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Innovative application of marine biomaterials in microwave and antenna technologies: The study of *Monodonta turbinata*

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A B S T R A C T

This study investigates to use electromagnetic properties of *Monodonta turbinata* shells as a sustainable biomaterial for microwave and antenna applications. Shells were collected from Iskenderun Bay, Türkiye, and processed by washing, drying, and grinding to obtain fine powders. These powders were calcined at 800°C, 1000°C and 1200°C to produce samples. The calcined powders were then analyzed for their complex dielectric properties within the 1 GHz to 20 GHz frequency range. The dielectric measurements revealed significant changes in the electromagnetic properties with varying calcination temperatures, highlighting the potential of *M. turbinata* shells as tunable dielectric materials. The materials were further used as substrates in traditional patch antenna simulations. The results showed excellent behavior in terms of the S11 parameter, with a notably wider bandwidth compared to conventional dielectric substrates (i.e. FR-4 and RT-5880). These findings demonstrate the feasibility of using *M. turbinata* shells as eco-friendly and cost-effective materials for advanced microwave and antenna technologies. The study not only suggests a novel application of marine biomaterials but also provides insights into the potential of sustainable alternatives in the development of broadband communication systems.

INTRODUCTION

Monodonta turbinata, a marine gastropod, is widely distributed across the rocky intertidal zones of the Mediterranean Basin, including the Aegean, Tyrrhenian, Ionian, Adriatic, and Cretan Seas (Alyakrinskaya, 2010; Conti et al., 2006). This species thrives in challenging environments, exhibiting remarkable resilience to extreme conditions such as prolonged drought, high temperatures, wave impacts, and water pollution (Conti et al., 2006). *M. turbinata* primarily feeds on algae and plant residues scraped from rocks, playing a critical ecological role in maintaining the balance of marine ecosystems (Alyakrinskaya, 2010). Its shell, composed predominantly of calcium carbonate ($CaCO_3$) in aragonite form, exhibits a natural hierarchical structure that enhances its mechanical strength and durability, making it an attractive candidate for engineering and material science applications.

Till date, studies on *M. turbinata* have primarily focused on biological and ecological aspects, including its role as a bioindicator of heavy metal pollution, nutritional properties, chitin and chitosan production from shells and population dynamics (Uğurlu, 2024; Duysak and Ersoy, 2014; Alyakrinskaya, 2010; Boucetta et al., 2008; Conti et al., 2017, 2006; Belhaouari and Boutiba, 2009). Despite its abundance along Mediterranean coasts, particularly in Iskenderun Bay, and its lack of economic significance, limited attention has been given to its potential as a biomaterial for advanced technological applications. The exploration of marine shells as functional materials has gained traction in recent years, with particular emphasis on their electromagnetic properties. For example, Alyakrinskaya (2010) noted that the compositional uniformity and resilience of gastropod shells make them promising candidates for industrial applications such as bone implants, cement additivies, catalysts and adsorbents.

Recent studies have demonstrated the potential of marine biomaterials for electromagnetic and microwave technologies. Uğurlu et al. (2023) investigated the dielectric properties of *Diadema setosum* shells, demonstrating their suitability as substrate layer for microwave and radome applications. Their work highlighted how thermal treatment processes could optimize the dielectric behavior of such shells, paving the way for their use in high-frequency systems. Similarly, Raman et al. (2023) used biomaterials for microwave applications by using Arecanut palm leaf. These studies underscore the growing interest in natural biomaterials for electromagnetic applications, driven by their eco-friendliness, cost-effectiveness and tunable properties.

The dielectric properties of marine biomaterials have been a focal point in advancing wireless communication technologies (Kaidarova et al., 2023). For example, Wang et al. (2022) studied the marine polysaccharide-based electromagnetic absorbing and shielding materials and its design principles. Bedi et al. (2022) explored biosensor fabrication which is marine biological macromolecules as matrix material. Moreover, Sun et al. (2022) explored the enhancement of triboelectric performance in chitosan-based materials. showing their potential in environmentally friendly and wearable triboelectric nanogenerators for multi-modal sensing applications (i.e including motion, pressure, and humidity detection). Sahin et al. (2023) demonstrated that polyaniline based composites with different Cu contents exhibit high microwave shielding effectiveness in the 0-8 GHz range, and this effectiveness can be adjusted by varying the amount of polyaniline. Wang et al. (2025) have analyzed a novel carbothermal shock method for synthesizing carbon-supported nanoscale high-entropy alloys, achieving efficient electromagnetic wave absorption through tailored electron migration modes, anisotropic dipole polarization, and ultra-thin composite designs. Rupčić et al. (2024) evaluated the electromagnetic radiation absorption efficiency of biomaterial-based harvest residues, revealing that factors like thickness, moisture, and frequency significantly influence transmission reduction, with soybean straw achieving a maximum attenuation of 43.80 dB at 4.93 GHz.

