PhD THESIS

Integrated biosystem for the production of functional compounds from cereal residues

PhD student **Silvia Amalia Nemeș**

(SUMMARY OF THE DOCTORAL THESIS)

Scientific coordinator

Prof.univ. dr. Dan Cristian Vodnar

SUMMARY

The global production of cereals is a fundamental aspect of agriculture, providing essential nutrients to the population worldwide. Wheat (*Triticum aestivum L*. and *Triticum durum L*.) continues to be the most consumed staple food worldwide, cultivated on over 215 million hectares in 2023. Oat (*Avena sativa L*.), though consumed in lower quantities, has seen a significant increase in production, surpassing 30 million tons in 2023. However, this large-scale production results in substantial by-products, particularly cereal bran, which often remains underexploited. Cereal bran, primarily derived from the outer layers of grains, is abundant in dietary fiber, vitamins, minerals, and bioactive compounds. Despite its nutritional potential, a considerable portion of bran is frequently directed towards low-value applications, such as animal feed, or is discarded altogether, underscoring the pressing need for innovative valorization methods.

Phenolic acids are a group of phytochemicals in plant-based foods that exhibit antioxidant, anti-inflammatory, prebiotic, and anti-cancer properties. These may help reduce the risk of chronic diseases, making them of considerable interest in the food and pharmaceutical industries. The consumption of phenolic acids has been associated with a lower risk of cardiovascular disease due to their ability to reduce inflammation and oxidative stress, lower blood pressure, and improve lipid profile. In addition to their potential health benefits, phenolic acids have also been found to improve gut health by promoting the growth of beneficial bacteria and suppressing harmful bacteria, thus contributing to overall digestive health. Studies on the phenolic profile of cereal bran have shown that ferulic acid is one of the most significant compounds, as it is closely associated with lignin and cell wall polysaccharides. Other important compounds include p-hydroxybenzoic acid, vanillic acid, syringic acid, salicylic acid, caffeic acid, and p-coumaric acid. Microbial fermentation is particularly effective at releasing these bound phenolic compounds and producing new metabolites, such as ferulic, caffeic, and vanillic acid derivatives. *Aspergillus niger*, a widely used species of the *Aspergillus* genus, is capable of producing over 19 types of enzymes, such as cellulase, pectinase, and protease, through SSF of various agro-industrial by-products. Additionally, it can generate valuable bioactive products, including antioxidant polyphenols.

This study was significant in its use of ultrasound and microwave effects as pretreatments for solid-state fermentation to improve the release and solubility of bioactive components from cereal bran, such as phenolic compounds. These green technologies were demonstrated to considerably improve the efficiency of following fermentation processes, hence increasing the bran's overall bioactivity and nutritional value. The study carefully evaluated the nutritional and bioactive characteristics of wheat and oat bran after different pretreatment and fermentation methods. The study determined the most effective conditions for boosting antioxidant-related chemical output through investigating the effects of acid and alkaline pretreatments associated with solid-state fermentation.

Therefore, the study promotes the full exploitation of cereal crops, which aids in the establishment of a circular economy in the food production sector. The approaches and insights obtained from this study can be extended to other agricultural by-products, increasing their value and sustainability.

The main objectives of this PhD thesis were:

The central hypothesis of this Ph.D. project is that wheat bran (WB) and oat bran (OB), typically considered agro-industrial wastes, can be effectively valorized into valuable bioactive compounds through innovative processing methods. These methods will enable the sustainable recirculation of these by-products within the framework of a circular economy, ultimately reducing waste and contributing to food security and environmental sustainability. To test this hypothesis, several specific objectives have been established to guide the research process and ensure comprehensive exploration and validation of the proposed valorization approach. These objectives are:

O1. Integrated Technology for Cereal Bran Valorization: Develop and evaluate integrated technological processes for the sustainable valorization of wheat and oat bran, focusing on industrial scalability and environmental impact reduction.

O2. Enhancing Nutritional Quality and Bioactivity: Investigate the effects of acid and alkaline pretreatments on the nutritional quality and bioactivity of wheat bran, aiming to optimize these treatments for maximum health benefits.

O3. Phenolic and Lipid Compound Production: Enhance the production of phenolic and lipid compounds in oat bran through acid pretreatment and solid-state fermentation using *Aspergillus niger*, with a focus on improving bioactive compound yields.

