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Decolonizing green chemistry research through Matharu plots

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Research decolonization is necessary to forge diverse workspaces and foster equitable opportunities for underrepresented populations in science. The prevailing power structures in which the scientific enterprise operates are deeply rooted in colonial frameworks, perpetuating bias and discrimination towards people from the Global South. Therefore, there is an urgent need to dismantle these systemic disparities. Change must start at the educational level. In this work, we introduce the concept of a Matharu plot as an example of a practical and impactful tool to generate critical discussions and drive tangible change towards decolonized and inclusive research. A Matharu plot is a one-page infographic that shows the geographical distribution of cited research with an accompanying narrative. A Matharu plot highlights any potential biases that may be inherent in the literature and thus facilitates a shift in mindset towards inclusive, decolonized research. Matharu plots can be easily integrated into undergraduate, master's, and doctoral-level chemistry curricula and any other academic discipline, serving as a versatile and transformative resource that advances equitable chemical education in sustainability.

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Sustainability spotlight

To achieve sustainability and provide solutions for the many current global grand challenges, for example, SDG 2: zero hunger, SDG 3; good health and well-being, SDG 6; clean water and sanitation, and SDG 12: responsible consumption and production, change must start at the educational level (SDG 4) that recognizes and addresses inequalities (SDG 10) and is globally encompassing (SDG17). Matharu plots are a practical and impactful educational tool to generate critical discussions and drive tangible change towards inclusive education and research.

An introduction to Matharu plots

Where does science come from, and how has it evolved through the years? Such fundamental questions are not regularly considered but are crucial to understanding the underlying fabrics in which science operates today. Modern science is produced through a colonial mindset, segregating people from the Global South and other individuals from equity denied populations.[1–6] This realization is an opportunity for the scientific community to critically examine the historical and cultural evolution of science and re-imagine an inclusive and equitable future.

Decolonizing research by means of promoting diversity and inclusion in the workplace is known to generate significant improvements in creativity, innovation, collective intelligence, and outcomes in science.[6–8] However, colonial systems are still driving academia even though efforts have been made to create impactful change.[9–17] Institutions are not doing enough and we need a radical change in the way science is produced, researchers are recruited, and opportunities are created.

Curricular changes have been suggested to make lectures more representative of the variety of locations where knowledge is generated.[18–22] However, these efforts continue to be quick and insufficient fixes to a much larger issue and have a high chance of falling by the wayside in the long term. Thus, incisive initiatives that challenge colonial systems need to be established to bring about awareness and action towards change.

To contest colonial power structures and foster deep thought on the topic, Matharu plots[18,23] present infographics that display an overview of the location of the research institutions cited in a thesis or an extended essay document. In addition to the infographic, a short personal statement is written reflecting on the trends uncovered through the infographic with the aim of creating awareness about science decolonization, effectively starting a much broader conversation on the topic and ultimately leading to a more systemic and sustained impact. A detailed step-by-step guide on how to produce a Matharu plot is given in the ESI. Matharu plots have now been used by over 60

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students in the Postgraduate Taught Masters in green chemistry and sustainable industrial technology as part of their degree awarding marks and as a formative exercise with over 150 final year chemistry undergraduates at the University of York. At Postgraduate Taught Masters (Level 7), Matharu plots (decolonisation of research) are integrated as part of its research project and are a specific part of the overall programme learning outcomes which state, "Critically evaluate and debate research literature and explain its relevance to green chemistry frameworks, including and beyond the 12 Principles, development of circular biobased economies, UN SDGs and decolonisation of research." At the undergraduate level, Matharu plots are part of the University of York Chemistry Department's MChem final year (Level 6) Professional Research Development 20 credit module comprising a literature review (18 credits) and a critical skills reflection (2 credits). The goal is for students to develop an understanding of structural geographical biases within the literature on their research topic and to increase their awareness of the importance of citing all of the research available on the topic regardless of geographic origin. This important change in pedagogy empowers students to shift the research culture of organizations as they traverse their career journey.

Observations and questions

The Matharu plot presented in Fig. 1 shows a summary of the geographic location in which the research for all the references of F. Y. V.'s thesis was conducted.[24] The work cited in the thesis is overwhelmingly predominant in the Global North with North America accounting for more than half of the cited work at 51%.[25] Then, Europe and Asia account for nearly all of the remaining work with a joint total of 46.8%. Oceania and South America make minimal contributions to the referenced work while no citations from Central America or Africa were included.

Before generating this infographic, F. Y. V. suspected that most of the cited research in his thesis came from the US and Europe. However, the magnitude of the disparity in the concentration of nanocrystal-related research was shocking. Considering that nanocrystals find use all around the world in various technological sectors, a broader distribution of countries to be involved in the scientific development of these technologies was expected. F. Y. V.'s first action after seeing the finalized infographic was to look into the literature for nanocrystal research in those regions that are clearly underrepresented (*e.g.,* Central/South America, Africa, and the Middle East). F. Y. V. thought that it is possible that in the process of finding literature references, he was biased and only cited people that he knew and publications from renowned journals. However, this does not seem to be the case. Instead, F. Y. V. now views that this biased distribution is more likely to have another source, which is discussed below.

