The OPL powder has been characterized using attenuated total reflection Fourier transform infrared (ATR–FT–IR) spectroscopy, thermogravimetric analysis (TGA), and scanning electron microscopy (SEM). In detail, ATR FT–IR analysis was conducted in the frequency range 650–4000 cm−1 using a PerkinElmer Spectrum One FT–IR spectrometer equipped with a Universal ATR sampling accessory. For each spectrum, 32 scans were performed with a resolution of 2 cm−1. Thermal stability was assessed by thermogravimetric analysis (TGA), subjecting the sample to heating from 50 to 800 °C at 10 °C/min in a nitrogen atmosphere (40 ml/min), using a PerkinElmer TGA4000 apparatus. The morphology was investigated, after gold sputtering, by a FEI XL 20 SEM, equipped with a secondary electron detector. To assess the polyphenol content, the Folin–Ciocalteu assay was used. Specifically, 0.5 g of OPL powder underwent extraction with 5 ml of ethanol/water (70:30, vol/vol) in glass vials using an ultrasonic bath for 120 min, followed by 15 min of vortex mixing. Subsequent to centrifugation (5 min at 2500 rpm), the supernatants were collected, and the residual OPL pellet underwent a second complete extraction under identical conditions [39]. The two resulting liquid extracts were combined, filtered, and stored at − 20 °C prior to analysis, conducted at = 765 nm using a UV–Vis Spectrophotometer (Varian Cary 100 bio, Dual Beam). Gallic acid served as the standard, and the concentration was expressed as milligrams of gallic acid equivalent (GAE) per gram of dry weight (DW). The overall antioxidant activity of OPL was assessed through ferric ion reducing power (FRAP) and the DPPH assay following the methodologies outlined by Benzie et al. [40] and Floegel et al. [41], respectively. In the FRAP assay, 20 l of the previously extracted liquid from OPL was combined with 60 l of the FRAP working solution, produced by mixing a 10:1:1 solution of 0.3 M acetate buffer, 10 mM TPTZ solution in 40 mM HCl, and 20 mM ferric chloride. Following a 60–minute incubation in dark conditions, the absorbance at 593 nm was measured. The FRAP antioxidant activity was quantified in mmol Fe2+/g of DW, and values were compared against a standard curve of ferrous sulfate. For the DPPH assay, 25 l of the extracted liquid and 25 l of H2O were mixed with 3.45 ml of DPPH 100 M. After a 30–minute incubation at room temperature in the dark, the reduction in absorbance at 517 nm was measured. DPPH antioxidant activity was expressed as mmol Trolox/g of DW. Values obtained from the FRAP and DPPH assays were presented as mean ± SD, with each sample analyzed in triplicate.

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