Encapsulation of emulsions in monodisperse alginate capsules: a high-throughput droplet millifluidics approach

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Microfluidics is a well-established emulsification technique to produce complex liquid multiphase systems with high accuracy [1] . By adding a phase changing step to the process, even structured systems such as core-shell capsules with a liquid core and a gelled shell can be achieved [2] . A formulation based on biopolymers turns these capsules into interesting candidates for a wide range of application in life science related research and industries [3] . However, it remains a challenge to overcome the gap between process specific and formulation related limitations and the requirements set by an application in food production. This industry commonly requires high mass flows and convenient process set-ups, whereas microfluidics is known for its limitations regarding throughput and process stability over time.
Therefore, this research focuses on developing and adapting a microfluidic process based on a glass capillary device so that it is capable of producing significant amounts of alginate-based core-shell capsules with high accuracy. It explores the interplay between increased capillary diameters and adjusted formulation parameters, along with their impacts on process stability and product properties, at the interface between micro- and millifluidics.
As a result of this study, millimeter-sized core-shell capsules, consisting of a liquid water-in-oil emulsion core and a gelled calcium alginate shell, were produced, see Figure 1. In a coaxial glass capillary system, the two immiscible liquid phases formed a ring stream from which droplets periodically detached. The vertical alignment enabled the formation of large droplets in ambient air, the aqueous shell was furthermore gelled externally in reactant solution. The process was controlled by the orifice size of the outer capillary, fluid flow rates and alginate concentration. The optimized parameters were process stability over time, maximum achievable volume flow rates, droplet size and droplet size homogeneity, and core-shell ratio.
The developed process can be used to produce novel encapsulation systems for foods at relatively high throughputs. Stable production of spherical, monodisperse capsules with controlled product properties were achieved at up to 240 ml/h in dripping regime with nearly 100 % encapsulation efficiency. Furthermore, the influence of the gelation step on capsule size and loading capacity was elucidated and a developed model predicted the final properties with an accuracy above 97 %. The findings of this study confirm the ability of in-air millifluidics to efficiently encapsulate inner phase of variable viscosity by creating structured particles with precisely controlled attributes like core diameter, shell thickness and shell hardness.

Keywords:
alginate hydrogels, emulsion, core-shell capsule, co-flow

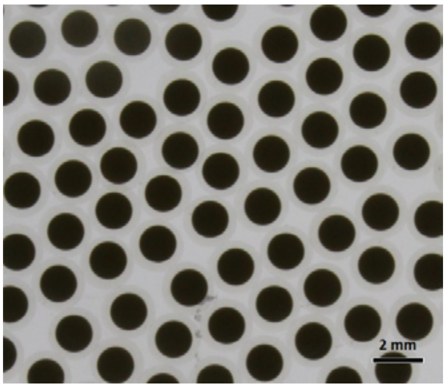

Figure 1: Monodisperse milli-capsules with a gelled alginate shell and a liquid water-in-oil emulsion core

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