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Electrospun Coating of Macroscopic Particles: Morphology, Hydrophobicity, and Release Properties

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ABSTRACT

Electrospinning is an effective method for generating coatings with tunable morphology and diffusion properties, yet its application to macroscopic particles remains challenging because curved surfaces disrupt the electric field, promote nonuniform deposition, and can lead to particle agglomeration. In this work, we developed an electrospinning strategy for coating macroscopic particles under dynamic rotational motion, enabling uniform coverage of the entire particle surface while reducing electrostatic clumping. Using urea granules as a model substrate, biodegradable beeswax/polycaprolactone (BW/PCL) coatings were applied with distinct bead, bead/fiber, and fiber architectures by varying solution concentration and operating conditions. These structural changes were used to tune coating thickness, porosity, hydrophobicity, water vapor permeability, and mechanical strength, with the aim of designing improved controlled-release fertilisers.

Compared with conventionally prepared spray coatings, the electrospun coatings provided more uniform surface coverage and greater control over coating structure. The bead-type coating was particularly promising, exhibiting the lowest water vapor permeability of 0.08×10^{-7} *g m* h^{-1} m^{-2} Pa^{-1}*, compared with* 0.13×10^{-7} *g m* h^{-1} $m{-}2$ Pa^{-1} *for the spray-coated sample, corresponding to a 38% reduction in permeability. Structural differences also affected wetting and barrier performance, with the bead/fiber architecture showing the highest water contact angle, while the bead architecture formed a denser and less permeable coating. In addition, electrospun coatings improved granule strength and compressibility relative to uncoated urea, indicating potential advantages not only in nutrient release but also in handling and storage. Most importantly, the optimized electrospun bead coating prolonged urea release in water from 12 to 26 days, demonstrating that coating morphology alone can strongly influence nutrient diffusion without changing the coating chemistry.*

Building on these findings, our ongoing work explores a new multilayer coating concept in which a water-absorbent intermediate layer is incorporated within the inner and outer shell structures. The purpose of this layer is to trap and temporarily retain diffusing water, thereby delaying transport to the urea core and introducing an additional delay in the start of the release mechanism beyond simple barrier effects. Early soil tests indicate that this multilayer *design can generate an additional delay of approximately 5 days in urea release. This emerging strategy is particularly attractive because it combines the structural tunability of electrospinning with functional layer-by-layer design, opening a pathway toward next-generation controlled-release fertilisers with improved delayed-control, reduced nutrient loss, and greater adaptability to agricultural requirements. Together, these results highlight electrospinning as a tunable method for engineering particle coatings and demonstrate the potential of multilayer absorbent-barrier structures for advancing sustainable fertiliser technologies.*

KEY WORDS

electrospinning; particle coating; nanostructured coatings; morphology control; uniform coating ; coating architecture

BIOGRAPHY

Majid Noorbakhsh Soltani is a PhD candidate in the Department of Chemical Engineering at the University of Melbourne and a member of the ARC Research Hub for Smart Fertilisers. His research is focused on engineering biodegradable coatings for controlled-release fertilisers using electrospinning and multilayer coating design. His work investigates how coating structure influences permeability, mechanical properties, and nutrient release behavior. He has expertise in polymer-based coating systems, experimental design, and material characterization. His broader goal is to develop scalable and sustainable fertiliser technologies that improve nutrient efficiency, reduce environmental losses, and support more sustainable agricultural production.

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