EDITORIAL

Circular Economy in Agriculture: The Case for Bioactive Compounds from Sea Buckthorn By-products

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The implementation of closed-loop manufacturing models in berry farming represents a transformative approach to sustainable agriculture, enhancing both environmental sustainability and economic resilience. By integrating waste materials back into the production cycle, these models minimize environmental impact while maximizing resource efficiency. In the context of sea buckthorn (*Hippophae rhamnoides L.*), a crop with significant nutritional and medicinal properties, utilizing by-products such as fruit residues pomace, leaves and twigs offers a practical solution to waste management challenges while creating high-value products for the food, cosmetic, and pharmaceutical industries. Food Institute of Kaunas University of Technology has implemented the project "Circular manufacturing model for producing biologically active materials", validating the soundness of closed-loop manufacturing systems for berries by demonstrating sustainable practices for the extraction and utilization of bioactive compounds from sea buckthorn by-products. The project results emphasize the feasibility of integrating eco-friendly extraction methods while addressing environmental and economic challenges.

Transformative Potential of Closed-loop Systems

Closed-loop systems not only address waste reduction but also create opportunities for economic diversification. Valorization of sea buckthorn by-products enhances profitability by opening new income streams for farmers, reducing dependency on external inputs and fostering resilience to market fluctuations. Moreover, integrating these systems promotes practices that enhance soil health and biodiversity, contributing to long-term agricultural sustainability (Velten et al., 2015; Oyewole and Sennuga, 2020). The rising demand for sustainable and ethically produced food further underscores the relevance of these systems, enabling farmers to meet evolving consumer preferences while reinforcing environmental stewardship (Eririogu et al., 2019).

Key results from sea Buckthorn By-product valorization

The project results reveal that sea buckthorn by-products are rich in bioactive compounds, such as polyphenols, flavonoids, and omega fatty acids. For instance, aqueous sea buckthorn leaf extracts contained up to 61.22 mg/g of phenolic compounds with antioxidant activity reaching 82%, while twig extracts contained up to 33.96 mg/g of phenolic compounds with antioxidant activity reaching 90%. Oil sea buckthorn pomace extractions yielded vitamin E (100.76 mg/100 g) and β-carotene (1.96 mg/100 g), underscoring the potential of these by-products for high-value applications.

Using water-based and enzymatic processes for extraction of bioactive compounds can be considered eco-friendly, as they allow recovering bioactive compounds with minimal environmental footprint. These techniques align with the goals of bioeconomy, which emphasizes creating sustainable products from biological materials with minimal environmental impact (Olba-Zięty, 2023). Importantly, the findings also indicate that shorter extraction cycles can achieve similar results to longer processes, reducing energy and time requirements without compromising yield.

Food safety considerations

Utilizing agricultural by-products in food and nutraceutical applications necessitates rigorous attention to food safety. Sea buckthorn residues, leaves, and twigs may harbor microbiological or chemical hazards,

including mycotoxins, or heavy metals. Effective risk management strategies, such as regular monitoring of raw materials, adherence to good agricultural practices, and the use of clean extraction technologies, are essential for mitigation of these risks (Bartkienė et al., 2021; Sandulachi et al., 2020). The project results demonstrated that the collection and initial processing of sea buckthorn berries was efficiently conducted, minimizing the risk of microbial proliferation. *Bacillus cereus, Escherichia coli, Staphylococcus aureus, Listeria monocytogenes, Salmonella, Enterobacteriaceae*, and yeast were not detected in processed raw materials. The number of microorganisms in ground leaves, twigs, and pomace varied between $< 1.0\times10^1$ and 2.4×10^5, while the number of mold fungi varied between $< 1.0\times10^1$ and 3.6×10^5. As a result, the microbiological profiles of leaves, twigs, and berry pomace ensure their suitability and safety for subsequent processing into biologically valuable products.

Challenges and opportunities

While closed-loop systems for sea buckthorn valorization demonstrate immense potential, challenges persist in achieving scalability and consistent product quality. Variations in raw material composition, extraction conditions, and processing techniques can impact bioactive compound yields. Addressing these challenges requires continued research and development, as well as validation through methodologies such as life cycle assessment (LCA). LCA not only quantifies environmental benefits but also ensures economic viability, providing stakeholders with actionable insights for improving resource use and minimizing waste (Yadav et al., 2022). Results reveal that in the case of aqueous extraction, the greatest environmental impact is due to the use of tap water; in the case of aqueous ethanol extraction, the greatest impact is due to the use of electricity and the cultivation of the plants from which ethanol is produced; and in the case of oil extraction, the greatest impact is due to the use of herbicides and pesticides on sunflowers from which the oil is obtained. The profitability is highest in oil extraction.

To summarize, the closed-cycle bioactive substance farming model exemplifies the synergy between sustainability and economic viability in agriculture. By optimizing extraction processes, incorporating food safety measures, and validating environmental benefits through LCA, sea buckthorn by-products can be transformed into high-value products that meet the demands of diverse industries. This approach not only enhances resource efficiency but also supports the transition to a more sustainable and resilient agricultural system. Through continuous innovation and cross-sectoral collaboration, the potential of sea buckthorn by-products can be fully realized, paving the way for a circular economy in agriculture.

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