SUSTAINABLE FOOD INNOVATIONS:

PRODUCT DEVELOPMENT, PACKAGING, AND WASTE VALORIZATION

Innovations in Sustainable Food Processing, Functional Foods and Smart Technologies

Edited by

Kamlesh Prasad, PhD
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About the Editor

Kamlesh Prasad, PhD

Prof. Kamlesh Prasad is a distinguished academician, researcher, and food technologist with extensive experience in teaching, research, academics, administration, and scholarly publishing. He is currently serving as Professor in the Department of Food Engineering and Technology at Sant Longowal Institute of Engineering and Technology (SLIET), Longowal, Punjab, India. In addition to his academic responsibilities, he has served as Head of the Department (Food Engineering and Technology), Coordinator of the Internal Quality Assurance Cell (IQAC), Chairman of the Rajbhasha Hindi Cell, and Public Grievance Officer (PGO) of the institute. He is also the Chairman of the Conference on Future Innovations, Food Allergies, and Traditional Foods (FIFATF-2025 and FIFATF-2026).

Prof. Prasad obtained his postgraduate degree in Food Technology from the CSIR-CFTRI, Mysore. He subsequently earned his doctoral degree in Food Technology from GBPUA&T, Pant Nagar. His major areas of specialisation include fruit and vegetable processing, non-destructive quality evaluation of foods, image analysis, food process optimisation, nanotechnology applications in food systems, engineering properties of biological materials, innovative food processing technologies, and traditional foods to combat hidden hunger.

Prof. Prasad has authored and co-authored more than 200 research papers published in reputable national and international journals and conference proceedings. He has also authored several books, edited scholarly volumes, and contributed chapters to books published by leading national and international publishers. His publications have served as valuable references for researchers, students, and professionals in food science, food engineering, and postharvest technology. Also associated with several prestigious professional societies and scientific organisations, including the ASABE, IFT, AFST(I), NSI, USI, IEEE, and other national and international professional bodies. In addition to his research accomplishments, Prof. Prasad has actively contributed to academic leadership, curriculum development, student mentoring, and research capacity building.

This edited book is being published as part of the conference proceedings, reflecting his commitment to advancing research and disseminating knowledge in these critical domains.

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Mr Shubhra Shekhar is a PhD candidate in the School of Chemical Engineering at the University of New South Wales (UNSW), Sydney, Australia. He is currently a member of the Faculty Board, holds higher-degree research student positions in engineering, has served as President of the Chemical Engineering Research Society (CERS), and is a member of the AGSE Industry PhD cohort, actively engaging with both industry and academic partners. His research focuses on non-destructive sensing and advanced characterisation methods to improve quality assurance and process understanding in modern food systems. His work brings together principles from chemical engineering, computer science, and data-driven modelling to develop innovative approaches for analysing complex food products and their behaviour.

He is a GATE achiever and has completed an M. Tech. (Food Process Engineering) from NIT, Rourkela. He received the Best Student Award from the Association of Food Scientists and Technologists, India (AFSTI), Mysuru, in 2021 and ranked top in the deemed-to-be university at graduation. He was also the All-India Topper (Elite) and received a Silver Medal for the NPTEL Course conducted by IIT Kharagpur. Got an appreciation letter from Nestle India Ltd., Moga, for his contributions in the form of recommendations. Won several prizes in academics, co-curricular and extracurricular activities. Received letters of appreciation for his contributions to several events and activities. He has successfully delegated his responsibilities as the in-charge of the Society of Food Technocrats (SOFT), the Photography Club (SVIESA), and numerous other professional committees and events. He has industrial exposure with Mondelez India Foods Private Limited, Baddi, HP; Mrs Bector's Food Specialities Limited, Greater Noida, UP; and Nestle India Limited, Moga, Punjab. He is a widely travelled person and has visited countries including Australia, Switzerland, Italy, France, Vatican City, Belgium, the Netherlands, Germany, the Czech Republic, Austria, Hungary, Singapore, Thailand, and Hong Kong. His work is published as articles in books, journals, and conference proceedings of international repute.

Harish Kumar Sharma, PhD

Harish Kumar Sharma S/o Mrs Sharda Sharma and Late Shri M. M. S. Sharma is a Professor (HAG) of Sant Longowal Institute of Engineering & Technology (SLIET) (Deemed University) (Established by: Government of India) and worked as Director, National Institute of Technology (NIT) (An Institution of National Importance), Agartala and Founder Mentor Director of Indian Institute of Information Technology (IIIT), Agartala. Professor Sharma is involved in Teaching, Research, and Administration and has published 167 papers in peer-reviewed Journals and a total of 205 papers in National/International Journals/Proceedings. He has supervised 18Ph.Ds and 44 M.Tech. students for their theses and authored/edited (10) books, (02) proceedings, and (02) manuals, published by reputed National and International Publishing Houses. He contributed 34 book chapters published by National and International Publishing Houses and visited different countries. Professor Sharma has successfully handled several projects and successfully transferred technology on a commercial scale. He has filed two patents, holds four copyrights, and provided technical assistance to various industries.

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Preface

It gives us immense pleasure to present ***Sustainable Food Innovations: Product Development, Packaging, and Waste Valorization***, an edited volume bringing together the research contributions addressing important contemporary challenges and opportunities in sustainable food processing, food product development, packaging, and resource valorization.

The food sector increasingly needs to meet growing demand for nutritious, safe, affordable, high-quality foods while using natural resources efficiently and reducing food and agricultural waste. Sustainable food innovation therefore requires approaches that integrate product development, nutritional improvement, efficient processing, waste reduction, value addition, and environmentally responsible packaging.

The book comprises fourteen chapters covering diverse themes. These include food applications for addressing celiac disease, techno-economic evaluation of wheat bran for fibre-rich food products, rice straw for sustainable packaging, utilization of underexplored banana species, food allergen reduction using cold plasma, and the nutritional and functional potential of tangerine peel waste.

Several chapters emphasize the valorization of underutilized crops and food resources**.** The volume includes studies on Tardi (*Dioscorea bellophylla*) starch, amla cultivars, multi-millet formulations, bitter gourd, jute leaves, asparagus bean flour, dietary-fibre recovery, and bioactive compounds from stinging nettle. These contributions show the potential of diverse plant resources and food-processing residues as sources of nutrients, functional ingredients, bioactive compounds, and value-added food products.

The book also highlights sustainable packaging and innovative processing technologies. Converting rice straw into packaging materials offers a way to create value from agricultural residue, while starch-based antimicrobial films show the potential of renewable materials for functional packaging applications. Other contributions address cold plasma treatment, drying technologies, extraction processes, and hydrothermal recovery of dietary fibre.

An important feature of this volume is its multidisciplinary approach, bringing together perspectives from food technology, food engineering, agricultural sciences, nutrition, biotechnology, materials science, and related disciplines.

We hope that "*Sustainable Food Innovations: Product Development, Packaging, and Waste Valorization"* will serve as a useful reference for researchers, academicians, postgraduate and doctoral students, food technologists, engineers, industry professionals, and other stakeholders.

We sincerely thank all the authors, reviewers, institutions, colleagues, students, and supporters whose contributions have made this volume possible.

K. Prasad, S. Shekhar, and H. K. Sharma (Editors)

Acknowledgement

The publication of *Sustainable Food Innovations: Product Development, Packaging, and Waste Valorization* has been made possible through the collective efforts, cooperation, and support of numerous individuals and institutions. As editors, we sincerely acknowledge everyone who contributed to preparing and completing this volume.

