A Review of Different Methods for Superhydrophobic Textiles and Fabrics Using Nanotechnology

Eduardo Fischer Kerche[1]*, Débora Leal[1], Vinícius Oliveira[1], Paulo Correia[1], Rodrigo Polkowski[1]
[1]*TRL9 Tech – Research and Development; Salvador, Bahia, Brazil*

Recent developments in superhydrophobic textiles involve many technologies and fields of knowledge, such as textile engineering, surface treatments, and nanomaterials. Several methods can be employed to achieve the superhydrophobicity of fabrics, including dip coating, *in situ* growth, the sol-gel approach, and immersion. This review presents each method and investigates its peculiarities, correlating it with reagents and results. A brief conclusion is also presented with future perspectives. The P.R.I.S.M.A. (Preferred Reporting Items for Systematic Review and Meta-Analysis) protocol was followed, aiming to select the most relevant papers for the area and to evaluate the results accordingly. Selected keywords were superhydrophobic AND [textile OR fabric OR cloth] AND [coating OR immersion OR gel]. Furthermore, only articles published between 2019 and 2024, in the English language, were selected.
Keywords: Systematic Review. Superhydrophobic Textile. Nanotechnology. Advanced Methods.

Superhydrophobic textiles are components with many applications in the engineering field [1]. Some examples include antivirus and antibacterial fabrics, oil-water separation, self-cleaning properties, and the facile removal of surface impurities. Applications of superhydrophobic textiles can range from outdoor clothing and sportswear (to keep athletes dry and comfortable), to medical textiles (for water-repellent bandages and surgical gowns), and even in everyday items like furniture upholstery and automotive interiors. They offer benefits such as self-cleaning properties, stain resistance, and improved durability in wet conditions [2].

These textiles are designed to exhibit extremely high contact angles with water, typically exceeding 150°. This means that when water comes into contact with the surface of a superhydrophobic textile, it forms spherical droplets that roll off easily, carrying dirt and debris away with them.

The superhydrophobic properties of these textiles are typically achieved through surface modification techniques, such as coating the fabric with hydrophobic substances or altering the surface structure at the nanoscale level. This modification creates a rough or textured surface that minimizes contact between the water droplets and the fabric, leading to the repelling effect [3].

In a recent review report, the most recent materials used for manufacturing hydrophobic textiles were presented in studies from the past five years. Many studies using natural fibers, such as cotton, have been the focus in the last decade.

However, some disadvantages of these types of fibers are known, such as the difficulty of incorporating nanomaterials to improve mechanical response. In this regard, synthetic fibers may be used. Several studies have reported on the use of PET polyester fabrics as the primary fiber for producing superhydrophobic textiles.

Some advantages include excellent mechanical response, high reliability, and commercially available textiles in various forms [4].

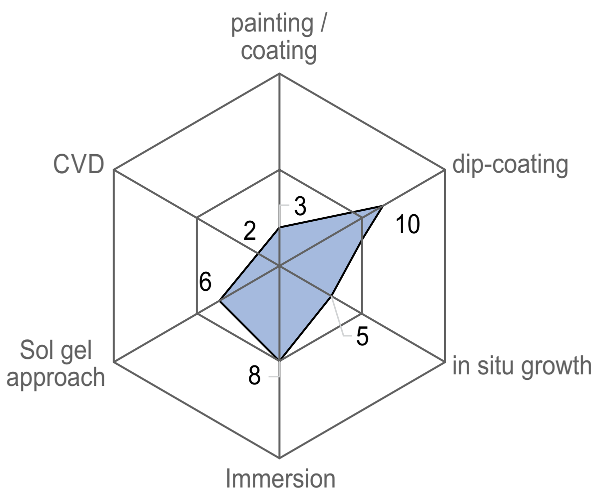
Among the nanofillers used for modifying those textiles, silane treatment and silica use are the most notable. Additionally, poly (dimethylsiloxane) is the most commonly used additive for increasing the contact angle of textiles, a crucial parameter for measuring hydrophobicity. As a conclusion to such a study [4], many techniques can be used for modifying textiles. Figure 1 highlights the most commonly employed methodologies for fabricating superhydrophobic textiles when

Received on 18 March 2025; revised 27 May 2025.
Address for correspondence: Eduardo Fischer Kerche. SENAI CIMATEC University. Avenida Orlando Gomes, 1845. Zipcode: 41650-010. Salvador, Bahia, Brazil. E-mail: eduardo.kerche@trl9.tech.

