Tropentag, September 16-18, 2026, hybrid conference

"Towards multi-functional agro-ecosystems
promoting climate resilient futures"

Development and optimisation of bioactive-enriched gluten-free biscuits using oat (*Avena sativa*) and stinging nettle (Urtica spp.) leaves

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Abstract

Oat (*Avena sativa*) and stinging nettle (Urtica spp.) are recognised for their high nutritional value and health-promoting properties; however, oat–stinging nettle-based value-added products are not yet available on the market. This study aimed to develop bioactive-enriched gluten-free biscuits from oat flour and stinging nettle (Urtica simensis) leaf flour, and to optimise their physicochemical, functional, and bioactive properties. Pre-processing of oats (germination and roasting) and pulsed electric field (PEF) treatment of nettle leaves were applied to enhance nutritional quality and promote the release of bioactive compounds. A D-optimal mixture–process design (quadratic mixture model with a linear process-variable model) generated 23 experimental runs within the constraints of 72–81 % oat flour, 9–18 % nettle flour, 10 % premix, and baking conditions of 195–205 °C for 10–16 minutes. Experimental design, model evaluation, and optimisation were conducted using Stat-Ease 360 software. Results indicated that increasing oat flour under lower baking severity enhanced fat, carbohydrate, and energy content, while increasing nettle flour improved crude fiber, protein, ash, and bioactive compounds (total phenolics and flavonoids). Higher oat levels at moderate to high baking severity improved spread ratio, thickness, volume expansion, and colour, while reducing hardness and bulk density. In contrast, higher nettle levels reduced expansion and colour attributes but increased hardness and density. The optimised formulation and baking conditions (74.95 % oat flour, 14.05 % nettle flour, 201 °C, 14.5 min) produced biscuits with satisfactory consumer acceptability. Model validation confirmed good agreement, with protein, total phenolic content, texture, and colour aligning with optimisation targets. Sensory evaluation showed acceptable aroma, appearance, texture, and overall acceptability, although wheat-based biscuits were preferred due to familiarity. Overall, the findings demonstrate that oat–stinging nettle composite flour can be used to produce bioactive-enriched gluten-free biscuits with acceptable quality. The use of underutilised plants like nettle, combined with emerging technologies such as PEF, offers a promising approach to developing functional foods and enhancing sustainable, nutrition-sensitive food systems.

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Keywords: Composite flour, functional foods, gluten intolerance, Oats, phenolic compounds, physicochemical properties, sensory attributes, Stinging nettle