To investigate the origin of the geographical distribution bias of F. Y. V.'s thesis, a simple literature search exercise was performed using CAS SciFinder. The word "nanocrystal" was searched which showed 835 016 references in total from years 1973 to 2024. Out of those references, the top 50 most cited institutions were mostly from the US, Russia, and China. These were then filtered using the same "nanocrystal" query by year to isolate the 2010–2020 range, with the expectation that

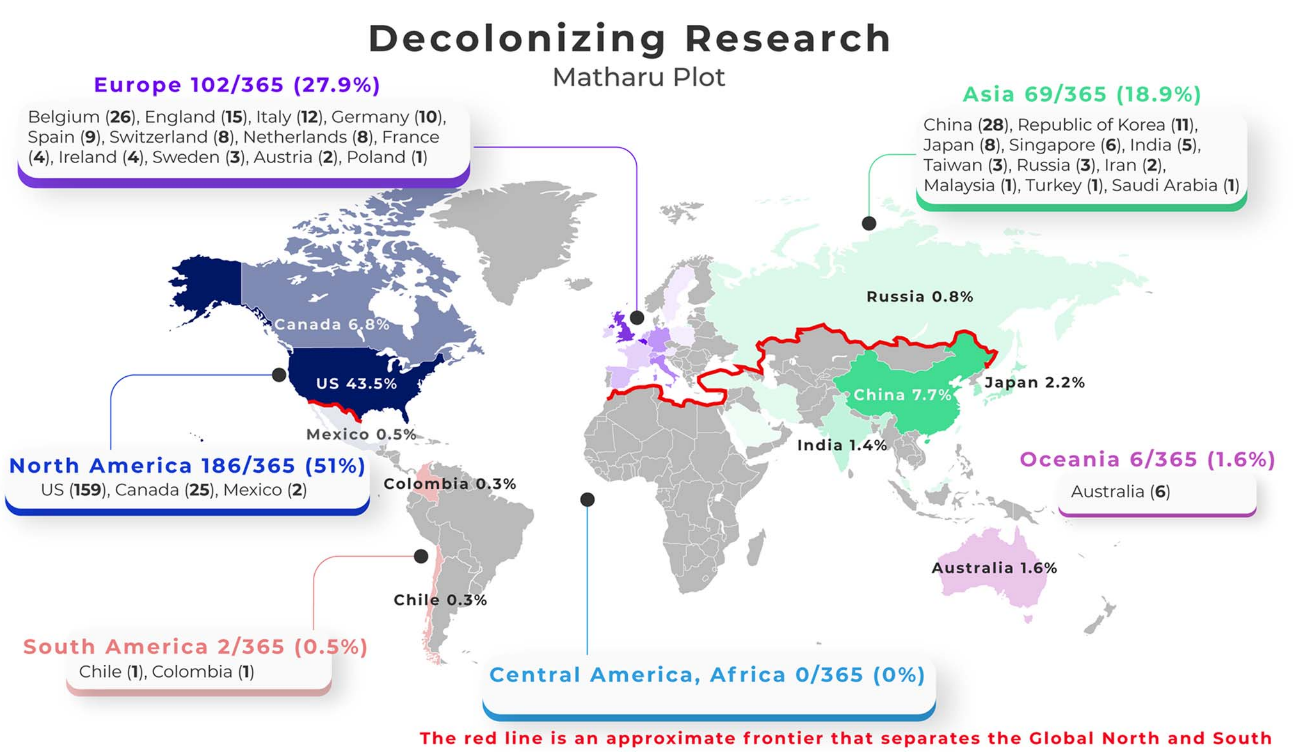

Fig. 1 Matharu Plot infographic (template from https://www.freepik.com). There is a bias towards citing institutions in the Global North.

institutions in the Global South would have developed appreciable research programs on nanocrystals following the boom from the 90 s and 2000 s. Within this search, the research published by the highest ranked universities in Egypt, Ghana, Uganda, Nigeria, Morocco, Kenya, South Africa, Lebanon, Iran, Panama, Guatemala, Costa Rica, Honduras, El Salvador, Nicaragua, Chile, Bolivia, Peru, Paraguay, and Argentina was explored. Amongst the associated manuscripts, only a few were even distantly related to the topic, prompting an immediate change to the reference list. Moreover, a large portion of these manuscripts were published in lesser-known journals raising the issue of equity in publishing. Interestingly, the most relevant manuscripts in this search came from institutions in which the country's GDP is higher than 100 billion US dollars. Therefore, the geographical bias of citations in F. Y. V.'s thesis towards institutions in the US, Europe, and China could easily be viewed as correlated with the broader lack of financial resources in other regions of the globe.

The geographical bias observed in F. Y. V.'s thesis is not an isolated case. The 200+ Matharu plots reviewed by A. S. M. covering all branches of chemistry, including biological chemistry, have shown unequal distribution of citations, thus uncovering a deeper and broader issue in the distribution of knowledge and resources.