J Bioeng. Tech. Health 2025;8(3):311-316

nanotechnology is utilized. Dip-coating is the most commonly employed method, as well as immersion, due to the ease and low cost of these processes.

Figure 1. Main methods applied, using nanotechnology for hydrophobic textiles.



Despite the excellent results for hydrophobicity from such studies, no correlations have been reported between the used methodologies and their influence on the superhydrophobicity of these textiles elsewhere. The primary objective of this study is to present the methodologies employed for improving the hydrophobicity of textiles and fabrics.

Materials and Methods

The research method, papers' organization, and results presentation of this research were based on previous work of the group [5–8]. Additionally, to support this systematic review, the online software "Parsifal" and its associated tools (parsif.al) were utilized. "Scopus" (scopus.com), "Web of Science" (webofknowledge.com), and "Multidisciplinary Digital Publishing Institute (MDPI)" (mdpi.com) were used as databases to search for articles. For that, "superhydrophobic AND [textile OR fabric OR cloth] AND [coating OR immersion OR gel]" were used as keywords. Review articles, book chapters, and conference papers were excluded, and only papers published in English within the last 5 years (2019-2024) were selected. Then, some articles were obtained, as shown in Figure 2. Subsequently, duplicated records were removed, leaving 1083 articles for selection of the relevant ones.

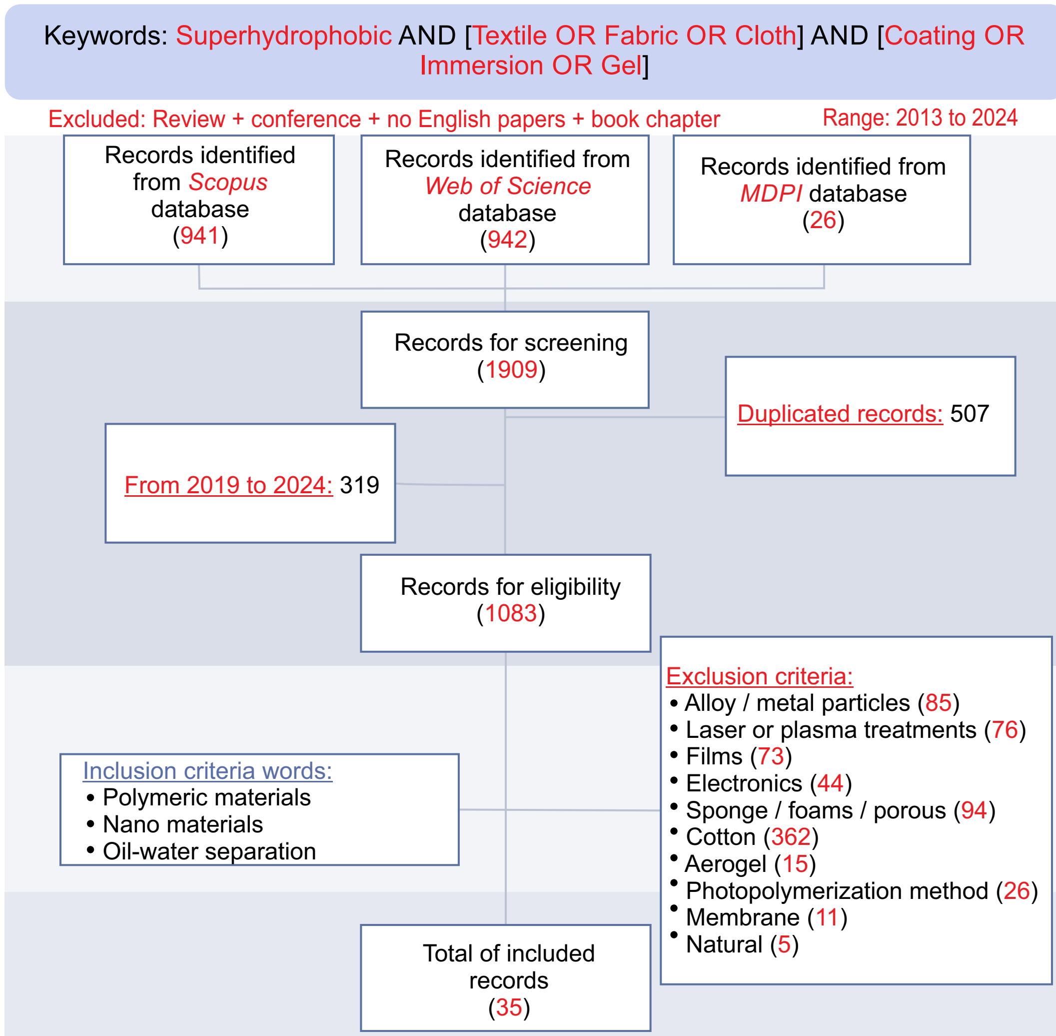
As exclusion criteria, no textile OR cloth OR fabric, development of coatings (or when only the coating was analyzed), laser/plasma surface treatments, metal/alloy particle surface treatment, when no nanomaterials were employed. Additionally, certain materials, including films, sponges/foams, aerogels, and membranes, were excluded. Textiles for electronics were excluded, as were those that used photo treatments. Additionally, inclusion criteria were selected when only polymeric textiles were used, when nanomaterials or nanotechnology were applied, and when the textile was developed explicitly for oil-water separation. At the end of the papers' screening, 35 articles were selected and fully read, and used for data acquisition and comparison of results.

