Abstract

Although water is a dominant ingredient in many cosmetic and personal care formulations, it has no direct cosmetic effect on the skin. Instead, it mainly serves as a base component and solvent for other ingredients. Emulsion is a biphasic system comprising aqueous and oily phases, which are stabilized by emulsifiers. Bigel is formed by combining hydrogel and oleogel, consisting of a water-based phase containing hydrophilic polymers and an oil phase gelled with an organogelator. The growing awareness of environmental challenges, including the global water crisis, has increased interest in developing sustainable technologies across various industries. In cosmetics, this is crucial due to their enormous production – most consumers worldwide use several cosmetic and personal care products every day. Owing to the rapidly shrinking resources of clean and accessible water, water recovery during product formulation is a responsible attitude towards climate change and the global water crisis.

The objective of this research was the design, methodology development and characterization of novel eco-friendly materials based on freeze-dried emulsions and bigels composed of natural polymers, lipids and cryoprotectants intended for cosmetic and dermatological applications. Moreover, polymer microparticles loaded with *Sambucus nigra* (elderflower) extract were incorporated into prepared materials. This extract was selected as the model active compound due to its high antioxidant content and proven beneficial effects on skin condition. Encapsulation of the extract in microparticles prior to freeze-drying aimed to protect it during processing and enable its controlled release during application to the skin. The developed material was designed to rehydrate into a functional emulsion or bigel using only a minimal amount of aqueous solvent immediately before use (during spreading on the skin), offering a new, sustainable alternative to conventional water-based cosmetic products. Accordingly, it is hypothesized that it is possible to reduce water consumption during the preparation of cosmetic materials while preserving the functional properties of a prototype based on freeze-dried emulsions and bigels containing plant extract-loaded microparticles.

Extracts from commonly found Polish medicinal plants – *Viola tricolor*, *Veronica officinalis*, *Glechoma hederacea*, *Plantago lanceolata*, *Achillea millefolium*, *Sambucus nigra*, *Tilia cordata*, and *Potentilla erecta* – were obtained using Soxhlet extraction with water and ethanol. These extracts were characterized according to total polyphenol content (TPC), total flavonoid content (TFC), and antioxidant activity using CUPRAC, FRAP, and DPPH assays.

Selected extracts were encapsulated into chitosan microparticles, and their loading capacity and *in vitro* release profiles were studied. The highest level of TPC, TFC and antioxidant activity was noted in *Sambucus nigra* aqueous extract.

The microparticles were then introduced into emulsions and bigels composed of biopolymers (sodium alginate, whey protein isolate, ethylcellulose), cryoprotectants (glycerin, propylene glycol, sorbitol, mannitol, trehalose), lipids (sunflower oil, sea buckthorn oil, beeswax), and an emulsifier (Span-80). The homogenization time and speed were evaluated to optimize the size distribution of the oily phase droplets. The prepared freeze-dried emulsions and bigels were characterized by scanning electron microscopy (SEM), mechanical properties, residual moisture content, porosity and density measurements, degradation properties, swelling ratio, and biophysical skin parameter analysis, including skin hydration, color and barrier quality – transepidermal water loss (TEWL).

The results of this research contribute to:

- the development in the field of cosmetic chemistry and materials science – the methodology development of a new cosmetic form, i.e., freeze-dried emulsions and bigels (dissolving in a minimal amount of an aqueous solvent) containing microparticles with enclosed plant extract (released during the material application),
- the development of solutions for health, especially for people allergic to preservatives – reduced water content in the material can reduce the material's susceptibility to microbial growth, potentially reducing the amount of added preservatives,
- environmental protection – reducing water usage due to the potential to reuse water sublimed during freeze-drying and reducing the plastic needed for packaging of developed materials (they are in dry form and have a lower mass than traditional emulsions).

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