First, we express our heartfelt gratitude to all the contributing authors for sharing their research findings, knowledge, and expertise. The fourteen chapters covering sustainable food product development, agricultural and food-waste valorization, sustainable packaging, functional ingredients, food allergen management, processing technologies, nutritional enhancement, dietary-fibre recovery, and bioactive compounds form the foundation of this book.

We sincerely thank the reviewers and subject experts for their valuable time, critical evaluation, and constructive suggestions. Their scholarly inputs have helped improve the quality, scientific content, and presentation of the chapters.

We gratefully acknowledge Sant Longowal Institute of Engineering and Technology (SLIET), Longowal**,** for providing the institutional support and academic environment necessary for this scholarly initiative. We particularly appreciate the support of all FIFATF-2025 sponsors in bringing this edited volume to publication.

We also acknowledge the valuable contribution of the Department of Food Engineering and Technology, SLIET, Longowal, whose academic and research environment continues to encourage innovation and knowledge dissemination in food engineering and technology.

We extend our sincere thanks to the collaborating institutions and academic partners whose researchers contributed to this volume. We particularly acknowledge the association of researchers from national and international institutions**.**

We thank our research scholars, students, faculty members, colleagues, collaborators, and well-wishers for their valuable support, encouragement, and academic contributions. We also appreciate the efforts of all those who assisted with manuscript preparation, editing, compilation, formatting, proofreading, correspondence, and publication. Special thanks to my scholars, Gunjan Thakur and Sunil Kumar, for their efforts in shaping this book in its present form.

Finally, we express our heartfelt gratitude to our families and friends for their patience, encouragement, and continued support throughout the preparation of this book. Thanks are also extended to the administrations of the institute and the Ministry of Food Processing Industry for their support.

We sincerely hope that this volume will contribute to advancing research and innovation in sustainable food product development, resource-efficient processing, sustainable packaging, agricultural and food-waste valorization, nutritional enhancement, and the development of environmentally and economically sustainable food systems.

K. Prasad, S. Shekhar, and H. K. Sharma (Editors)

An Approach to Combat Celiac Disease through Food Applications

Neerja, Shubhra Shekhar, Kaushal Kishor Prasad, and Kamlesh Prasad

Abstract. Celiac disease (CD) is a prevalent autoimmune condition that affects a significant portion of the population, resulting in an immune reaction to gluten that damages the small intestine and triggers a range of symptoms. It manifests in various ways, including gastrointestinal issues like chronic diarrhea and abdominal discomfort, as well as extraintestinal symptoms such as dermatitis herpetiformis. The primary treatment for CD is strict adherence to a gluten-free diet (GFD), which has become increasingly popular among those without the disease due to perceived health benefits. This shift has driven growth in the gluten-free product market, improving dietary options for those with CD. Effective management of CD requires addressing nutritional imbalances and preventing associated complications like osteoporosis and cancer. Progress in gluten-free ingredient development and food technology plays a crucial role in enhancing the nutritional quality of these diets and supporting overall well-being. Continued research and innovation are essential to advance care and improve quality of life for individuals with CD.

Keywords: Celiac disease, Celiac sprue, Gluten-sensitive enteropathy, Wheat, Allergy, Symptoms.

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1. Introduction

Celiac disease (CD) is a chronic autoimmune condition that affects approximately 2% of the global population, with a higher incidence among women (Yilmaz and Polat, 2023). It can occur at any age and presents with a wide variety of symptoms, ranging from gastrointestinal disturbances to extraintestinal issues. Although wheat or wheat bran contains ample amounts of fiber (Saini et al., 2023a; Saini et al., 2023b; Saini et al., 2024, 2025a, b) but the disease is triggered by the ingestion of gluten, a protein found in wheat, barley, and rye, which causes an abnormal immune response in genetically predisposed individuals (Prasad et al., 2007; Prasad et al., 2010a; Prasad et al., 2010b). This immune response results in chronic inflammation and damage to the lining of the small intestine (Gaba et al., 2024; Jafari et al., 2024). Central to CD pathophysiology is gliadin, a component of gluten, which increases intestinal permeability. This process is aggravated by the enzyme transglutaminase, which deaminates gluten into glutamic acid, further exacerbating the inflammatory response (Alzahrani, 2024). Historically, CD diagnoses were often delayed until patients, typically older individuals, exhibited severe malabsorption symptoms such as weight loss, diarrhea, or steatorrhea. Children with GI symptoms and growth issues were sometimes diagnosed earlier (Rossi et al., 2024). The cornerstone of managing CD is strict adherence to a gluten-free diet (GFD), which must be maintained for life to prevent disease progression and alleviate symptoms (Zhang et al., 2022). The rise in popularity of GFDs has been driven in part by the “health halo” effect, the belief that GF products are inherently healthier. This trend extends beyond individuals with CD to those without gluten sensitivity who adopt a GFD for perceived health benefits (Papagianni et al., 2024). The expansion of the GF food market has played a significant role in supporting those with gluten-related disorders (Capriles et al., 2023).

1.1 Symptoms

Celiac disease manifests through a wide range of symptoms, both gastrointestinal and extra-intestinal (Table 1; Fig. 1). Gastrointestinal symptoms are frequently observed and include chronic diarrhea, abdominal pain, bloating, and unintended weight loss, reflecting the disease’s impact on nutrient absorption (Ludvigsson and Murray, 2019). Children may particularly suffer from growth retardation due to malabsorption (Gessaroli

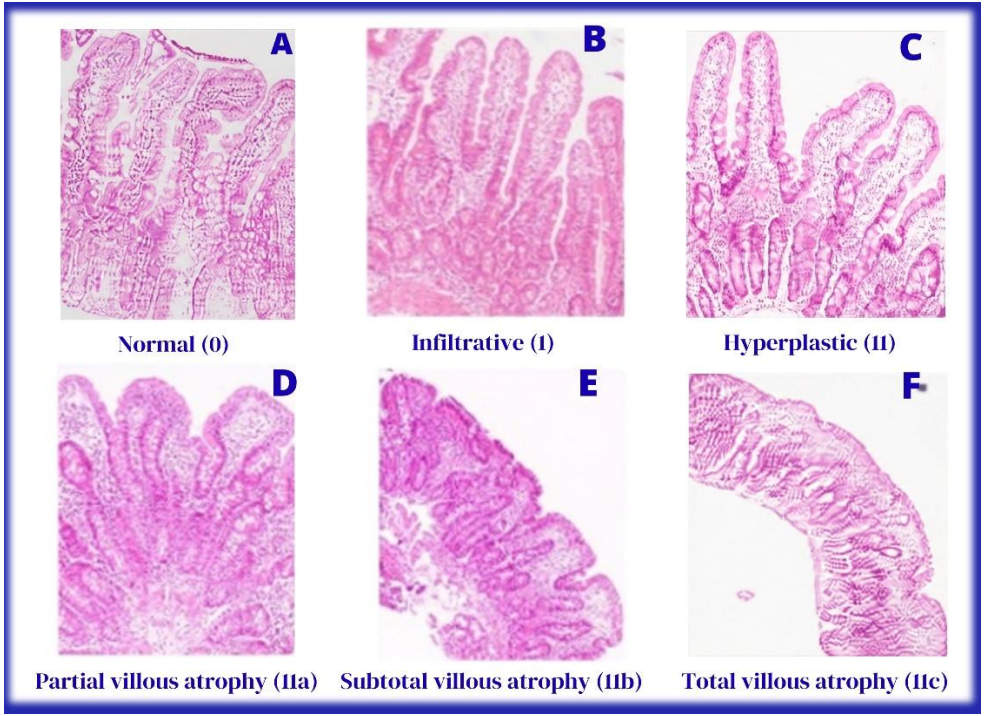


Fig. 2 Modified Marsh Oburhuber classification of Celiac disease.

and market appeal of these products. This approach will be crucial for expanding the market and improving dietary options for individuals with gluten sensitivities and CD (Escudero-Hernández et al., 2015).