Results and Discussion

Figure 3 shows the evolution of papers published in the last 5 years. A clear trend of increasing the number of publications is observed, primarily on the Web of Science platform. A trend of maintaining a constant publication rate over time is observed on the Scopus platform, as well as in MDPI, with only one paper published per year.

Figure 4A shows the main results from those 35 papers selected, using the inclusion and exclusion criteria. As can be seen, the coating process is the most highlighted, with 28 of the 35 papers selected. This result may be attributed to the ease, affordability, and high-quality finished parts produced when this method is employed [9]. In addition to the coating method, some studies also applied Ultraviolet light (UV), aiming to improve the surface's quality and adhesion between the coating and the textile surface [4]. Additionally,

Figure 2. Systematic review diagram, showing the screening steps for the paper's selection.



UV is used for curing the coating in some cases, aiming to speed up the curing process and also improve the process's productivity [4, 10].

Immersion is one of the most used methods. This is perhaps due to the ease of such a process even when a non-uniform distribution of the coat occurs [11]. Chemical Vapor Deposition (CVD), as well as condensation, have been explored as methods for producing superhydrophobic cloths, which are expected to have low commercial viability due to the high cost and difficulty of producing a soft surface [10]. Finally, the sol-gel approach yielded a relatively low number of publications, whereas dip-coating is a technique used to create coatings on various substrates. Dip-coating is a technique used to apply a coating to a material by immersing it in a solution or suspension of the coating substance. It is widely used in various industries, including manufacturing, electronics, and pharmaceuticals, for creating uniform coatings on objects. Briefly, dip-coating consists of six steps: preparation (cleaning) of the surface, coating of the solution, immersion, withdrawal, drying/curing, and inspection. Some advantages include uniform coating, cost-effectiveness, versatility, and scalability. Dip-coating is utilized in various applications, including electronics, manufacturing, pharmaceuticals, and textiles [12]. This step is crucial for enhancing the durability and stability of the superhydrophobic coating [13]. Post-treatment steps may also involve chemical modification or functionalization of the surface to enhance its superhydrophobic properties. This could include using silanes or fluorinated compounds to lower surface energy and increase water repellency [14].

Figure 4B presents the most used nanomaterials and additives for the improvement of the superhydrophobicity of textiles and cloths. Silica and silane-based treatments were the most commonly used, which may be related to the non-polar nature of silanes and their weak interactions with water molecules. Similarly, Poly(dimethylsiloxane) (PDMS) was the second most commonly applied treatment. PDMS is known for its flexibility, low glass transition temperature (typically around -125°C), and high thermal stability. It is resistant to heat, water, oxidation, and various chemicals, with some of its advantages presented in Figure 5B.

Additionally, it offers easy processability and is biocompatible. PDMS has numerous applications in various fields, including mold making (due to its ability to reproduce intricate details and easy mold release properties), microfluidics (characterized

Figure 3. Evolution of papers' publication with time, during the last 5 years.

