21 Ružičkini dani
DANAS ZNANOST – SUTRA INDUSTRIJA
9. – 11. rujna 2026. • Vukovar • Hrvatska

Preserving the bioactivity of elderflower through multifunctional microparticles

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Introduction

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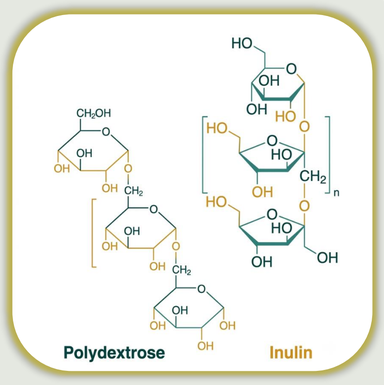
Elderflowers has attracted considerable scientific and commercial interest due to its **abundance of polyphenols and flavonoids**, which confer anti-inflammatory, antimicrobial, and antioxidant properties supporting its traditional and potential **therapeutic applications** in respiratory health, atherosclerosis prevention, and diabetes management.

- **Inulin and polydextrose** are effective polysaccharide carriers that enhance the **stability** and **protection** of bioactive compounds.
- Together, they **provide dual functionality** by improving bioactive stability while enhancing the nutritional and functional value of the final product.

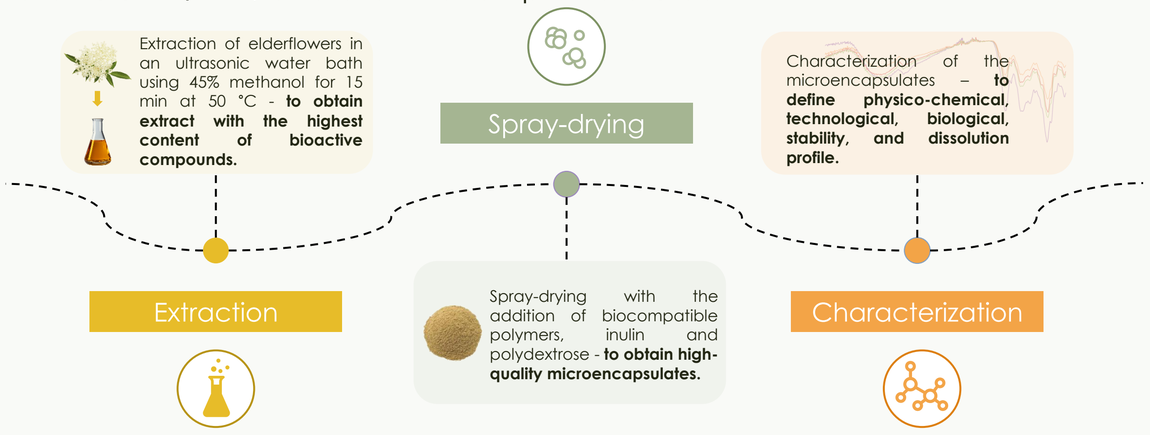


Main aim

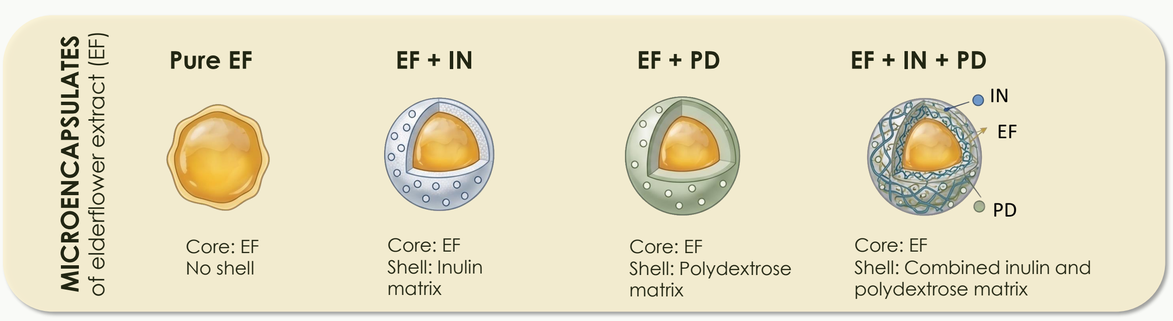
To develop high-quality **microencapsulates** of elderflower extract using inulin and polydextrose as carrier materials, providing **dual functionality** by enhancing the **stability and protection** of sensitive bioactive compounds during processing and storage, while **simultaneously improving the nutritional and functional properties** of the final product.

