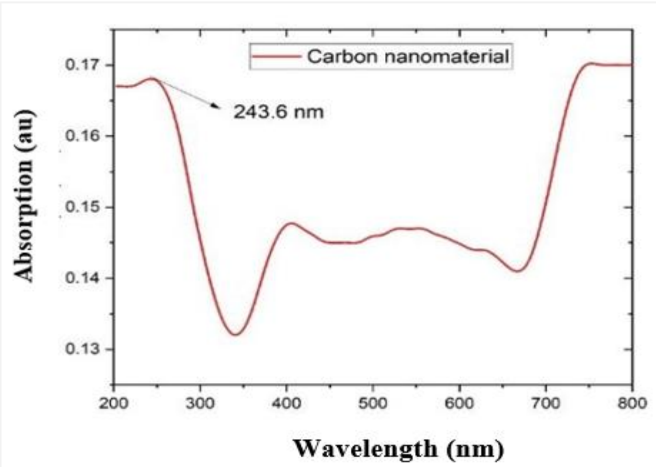

Figure 6. The absorption spectrum of the carbon nanomaterials

Finally, the UV-Vis spectrophotometer is used to measure the UV-Vis absorption of a material. Usually, the absorption of carbon nanomaterials is observed in the wavelength range of 200-800 nm showing transitions from the core ($\pi \rightarrow \pi^*$) dan surface state ($n \rightarrow \pi^*$). The absorption spectrum of the carbon nanomaterials in Figure 6 shows several absorption peaks. The highest peak is at a wavelength of 243.6 nm, which is in the UV range, namely 200 - 400 nm. Apart from that, the higher the absorption value, the more carbon nanomaterials are formed in the sample. Based on the UV-Vis characterization result, the carbon nanomaterial produces one absorption peak in the UV range. This is in accordance with research by Bazaka et al. (2016), which shows that the absorption spectrum of carbon is in the wavelength range of 200 - 800 nm.

The capacitance measurement results of the parallel-plate capacitor system using carbon nanomaterial from watermelon skin wastes as the dielectric filler is shown in Figure 7. The graph shows the relationship between the number of tissue layers and the resulting capacitance value. The quadratic regression equation obtained is $y = 1.97x^2 + 2.23x + 2.48$ with determination coefficient (R^2) of 0.99. There is a very good correlation between the variation of the number of tissue layers and the increase in capacitance value. The R^2 of 0.99 shows that almost all of the variation in the capacitance data could be explained by the regression model. This indicates the validity of the experimental data and the consistency of the number of tissue used on the capacitor system (Yudaev et al., 2023; Olsommer & Ihmig, 2020). From the data, the capacitance value increases with increasing number of tissue layers. The quadratic equation of the capacitance increase shows a significant influence of the material utilized, including the ability to store higher electrical charges due to interactions between layers of the carbon nanomaterials.

The significant increase in capacitance at certain number of tissue layers indicates that the carbon nanomaterials have excellent and consistent dielectric properties. The ability of the carbon nanomaterials to form structures with a high surface area and optimal interaction with the HCl-dropped tissue paper increases the effectiveness of the energy storage.

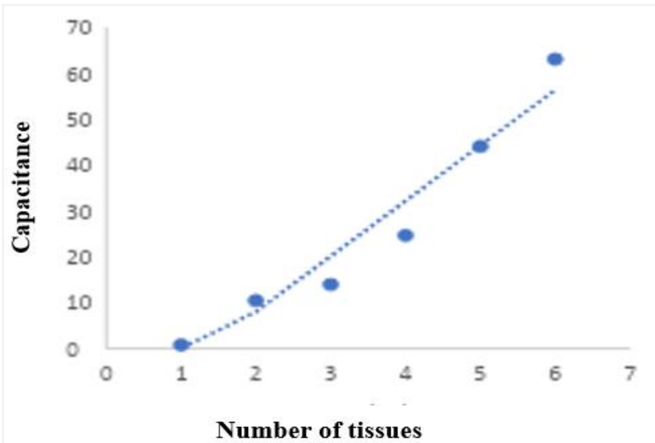

Figure 7. Capacitance measurement results

The performance of the parallel-plate capacitor using carbon nanomaterials from watermelon skin wastes is supported by the nanomaterials' unique properties, including relatively high electrical conductivity, thermal stability, and the capacity to store charge in an electric field. The carbon nanomaterials significantly increase the dielectric constant of the capacitor, allowing more efficient energy storage than conventional materials (Lakshmi & Vedhanarayanan, 2023). This demonstrates its ability to replace metal-based or synthetic polymer materials, which are often expensive and less environmentally friendly (Jiang et al., 2023). This research not only identifies watermelon skin wastes-based carbon nanomaterials as an innovative material for increasing the dielectric constant of capacitors, but also paves the way for the application of other environmentally friendly materials in the energy storage sector (Robinson et al., 2022; Ahmed et al., 2024). Utilizing watermelon skin wastes as the raw material support sustainability and low cost, which is relevant for future energy needs (Lee et al., 2024; Sharma et al., 2022). By using appropriate technology, carbon compounds can be produced more environmentally friendly and also renewable (Wenten et al., 2024). Hence, carbon nanomaterials from watermelon skin wastes provide an important contribution to dielectric material innovation in capacitor technology (Khaled et al., 2015).

Conclusion

The conclusion from these results is that carbon nanomaterials based on watermelon skin wastes are able to significantly improve the performance of parallel-plate capacitors. This shows the material's potential as an environmentally friendly alternative for energy storage applications. Further studies are needed to optimize the performance of this material and expand its use in other energy storage device applications. Furthermore, more characterizations of the carbon nanomaterials can also be conducted in future studies, especially using imaging techniques, such as scanning electron microscope (SEM) and high resolution-transmission electron microscope (HR-TEM).

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Author Contributions
Conceptualization, E.A.R.B., N.H.M., Y.I.D., and S.; methodology, E.A.R.B., N.H.M, Y.I.D, and W.S.B.D; software, E.A.R.B., N.H.M., and Y.I.D; validation, S. and W.S.B.D; formal analysis, E.A.R.B, N.H.M., and Y.I.D; investigation, E.A.R.B, N.H.M, and Y.I.D; resources, S. and W.S.B.D; data curation, E.A.R.B., N.H.M., and Y.ID; writing—original draft preparation, E.A.R.B., N.H.M., and Y.I.D.; writing—review and editing, E.A.R.B., and W.S.B.D; supervision, S. and W.S.B.D; project administration, E.A.R.B.

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Conflicts of Interest
The authors declare no conflict of interest.

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