

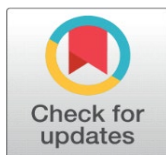
COMPARATIVE ANALYSIS OF SUSTAINABLE MICRO AND NANO MATERIALS DERIVED FROM PLANT EXTRACT AND MICROBIAL STRAIN PRECURSOR

Prabha Modi ¹, Rutu Vasava ² , Preeti Joshi ³

¹ Department of Applied Sciences and Humanities, Faculty of Engineering and Technology, Parul University, Limda Waghodia, India

² Department of Applied Sciences and Humanities, Faculty of Engineering and Technology, Parul University, Limda Waghodia, India

³ Department of Applied Sciences and Humanities, Faculty of Engineering and Technology, Parul University, Limda Waghodia, India



ABSTRACT

This study presents thorough comparative analysis of sustainable micro and nano materials derived from plant extracts and microbial strain precursors, showcasing the transformative potential of Green Chemistry in nanomaterial production. By assessing the efficiency, yield and environmental impact of key precursors – such as Neem and Moringa leaf extracts, along with microbial strains like rochei and Bacillus subtilis. The research emphasis on the advantages of bio-based methods over traditional chemical approaches. A systematic optimization of the precursor concentration along with the synthesis parameters and phytochemical profiling, effective strategies were designed for enhancing the nanoparticle yield and its quality, reducing the ecological impact. The use of advanced characterization and sustainability indicators were incorporated highlighting the potential of different green pathways for scalable, eco-friendly nanotechnology. The survey not only contributes to scientific knowledge but also creates a stage for innovative, sustainable solutions in material science and environmental engineering.

Received 27 February 2026

Accepted 19 April 2026

Published 06 May 2026

Corresponding Author

Rutu Vasava, vasavarutu15@gmail.com

DOI

[10.29121/shodhkosh.v7.i7s.2026.7947](https://doi.org/10.29121/shodhkosh.v7.i7s.2026.7947)

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Copyright: © 2026 The Author(s).

This work is licensed under a [Creative Commons Attribution 4.0 International License](https://creativecommons.org/licenses/by/4.0/).

With the license CC-BY, authors retain the copyright, allowing anyone to download, reuse, re-print, modify, distribute, and/or copy their contribution. The work must be properly attributed to its author.

Keywords: Nanomaterial, Biomaterial, Sustainable, Ecofriendly



1. INTRODUCTION

The exploration of sustainable micro and nano materials derived from the plant extracts and microbial strains is an emerging field of research, driven by the need for environmentally friendly alternatives across various application in the field of Engineering and Technology. Recent studies have highlighted the importance of innovative diagnostic techniques and environmental disclosures, which had contributed to a broader understanding of sustainability in material sciences. In the field of medical imaging, advanced magnetic resonance imaging (MRI) techniques also, it has improved the detection of conditions such as sacroillitis. A study by Elif et al. in 2024, had emphasized on the significance of diffusion weighted imaging in diagnosing inflammatory diseases. This advancement can be compared to the requirement of a

precise and sustainable methods for material development. The synthesis of micro and nano materials from sustainable and green sources, progress to meet the demands of modern applications. Rehneke and Schafer in 2024 examine how microbial strains can enhance plant resilience by investigating the potential of the microbial effectors to modify plant traits for better climate adaptability. This survey aligns with the comparative analysis of sustainable materials, suggesting that the substances derived from microbes can be used to develop innovative materials that not only meet functional requirements but also can promote the sustainability in the environment.

The exploration of sustainable material which are sourced from the plant extracts and microbial strains were increasingly important in the context of environmental ethics and sustainable agriculture. The principles of agro ecology, as articulated by Thomas and KEvan in 1993, had also emphasized the necessity of maintaining the ecological balance within agricultural systems. This perspective was found to be essential when considering the development of nanomaterials without disrupting the existing ecosystem.

1.1. HISTORICAL BACKGROUND

The historical context of material production as mentioned by Coyle and McKinstry in 2023 had stated that the bioethical concerns and environmental degradation associated with the mass production, had urged the researcher to develop sustainable alternatives such as bio-based micro and nano products. These innovations in which bio extracts are utilized, aimed to lessen the negative impacts of traditional production methods.