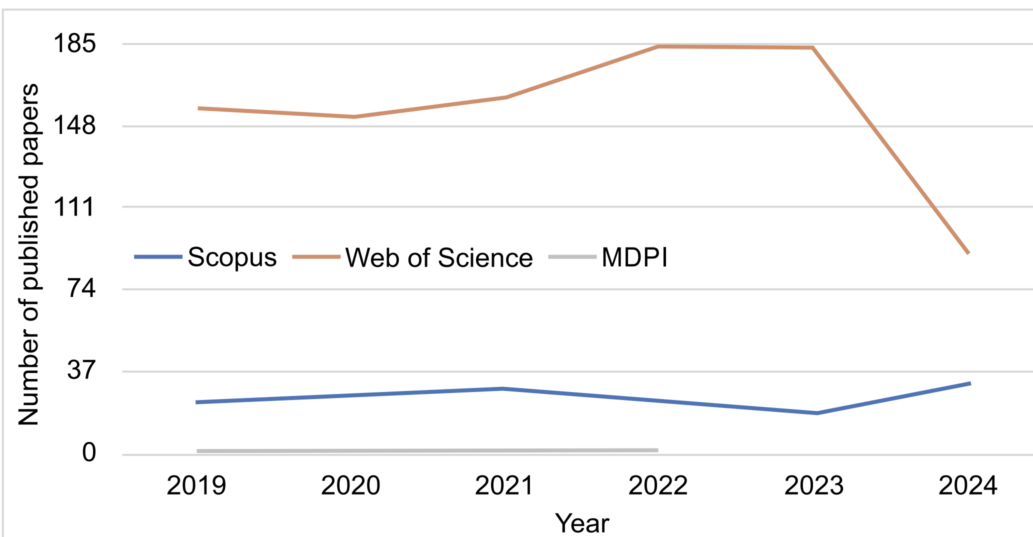


Figure 4. Type of modification process used for the fabrication of superhydrophobic textiles (A) and the type of nanomaterial and/or additive used for the superhydrophobic textile manufacturing (B).