5. Conclusion

Celiac disease (CD) remains a complex autoimmune condition with diverse manifestations, making diagnosis and management challenging. The disease is triggered by an adverse immune reaction to gluten, causing damage to the small intestine and leading to a variety of gastrointestinal and extra-intestinal symptoms. The variability in symptom presentation complicates diagnosis and underscores the need for more reliable, accessible diagnostic tools. The cornerstone of treatment is a lifelong adherence to a GFD, which is crucial for alleviating symptoms and preventing long-term complications. Although GFDs are widely advocated, greater awareness of the disease is needed to avoid misunderstandings and ensure effective management. The growing market for GF products has expanded the range of options available, improving quality of life for individuals with CD. Innovations in GF product development, including alternative flours and advanced processing techniques, have improved both nutritional value and sensory appeal. However, these advancements also bring challenges related to the nutritional adequacy and cost of GF foods. Moreover, ongoing research is essential to address complications such as refractory CD and related conditions, including nutrient deficiencies and the risk of malignancies. In essence, while significant progress has been made in understanding and managing CD, continued research and innovation are imperative. Advances in diagnostic methods, dietary interventions, and GF food technologies are crucial for improving patient outcomes. By addressing the challenges and leveraging new developments, the quality of life for individuals with CD can be substantially enhanced, providing a clearer path toward effective management and improved health.

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Innovation in Wheat Bran Modification: A Techno-Economic Analysis for the Development of Fiber-Rich Food Products

Praveen Saini, Akhouri Sanjay Kumar Sinha and Kamlesh Prasad

Abstract. Present study is on the comprehensive techno-economic analysis (TEA) for the commercial viability of a novel wet refining process to valorize underutilized wheat bran into high-value functional food products. The analysis is based on a pilot-scale plant with a capacity of 10 kg/h of raw wheat bran (RWB), designed to produce two distinct consumer goods: a savoury Ready-to-Use (RTU) powder formulation and high-fiber cookies. The wet refining process utilized found to significantly enhance the nutritional profile of the bran, increasing its total dietary fiber content from 41.63% to 70.22%. The financial model was developed for a 10-year operational lifetime, incorporating conservative, market-aligned assumptions. This includes wholesale-realized product prices of Rs. 220/kg for the RTU powder and Rs. 180/kg for the cookies, a phased market ramp-up achieving a steady-state utilization of 80%, and a detailed operational cost structure. The results indicate a total initial capital outlay of Rs. 1.68 crore, inclusive of working capital. The base-case financial projections show the project is highly viable, with a payback period of approximately 3.19 years, an Internal Rate of Return (IRR) of 40.2%, and a Net Present Value (NPV) of Rs. 2.67 crore at a 12% discount rate. A multi-variable sensitivity analysis confirms the project's financial resilience, demonstrating profitability even under pessimistic market conditions. The study concludes that the proposed venture is technically sound and financially robust, presenting a compelling investment opportunity. The critical path forward involves securing regulatory approval from the Food Safety and Standards Authority of India (FSSAI) for the modified bran as a novel food ingredient.

Keywords: Techno-Economic Analysis (TEA), Wheat Bran Valorization, Wet Refining, Functional Foods, Dietary Fiber.

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1. Introduction

Developments have made people more aware of the importance of a healthy diet in preventing lifestyle-related disorders. Several factors, including dietary fiber, help in the improvement of gut health, control blood sugar levels, and reduce the risk of obesity and heart diseases (Kumar et al., 2026; Prasad et al., 2022; Saini et al., 2023a). Despite of abundant fiber in nature, many people do not get enough fiber in their daily diet (Cheng et al., 2022; Islam et al., 2023). To help solve this problem, two wheat bran-based fiber-rich products can be useful: ready-to-use (RTU) fiber-rich powder and fiber-rich cookies (Asadi et al., 2021; Indriati et al., 2021; Olawoye et al., 2017; Saini et al., 2025b). Wheat bran-based RTU fiber-rich powder is a convenient product that can be easily added to different foods. It provides a simple way to increase fiber intake without changing the taste or texture of meals (Burgos-Araiza et al., 2022; Sharma et al., 2016). It can be used by mixing with foods like smoothies, soups, bread, and other everyday recipes. This makes it an easy option for those looking to improve their fiber intake without making big changes to their diet. On the other hand, wheat bran-based fiber-rich cookies offer a ready-to-eat snack option for people who want a healthier alternative to regular cookies. Traditional cookies are often made with refined flour and sugar, which provide little nutritional value. In contrast, fiber-rich cookies contain wheat bran, which makes them a better choice for digestion, weight management, and overall health (Asadi et al., 2021; Sozer et al., 2014). These cookies are a convenient and tasty way for people to get more fiber in their diet.

The demand for healthy and functional fiber rich foods is growing as more consumers seek nutritious and convenient food options (Prasad et al., 2008; Prasad and Nirgude, 2025; Ramteke and Prasad, 2026). The RTU fiber-rich powder is beneficial for those who prefer to add fiber to their meals, while fiber-rich cookies serve as an easy snack alternative. Both products have strong market potential as people become more conscious of their food choices.

Studies on technical and economic feasibility analysis have received relatively much attention from academics across various industrial fields, including agro-based and food processing industries. Techno-economic feasibility is a crucial assessment that evaluates the viability of a product or process by integrating both technical and financial considerations. In food

Table 8 Sensitivity Analysis of Key Financial Metrics

Case scenario	Main changes	IRR	Payback period	NPV @ 12% (Rs)
Best case	+10% selling price, -10% raw material cost, 85% utilization from yr 3	60.3%	2.18 yrs	Rs 4.97 Cr
Base case	As per model	40.2%	3.19 yrs	Rs 2.67 Cr
Worst case	-10% selling price, +15% raw material cost, 70% utilization from yr 2	12.9%	9.74 yrs	Rs 0.07 Cr

4. Conclusion and Recommendations

The techno-economic analysis of the project to produce modified wheat bran (MWB) functional foods confirms the technical and financial suitability. By incorporating conservative, market-aligned assumptions, the model demonstrates that the venture remains a robust and attractive investment. The project's key strength is the significant value addition of converting a low-cost agricultural by-product into differentiated consumer products that cater to the growing health and wellness market in India. The financial metrics: a payback period of approximately 3.19 years and an IRR of 40.2% are both representative and convincing for a pilot-scale food manufacturing project. The sensitivity analysis further reveals that the project has a strong margin of safety and does not register losses even under pessimistic market conditions. The project represents a significant commercial opportunity with a robust scientific foundation and exceptional financial promise. Careful execution of the pilot phase and proactive navigation of the regulatory landscape will be key to realizing its full potential. The financial projections clearly support moving forward with the Rs ~1.68 Cr investment to set up the pilot plant. To ensure profitability, it's essential to manage raw material costs effectively and maintain pricing power, this means securing a reliable supply chain and building a strong brand presence. At the same time, the most urgent priority should be obtaining regulatory approval from the Food Safety and Standards Authority of India (FSSAI) for the MWB as a novel food or non-specified food ingredient. Initiating this process immediately will be key to launching the product on time and gaining early market traction.

