Valorization of wastes from lavender distillation through optimized extraction and encapsulation processes

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Lavender is a fragrant herb widely recognized for its therapeutic and aromatic properties with many applications such as medicine and cosmetics. Specifically, lavender's essential oil is the main factor for its wide array of uses as it is a valuable natural product known for its soothing and calming effects. The ever-increasing demand for lavender essential oil in various industries encourages the continuous optimization of the extraction procedures for higher efficiency yields. The primary method for the lavender essential oil extraction is distillation, a process that is widely used in essential oil production and efficiency levels vary greatly with equipment and operational conditions (de Elguea-Culebras *et al* 2022). However, production of lavender essential oil results in excessive quantities of waste and this phenomenon is further exacerbated by the low amounts of essential oil present in the plant.

The limited efficiency in essential oil production (0.8-1.3%) demands huge quantities of raw lavender material that produces different fractions of residual waste. Liquid fractions constitute of either condensed vapors named hydrosols or leachates, which are the residual waters infused by the distillation raw material. Solid wastes stem from the plant parts, such as stalks, flowers and leaves that remain after the distillation process, contain a significant amount of bioactive compounds, such as phenolic acids and flavonoids that could be utilized for human benefit (Vasileva *et al*, 2018). An extraction procedure could be adequate in acquiring a significant fraction of these residual waste phytochemicals as depicted in the studies of Ivanov *et al* (2018) and Turrini *et al* (2021), utilizing aqueous-solvents solutions and green techniques, such as maceration and ultrasounds, to enhance the extraction process. Extractability and efficiency could also be augmented with technologies such as microwaves. However, it should be noted that such extracts deteriorate at an extreme rate.

Phenolic extracts feature unsaturated bonds in their structure and are prone to oxidative compounds and exposure to light and heat. The liquid forms of these extracts also present higher mass volumes that are difficult to transport and storage, while microbial and biochemical stabilization also proves to be a problem (Ahmad-Qasem *et al*, 2016). To combat this adversity, encapsulation could be a valuable asset in retaining the biological ability of such susceptible compounds and controlling their release in the gastrointestinal tract. Effective methods of encapsulation include spray drying, ionic gelation, and co-crystallization and have been utilized successfully in *Aronia melanocarpa* phenolic extracts to protect them from deterioration, maintain their biological qualities, and mask astringent flavors (Tzatsi and Goula, 2021).

In spray drying the encapsulated compounds are trapped in a glassy polysaccharide or proteinaceous matrix due to contact with hot air of the liquid slurry consisting of the wall material and the extract. Product quality is surprisingly high, considering the high air temperature, a fact that can be attributed to the low drying time. Spray drying has been utilized to encapsulate lavender essential oil (Burhan *et al*, 2019) and other plant waste such as pomegranate peels extracts (Kaderides and Goula, 2019). Ionic gelation is a drop-wise extrusion that most commonly uses alginate gels by ionic cross-linking with multivalent cations to capture the extract inside a biopolymer matrix. The most recognized mechanism is the egg-box model, which refers to a caging configuration adopted by adjacent l-guluronate residues when alginate solutions come into contact with calcium chloride. The specific encapsulation method has been reported by Gorbunova *et al* (2018) for beet greens and Otalora *et al* (2018) for betaxanthins from cactus. Co-crystallization is a process where the active ingredient is trapped inside the conglomerate of crystals formed by sucrose. This method is based on the modification of sucrose's crystalline structure from perfect to imperfect and irregular crystals, resulting in the formation of a porous matrix to cage the phenolic ingredients. High temperatures and rapid crystallization of a supersaturated sucrose solution at low moisture are necessary (Chezanoglou and Goula, 2021). Co-crystallization has limited applications in food industry, but has been utilized for the encapsulation of extracts from banana pulp and peel (Khawas and Deka, 2017) and pomegranate peel (Chezanoglou *et al* 2023).

Encapsulation is reported as an effective technology to ensure the quality and stability of phytochemical compounds, but lavender has scarce reports regarding the utilization of its extracts. Furthermore, it seems that lavender waste specifically has not been investigated as a potential phenolic compound candidate for encapsulation, yet. Considering its residual phytochemical content, it could very well be upcycled to isolate and capture these beneficial substances for human benefit while also removing them from waste reduces its negative environmental impact. Thus, the objective of this work is to optimize the aforementioned encapsulation methods for lavender flower waste extracts resulting from essential oil distillation processes. Depending on the experimental design the optimum encapsulation conditions were determined along with the effects of such parameters on encapsulation efficiency. Statistical analysis was enrolled in order to determine the importance of each parameter and possible factorial interactions. The main physicochemical properties of the obtained encapsulated products, such as moisture content, bulk density, wetting time, hygroscopicity, particle morphology, and release kinetics in water, were also studied. The obtained final dried extract could be used as a functional component to supplement foods while pertaining to the values of a circular and sustainable economy.

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