Nanotechnology in the development of optical sensors

Roccopio Malaespina[1,*], Alberto Leon Cecilla[2], María Dolores Fernández Ramos[1], Vanesa Martos Núnez[3], Modesto T. López-López [2,4] , Antonio Luis Medina Castillo[1,4]

[1]Departamento de Química Analítica, Universidad de Granada, Avd. Fuentenueva s/n, 18071 Granada, España;
[2]Departamento de Física Aplicada, Universidad de Granada, Avd. Fuentenueva s/n, 18071 Granada, España;
[3]Departamento de Fisiología vegetal, Universidad de Granada, Avd. Fuentenueva s/n, 18071 Granada, España;
[4]Instituto de Investigación Biosanitaria Ibs.GRANADA, E-18014 Granada, Spain.

The engineering of nano- and micro-structured materials functionalized with fluorescent probes represents an emerging strategy for developing faster, miniaturizable, and cost-effective detection systems. In this context, the high surface area, tunable functional density, and compatibility with optical platforms make nanotechnology a highly promising approach for sensitive analytical signal transduction (1). In this work, we present the design, synthesis, and characterization of two sensing platforms for the determination of Diacetyl (DA). DA is a common secondary metabolite generated during fermentation processes and is characterized by an extremely low sensory threshold, severely affecting the organoleptic quality of fermented products such as beer and wine. Conventional DA analysis is typically performed by HPLC-MS, a highly sensitive but costly technique requiring complex sample-preparation procedures, advanced instrumentation, trained personnel, and the use of non-sustainable solvents (2). Rhodamine B is known to undergo fluorescence quenching in the presence of hydrazine; however, the Rhodamine B–hydrazine complex regains fluorescence upon selective reaction with carbonyl groups such as those present in DA (3). First of all, core–shell magnetic microparticles (magnetic core/polymeric shell) functionalized with the Rhodamine B–hydrazine complex and integrated into a fiber-optic-based detection device for DA sensing in fermented beverages. The particles were obtained through a three-step synthetic process: (i) synthesis of oleic-acid-coated magnetite nanoparticles (Fe_3O_4–OA, 10–15 nm) followed by silica coating (Fe_3O_4–OA–CNCs@SiO_2); (ii) growth of a hydroxyl-rich polymer shell via precipitation polymerization (Fe_3O_4–OA–SiO_2@POLYMER–OH); (iii) functionalization with the Rhodamine B–hydrazine complex (Fe_3O_4–OA–SiO_2@POLYMER–RBH). In parallel, an automated interface (Elec-INFaz) was developed to position the particles within the optical fiber's field of view, enabling stable and reproducible fluorescence measurements. An alternative sensing platform was also investigated to improve sustainability and simplify synthesis, based on a cellulose membrane with a high density of hydroxyl groups, functionalized with the same Rhodamine B–hydrazine complex. This system exhibited higher sensitivity and faster response times than the core–shell particles, demonstrating significant potential for next-generation DA sensors in the fermented-beverage industry.

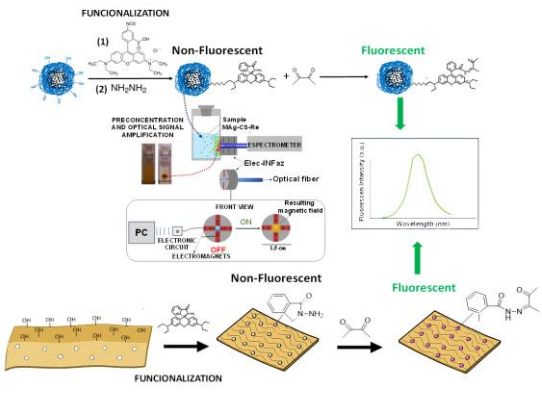

Fig.1. Schematic representation of the synthesis and activation pathways for both the magnetic core–shell particles and the functionalized cellulose membrane.

Keywords. Magnetic particles, cellulose membrane, optical sensors, fiber optic, nanotechnology, diacetyl, beer.

Acknowledgements. This work was supported by This work also was supported by the project PID2024–157217OB-I00 funded by Ministry of Science, Innovation and Universities, State Plan Reseach Projects, Call for Proposals 2024, and also this work is part of the Grants C. EXP. 030. UGR23 and C. EXP. 103. UGR23 funded by Consejería de Universidad, Investigación e Innovación and by ERDF Andalusia Program 2021-2027,
References:

1) Pateraki, C., Paramithiotis, S., & Drosinos, E. H. (2023). Current state of sensors and sensing systems utilized in beer analysis. Beverages, 9(1), 5. https://doi.org/10.3390/beverages9010005
2) Cordeiro, T., Vilela, A., Amaro, L. F., & Torres, C. (2012). Development and validation of a high-performance liquid chromatography method for the determination of diacetyl in beer. Journal of Agricultural and Food Chemistry, 60(13), 3453–3458. https://doi.org/10.1021/jf205107w
3) Cheng, Y., Zhao, D., Lv, X., Xu, K., & Li, J. (2009). A fluorescent probe for diacetyl detection. Journal of Fluorescence, 19, 63–70. https://doi.org/10.1007/s10895-008-0450-y