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Techno-Economic Evaluation of Rice Straw Conversion into Sustainable Packaging: A Viable Solution to Stubble Burning

Makdud Islam, Akhouri Sanjay Kumar Sinha, and Kamlesh Prasad

Abstract. Open-field burning of rice straw in paddy-producing countries poses a significant environmental challenge, contributing substantially to greenhouse gas emissions and particulate pollution. This study addresses this issue by converting rice straw into cellulose nanofiber (CNF)–based nanopaper for food packaging applications. Rice straw was processed through optimised organosolv pulping using a formic acid–acetone solvent system, followed by a three-stage DED (chlorine dioxide–alkali–chlorine dioxide) bleaching sequence to obtain high-purity cellulose pulp. The bleached pulp was mechanically fibrillated to 90° SR using a Valley beater and formed into nanopaper sheets by vacuum filtration and drying. To enhance moisture resistance and surface hydrophobicity, the nanopaper was surface sized with 1 wt.% alkyl ketene dimer (AKD) wax and thermally cured. In a previous study, the developed CNF nanopaper exhibited a 2.6-fold increase in tensile index and a 3.8-fold increase in burst index compared with less-refined pulp sheets, confirming the formation of a dense and well-bonded nanofiber network. AKD sizing also significantly reduced the water vapour transmission rate (WVTR) and Cobb values, imparting improved water, oil, and grease resistance suitable for dry-food and secondary packaging applications. To evaluate industrial feasibility, a comprehensive techno-economic analysis (TEA) was conducted for a nominal production capacity of 1,500 kg day^{-1} under MSME-scale conditions. The total fixed capital investment was estimated at ₹3.0 crore, while the all-in production cost was calculated as ₹234.48 per kg. At an assumed selling price of ₹260 per kg, the process generates an annual revenue of ₹11.70 crore and a net annual profit of approximately ₹1.15 crore, resulting in a payback period of 2.61 years. Sensitivity analysis identified solvent recovery efficiency, raw material price, and utility consumption as the dominant economic drivers influencing profitability. Overall, this study demonstrates that rice straw-derived, AKD-sized CNF nano paper is a technically feasible, economically viable, and environmentally sustainable packaging solution, enabling agricultural residue valorisation, stubble-burning mitigation, and circular bioeconomy development with strong potential for MSME-scale deployment.

Keywords: Rice straw, Cellulose nanofibers, Sustainable packaging, Techno-economic analysis, Circular bioeconomy

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1. Introduction

With growing global concern over plastic pollution, there is an urgent need for sustainable alternatives, which has significantly intensified research into biodegradable and renewable packaging materials. Among nanocellulose-based packaging materials, cellulose nano paper has attracted considerable attention due to its exceptional mechanical strength, optical transparency, thermal stability, and inherent biodegradability. However, commercial adoption depends not only on functional performance but also on the economic viability of industrial-scale production (Sun et al., 2024). This becomes particularly important for Asian countries such as India and China, where the packaging sector is expanding rapidly and relies heavily on conventional petroleum-based plastics. At the same time, India faces a critical environmental challenge due to improper utilisation of the massive amount of rice straw produced, with over 765 million metric tons (MMT) annually (Islam et al., 2023b). A significant portion of this biomass is disposed of through open-field burning, contributing to severe air pollution, greenhouse gas emissions, and soil nutrient loss (Islam et al., 2023a). Converting rice straw into value-added cellulose-based products offers a strategic opportunity to address environmental issues while promoting rural industrial development (Islam et al., 2026). In this context, using rice straw as a raw material to produce high-barrier, high-strength cellulose nano paper sheets not only supports circular economy principles but also provides an accessible feedstock for MSME-level enterprises. Despite its promise, rice straw presents inherent challenges because of its high silica content and the difficulty of pulping it through conventional kraft or soda processes. To overcome these limitations, we used a previously optimised organosolv pulping method with formic acid and acetone, which ensures selective delignification, high cellulose purity, improved fibre characteristics, and efficient solvent recovery (Islam et al., 2024). The resulting pulp is further refined into cellulose nanofibers (CNFs) through high-intensity mechanical fibrillation, enabling the formation of dense nanopaper structures with enhanced strength and uniformity. However, native cellulose and CNF networks are inherently hydrophilic, limiting their use in food packaging systems that require effective resistance to moisture, grease, and vapour transmission under humid conditions. Chemical and surface modifications are often necessary to improve water vapour barrier performance and broaden

MSMEs interested in sustainable packaging technologies. However, the analysis also shows that raw materials and utilities account for more than 82% of total operating costs, underscoring the need for efficient resource management, high solvent recovery (95%), and energy-saving strategies to sustain profitability. Sensitivity analysis underscores the process's financial sensitivity to fluctuations in selling price, raw material cost, and energy consumption. A reduction in selling price or an increase in rice straw or utility costs significantly extends the payback period, indicating that stable supply chains and optimised energy use are vital for economic resilience. Overall, the study establishes that rice straw-derived AKD wax-coated cellulose nano paper offers a viable and sustainable alternative to petroleum-based packaging materials, with clear environmental benefits such as reducing crop residue burning and promoting circular economy practices. The outcomes provide a strong foundation for scaling this technology and integrating it into rural manufacturing systems, supporting both environmental sustainability and rural economic growth.

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Significance of the Edible Banana Species of Mizoram: Research Status and Prospects

Lalhmangaihi and Himjyoti Dutta

Abstract. The Indian state of Mizoram is in a special geographical position, sharing two international boundaries with Myanmar and Bangladesh. Currently, prospective trade routes and tourism have necessitated urgent technological upgradation towards commercialization of the locally grown produce of this forest-clad state. Mizoram's natural conditions support a wide diversity of banana and plantain species that have played a key role in ensuring the health, nutritional, and economic security of local tribal populations. Till date, fourteen banana species belonging to *Musa* L. and *Ensete* Bruce ex Horan. species have been formally identified and reported from the state. Latest improvements in technological know-how have enabled the local small-scale processors to commercialize value-added products in packaged or ready-to-serve forms. However, the traditional practices of consuming the edible pseudostem, flowers, and inflorescence have yet to be scientifically explored, given recent global research and developments in other banana-producing zones in India and worldwide. Local ethno-medicinal knowledge systems also suggest using banana fruits to treat anaemia, hypertension, diarrhoea, burns, wounds, and stomach ulcers, and pseudostem juice for kidney problems. In addition, the stem layers and leaves have several other traditional uses, such as packaging material for fermented and aquatic foods, water-resistant roofing, and biodegradable cutlery. This paper briefly reviews the current research status and future opportunities for research on Mizoram's banana resource.

KEYWORDS: Tribal knowledge, Organic, Product development, Technology upscaling, Antioxidant

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1. Introduction

Banana (*Musa species*), as an important cash crop, is one of the most widely grown tropical fruits worldwide (Das et al., 2025; Prasad et al., 2022). India is the largest producer, followed by China and Indonesia. The state of Mizoram, often referred to as the "Land of the Highlanders", lies between 21º58'-24º35'N latitude and 92º16'-93º29'E longitude, and shares international borders with Myanmar and Bangladesh. According to the Indian State of Forest Report (2021), Mizoram has the highest forest coverage among the Northeast states, with approximately 84.53% of its geographical area under forest cover. The region with transitioning zones of lowland and highland is also unique since the landmasses of the southern and northern hemispheres meet in this area, leading to increased species diversity (Singh, 2010). A significant proportion of the local 'Mizo' population of Mizoram is dependent on forest resources for livelihood, making it the second largest source of subsistence in the state (Sati and Vangchhia, 2016). Mizoram's natural climatic and ecological conditions produce a wide variety of banana and plantain species. While several wild banana fruits are considered inedible, many have long been consumed and cultivated. These have traditionally met locals' nutritional needs. Today, banana cultivation and sales in local markets (Fig. 1) are a notable source of economic security for many Mizo people. However, scientific documentation of banana species and types grown in Mizoram has been limited. Fourteen banana species belonging to *Musa* L. and *Ensete* Bruce ex. Horan species have been formally identified and reported (Lalfakzuala et al., 2015; Lalrinfela and Thangjam, 2012).