The aim of the study wasto bridge the literatüre gap by investigating the electromagnetic properties of *Monodonta turbinata* shells and their applications in microwave and antenna technologies. *M. turbinata* shells were chosen due to their natural abundance, biocompatibility, and unique microstructure, which creates for tunable dielectric behavior when subjected to different calcination temperatures. Unlike conventional materials such as FR-4 and RT-5880, *M. turbinata* shells offer a sustainable and cost-effective alternative with promising electromagnetic performance across a wide frequency range. By analyzing their dielectric properties and integrating them as substrates in microwave equipment, this study explores their feasibility for high frequency systems. The findings not only contribute to the development of eco-friendly materials for advanced communication systems but also provide a new perspective on the utilization of marine biomaterials in engineering applications. This work represents a significant step toward the broader adoption of renewable biomaterials in modern electromagnetic technologies.

MATERIAL AND METHODS

Monodonta turbinata, a marine biomaterial, was collected from the rocky coastal areas of Iskenderun Bay, Türkiye, using a sharp knife to carefully extract the shells from the marine environment. This area was chosen due to its rich biodiversity and the availability of shells suitable for this study. Once the shells were collected, the soft tissues inside were removed manually to ensure that only the shell material was used in subsequent processes. The cleaned shells were then subjected to a two-step washing procedure. Initially, they were washed with tap water to remove any surface debris and salts. Following this, the shells were further washed with bidistilled water to eliminate any remaining contaminants, ensuring the purity of the material for further analysis.

After the washing procedure, the shells were dried in an oven set to 70°C for 24 h. This drying step is crucial to reduce the moisture content of the shells and prepare them for grinding, as excess moisture could affect the subsequent processing and analysis. Once completely dried, the shells were ground into a fine powder using a grinder, making them suitable for various material characterizations, including electromagnetic testing. The powdered shells were then stored at +4°C in sealed containers until further analysis, ensuring that they remained stable and uncontaminated during storage (Figure 1).

Following the methodology adapted from Park et al. (2007), the dried *M. turbinata* shell powders were calcined at three different temperatures to evaluate the effect of thermal treatment on their properties. The calcination process was performed in a muffle furnace (Protherm-Furnaces) with a precise heating rate of 5°C/min. The powders were calcined at temperatures of 800°C, 1000°C and 1200°C for 1 h. These temperatures were selected to explore the impact of different calcination conditions on the electromagnetic properties of the shell material. The choice of calcination temperatures was based on previous studies and theoretical models suggesting that higher temperatures would lead to enhanced crystallization and potentially improve the material's dielectric properties (Figure 1).