The exploration of graphical abstracts in academic research, especially regarding the nanoparticles yield and phytochemical mechanisms, had emphasized on the importance of the visual representation. In 2025 Charise had introduced Comics – based research as a method for disseminating academic findings by using graphic media to present complex ideas in an engaging manner. This approach can enhance interdisciplinary collaboration and public engagement.

2. ENVIRONMENTALLY FRIENDLY MATERIALS

Recent advancement in technology, such as those explored by Oladipo et. Al. in 2022 had demonstrated the potential for innovative approaches in material science. Their study on age estimation techniques using feature extraction methods highlights the importance of accuracy and robustness in the development of new technologies. Moreover, the sustainable Development Goals (SDGs) established by the United Nations provide a framework for addressing the global challenges, including hunger and climate change. Lastly the ethical considerations surrounding end-of-life, as discussed by Tanaka et al. in 2020, can be compared to the ethical implications involved in developing sustainable materials.

3. PLANT EXTRACT AND MICROBIAL STRAIN PRECURSOR

In 2024 Fischer had emphasized on the role of plant based economies in promoting sustainability by giving the idea of liking the food security with environmental concerns. In the field of bio product recovery, in 2008, Champagne and Li studied the hydrolysis of lingo-cellulosic material sourced from poultry manure. Their research indicates that pretreating the feedstock, significantly enhances the glucose conversion rates. This study highlights the potential of using agricultural waste as low cost source for biofuel production, contributing to sustainable energy solutions. The findings suggest that incorporating agricultural by-products into the production of micro –nano materials yielding dual benefits of waste management and resource recovery.

Additionally, Thomas and Kevan in 1993 had stressed the importance of maintaining the biodiversity and soil health, both of which are crucial for the resilience of agroecosystems. Plant extracts from Neem (*Azadirachta indica*) and Moringa (*Moringa Oleifera*) consistently produce some of the highest quantities of silver nanoparticles in green synthesis studies. Neem leaf extract is particularly effective due to its high content of polyphenols and flavonoids, which act as strong reducing and capping agents, resulting in the rapid formation of nanoparticles in large quantities. Moringa leaf extract also shows substantial yields.

Additional plant extracts that produce significant amounts of silver nanoparticles include mango leaves, Tulsi (*Ocimum sanctum*) and Turmeric (*Curcuma longa*). These plants are rich phytochemicals that facilitate the efficient nanoparticle synthesis and favored for their availability, eco – friendliness and reproducibility in large scale nanoparticle production.

Among the natural precursors, yeast and algae are recognized for yielding the highest amounts of nanoparticles through green synthesis. Yeast, in particular, produces significant quantities of extracellular enzymes that effectively reduce metal ions, leading to higher yields compared to bacteria or plant extracts. Algae also contribute to high percentage of yields due to the rapid growth rates, abundance of reducing enzymes and pigments, with low energy requirements during the synthesis process. The plant extract, especially those rich with polyphenols, flavonoids and polysaccharides (including neem, aloe vera and Acacia gum), also leads to greater yield and are frequently used due to their ease of extraction. However, the yields from yeast and algae generally surpass those from plant sources, making them the most efficient natural precursors for the high yield nanoparticle production.

The concentration of the precursors used also plays a crucial role in determining the yield and the characteristics of nanoparticles. Precursor higher concentration lead to increased product development and improved particle formation due to greater availability of the metal ions. However, when the concentration exceed an optimum level, the yield percentage may plateau or even decline due to the aggregation or incomplete reduction. In the synthesis of ZnO NPs, both yield and purity show improvement upto certain threshold but beyond this point, the particle size tends to increase while the yield may decrease. Similarly, in the synthesis of Iron oxide NPs, an increase in concentration initially boost both yield and particle size, but at higher levels, these metrics may decline due to the presence of surfactants used and the nucleation process.

Therefore, finding the optimal precursor concentration is essential for maximizing yield while controlling particle size and purity. Table -1 provides a concise overview of the most effective natural precursors and their influence on NPs yield, emphasizing the importance of optimizing precursor concentration for achieving maximum efficiency.