2. Traditional Uses of Edible Banana in Mizoram

The Mizo tribe have a rich cultural heritage associated with the utilization of banana in their daily lives. Bananas are not only a staple food in different cuisines, but are also believed to have many medicinal properties. Although these practices have been followed for generations, many nutritional and therapeutic claims have been only recently received scientific attention (Lalfakzuala et al., 2015). Local food processors have developed value-added products from different parts of the plant in packaged or instantly consumable forms. Ripe fruits are either consumed fresh or fermented into wines and probiotic drinks, while unripe fruits are processed into ready-to-eat snacks,

product and process innovations remain unstandardized. Evidence-based studies on processing parameters, shelf-life extension, packaging improvements, and sensory and quality evaluation are needed. Utilization of banana pseudostem, including fiber extraction, biodegradable packaging and eco-textiles has also gained global attention but remains underexplored in Mizoram. Agronomic evaluation of local banana landraces would support crop improvement and conservation strategies, as well as the potential for GI-tag registration for unique types.

6. Conclusion

Banana is an essential biological and cultural resource in Mizoram, supporting nutrition, traditional medicine and rural livelihoods. Although fourteen species of *Musa* and *Ensete* have been identified, scientific research on their nutritional and antinutritional value, phytochemical properties, and processing potential remains limited. Different plant parts, such as the pseudostem, flowers, and inflorescence, widely used in Mizo cuisine remain underexplored. Strengthening interdisciplinary research, integrating traditional knowledge with scientific evidence, and promoting technology-driven value addition remain essential to unlock the full potential of Mizoram's banana resources and enhance economic resilience for local communities.

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In-situ cold plasma treatment for removing food allergens - A short review of effectiveness, mechanisms and implementation strategies

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Abstract. Cold plasma (CP) is an effective technique for reducing food allergen antigenicity, with studies showing reductions of more than 50% in specific allergen proteins. In recent decades, CP has been explored to reduce the IgE-reactivity of major food allergens (peanut, milk, egg, shrimp, soy, wheat, sesame) by generating reactive oxygen and nitrogen species that modify protein structures by oxidizing amino acids, forming new disulfide bonds, altering secondary protein structures and increasing surface hydrophobicity. The in-situ approach, or direct plasma exposure of grains, nuts, or seeds in their natural state, eliminates the need for chemical, enzymatic, or wet pretreatments. It also significantly reduces material-handling costs and losses. Therefore, this short review explores recent studies to assess evidence of allergenicity reduction, the physicochemical mechanisms, and practical strategies for in situ cold plasma implementation.

Keywords: Cold Plasma, Food allergens, Protein, Antigenicity

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1 Introduction

Food allergies are an increasing public-health and food-industry challenge, affecting approximately 2–10% of the population and contributing to severe allergic reactions. Common food allergens include proteins from milk (casein, whey), eggs (ovalbumin, ovomucoid), peanuts, tree nuts, soy, wheat (gliadin), fish, and shellfish. These allergens can provoke immune responses even at trace levels, making effective mitigation strategies crucial for public safety and food industry compliance. Traditionally, processing methods like thermal processing, hydrothermal processing, soaking, enzymatic hydrolysis, and fermentation have been used to reduce allergenicity (Gull et al., 2016a; Gull et al., 2015, 2016b, 2017; Kaur and Prasad, 2024; Kaur et al., 2021; Kaur et al., 2024). Heat treatments can denature proteins but may not eliminate allergenicity completely and can negatively affect nutritional and sensory quality. Enzymatic hydrolysis or fermentation can damage allergenic proteins but may leave residual allergenic fragments and can alter product texture and flavor (García Arteaga et al., 2022). Chemical treatments, which can target specific proteins, are sometimes effective but raise concerns about safety, regulatory approval, and consumer acceptance. Overall, these methods offer a reduction in allergenicity but can deteriorate nutritional or sensory attributes and are not effective across all allergens or matrices (Narciso et al., 2024). In this context, in situ cold plasma (CP) treatment has emerged as a promising non-thermal technology that can modify allergenic proteins without compromising food quality (Kaur et al., 2022; Shekhar et al., 2025). CP generates reactive species (reactive oxygen and nitrogen species) that interact with proteins to alter their structure, reduce immunoreactivity, and inactivate allergens. CP treatment does not need water, can maintain low temperature and can also inactivate microbes and modify biomolecules through short-lived reactive species (Zhang et al., 2021). In the context of allergen control, CP have been reported to reduce IgE binding (antigenicity) and the capacity to trigger immune responses (allergenicity) while preserving food quality (Cheng et al., 2023). Therefore, this short review examines current evidence on the effectiveness of in situ cold plasma for allergen reduction, explores the underlying molecular mechanisms, and discusses implementation strategies for practical application in the food industry.

6. Conclusion

Cold Plasma has emerged as a promising non-thermal technology for reducing the allergenicity of major food proteins such as those found in peanuts, soy, milk, eggs, cereals, and shellfish. Recent studies show that CP can reduce IgE-binding capacity by 30% to over 75%, depending on the food matrix, treatment parameters, and plasma type. The underlying mechanisms include oxidation of amino acid residues, disruption of secondary structures, disulfide bond formation, and protein aggregation, all of which contribute to masking or destroying allergenic epitopes. From a practical standpoint, in-situ CP treatment offers several advantages over conventional methods:

- It avoids chemical or enzymatic pretreatments, reducing cost and complexity.
- It preserves nutritional and sensory quality better than heat or chemical approaches.
- It can be integrated into existing processing lines through modular plasma reactors (DBD, APPJ, plasma bubbling).
- In-package CP treatment provides additional safety by minimizing recontamination risks.

However, successful industrial adoption requires careful optimization of parameters such as gas composition, exposure time, and moisture levels to balance allergen reduction with product quality. Regulatory acceptance will depend on standardized dose metrics, validated allergen quantification methods, and clinical evidence of reduced allergenic risk.

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Nutritional, Bioactive Compounds and Application of Tangerine Peel Waste in Food Industries

Avantika Thakur, Barinderjit Singh, and Simple Sharma

Abstract. *Citrus reticulate*, commonly known as the tangerine, is a fruit crop with a significant portion used for raw juice production. A substantial amount of fruit, especially peel, is wasted, creating disposal issues. However, citrus peel, specifically tangerine peel, is high in bioactive compounds, essential oils, and dietary fiber, making it a potential raw material for further value-added products. This review summarises the literature on using tangerine peel to produce peel powder, including processing parameters, nutritional benefits, bioactive compounds, and potential industrial applications. Using tangerine peel as a resource minimizes waste as well as enhances economic returns to the citrus industry. Peel powder is prepared by drying and milling the peel into a fine powder, which can be incorporated into teas, bakery items, beverages, and dietary supplements as a natural flavouring and functional ingredient. Peel powder helps increase economic value for farmers, food processors, and industries. Additionally, the presence of bioactive compounds, viz., flavonoids, phenolics, terpenoids and pectin, enhances functional properties such as antimicrobial activity, antioxidant potential, and flavour retention, making them suitable for use in health foods, nutraceutical formulations, and clean label food products.