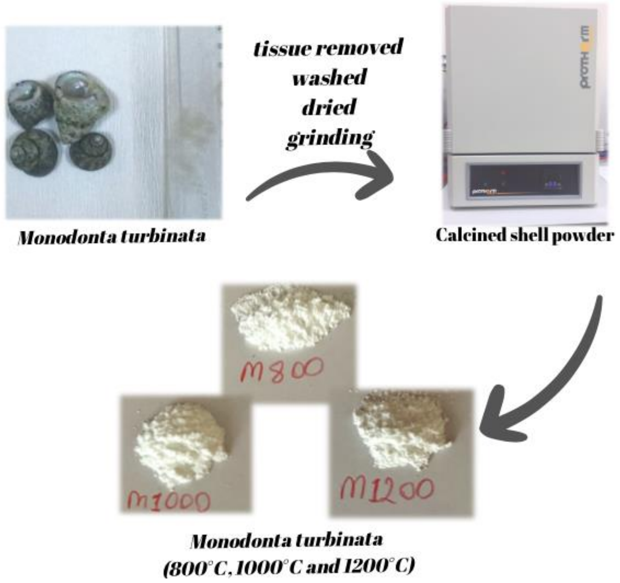

Figure 1. Calcination process in *M. turbinata* shells

Once calcined, the shell powders were carefully stored in a desiccator to maintain their dryness and prevent any absorption of moisture from the air, which could alter their dielectric characteristics. Each batch of calcined material was labeled according to its treatment temperature: M1 for the 800°C sample, M2 for the 1000°C sample, and M3 for the 1200°C sample. The labeled powders were then transferred to sealed falcon tubes, ensuring they remained isolated from environmental factors and ready for the next phase of the study. These samples were prepared specifically for use in experiments designed to measure their complex dielectric properties in microwave analysis. After completing the preparation steps, the samples underwent detailed microwave testing to investigate their electromagnetic behavior, forming the core of the study.

Microwave Analysis

In the microwave analyses, precise calibration was performed to ensure accurate measurements of the complex dielectric parameters of the materials under test (MUT). This calibration process is essential for minimizing measurement errors and ensuring reliable data. The setup used for these measurements is shown in Figure 2.a, where a dielectric probe is used to measure both the real and imaginary parts of the material's dielectric characteristics over the frequency range of 1 GHz to 20 GHz. This dielectric probe is specifically designed for use with a variety of materials, including liquids, semi-liquids, and powders, which enables a comprehensive characterization of their electromagnetic properties. Figure 2.b illustrates the first step of the calibration process, where measurements are in an open-air condition. This step provides a reference data by using for environmental factors that could influence the accuracy of the measurement. Moreover, Figure 2.c shows the use of a shorting probe as part of the calibration. The shorting probe is crucial for setting the reference impedance and provides that any discrepancies caused by the probe's interaction with the sample are corrected. This step guarantees that the system can accurately measure the material's properties without interference from the measurement setup itself. Figure 2.d illustrates the final calibration step, where a distilled water is used as a reference material. Distilled water, with well-known and stable dielectric properties, serves as an ideal calibration standard. By measuring its known dielectric response, the system can further adjust for any remaining errors in the probe or measurement system. Once these calibration steps are complete, the dielectric probe kit is ready to accurately measure a wide range of materials, from liquids to powders, it shows the characterization of their complex dielectric parameters.

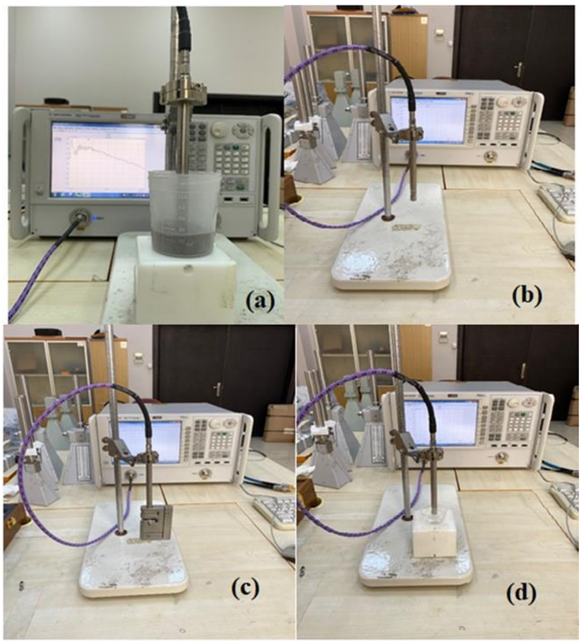

Figure 2. Complex dielectric measurement setup by a coaxial dielectric probe kit a) during measurement, b) open-air measurement, c) shorting probe for calibration and c) calibration by distilled water

RESULTS AND DISCUSSION

Figure 3 presents a comprehensive analysis of complex dielectric constants and their impact on antenna performance of *Monodonta turbinata* samples. Subfigures (a) and (b) illustrate the real and imaginary parts of the permittivity across a wide frequency range, including the target frequency of 10 GHz. The data shows that *M. turbinata*, a novel dielectric material, exhibits tunable permittivity properties depending on its heating temperatures 800°C, 1000°C, and 1200°C. The real permittivity (a) indicates enhanced values compared to air, with a clear increase as heat temperature rises, suggesting stronger polarization capabilities. In contrast, the imaginary permittivity (b), which correlates with energy loss or dissipation, also varies with heat temperature, that indicates the material's potential for controlled dielectric loss applications. At 10 GHz, the properties appear well-suited for effective antenna performance, balancing polarization strength with minimal energy loss.

