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# Sustainable NADES-Based Extraction of Bioactive Compounds from Coccoloba Uvifera: Elucidating the Potential of a Coastal Resource for Functional Foods

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## Abstract

Extraction of bioactive compounds from locally available raw materials has become a key strategy for developing functional ingredients with added value and a sustainable focus. In this context, *Coccoloba uvifera* (sea grape), a member of the Polygonaceae family and widely distributed across the insular Caribbean, southern Gulf of Mexico coastline, Caribbean shores of Central America, and the northern region of South America, stands out as a coastal resource with high potential for the recovery of bioactive compounds. As a perennial evergreen shrub or small tree native to tropical and subtropical shorelines, its physiology, adapted to extreme conditions of salinity, intense solar radiation, strong winds, and nutrient-poor sandy soils, favours the synthesis of metabolites associated with photoprotection, osmotic regulation, and environmental tolerance. These adaptive traits, characteristic of dune and littoral vegetation, contribute to its ecological resilience and reinforce its relevance as a promising source of bioactive compounds. These secondary metabolites, particularly flavonoids and phenolic acids, are associated with antioxidant activities and potential beneficial effects on cellular processes related to oxidative stress and human health, which strengthens the interest in recovering them through sustainable extraction strategies. This combination of ecological resilience, regional availability, and phytochemical richness positions the fruit as an attractive matrix for producing phenolic-rich extracts using green extraction technologies. The aim of this study was to investigate the recovery of bioactive compounds using three extraction systems: 80% methanol (Met80%) and two natural deep eutectic solvents (NADES): citric acid:water (1:1; 60% w/w) (AC) and fructose:water (1:1; 60% w/w) (FRUC), while also examining the effects of fruit maturity (ripe and unripe) and anatomical fraction (seed, pulp, and whole fruit). NADES-AC extracts yielded the highest levels of total flavonoids, reaching 53.65 ± 0.44 mg QE/g DW in ripe seeds, markedly outperforming both Met80% and NADES-FRUC and highlighting the strong affinity of NADES systems for flavonoid-rich matrices. In contrast, total polyphenols reached their peak concentration with Met80%, particularly in unripe seeds (196.50 ± 1.25 mg GAE/g DW). Vitamin C content also attained its maximum under Met80% extraction in unripe seeds (227.35 ± 41.28 mg AA/100 g DW), indicating pronounced solvent-dependent differences across maturity stages and fruit fractions. Antioxidant capacity assessed through the DPPH assay exhibited substantial variation among treatments, with the highest inhibition value

recorded at 94.49 ± 0.72%, corresponding to the NADES-AC extract obtained from unripe pulp. Although Met80% produced the highest concentrations of total polyphenols and vitamin C, the NADES systems exhibited a distinct advantage in the selective recovery of phenolic acids and flavonoids, a trend further supported by ultra-performance liquid chromatography. Collectively, these results underscore the value of *Coccoloba uvifera* as a high-potential coastal resource and open pathways for sustainable valorisation through green extraction technologies aimed at generating functional ingredients.

**Keywords:** Coccoloba uvifera, bioactive compounds, emerging coastal resource, NADES extraction, functional food

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