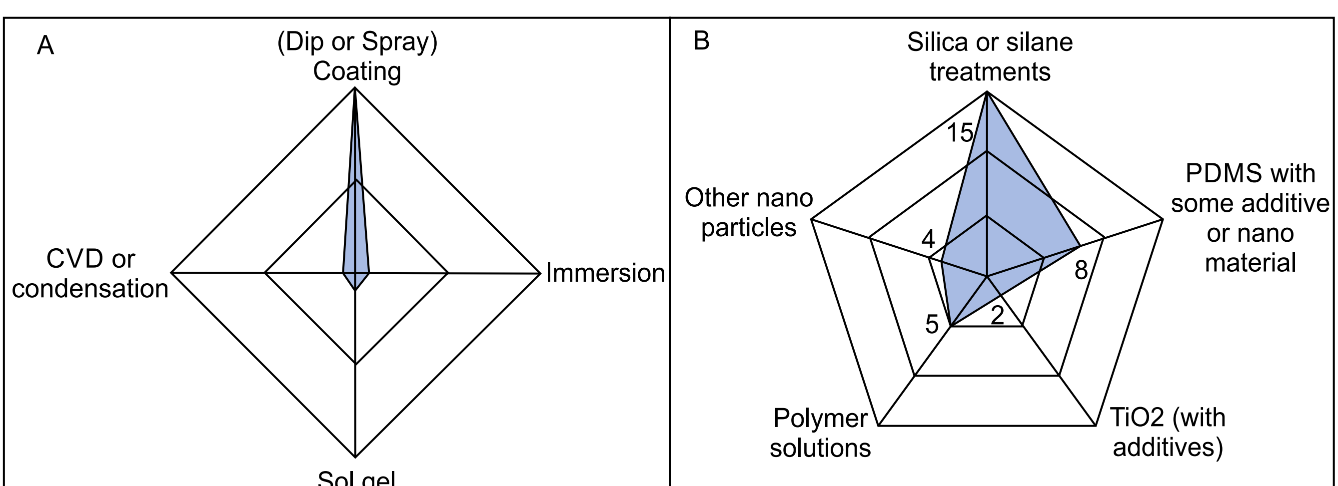
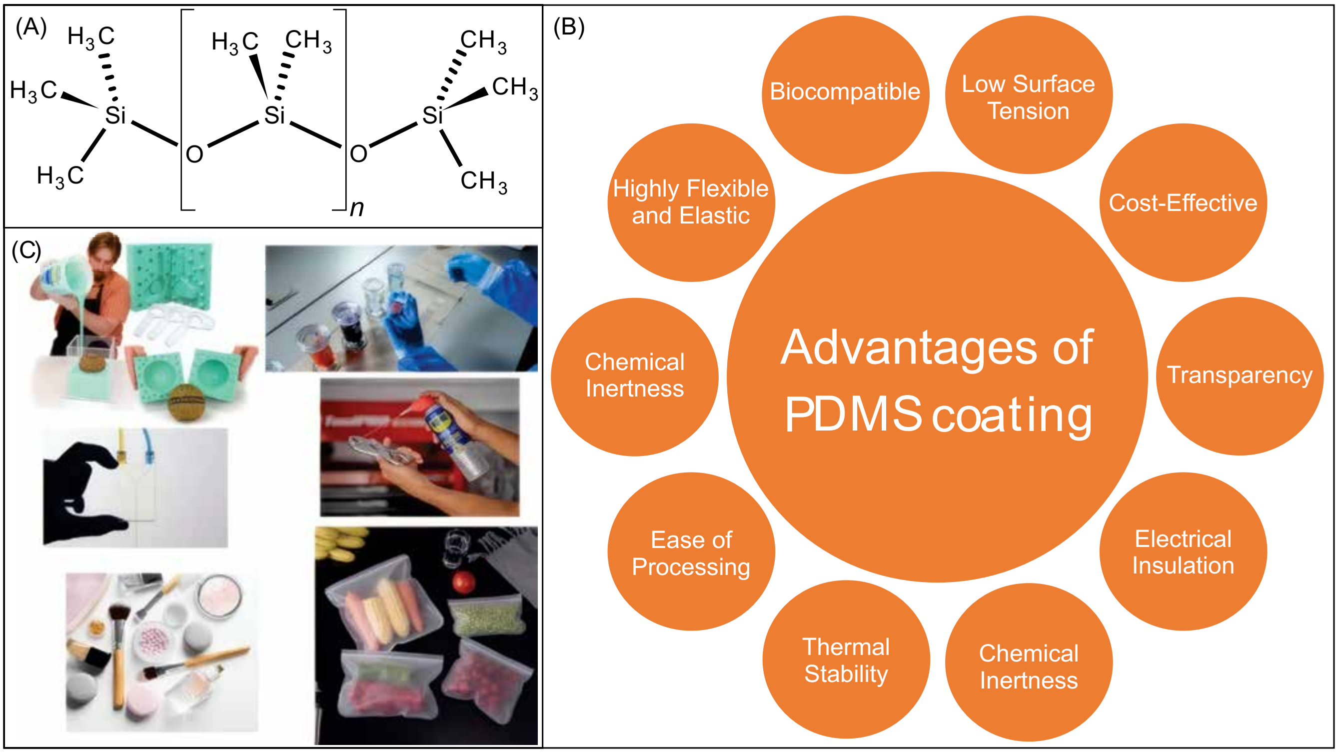


Figure 5. Molecule structure of PDMS (A), Advantages of PDMS coating (B), and Applications of PDMS in many fields (C).



by transparency, biocompatibility, and ease of fabrication), biomedical applications (such as catheters, prosthetics, and components in contact lenses), lubricants, cosmetics, and food packaging. Figure 5C presents some fields of application for PDMS and some advantages of the additive.

Finally, other nanomaterials have also been used to increase the hydrophobicity of textiles, including calcium nanoparticles, metal oxide nanoparticles, zinc oxide nanoparticles, and cellulose nanocrystals. Additionally, polymeric solutions were also identified, highlighting fluorinated polymers such as polytetrafluoroethylene and poly(perfluorohexyl ethyl acrylate-co-isocyanate ethyl methacrylate).

Conclusion

This paper showed the main results of a systematic review of manufacturing techniques used for superhydrophobic textiles and fabrics. The results showed that many papers have been published in the field over the last 5 years, utilizing nanotechnology, and it is expected that more papers will be published in the future. Additionally, the development of nanotechnology is also expected to utilize as-received textiles. The highlighted techniques include dip-coating and immersion, with some studies using CVD and the sol-gel approach. The main filler used was silica or silicate treatments, followed by PDMS treatments. PDMS is the leading modifier agent used for textiles when superhydrophobicity is required, offering numerous advantages and applications in various industries, including biomedicine, cosmetics, and packaging. Future research papers are expected to utilize nanotechnology, with a focus on silica, silicates, and innovative methodologies.