Table 1

Table 1 Natural Precursors and Their Impact on Nanoparticle Yield				
Precursor Type	Example Source	Nanoparticle Yield (Relative)	Key Phytochemicals/Mechanism	Notes on Optimization /Impact
Plant Extract	Neem (<i>Azadirachta indica</i>)	High	Polyphenols, flavonoids, proteins	High yield due to strong reducing agents
Plant Extract	Moringa (<i>Moringa oleifera</i>)	High	Flavonoids, phenolic	Rapid reduction, high yield
Plant Extract	Mango leaf, Tulsi, Turmeric	Moderate-High	Polyphenols, curcuminoids	Good for large-scale production
Microbial Strain	<i>Streptomyces rochei</i>	High	Extracellular enzymes	Efficient for silver nanoparticles
Microbial Strain	<i>Bacillus subtilis</i>	High	Enzymes, proteins	High optical density, efficient reduction
Microbial Strain	<i>Pseudomonas aeruginosa</i>	High	Enzymes, proteins	High yield, scalable
Microbial Strain	<i>Penicillium citreonigrum</i>	High	Fungal metabolites	Fungi often outperform bacteria
Microbial Strain	<i>Candida utilis</i> (yeast)	High	Proteins, sugars	High yield for silver nanoparticles
Precursor Concentration	Varies by system	Optimal range (e.g., 1 g for ZnO)	Metal ions (AgNO ₃ , ZnSO ₄ , etc.)	Yield increases up to threshold, then plateaus/decreases

3.1. GREEN SYNTHESIS PATHWAYS FOR SUSTAINABLE MICRO AND NANO MATERIALS DERIVED FROM NATURAL RESOURCES

The Green synthesis pathways for Micro-Nano materials derived from natural resources primarily rely on extract from plant based resources, microorganisms (such as bacteria, fungi and algae) and agricultural or food waste as reducing and stabilizing agents. These methods avoid formation of toxic chemicals and energy intensive processes, resulting in materials that are ecofriendly, cost effective and scalable. Fig-1 depict the comparison between the different sources of natural materials with the types of reactions.

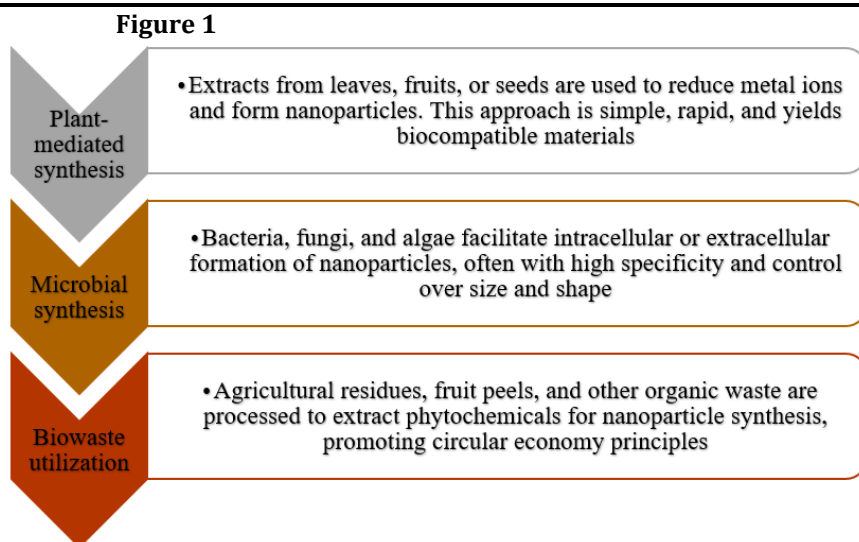


Figure 1 Comparison Between Plant Based, Microbial Based and Bio-Waste Synthesis

The integration of the extracts and strains for developing Micro- Nano materials is supported by empirical evidence from various literature studies. The Table-2 below show summarized key data of different types of extract, precursors and their applications in sustainability. This format highlights the sources, synthesis method, particle size yield, and key observations based on the typical experimental data by green synthesis routes and findings.