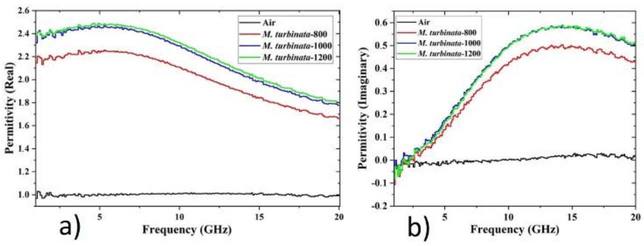

Figure 3. Experimentally measured a) real part and b) imaginary part of the prepared *M. turbinata* samples by using coaxial probe kit

Figure 4 shows a patch antenna designed using *M. turbinata* at a heating temperature of 1000°C, explains how this material integrates as a substrate in an antenna system. The use of a dielectric substrate is critical in determining antenna characteristics such as impedance matching and radiation efficiency. The unique properties of *M. turbinata*, as highlighted in the permittivity data, likely optimize the antenna's bandwidth and operating frequency. By focusing on 10 GHz, a key frequency for modern wireless communication systems, the design indicates the material's dielectric behaviour to achieve enhanced performance in a compact and efficient form factor.

In the S-parameter diagram in Figure 4 deeply illustrates the performance metrics of the antenna. Moreover, this S11 characteristic provides the reflection coefficient comparison between antennas with "*M. turbinata* 1000°C", FR-4, and RT-5880 substrates. The "*M. turbinata* 1000°C" substrate achieves better impedance matching near 10 GHz than FR-4, with performance approaching the premium RT-5880 substrate. As illustrated in Figure 4, *M. turbinata* has wider band characteristics and has relatively acceptable good radiation gain as 8.09 dBi. As given, FR-4 and RT-5880 has narrow bands and 7.06 and 8.62 dBi gain characteristics, respectively. This result underscores the material's suitability as a cost-effective alternative for high frequency applications. Another figure demonstrates the radiation pattern at 10 GHz, which presents a well distributed gain profile. The maximum gain, indicated by the colour scale, confirms that *M. turbinata* facilitates effective electromagnetic wave propagation, essential for reliable wireless communication. This combination of dielectric analysis and practical antenna application highlights the promising role of *M. turbinata* in advanced antenna technologies.

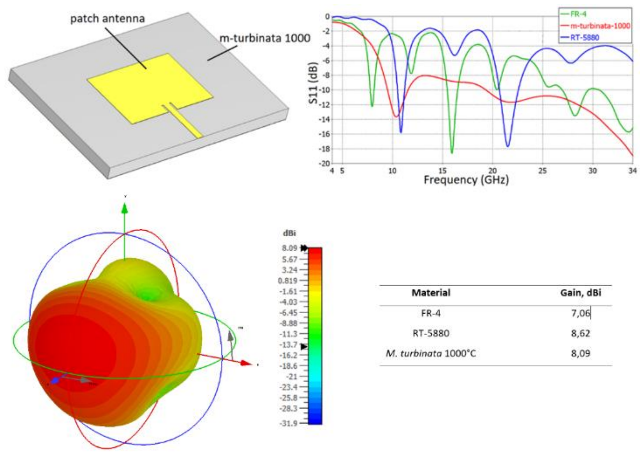

Figure 4. Designed patch antenna for ultra-high frequency application based on *M. turbinata* substrate

Furthermore, the constitutive parameters of "*M. turbinata* 1000°C", FR-4 and RT-5880 are given in Table 1. With its high loss level, "*M. turbinata* 1000°C" creates ultra-wide bandwidth characteristics in communication frequencies especially for 5G.