O4. Combining Pretreatments with Solid-State Fermentation: Assess the combined effects of ultrasound and microwave pretreatments followed by solid-state fermentation on wheat bran, to enhance the release of sugars, organic acids, and phenolic compounds, thereby improving the functional properties of the bran.

By achieving these objectives, this Ph.D. project aims to provide a significant contribution to the field of sustainable food production and environmental conservation, aligning with global efforts to reduce food waste and promote circular economy principles.

The general conclusions of this PhD thesis were:

1. The research demonstrated that integrating advanced technological processes for cereal bran valorization can significantly enhance the economic and environmental sustainability of cereal production. The developed methods effectively transformed wheat and oat bran, traditionally low-value by-products, into high-value functional compounds, thereby promoting waste reduction and resource efficiency in the cereal industry.

2. The application of acid and alkaline pretreatments, followed by solid-state fermentation with *Aspergillus niger*, significantly increased the nutritional quality and bioactivity of wheat and oat bran. The research optimized these treatments to maximize health benefits, indicating their potential for developing functional foods with enhanced health-promoting properties.
3. Ultrasound and microwave pretreatments were proven to be highly effective green technologies for enhancing the release and solubility of bioactive compounds from cereal bran. These techniques, in combination with traditional acid and alkaline pretreatments, significantly improved the efficiency of subsequent fermentation processes, demonstrating their potential for industrial scalability.
4. The combination of ultrasound and microwave pretreatments with solid-state fermentation notably enhanced the production of phenolic and lipid compounds in oat bran and the release of sugars, organic acids, and phenolic compounds in wheat bran. This integrated approach demonstrated substantial improvements in the yields of bioactive compounds, which are crucial for developing value-added products from cereal by-products.
5. The research demonstrated the efficiency of *Aspergillus niger* in the solid-state fermentation of cereal bran, significantly enhancing its nutritional quality and bioactivity. This underscores the potential of *Aspergillus niger* in producing functional foods and nutraceuticals from cereal by-products.
6. The findings of this Ph.D. thesis offer practical applications for the cereal industry, providing innovative methods for utilizing cereal bran in the production of functional foods and nutraceuticals. The research contributes to a more sustainable agricultural practice by promoting the full utilization of cereal crops, thus supporting the development of a circular economy within the food production sector.

Further studies might explore the application of different novel pretreatments to improve the solubility and bioavailability of these compounds. Additionally, integrating the bioactive-rich cereal bran into food products could enhance their nutritional value and market appeal

Originality and personal contributions:

This Ph.D. thesis presents several original contributions to the field of sustainable food production, particularly in the innovative valorization of cereal bran. The research introduces novel methodologies and provides significant advancements in the understanding and application of bioprocessing techniques for wheat and oat bran.

One of the primary contributions of this research is the development of integrated technological processes for the sustainable valorization of wheat and oat bran. The research successfully demonstrated how these traditionally low-value by-products could be transformed into high-value functional compounds through innovative processing methods. This approach not only reduces waste but also promotes resource efficiency within the cereal industry. The processes were designed with industrial scalability in mind, ensuring the feasibly on a larger scale.

This research was pioneering in the application of ultrasound and microwave actions as pretreatments on solid-state fermentation to enhance the release and solubility of bioactive compounds from cereal bran, such as phenolic compounds. These green technologies were shown to significantly improve the efficiency of subsequent fermentation processes, thus enhancing the overall bioactivity and nutritional quality of the bran. The research provided a thorough evaluation of the nutritional and bioactive profiles of wheat and oat bran following various pretreatment and fermentation processes. By investigating the effects of acid and alkaline pretreatments, combined with solid-state fermentation, the study identified optimal conditions for maximizing antioxidant-related compounds yield. This comprehensive approach contributes to the understanding of how different treatments impact the bioactivity of cereal bran, paving the way for the development of enhanced functional food products.

By promoting the full utilization of cereal crops, this research supports the development of a circular economy within the food production sector. The methodologies and insights gained from this study can be applied to other agricultural by-products, further enhancing their value and sustainability.

Looking ahead, the research sets the stage for several future directions. These include further optimization of the bioprocessing techniques for a broader range of cereal by-products, scaling up the processes for industrial applications, and integrating the bioactive-rich cereal bran into food products to enhance their nutritional value. Additionally, future studies might explore the application of different novel pretreatments to improve the solubility and bioavailability of bioactive compounds. By continuing to refine and expand upon these findings, the research can further contribute to sustainable agricultural practices and support global efforts to reduce food waste and promote environmental sustainability.