Comparing the environmental footprints of top green synthesis routes, the leading methods can be evaluated using key metrics such as E- factors (waste generated per kilogram of product), solvent intensity and overall yield. Generally, plant mediated and microbe assisted methods have lower environmental footprints compared to traditional chemical or step-by-step processes, especially when optimized for one pot synthesis routes as depicted in Fig – 2.

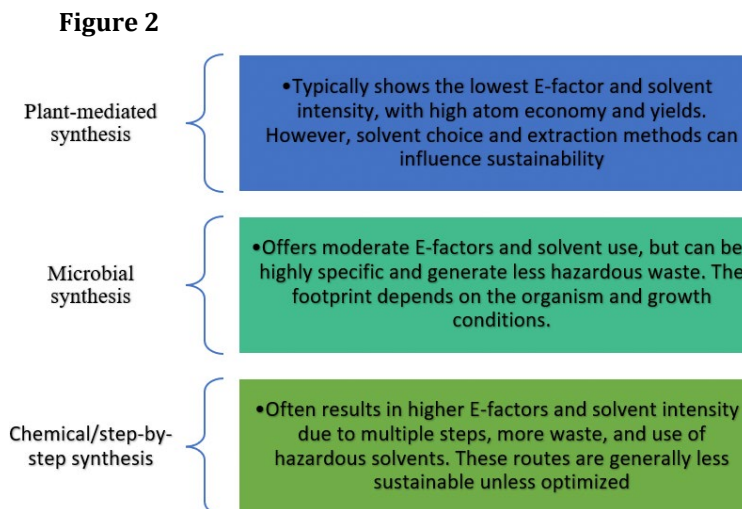


Figure 2 Step by Step Processes for One Pot Synthesis Roustes

Table -2 Experimental data of synthesized micro and nano materials through green pathways can be presented in a tabular format for comparative analysis

Table 2

Table 2 Experimental Data of Synthesized Micro and Nano Materials Through Green Pathways				
Natural Source	Synthesis Method	Particle Size (nm)	Yield (%)	Key Observations
Neem leaf extract	Plant-mediated reduction	20–40	85	High antimicrobial activity
Aloe vera gel	Plant-mediated reduction	15–35	90	Excellent stability, biocompatible

Fungal mycelia	Microbe-mediated reduction	30–50	70	Moderate yield, slow kinetics
Seaweed extract	Plant-mediated reduction	10–25	88	Good photocatalytic properties
Fruit peel extract	Plant-mediated reduction	25–45	82	High antioxidant activity

This literature survey highlights the different potential of plant based and microbial derived materials in promoting sustainability for a more resilient future. The momentum for integrating sustainability into various sectors is particularly evident in micro-nano materials from bio based extracts and strains. Recent findings indicate that there are significant and economic application of these finding in the field of Engineering and Technology

Arya et al. in 2021 investigate designer NPs from plant cell cultures, shows that they can stimulate specialized metabolic pathways to boost high value metabolite yields. This method promotes and offers good commercial prospects. Lasly, Richards et al. in 2024 stated the complexities of digital technology in agricultural field, which help in managing climate risks and may also undermine producers agency.

3.2. COMMON PHYTOCHEMICALS THAT INFLUENCE NANOPARTICLE PROPERTIES

Common phytochemicals that influence nanoparticle properties include flavonoids, phenolics, terpenoids, alkaloids, tannins, proteins, and polyphenols. These compounds act as reducing, stabilizing, and capping agents during green synthesis, affecting particle size, shape, stability, and biological activity.

Table 3

Phytochemical Class	Method of Quantification	Value / Result	Role in Synthesis	Impact on Nanoparticle Properties
Phenolics	Folin-Ciocalteu	mg GAE/g d.wt	Reducing, capping	Smaller size, improved stability
Flavonoids	Aluminum chloride	mg QE/100g d.wt	Reducing, stabilizing	Enhanced bioactivity
Terpenoids	GC-MS/HPLC	mg/g d.wt	Reducing, nucleation	Controlled shape, size
Alkaloids	GC-MS/HPLC	mg/g d.wt	Stabilizing	Improved stability
Proteins	Bradford/Lowry assay	mg/g d.wt	Capping, stabilizing	Enhanced biocompatibility
Tannins	Folin-Ciocalteu	mg GAE/g d.wt	Reducing, capping	Better dispersion