Methods

Elderflower extract (EF) was prepared using **45% methanol** in an **ultrasonic water bath** for 15 min at 50 °C. The obtained extract was subsequently utilized for the development of advanced delivery systems.
Based on **spray-drying technology**, four formulations were prepared **using inulin (IN)** and **polydextrose (PD)** as carrier materials: (1) pure elderflower extract (EF) without carrier, (2) EF with 20% IN, (3) EF with 20% PD, and (4) EF with a combination of carriers (10% IN and 10% PD). Spray drying was performed under the following operating conditions: inlet temperature 145 ± 5 °C, outlet temperature 70 ± 5 °C, drying air flow rate 75 m³/h, liquid feed rate 10.5 mL/min, and atomization pressure 3 bar.



Comprehensive characterization of the resulting microencapsulates was conducted using HPLC for phytochemical profiling and stability evaluation, while particle size distribution, Fourier-transform infrared (FTIR) spectroscopy, and differential scanning calorimetry (DSC) were employed for **physicochemical and technological characterization.**
The **antioxidant and hypoglycemic potential** of the spray-dried powders was evaluated through *in vitro* assays, whereas the release profiles of the major bioactive compounds were investigated using **dissolution testing** at pH 1.2, 4.5, and 6.8.



Results and Discussion

The **total phenolic content** (TPC) of the microencapsulated elderflower extracts ranged from 103.54 to 124.46 mg GAE/g dry extract (Table 1). **Rutin and chlorogenic acid** were identified as the predominant compounds, with rutin present at slightly higher levels (36.34–44.10 mg/g) than chlorogenic acid (31.43–38.75 mg/g). The stability study demonstrated that, **after three months** of storage at 25 °C and 40 °C, **no statistically significant changes** were observed in either TPC or the levels of individual compounds in any formulation compared with the initial values.

Table 1. Phytochemical profiling of microencapsulates

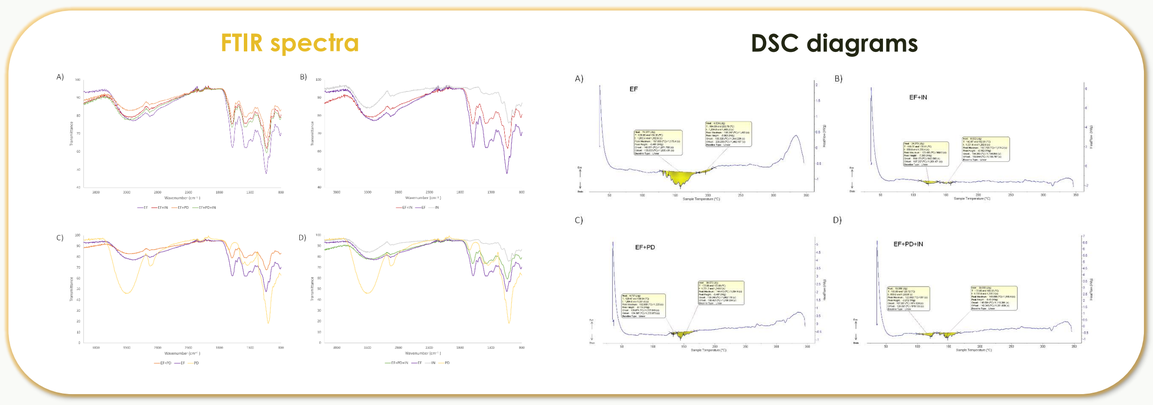
Sample	Chlorogenic acid (mg/g)	Rutin (mg/g)	TPC (mg GAE/g)
EF	38.75 ± 1.94 ^{a}	44.10 ± 2.71 ^{a}	124.46 ± 2.26 ^{a}
EF+IN	31.43 ± 1.51 ^{b}	36.34 ± 1.34 ^{b}	103.54 ± 5.19 ^{b}
EF+PD	32.11 ± 0.57 ^{b}	37.12 ± 1.80 ^{b}	107.72 ± 0.34 ^{b}
EF+IN+PD	31.80 ± 1.04 ^{b}	36.96 ± 1.02 ^{b}	106.36 ± 1.73 ^{b}