Table 1. Constitutive parameter comparisons at 10 GHz

Material	Loss tangent δ	Reel part of ε
FR-4	0,025	4,3
RT-5880	0,002	2,28
M. turbinata 1000°C	0,21	2,35

Based on the findings of this study, future research should explore several key aspects to further establish the viability of *M. turbinata* shells as a sustainable biomaterial for microwave and antenna applications. Firstly, a more extensive frequency range, extending beyond 20 GHz, should be investigated to assess the suitability of these calcined shells for applications in millimeter-wave and terahertz technologies, which are critical for next-generation wireless communication and imaging systems.

Additionally, alternative calcination methods, such as rapid thermal processing or controlled atmosphere calcination, could be explored to fine tune the dielectric properties with greater precision. The incorporation of different shell integrated composites, such as polymer matrix or ceramic matrix composites, could also be examined to enhance mechanical durability while preserving favourable electromagnetic characteristics.

Finally, a comparative literature review is given in Table 2 with details. Different materials have varying dielectric properties, which makes these materials useful for microwave applications. Coal (2.216 GHz) and materials like Teflon, wood, and corn (2.4-2.5 GHz) have narrow application bands. In contrast, apple pulp waste (3-18 GHz), rice-based materials (1-20 GHz), and polybutylene succinate (2.3-11.7) show wider frequency ranges, which are in use across different applications in microwaves. Furthermore, this study shows that *M. turbinata shells* (1-20 GHz) have advanced properties, as explained it is suitable for microwave substrate applications. These findings suggest *M. turbinata* could be a sustainable option for microwave applications.

Table 2. Literature comparison

Material	Frequency (GHz)	Application	Reference
Coal	2.216	Not specified	Marland et al., 2001
Apple pulp waste	3-18	Microwave absorbers	Baltacıoğlu et al., 2021
Teflon, wood, paper, white corn, yellow corn, sorghum	2.4-2.5	Not specified	Hernández-Gómez et al., 2014
Rice husk, rice straw, sugar cane bagasse and banana leaves	1-20	As a substrate material in microwaves	Zulkifli et al., 2017
Polybutylene succinate (PBS)	2.3-11.7	Antenna substrate	Habib Ullah et al., 2015
***M. turbinata* shells**	**1-20**	**Microwave substrate**	**This study**

Moreover, the scalability of this biomaterial for industrial applications should be evaluated by developing standardized processing techniques and testing the long term stability of the calcined shells under various environmental conditions, including humidity, temperature fluctuations, and mechanical stress. Further studies could also investigate the potential of integrating *M. turbinata* substrates into flexible and conformal antenna designs, particularly for wearable and biomedical communication applications.

From a sustainability perspective, future research should address the environmental impact and life cycle assessment of processing *M. turbinata* shells. In addition, interdisciplinary collaborations incorporating materials science, computational electromagnetics, and environmental engineering could lead to novel applications and optimizations, which paves the way for the widespread adoption of marine biomaterials in modern communication systems. Future studies could also explore the scalability of *M. turbinata* shell processing to meet industrial demands. Investigating the long-term stability and performance of these biomaterials under varying environmental conditions would be valuable for practical applications. Furthermore, developing cost-effective and eco-friendly processing techniques could enhance the feasibility of large scale implementation.

CONCLUSION

This study highlights the potential of *M. turbinata* shells as an innovative and sustainable biomaterial for microwave and antenna applications. By systematically processing the shells through washing, drying, grinding, and calcination at varying temperatures (800°C, 1000°C, and 1200°C), the electromagnetic properties of the resulting samples were thoroughly characterized. The dielectric measurements revealed that the calcination temperature significantly influences the real and imaginary components of the permittivity, which creates a property for the material to exhibit tuneable dielectric behaviour. This tunability, particularly at 10 GHz, positions *M. turbinata* shells as a viable candidate for applications requiring precise control over electromagnetic properties. The incorporation of *M. turbinata* derived substrates in patch antenna designs demonstrated promising results. The antenna using the M2 substrate (calcined at 1000°C) achieved superior impedance matching and bandwidth performance at 10 GHz, outperforming traditional FR-4 and closely approaching the performance of RT-5880, a high-grade substrate material. The S11 parameter and radiation pattern analyses further underscored the material's potential to enhance antenna efficiency, gain, and overall electromagnetic performance, making it a cost-effective alternative for high frequency communication systems. From a practical perspective, the use of *M. turbinata* shells as a dielectric substrate provides a sustainable and economical solution for the development of advanced antenna technologies. This approach not only reduces dependence on synthetic and petroleum-based materials but also promotes the utilization of renewable marine resources. The demonstrated dielectric tunability enables the design of reconfigurable antennas, which are crucial for emerging applications such as 5G, 6G, and radar systems requiring adaptable electromagnetic responses. Overall, this study not only establishes the feasibility of using *M. turbinata* shells as eco-friendly and cost-effective materials for microwave and antenna technologies but also contributes to the advancement of sustainable alternatives in modern communication systems. By providing the unique electromagnetic properties of marine biomaterials, this research paves the way for future studies focused on the integration of renewable resources in advanced electronic and communication applications.