The analysis of different phytochemical can be done by different methods which are depicted in Fig- 3, and this approach ensures systematic documentation of phytochemicals and their influence on nanoparticle synthesis and properties. The figure-3 outlines a three-step approach to studying plant compounds in nanoparticle formation:

- 1) Quantitative analysis: Measures the amounts of certain compounds. Total phenolic content is determined using the Folin–Ciocalteu method (reported as mg gallic acid equivalents per g dry weight), while total flavonoids are measured via the aluminum chloride method (reported as mg quercetin equivalents per 100 g dry weight).
- 2) Qualitative analysis: Identifies the specific phytochemicals present using techniques like HPLC or GC-MS, providing retention time and peak area for estimation.
- 3) Functional role: Describes the compounds' roles, such as reducing agents, capping agents, and stabilizers, which influence nanoparticle size, shape, and stability.

In simpler terms, the process involves measuring phenolics and flavonoids, identifying specific chemicals, and explaining their roles in forming and controlling nanoparticles—common in green synthesis using plant extracts instead of harsh chemicals. These phytochemicals are crucial for both particle formation and the final properties of nanoparticles.

Figure 3

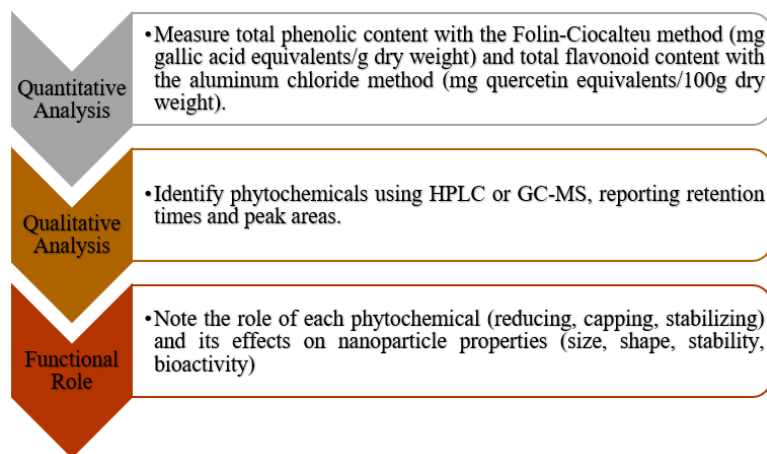
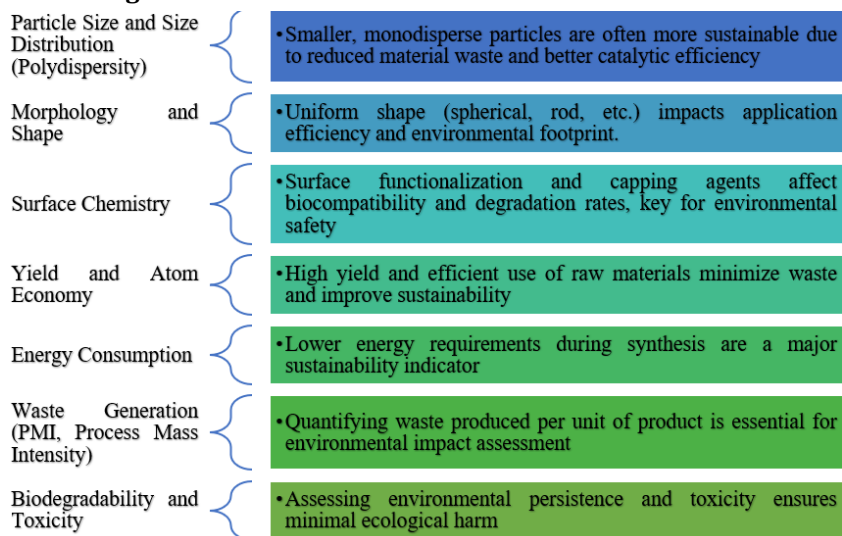