Keywords: Antioxidant activity, Bioactive compounds, Health benefits, Peel, Waste utilization

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1. Introduction

Citrus fruits are among the top primary fruit crops worldwide, and millions of tonnes are processed each year in the form of juices, concentrates, canned segments, and flavored products (FAO, 2023). At the same time, peel accounts for close to 3050% of the total fruit weight, and thus, it is the largest by-product of the citrus industry (Braddock, 1999; Khan et al., 2010). The tangerine (*Citrus reticulata*) is one of the most popular fruits, not only because it tastes good and is easy to peel but also because it has a very good nutritional profile (Li et al., 2006). As a result, it is a major contributor to this waste stream. The disposal of citrus peel waste has become a significant source of environmental pollution due to fast microbial spoilage caused by the high moisture, sugar, and essential oil content which leads to the production of unpleasant odor and increases biochemical oxygen demand (BOD) in case of unappropriated disposal (Bocco et al., 1998). Besides, this wastage attracts insects and rodents and thus, is gaining more and more processing units' disposal costs. While tangerine peel may be considered a byproduct, it is loaded with valuable chemicals. It is the outer flavedo, and the inner albedo segments are packed with dietary fiber, pectin, essential oils, flavonoids, phenolic acids, carotenoids, and a range of terpenoids, thus, the peel is not only nutritionally richer but also more biologically active than the edible pulp (Gorinstein et al., 2001; Li Han et al., 2020). These compounds have been shown to provide health benefits, including antioxidant, antimicrobial, anti-inflammatory, and cholesterol-lowering effects (Gorinstein et al., 2001; Hamdan et al., 2013; Kaur et al., 2022b; Prakash et al., 2024; Shekhar et al., 2023). Biochemically, this makes tangerine peel an attractive candidate for future functional food ingredients, nutraceutical formulations, natural preservatives, and bio-based polymer development (Putnik et al., 2017; Sharma et al., 2015). As a result of the worldwide focus on zero-waste processing, circular bioeconomy, and clean-label food production, extracting value from citrus peel is of great industrial significance. On the one hand, the conversion of the peel into high-value commodities- such as peel powder, pectin, essential oils, dietary fiber concentrates, and phytochemical extracts- helps to alleviate the environmental burden. On the other hand, it opens up new income avenues for farmers, processors, and ingredient manufacturers. Moreover, peel-

solubility and enabling targeted release in food applications. Moreover, sensory and consumer research is largely unexplored, though strong citrus aroma, bitterness, and color from peel components can significantly impact consumer acceptance. Sensory evaluations, testing consumer preference, and market segmentation studies are thus very important in defining ideal usage levels, suitable categories of food, and perceptions held by consumers of products enriched with peels. These ensure the development of standardized, safe, stable, and consumer-acceptable tangerine peel products that can be integrated into modern food systems at economically viable and scalable levels.

7. Conclusion

The peel of mandarin orange is by far the most important by-product of citrus processing packed with dietary fiber, pectin, essential oils, flavonoids, and other antioxidant phytochemicals. Such substances have the potential to create value-making ingredients suitable for functional foods, natural preservatives, nutraceuticals, and even biodegradable packaging products. In fact, with properly optimized methods-e.g., drying under control, efficient extraction, and proper standardization-the peel can be transformed into safe and top-quality ingredients matching customers' demands for health and clean-label products. Nevertheless, there are quite a few obstacles to large-scale marketing of them, such as obtaining good-quality raw materials consistently, locating pesticide residues and heavy metals, and coming up with strong techno-economic models for the economic feasibility side of things. Also, the proof of health benefits through clinical studies, especially well-designed ones, is still very much required for products that want to make functional or therapeutic claims. On the whole, scientific literature to date is very positive about the potential of mandarin peel to be a recyclable and valuable resource which in fact points to the necessity of more research and industrial openness for the commercial and societal advantages to be unlocked.

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Isolation, characterization, and utilization of Tardi (*Dioscorea bellophylla*) starch in the development of antimicrobial films incorporated with silver nanoparticles

Divyanshi Thakur Rahul Das and Kamlesh Prasad

Abstract. Tuber and root crops are important food crops, mainly in tropics and subtropics. This study analyzed starch extract and flour of Tardi (*Dioscorea bellophylla*) and utilized the extracted Tardi starch (TS) to develop films incorporated with varying proportions (0.5%, 1%, 1.5%, and 2.0%) of silver nanoparticle (AgNPs) via the casting method. The results indicated that TS exhibited low fat, fiber, ash, and protein than flour but demonstrated superior solubility and swelling power. The amylose and amylopectin content were 24.56%, and 75.44%, respectively, with starch granules showed an elliptical morphology (35.212 µm). Rheological analysis revealed better pasting than Tardi flour (TF). TS had high gelatinization temperature, enthalpy, and peak viscosity, demonstrating excellent potential for industrial applications. AgNPs incorporation significantly influenced mechanical, functional, and the structural characteristics of TS films. FTIR analysis revealed slight peak shifts, while color assessment showed AgNPs films had an off-white tint. Transparency showed significant decrease as the concentration of AgNPs increased. Additionally, water vapor permeability (WVP) as well as solubility were decreased, while tensile strength (TS) improved. The films showed significant antimicrobial activity against gram-positive bacteria, making them effective for pathogen control. Given their enhanced properties, these films have potential applications as biodegradable barrier/coating on fruits and vegetables, extending shelf life as well as maintaining food safety.

Keywords: Tardi, flour, starch extract, silver nanoparticle, food coating, antimicrobial properties

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1. Introduction

Yams (*Dioscorea* spp.) belong to the Dioscoreaceae family that comprise over 650 species. Around 600 species are consumed in diverse geographical regions (Akoroda, 1993). It can be an important commodity for food security, traditional medicine, and socio-economic stability. Among tuber crops, yam ranks fourth following potato, cassava, and sweet potato. It ranks second in West Africa, after cassava. The total world production of yam in 2020 was 74.82 million tonnes, with Nigeria and Ghana being major producers (FAOSTAT, 2022). Edible starchy tubers, are culturally, economically, and nutritionally significant throughout tropical and subtropical regions (Zou et al., 2022). They contain a significant amount of carbohydrates, proteins, lipids, vitamins, and minerals. One lesser-known tuber grown in certain areas of Himachal Pradesh is "Tardi" (*Dioscorea belophylla*), a wild yam species. It grows naturally in forests at elevations from 1000 to 1800 m. It is indigenous to the western Himalayan mid-hills having a climbing vine with heart-shaped leaves that are about 5 mm thick. It has small, spherical, fruit-like structures that are not true fruits and are called "Tardolu" in the local language. Tardi tubers are brittle, milky white, and sticky inside. They are crisp and starchy when fresh. They contain several bioactive compounds that promote good health and combat diseases (Khan et al., 2024).