The addition of **PD markedly increased the drying yield** (60.91%) compared with the control (27.68%), while IN provided a moderate improvement (32.84%); the combined use of IN and PD also enhanced yield (50.26%), although to a lesser extent than PD alone (Table 2).

- **Hydrogen bonding** between the hydroxyl groups of the carriers and phenolic compounds facilitated **efficient encapsulation** of the bioactives within the polymer matrices, thereby enhancing the **thermal stability** of the powders.

Table 2. Physical characteristics of microencapsulates

Sample	Powder Yield	Moisture content	Bulk (g/mL)	Tapped (g/mL)	Carr index (%)	Hausner ratio
EF	27.68 ± 0.87^{d}	4.55 ± 0.23^{a}	0.292 ± 0.01^{a}	0.433 ± 0.01^{a}	32.56 ± 1.25^{b}	1.48 ± 0.07^{a}
EF+IN	32.84 ± 0.71^{c}	2.61 ± 0.08^{c}	0.280 ± 0.01^{a}	0.448 ± 0.02^{a}	37.50 ± 1.24^{a}	1.60 ± 0.06^{a}
EF+PD	60.91 ± 2.09^{a}	4.54 ± 0.10^{a}	0.305 ± 0.01^{a}	0.452 ± 0.01^{a}	32.52 ± 1.31^{b}	1.48 ± 0.06^{a}
EF+IN+PD	50.26 ± 2.46^{b}	3.33 ± 0.15^{b}	0.288 ± 0.01^{a}	0.443 ± 0.02^{a}	34.99 ± 1.38^{ab}	1.54 ± 0.06^{a}



The highest **antioxidant capacity** was observed for pure EF and EF+IN powders, with no significant difference between them, while EF+PD and EF+IN+PD exhibited slightly higher IC_{50} values (Table 3). All microencapsulates showed **greater inhibitory activity against a-glucosidase** than a-amylase, with the strongest a-glucosidase inhibition achieved by **formulations containing inulin**, either alone or in combination with polydextrose (Table 3).

Table 3. Biological evaluation of microencapsulates

Sample	DPPH IC_{50} (mg/ml)	a-glucosidase IC_{50} (mg/ml)	a-amylase IC_{50} (mg/ml)
EF	0.27 ± 0.02 ^{b}	4.18 ± 0.09 ^{a}	3.36 ± 0.74 ^{bc}
EF+IN	0.31 ± 0.02 ^{b}	3.66 ± 0.05 ^{b}	5.43 ± 0.57 ^{a}
EF+PD	0.42 ± 0.03 ^{a}	4.30 ± 0.05 ^{a}	2.83 ± 0.25 ^{c}
EF+IN+PD	0.42 ± 0.02 ^{a}	3.74 ± 0.06 ^{b}	4.64 ± 0.28 ^{ab}
Chlorogenic acid	0.011 ± 0.001 ^{c}	0.192 ± 0.008 ^{cd}	0.688 ± 0.010 *
Rutin	0.008 ± 0.000 ^{c}	0.114 ± 0.003 ^{d}	0.053 ± 0.003 *
Acarbose	/	0.285 ± 0.019 ^{c}	0.366 ± 0.018 *

Conclusion

Overall, the findings highlight the efficiency of inulin and polydextrose as natural carriers for the stabilization and delivery of phenolic-rich elderflower extracts, supporting their application in functional food and pharmaceutical formulations.

Acknowledgements: This research was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, grant number 451-03-33/2026-03/200003.