Figure 3 Different Approaches to Study Different Types of Phytochemicals

4. CHARACTERIZATION METRICS FOR SUSTAINABILITY COMPARISONS

For sustainability comparisons in nanoparticle synthesis, the following characterization metrics should be prioritized

Figure 4



5. CONCLUSION

Concluding the comparative analysis of Bio based Micro- Nano material (Plant extract and Microbial strains) requires an interdisciplinary approach. By integrating insights from medical imaging, environmental disclosures, agricultural practices, microbial interactions, we can gain a comprehensive understanding of how to advance in the field of Nanotechnology. Future research can emphasize collaboration across these domains to develop innovative and sustainable materials that address societal needs and challenges. The data summarize in the study addresses the research question regarding the precursor types, yield of NPs, key phytochemicals and its mechanism with optimization notes and green synthetic routes from diverse studies.

CONFLICT OF INTERESTS

None.

ACKNOWLEDGMENTS

We would like to express our gratitude to all the authors, publishers, for their support throughout literature survey.

REFERENCES

- Adolwa, I. S., Schwarze, S., Bellwood-Howard, I., Schareika, N., & Buerkert, A. (2017). A comparative analysis of agricultural knowledge and innovation systems in Kenya and Ghana: sustainable agricultural intensification in the rural–urban interface. *Agriculture and human values*, 34(2), 453-472.
- Arya, S. S., Lenka, S. K., Cahill, D. M., & Rookes, J. E. (2021, October 4). Designer nanoparticles for plant cell culture systems: Mechanisms of elicitation and harnessing of specialized metabolites. *BioEssays*. Wiley. <http://doi.org/10.1002/bies.202100081>
- Champagne, P., & Li, C. (2008). Bio-product recovery from lignocellulosic materials derived from poultry manure. *Bulletin of Science, Technology & Society*, 28(3), 219-226.
- Charise, A. (2025, January 24). The Comic Research Abstract: Graphic Medicine as Interdisciplinary Health Research (Example: Intergenerational Storytelling). *Journal of Medical Humanities*. Springer Science and Business Media LLC. <http://doi.org/10.1007/s10912-025-09931-y>
- Coyle, C., & McKinstry, A. (2023, March 29). The Benefits and Burdens of Meat Consumption. *Voices in Bioethics*. Columbia University Libraries. <http://doi.org/10.52214/vib.v9i.11036>
- Elgart, L. D., Schanfield, L., & Public Interest Enterprises, Inc. (1983). Abstract of More Blacks on Boards of Fortune 500 Companies. *Business and Professional Ethics Journal*. Philosophy Documentation Center. <http://doi.org/10.5840/bpej19832411>
- ELIF, H., SEMA, A., & ERCAN, I. (2024). Evaluation of Inflammatory Disease Activity in the Sacroiliac Joints Using Magnetic Resonance Imaging: A Comparative Analysis of Short-Tau Inversion Recovery, Post-Contrast, and Diffusion-Weighted Imaging–Preliminary Study. *EVOLUTIONARY STUDIES IN IMAGINATIVE CULTURE*, 142-152.
- Estelle Carol. (2018). *The Chicago Women's Graphics Collective: A Memoir*. Feminist Studies. Project MUSE. <http://doi.org/10.15767/feministstudies.44.1.0104>
- Fischer, J. (2024). Green Economies in the Age of Globalized Capitalism. In *Justifying Next Stage Capitalism: Exploring a Hopeful Future* (pp. 293-306). Cham: Springer International Publishing.
- Grewal, J., Hauptmann, C., & Serafeim, G. (2021). Material sustainability information and stock price informativeness. *Journal of Business Ethics*, 513-544.
- Gayadang, D., Mission, N. L. T., & Cajucom, E. L. (2023). BIOFORMULATION OF SILVER NANOPARTICLES FROM BETEL LEAF (PIPER BETEL) EXTRACT AND ITS ANTIOXIDANT, CYTOTOXIC AND ANTIBACTERIAL PROPERTIES. *International Journal of Engineering Technologies and Management Research*, 10(8), 33–44. <https://doi.org/10.29121/ijetmr.v10.i8.2023.1354>
- Healey, P. G. T., Swoboda, N., Umata, I., & King, J. (2007, March). Graphical Language Games: Interactional Constraints on Representational Form. *Cognitive Science*. Wiley. <http://doi.org/10.1080/15326900701221363>
- Hillary Chute. (2018). *Feminist Graphic Art*. Feminist Studies. Project MUSE. <http://doi.org/10.15767/feministstudies.44.1.0153>
- Kumari, A., & Singh, M. P. (2025). Employee Sustainability: Myth or Reality? Chasing SDGs 3, 8, and 10 in the Corporate Jungle With a Buddhist Torch. *Business and Society Review*.
- Marian, R. (2022, June). A Comparative Analysis of Environmental Disclosure Before and After EU Directive 95/2014 Implementation. In *International Conference on CSR, Sustainability, Ethics and Governance* (73-87). Cham: Springer Nature Switzerland.
- Moser, L. E., Melliar-Smith, P. M., Ramakrishna, Y. S., Kutty, G., & Dillon, L. K. (1996, January). Automated deduction in a graphical temporal logic. *Journal of Applied Non-Classical Logics*. Informa UK Limited. <http://doi.org/10.1080/11663081.1996.10510865>
- Ng, A. (2025). Transforming toxic materialities: Microbes in anthropogenically polluted soils. *Theory, Culture & Society*, 42(1), 37-52.
- Oladipo, O., Omidiora, E. O., & Osamor, V. C. (2022, March 25). Comparative analysis of features extraction techniques for black face age estimation. *AI & SOCIETY*. Springer Science and Business Media LLC. <http://doi.org/10.1007/s00146-022-01407-0>