In recent years, biodegradable polymer materials made from renewable resources have garnered significant attention. Natural polymers are being utilized to substitute or minimize the reliance on synthetic packaging. In the food sector, this idea is gaining attention as a substitute for artificial polymeric packaging and a way to reduce the adverse consequences of synthetic packaging (Ediyilyam et al., 2021). For extending the shelf life of fresh fruits, polysaccharide-based films offer a sustainable approach. Furthermore, the development of edible films may contribute towards environmental protection by minimizing reliance on non-biodegradable polymers and enhancing the bioeconomic food sector (Martins da Costa et al., 2020). Various natural biopolymers, including starch, cellulose, fibre, pectins, gums, gluten, fatty acids, and pullulans, are often employed to produce edible films with composability characteristics. These materials are preferable because they leave no hazardous residues (Deng et al., 2025; Ghosh et al., 2025). Starch is considered an important natural polymer for

3.10.8 Antibacterial activity

The study examined the antibacterial activity of silver nanoparticle-incorporated starch films against *S. aureus* (Gram-positive bacteria). Results showed that AgNP-incorporated films, rather than control formulations, had strong antimicrobial activity. Antibacterial activity depends on starch composition, AgNP concentration, and starch content. Results showed that antimicrobial activity positively correlated with AgNPs and starch, with varying AgNP amounts (0.5%, 1%, 1.5%, and 2.0%) producing inhibition zones of 1.7, 1.8, 2.0, and 2.2 mm. According to standard protocol SN (Swiss Standard) 195, 920-ASTM E2149-01, an inhibition zone exceeding 1 mm indicates an effective antibacterial substance. Gram-positive bacterial inhibition involves disruption of the cell wall structure, resulting in the subsequent leakage of intracellular substances (Huang et al., 2017). The interactions of AgNPs with bacterial cell membranes, subsequently limiting genetic material replication (DNA) and the cell division process, resulting in reduced metabolic activity and increased formation of reactive oxygen species (ROS). These findings correlate well with a previously reported paper on chitosan/starch-silver nanoparticles (Jung et al., 2018).

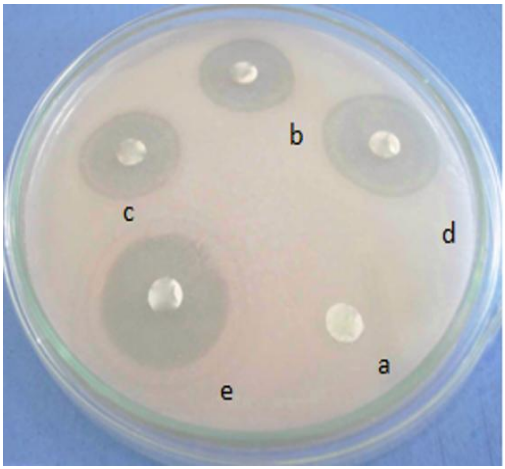


Fig. 6 Antibacterial activity of AgNPs against Gram-positive bacteria (*Staphylococcus aureus*) (a) TS film (b) TS/AgNPs-0.5% (c) TS/AgNPs-1% (d) TS/AgNPs-1.5% (d) TS/AgNPs-2% films

4. Conclusion

The research findings indicated that TF is high in protein, fat, crude fiber, and ash, whereas TS has higher carbohydrate content, primarily in starch form. TS exhibited lower amylose and high amylopectin content, making it a functional ingredient for various food applications. It showed low values for pasting parameters except for pasting time and temperature. Its superior physical and functional properties, along with a favorable color index, enhance its usability in food sector. TS starch showed significant potential to be utilized in food packaging/coatings and films to preserve freshness, protect against external factors, and improve visual appeal. Additionally, it is suitable for products like weaning meals, non-wheat noodles, and ice creams due to its low pasting parameters and high processability. In contrast, TF, with its lower retrogradation, offers benefits such as extended shelf life, improved texture, enhanced freeze-thaw stability, and better processability. These characteristics make it an essential ingredient in bakery products like bread and cakes, as well as in sauces and other processed food applications.

TS showed a type B crystallinity structure, with a higher relative crystallinity than flour, along with an elliptical shape and larger diameter. AgNP-modified Tardi starch (TS) films showed enhanced overall characteristics. Adding AgNPs reduced the films water vapor permeability and solubility while improving their mechanical strength. Furthermore, the films showed a pronounced antibacterial effect against the Gram-positive bacterium *S. aureus*, with effectiveness depending on the AgNP concentration. These results suggest strong potential for AgNP-infused TS films in advanced packaging applications, offering improved barrier properties and antimicrobial functionality. Future research can explore the optimization of AgNP concentration for maximum antibacterial efficacy, assess the films' performance against a broader range of pathogens, and investigate their environmental impact and biodegradability to ensure sustainable applications in food packaging and biomedical fields.

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Physico-chemical and phytochemical characterization of amla (*Emblica officinalis*) cultivars: Identifying a suitable genotype for juice extraction

Sumaiya Fatima and Vivek Kumar

Abstract. Indian gooseberry (*Emblica officinalis*), commonly known as amla, is a fruit of considerable nutritional and therapeutic significance in Ayurveda. It is an excellent source of vitamin C, minerals, and diverse phytochemicals contributing to its functional and health-promoting properties. Multiple amla cultivars are cultivated across India and vary in their morphological and biochemical characteristics. The present investigation aimed to evaluate seven prominent cultivars, Balwant, Banarasi, Chakaiya, Desi, NA-6, NA-7, and NA-10, for their potential in juice extraction. Comprehensive characterization of physical parameters of fruit (average fruit weight, flesh content, seed proportion, juice yield, pomace content, moisture, and total solids), physico-chemical attributes (pH, total soluble solids, titratable acidity, and reducing sugars), and phytochemical constituents of juice (ascorbic acid, total phenolic content, DPPH scavenging activity and tannin content). Banarasi cultivar exhibited the highest average weight, flesh content, and juice yield; however, it recorded the lowest seed and pomace content. Conversely, Desi recorded the lowest juice yield and the highest seed and pomace content. No significant changes were observed among cultivars in physico-chemical properties. Ascorbic acid and TPC ranged from 393.49 to 698.63 mg/100 mL and 238.28 to 582.10 mg GAE/L, respectively, with Desi having the highest values, followed by Chakaiya and Banarasi. DPPH scavenging activity and tannin content varied from 48.29 to 68.63% and 1.39 to 1.48%, respectively. Multivariate analysis also highlighted differences among the cultivars. Finally, considering superior juice yield and appreciably high phytochemical content, Banarasi was selected as the most suitable cultivar for amla juice extraction.

Keywords: Amla juice, Juice yield, Ascorbic acid, Principal component analysis

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1. Introduction

Indian gooseberry (*Emblica officinalis*), also called Amla, is known for its excellent therapeutic and nutritional properties. It is even considered one of the most important fruits in the traditional Indian medicinal system of Ayurveda (Khalid Muzaffar et al., 2022). It has opulent amounts of vitamin C, phenolics, flavonoids, minerals, and dietary fibre, which impart potential antioxidant, anti-inflammatory and immunomodulatory properties (Fatima and Kumar, 2025). Different amla cultivars are grown across diverse agro-climatic regions in India, each with distinct morphological, physico-chemical, and phytochemical attributes (Tewari et al., 2019). These distinct innate quality attributes not only affect their nutritional and sensory profiles but also influence their applicability for different processing, storage, and product development. Therefore, understanding the physico-chemical and phytochemical profiles of various cultivars is crucial to assess their compatibility in nutraceuticals, functional beverages, and value-added food formulations. The physical properties of amla fruits directly affect their handling, mechanical stability, and overall compatibility with industrial operations such as washing, drying, transportation, and packaging. Besides, variations in the physical properties among the different cultivars provide meaningful insights about the advantages in commercial utilization for that specific cultivar. Additionally, assessing the physico-chemical attributes of different cultivars is essential for establishing their sensory acceptability, flavour profile, stability during processing and storage, and so on. These parameters directly influence the processing and preservation techniques used for value-added food formulations prepared from amla fruits (Krishna and Prasad, 2025). Furthermore, determining phytochemical composition is crucial for understanding the nutritional, functional, and therapeutic value of the various cultivars. Variations in these attributes inform the selection of amla cultivars for developing functional products using amla fruit. Only a few studies have examined the physical and chemical characteristics of selected amla cultivars (Goyal et al., 2007). However, a comprehensive evaluation covering the physical, physico-chemical, and phytochemical attributes of widely cultivated commercial amla cultivars is needed, focusing on their suitability for potential utilization and processing. Such consolidated information is essential for understanding cultivar-specific suitability for processing, designing appropriate machinery for handling and value-added operations, and selecting ideal varieties for industrial applications. Therefore, this study systematically investigated the physical, physico-chemical, and phytochemical characteristics of major commercial amla cultivars.