Beginning to understand

After realizing some of the potential origins of the geographical bias in the citations, F. Y. V. spoke to five scientists in his network who presently reside and conduct active research in Brazil (spectroscopy),[26,27] Chile (bulk materials),[28,29] and Argentina (organic chemistry)[30–33] about their experience doing scientific research in this specific region of the Global South (*i.e.,* South America). The initial conversations were informal and occurred during a conference. They were then continued through email. The discussion was based on the following questions:

• Do you feel included by the international scientific community in terms of conference invitations, professional development, collaboration and funding opportunities?

• Do you observe a difference in the availability of resources (instruments, chemicals, and funding) between your country and the Global North?

• Do you have the opportunity to publish in top-tier journals?

A recurring topic with these scientists was the lack of resources overall. These include limited funding for chemicals, lack of instrumentation (*e.g.,* having to travel to other institutes to use basic/routine characterization techniques), and constrained budgets for publishing in top-tier journals.

All the scientists mentioned that most countries in the Global South are experiencing difficult financial situations. These scientists mentioned that researchers in their countries rarely publish in top-tier journals because they simply don't have the financial means for it. The lack of financial resources not only translates into not being able to afford a publication in a top-tier journal, but it also results in the inaccessibility of a wide range of key instrumentation and characterization techniques. The differences in the frequency of publishing in top tier journals seen between countries in the Global North and the Global South are clearly not due to differences in the quality or capability to conduct world-class research, but rather, other factors primarily contribute to these differences, especially financial and resource availability.

The interviewed scientists certainly do not feel ashamed of publishing in second/third-tier journals, but they did mention that they do feel inferior when they attend conferences in North America. "Seeing the number of resources (chemicals, instrumentation, and techniques) available to people in the Global North, coupled with their publications in the best journals, it definitely hurts your confidence a little. Often the wait time to receive chemicals, replacement parts for instruments, or technical help is 3–4 months. It really slows down research".

Anecdotally, conversations with these scientists expose the privilege that the Global North has in terms of generating new knowledge, output, communication, and training of the new generation of scientists, which is something that requires attention and further empirical investigation.[34] Additionally, outcomes of such discussions lead to the question of why science is so stratified, but more importantly, what are the implications of this segregation given that the outcome of scientific discoveries directly affects the people who are not being involved in the process? What are we in the Global North doing to bridge this gap? To continue to improve our understanding we need to undertake more formalized interviews with a large set of participants where the process of setting questions to acquiring participants is ethically approved.

Conclusions

The production of a Matharu plot is a first practical, but highly significant step in the journey towards decolonizing science, enhancing research culture and providing quality education. All educators, not only those practicing green and sustainable chemistry, must make curricular changes, moving beyond token inclusion to developing partnerships with Global South institutions for co-created curricula that highlight the vast geographical landscape in which knowledge has been generated.

F. Y. V. decided to explore and reflect over biases in science in his thesis through the eyes of Matharu plots and realized that there are many underlying systematic issues in how the scientific enterprise operates. This exercise fundamentally changed his approach to literature review to make sure that regionally diverse research is included in his work. Additionally, F. Y. V. views it as critical to integrate topics of geographical bias in the mentoring of students, ensuring a long-lasting paradigm shift in the next generation of scientists. Therefore, we would like to encourage other students and scientists to be similarly reflective in their research approach and more critical of where knowledge is being acquired from.

AI-driven tools will play a significant role in bridging the gap between the Global North and Global South. Academic search engines need to expand their capabilities to help academics discover under-explored research from the Global South, for example, by generating Matharu plots on keyword searches and implementing algorithm changes that actively boost the visibility of Global South journals and research. However, care must be taken to prevent AI from further perpetuating disparities in research where certain countries have superior computational resources, which coupled with more advanced instrumentation could dramatically stretch the gap.

In some cases, we need to acknowledge that most revolutionary discoveries, although realized in the Global North, stem from an older and more-diverse network of knowledge that was iteratively and, to an extent, purposely concentrated in this specific region of the world. Therefore, given that resources and knowledge continue to be concentrated in the Global North, a vital next step is to find and act on strategies to further decolonize the scientific enterprise.

Ultimately, we should strive to become a community in which knowledge is not transferred but exchanged between scientists across the globe. Thus, Matharu plots are a driver for positive change in chemical education for sustainability.

Author contributions

F. V. V.: data curation, formal analysis, investigation, writing the original draft, review and editing. D. J. I.: writing of a step-by-step guide to Matharu plots. A. S. M.: conceptualization; formal analysis; writing the original draft, review and editing.

Conflicts of interest

There are no conflicts to declare.

Data availability

The data supporting this article (Fig. 1) are included in ref. 24 and as part of the supplementary information (SI). Supplementary information contains a how to produce a Matharu Plot-step by step guide. See DOI: https://doi.org/10.1039/d5su00777a.

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