Acknowledgments

The authors are grateful to the TRL9 TECH Company and the Brazilian Research Agency, CNPq, for their technical and financial support.

References

1. Pakdel E, Zhao H, Wang J, et al (2021) Superhydrophobic and photocatalytic self-cleaning cotton fabric using flower-like N-doped TiO2/PDMS coating. Cellulose 28:8807–8820. https://doi.org/10.1007/S10570-021-04075- 3/FIGURES/10
2. Eslami E, Jafari R, Momen G (2021) A review of plasma-based superhydrophobic textiles: theoretical definitions, fabrication, and recent developments. Journal of Coatings Technology and Research 2021 18:6 18:1635–1658. https://doi.org/10.1007/S11998-021-00523-8
3. Laroche A, Ritzen L, Guillén JAM, et al (2020) Durability of Superamphiphobic Polyester Fabrics in Simulated Aerodynamic Icing Conditions. Coatings 2020, Vol 10, Page 1058 10:1058. https://doi.org/10.3390/COATINGS10111058
4. Zhou X, Sun S, Zhang C, et al (2020) Facile fabrication of durable superamphiphobic PET fabrics. J Coat Technol Res 17:711–718. https://doi.org/10.1007/S11998-019-00289-0/METRICS
5. Kerche EF, Fonseca E, Schrekker HS, Amico SC (2022) Ionic liquid- functionalized reinforcements in epoxy-based composites: A systematic review. Polym Compos. https://doi.org/10.1002/PC.26956
6. Ornaghi HL, Kerche EF, Neves RM, et al (2022) A Systematic Review of New Trends in Ionic Liquids Applied to Electrolytes on Polysaccharides. Polysaccharides 2022, Vol 3, Pages 502-514 3:502–514. https://doi.org/10.3390/POLYSACCHARIDES3030030
7. Lazzari LK, Kerche EF, Figueiredo FR, et al (2024) Polyurethane foam coated with organic filers for sound absorption: A briefre view. SAE Technical Papers. https://doi.org/10.4271/2023-36-0088
8. Kerche EF, Lazzari LK, de Bortoli BF, et al (2024) A systematic review of enhanced polyurethane foam composites modified with graphene for automotive industry. Graphene and 2D Materials 2024 1–20. https://doi.org/10.1007/S41127-024-00073-X
9. Tian N, Wei J, Li Y, et al (2020) Efficient scald-preventing enabled by robust polyester fabrics with hot water repellency and water impalement resistance. J Colloid Interface Sci 566:69–78. https://doi.org/10.1016/J.JCIS.2020.01.067
10. Liu Y, Liu J, Wang Z, et al (2022) Robust and durable superhydrophobic and oil- absorbent silica particles with ultrahigh separation efficiency and recyclability. Microporous and Mesoporous Materials 335:111772. https://doi.org/10.1016/J.MICROMESO.2022.111772
11. Li YL, Kinloch IA, Windle AH (2004) Direct Spinning of Carbon Nanotube Fibers from Chemical Vapor Deposition Synthesis. Science (1979) 304:276–278. https://doi.org/10.1126/science.1094982
12. Rostami A, Pirsaheb M, Moradi G, Derakhshan AA (2020) Fabrication of durable superhydrophobic nanofibrous filters for oil-water separation using three novel modified nanoparticles (ZnO-NSPO, AlOO-NSPO, and TiO2-NSPO). Polym Adv Technol 31:941–956. https://doi.org/10.1002/PAT.4828
13. Satria M, Saleh TA (2023) Synthesis of multifunctional superwettable zinc nanoparticle with pH-bidirectional responsive for efficient emulsion separation. Journal of Water Process Engineering 52:103501. https://doi.org/10.1016/J.JWPE.2023.103501
14. Saxena N, Paria S (2019) Fractal pattern mediated superhydrophobic glass and metallic surfaces using PTFE particles: a generalized simple approach. New Journal of Chemistry 43:8075–8084. https://doi.org/10.1039/C9NJ00620F