Compliance with Ethical Standards

Authors' Contributions

All authors contributed to the study conception and design. The article was written by E.U and F.Ö.A. with the contributions of all authors. The collection of seashell samples and material production were conducted by E.U. and Ö.D., while the measurement of complex dielectric parameters was carried out by M.K. and F.Ö.A. Each author contributed critical feedback and played a significant role in the research, analysis, and development of the manuscript. All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

The authors declare that formal consent is not required for this type of study.

Data Availability

The authors confirm that the data supporting the findings of this study are available within the article.

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REFERENCES

Alyakrinskaya, I. O. (2010). Some adaptations of *Monodonta turbinata* (Born, 1780) (Gastropoda, Prosobranchia, Trochidae) to feeding and habitation in the littoral zone. *Biology Bulletin*, 37(1), 63-68. https://doi.org/10.1134/S1062359010010097

Baltacıoğlu, K., Başar, M., Karaaslan, M., Alkurt, F., & Aripek, S. (2021) Electromagnetic Analysis of Organic Waste and Blust Furnace Slag Mixtures. *European Mechanical Science*, 5(3), 148–152. https://doi.org/10.26701/ems.860949

Bedi, N., Srivastava, D. K., Srivastava, A., Mahapatra, S., Dkhar, D. S., Chandra, P., & Srivastava, A. (2022). Marine biological macromolecules as matrix material for biosensor fabrication. *Biotechnology and Bioengineering*, 119(8), 2046-2063. https://doi.org/10.1002/bit.28122

Belhaouarı, B., & Boutıba, Z. (2009). Approche écobiologique chez un Mollusque Gastéropode *Monodonta turbinata* dans la côte oranaise orientale. *Bulletin de l'institut national des sciences et technologies de la mer de Tunisie*, 13, 86-90.

Boucetta, S., Derbal, F., Boutiba, Z., & Kara, M. H. (2008). First Biological Data on the marine snails *Monodonta turbinata* (Gastropoda, Trochidae) of Eastern coasts of Algeria. Laboratoire Bioressources Marines, Université Badji-Mokhtar, Algeria. Laboratoire Réseau de Surveillance Environmental, Université Es-Senia, Oran, Algeria. http://doi.org/10.13140/RG.2.2.20639.36007

Conti, M. E., Iacobucci, M., Mecozzi, M., & Cecchetti, G. (2006). Trace metals in soft tissues of two marine gastropod molluscs: *Monodonta turbinata* B. and *Patella caerulea* L. collected in a marine reference ecosystem. Environmental problems in coastal regions VI, including oil and chemical spill studies. *WIT Transactions on Ecology and the Environment*, 88, 3-11. https://doi.org/10.2495/CENV060011

Conti, M. E., Mele, G., & Finoia, M. G. (2017). Baseline Trace Metals Concentration in *Monodonta turbinata* Throughout Pontine Islands Archipelago, Italy. *International Journal of Environmental Research*, 11, 13-23. http://doi.org/10.1007/s41742-017-0002-x

Duysak, O., & Ersoy, B. (2014). A Biomonitoring Study: Heavy Metals in *Monodonta turbinata* (Mollusca: Gastropoda) From Iskenderun Bay North-Eastern Mediterranean. *Pakistan Journal of Zoology*, 46(5), 1317-1322.