- Rehneke, L., & Schäfer, P. (2024, February 22). Symbiont effector-guided mapping of proteins in plant networks to improve crop climate stress resilience. *BioEssays*. Wiley. <http://doi.org/10.1002/bies.202300172>
- Richards, C., Messner, R., & Higgins, V. (2024, September 16). Digital technology and on-farm responses to climate shocks: exploring the relations between producer agency and the security of food production. *Agriculture and Human Values*. Springer Science and Business Media LLC. <http://doi.org/10.1007/s10460-024-10624-w>
- Shields, J. A. E. (2023). *Phenomenology and Architecture: Examining Embodied Experience and Graphic Representations of the Built Environment*. Contributions to Phenomenology. Springer International Publishing. http://doi.org/10.1007/978-3-031-26074-2_15
- Smucler, E., & Rotnitzky, A. (2022, January 1). A note on efficient minimum cost adjustment sets in causal graphical models. *Journal of Causal Inference*. Walter de Gruyter GmbH. <http://doi.org/10.1515/jci-2022-0015>
- Tanaka, M., Kodama, S., Lee, I., Huxtable, R., & Chung, Y. (2020, October 16). Forgoing life-sustaining treatment – a comparative analysis of regulations in Japan, Korea, Taiwan, and England. *BMC Medical Ethics*. Springer Science and Business Media LLC. <http://doi.org/10.1186/s12910-020-00535-w>
- Thomas, V. G., & Kevan, P. G. (1993, March). Basic principles of agroecology and sustainable agriculture. *Journal of Agricultural and Environmental Ethics*. Springer Science and Business Media LLC. <http://doi.org/10.1007/bf01965612>
- Trappey, C. V., Trappey, A. J. C., Lin, H.-J., & Chang, A.-C. (2023, August 22). Comparative Analysis of Food Related Sustainable Development Goals in the North Asia Pacific Region. *Food Ethics*. Springer Science and Business Media LLC. <http://doi.org/10.1007/s41055-023-00132-8>
- Venkatesan, S., & Joshi, I. A. (2022, September). COVID-19, Graphic Medicine, and Thinking Beyond Data. *Perspectives in Biology and Medicine*. Project MUSE. <http://doi.org/10.1353/pbm.2022.0061>
- Veraart, F. (2018). *Building Materials and Construction: Sustainability, Dependency and Foreign Suppliers*. Well-being, Sustainability and Social Development. Springer International Publishing. http://doi.org/10.1007/978-3-319-76696-6_19
- Wilson, F. (1986). Hume and Derrida on language and meaning. *Hume studies*, 12(2), 99-121.