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O6: Impact of Pulsed Electric Fields and High Pressure Processing Pretreatments on Physicochemical, Sensory, and Microbiological Quality of Freeze-Dried Beetroot Snacks

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Freeze-drying is widely recognized as one of the most effective dehydration methods for preserving the organoleptic properties and nutritional value of fruits and vegetables when compared to conventional drying techniques. However, the high energy consumption resulting from long processing times constrains its application at an industrial scale¹. In this context, the development of assisted freeze-drying processes using emerging technologies has gained increasing attention. Nonthermal approaches such as Pulsed Electric Fields (PEF) and High-Pressure Processing (HPP) have demonstrated potential as a pretreatment to enhance drying efficiency, promote tissue permeabilization and induce structural modifications that facilitate mass transfer, while simultaneously preserving or even improving the quality and sensory attributes of the final products^{2,3}. These structural modifications are essential for enhancing flavour incorporation, enabling the efficient infusion of solutes into the vegetable matrix. Consequently, these strategies are especially relevant in light of the growing demand for high-quality vegetable snacks within more sustainable food systems, contributing to the development of value-added dehydrated products^{1,2}.

The present study aimed to evaluate the effect of nonthermal emerging processing technologies, namely PEF and HPP, as pre-treatments in the development of a freeze-dried beetroot snack produced from low-caliber beetroot. The impact of these approaches on the physicochemical, sensory, and microbiological properties of the final product was assessed, while simultaneously targeting the valorisation of non-marketable vegetables for the development of new value-added food products, within a framework of sustainability and the promotion of circular economy principles.

Low-caliber beetroot (*Beta vulgaris*) samples were sanitized and subjected to different pre-treatments using PEF (1.5 kV/cm; 5.4 kJ/kg) and HPP (450 MPa for 5 min) to enhance flavour incorporation by inducing cellular structural changes that modify membrane permeability and facilitate mass transfer. For the PEF pretreatment, beetroot samples were initially processed, then cut into cubes (10x10x10 mm) and mixed with salicornia and spices. For the HPP pretreatment, after sanitization, samples were cut into cubes (10x10x10 mm), mixed with salicornia and spices, vacuum-packaged, and subsequently subjected to HPP. Control samples were also prepared, consisting of cubed beetroot seasoned with salicornia and spices, without any pretreatment. Both pretreated and control samples were subsequently freeze-dried using an industrial freeze-dryer, with a total cycle time of 50 h and an initial temperature of -40 °C. Primary drying was carried out for 43 h, with temperatures ranging from -40 °C to 35 °C, under a vacuum between 1 mbar and 0.15 mbar. Secondary drying lasted 7 h, at temperatures between 37 °C and 40 °C, operating at an approximate vacuum of 0.025 mbar. Samples were then vacuum packed in polyamide/polyethylene bags to avoid rehydration. Sensory attributes (colour, aroma, flavour, texture, and overall acceptance) and purchase intention were evaluated. Analyses were performed in triplicate to evaluate physicochemical properties (texture and colour) and microbiological compliance within the scope of hygienic-sanitary control.

At the sensory level, both PEF and HPP pretreatments showed a positive impact compared to the control samples. However, between both technologies studied, HPP proved to be slightly more promising, particularly in colour and flavour. Samples treated with HPP were preferred by consumers and showed the highest purchase intention.

Regarding texture, significant differences were observed in the hardness parameter between control and those treated with PEF and HPP, indicating that the pretreatments influenced the mechanical resistance of the product. This result suggests increased crispness, in agreement with the sensory analysis findings.

When it comes to instrumental colour, significant differences were observed in the lightness (L^*), greenness/redness (a^*), and blueness/yellowness (b^*) parameters in HPP-treated samples compared to the others (PEF and control), corroborating the sensory analysis results, particularly in terms of consumer preference for colour.

From a microbiological perspective, HPP treatment showed a significant effect in reducing microbial load when compared to the control and PEF pre-treated samples. Indeed, a 2-log reduction was observed in the total number of viable microorganisms at 30 °C, while *Enterobacteriaceae* counts were below the detection limit in HPP-treated samples, while no significant reduction in microbial load was observed for the PEF pre-treatment. These results highlight the potential of HPP, as a nonthermal technology, to enhance the microbiological safety of food products.

The results highlight the potential of PEF and HPP technologies, when applied as pretreatments, in the development of dehydrated products, with particular emphasis on the improvement of sensory properties, where HPP stood out compared to PEF. In addition, HPP demonstrated high efficacy in reducing microbial load, reinforcing its relevance as a nonthermal technology for the development of freeze-dried products. Overall, these findings underline the contribution of these approaches to the valorisation of low-commercial-value raw materials through the production of value-added dehydrated foods.

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