Habib Ullah, M., Mahadi, W. N. L., & Latef, T. A. (2015). Aerogel poly (butylene succinate) biomaterial substrate for RF and microwave applications. *Scientific Reports*, 5(1), 12868. https://doi.org/10.1038/srep12868

Hernández-Gómez, E. S., Olvera-Cervantes, J. L., Corona-Chávez, A., & Sosa-Morales, M. E. (2014, October). Development of a low cost dielectric permittivity sensor for organic and inorganic materials in the microwave frequency range. In 2014 IEEE 9th IberoAmerican Congress on Sensors (pp. 1-4). *IEEE*. http://doi.org/10.1109/IBERSENSOR.2014.6995539

Kaidarova, A., Geraldi, N. R., Wilson, R. P., Kosel, J., Meekan, M. G., Eguíluz, V. M., Hussain, M. M., Shamim, A., Liao, H., Srivastava, M., Saha, S. S., Strano, M. S., Zhang, X., Ooi, B. S., Holton, M., Hopkins, L. W., Jin, X., Gong, X., Quintana, F., Tovasarov, A., Tasmagambetevo, A., & Duarte, C. M. (2023). Wearable sensors for monitoring marine environments and their inhabitants. *Nature Biotechnology*, 41(9), 1208-1220. https://doi.org/10.1038/s41587-023-01827-3

Park, H. J., Jeong, S. W., Yang, J. K., Kim, B. G., & Lee, S. M. (2007). Removal of heavy metals using waste eggshell. *Journal of Environmental Sciences*, 19(12), 1436-1441. https://doi.org/10.1016/S1001-0742(07)60234-4

Raman, S., & Skrivervik, A. K. (2023). Biomaterial devices on Arecanut palm leaf for microwave applications. *In 2023 17th European Conference on Antennas and Propagation (EuCAP*) (pp. 1-5). IEEE. https://doi.org/10.23919/EuCAP57121.2023.10133639

Rupčić, S., Mandrić, V., Kovačić, Đ., & Varga, M. (2024). Measurements of Electromagnetic Radiation Propagation through Biomaterial Samples Based on Harvest Residues. *Sustainability*, 16(2), 499. https://doi.org/10.3390/su16020499

Marland, S., Merchant, A., & Rowson, N. (2001). Dielectric properties of coal. *Fuel* 80(13), 1839-1849. https://doi.org/10.1016/S0016-2361(01)00050-3

Şahin, E. İ., Emek, M., Ibrahim, J. E. F., Yumuşak, G., & Kartal, M. (2023). Shielding effectiveness performance of polyaniline-NiFe2O4: Cu composites for sub-8 GHz applications. *Optical and Quantum Electronics*, *55*(6), 500. https://doi.org/10.1007/s11082-023-04791-z

Sun, J., Choi, H., Cha, S., Ahn, D., Choi, M., Park, S., Cho, Y., Lee, J., Park., T. E., & Park, J. J. (2022). Highly enhanced triboelectric performance from increased dielectric constant induced by ionic and interfacial polarization for chitosan based multi-modal sensing system. *Advanced Functional Materials,* 32(7), 2109139. https://doi.org/10.1002/adfm.202109139

Uğurlu, E. (2024). Evaluation of Gastropods as Biomaterials: *Monodonta turbinata* (Born, 1780). *Acta Aquatica Turcica*, 20(2), 97-107. https://doi.org/10.22392/actaquatr.1301286

Wang, H., An, Q., Xiao, Z., Tong, Y., Guo, L., Zhai, S., Xiao, L-P., & Ha, C. S. (2022). Marine polysaccharide-based electromagnetic absorbing/shielding materials: design principles, structure, and properties. *Journal of Materials Chemistry A*, 10(33), 17023-17052. https://doi.org/10.1039/D2TA03529D

Wang, H., Xiao, X., Zhai, S., Xue, C., Zheng, G., Zhang, D., Che, H., & Cheng, J. (2025). Spontaneous orientation polarization of anisotropic equivalent dipoles harnessed by entropy engineering for ultra-thin electromagnetic wave absorber. *Nano-Micro Letters*, 17(1), 1-15. https://doi.org/10.1007/s40820-024-01507-0

Zulkifli, N. A., Wee, F. H., Mahrom, N., Yew, B. S., Lee, Y. S., Ibrahim, S. Z., & Am Phan, A. L. (2017). Analysis of dielectric properties on agricultural waste for microwave communication application. *In MATEC Web of Conferences* (Vol. 140, p. 01013). EDP Sciences. http://doi.org/10.1051/matecconf/201714001013