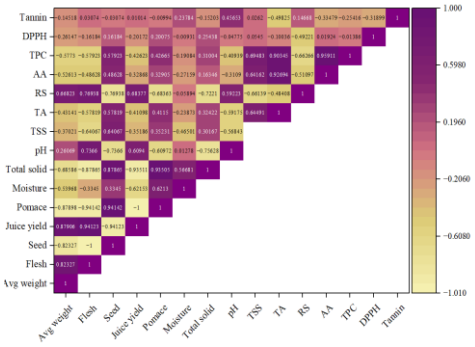


Fig. 4 Correlation between various attributes of different amla cultivars

4. Conclusion

The present study comprehensively evaluated the physical, physico-chemical, and phytochemical characteristics of seven commercially important amla cultivars. Considerable varietal differences were observed across all measured attributes. Among the physical properties, *Banarasi* exhibited higher flesh percentages and juice yield, while *Desi* recorded the lowest values, reflecting clear differences in processing suitability. Physicochemical analysis showed that pH remained low across all cultivars, confirming the inherently acidic nature of amla, whereas TSS and titratable acidity varied notably, with Banarasi, NA-6, and NA-7 showing a comparatively higher sweetness–acidity balance. Phytochemical profiling demonstrated that Desi possessed the highest ascorbic acid and total phenolic content, indicating strong antioxidant potential, while cultivars such as Chakaiya and Banarasi showed comparable levels of bioactive compounds. Furthermore, PCA revealed a strong positive correlation among average fruit weight, flesh, juice yield, ascorbic acid, total phenolic content, and titratable acidity. In addition, Banarasi and Chakaiya cultivars were grouped together, highlighting their similar attributes. Overall, the integrated assessment of physical, physico-chemical, and phytochemical attributes shows that cultivars like Banarasi, Chakaiya, and Balwant have superior potential for commercial utilisation, owing to their favourable fruit size and juice yield, while the Desi cultivar, characterised by its high antioxidant richness, is more appropriate for nutraceutical applications. Overall, given its higher juice

yield and notably elevated phytochemical levels, Banarasi emerged as the most suitable cultivar for amla juice extraction.

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Synergistic Effect of Multi-Millet Formulation on Polyphenol Stability and Antioxidant Potential: A Mixture Design Approach

Parinitha and Jyothi Lakshmi

Abstract. Millets are increasingly recognized as functional foods owing to their rich polyphenols and antioxidant compounds that contribute to health-promoting effects. This study aimed to investigate the synergistic potential of multi-millet formulations in enhancing polyphenol stability and antioxidant activity through optimized blending. A simplex centroid mixture design approach was employed to combine finger millet, pearl millet, and sorghum in varying ratios. Functional responses, including total polyphenol content (TPC), total flavonoid content (TFC), DPPH radical scavenging activity, and FRAP assay, were evaluated across experimental runs. Results revealed that the optimized blend (53% finger millet, 28% pearl millet, 18% sorghum) maximized TPC (639.59 mg/100g), TFC (57.17 mg/100g), and antioxidant responses, confirming finger millet as the primary contributor. Principal component analysis indicated a positive contribution of finger millet (0.345), whereas pearl millet and sorghum exerted negative effects on variance. The synergy index (SI > 1) demonstrated that optimized ratios enhanced functional properties beyond the additive effects of individual millets. These findings confirm the potential of millet-based formulations to deliver improved bioactivity and nutritional integrity through strategic ratio optimization. This study provides a scientific basis for developing multi-millet functional foods with superior health benefits.

Keywords: Multi-millet formulation, Polyphenol stability, Antioxidant potential, Product optimization, Synergy Index

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1. Introduction

Millets are gaining global attention as functional and sustainable food crops because of their rich content of bioactive compounds, particularly polyphenols and antioxidants, which contribute to their health-promoting potential. These small-grained cereals are known for their antioxidant, anti-inflammatory, and neuroprotective properties, making them valuable in addressing oxidative stress-related disorders and improving overall nutritional health (Senguttuvel et al., 2024). Despite their individual nutritional merits, single millet varieties often have limitations in bioactive concentration and functional efficiency compared with blended formulations. Combining different millet species may offer synergistic interactions among their phytochemical constituents, potentially enhancing bioactive stability and overall antioxidant functionality beyond the additive effects of individual grains. Such synergistic enhancement through multi-millet formulations could contribute to the development of novel functional foods with improved nutritional quality and health benefits.

To explore this synergistic potential scientifically, mixture design models, particularly the simplex centroid approach, provide a structured way to identify optimal blend ratios. These statistical designs allow systematic evaluation of individual and interactive effects of multiple components on key response variables, such as total polyphenol content (TPC), total flavonoid content (TFC), and antioxidant activity.

The present study investigates the synergistic interactions among finger millet (*Eleusine coracana*), pearl millet (*Pennisetum glaucum*), and sorghum (*Sorghum bicolor*) using a simplex centroid mixture design. The objective was to optimize blend ratios for maximum polyphenol stability and antioxidant potential, while identifying the key contributors through principal component analysis (PCA) and synergy index evaluation. The findings aim to provide a scientific foundation for formulating millet-based functional food products with enhanced bioactivity and nutritional integrity.

synergistic enhancement in TPC, TFC, and antioxidant responses, establishing finger millet as the dominant contributor. The simplex centroid mixture design effectively identified interactive effects among components, while PCA and SI analyses confirmed true synergy (SI > 1). These results provide a strong scientific basis for developing millet-based functional foods that combine sustainability, nutritional quality, and enhanced bioactivity.

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Taste-Masking Strategies for Bitter Gourd (*Momordica charantia*): A Review of Emerging Techniques for Functional Food Development

Pooja Yadav and Vipul Kumar

Abstract. Bitter gourd (*Momordica charantia*) is widely recognized for its antidiabetic, antioxidant, and health-promoting bioactive compounds such as charantin, polypeptide-P, and momordicosides. However, its intense bitterness poses a major barrier to consumer acceptance and industrial application in functional foods. This review provides a comparative evaluation of different taste-masking techniques developed to overcome this limitation, including β-cyclodextrin inclusion complexation, alginate bead encapsulation, hot melt extrusion, coating with natural polymers, and flavour modification approaches. β-Cyclodextrin (β-CD) forms host–guest complexes that entrap bitter molecules, while alginate beads prepared by ionotropic gelation act as a physical barrier providing controlled release. Hot melt extrusion approaches a solvent-free and scalable approach for embedding bitter compounds within polymer matrices, whereas coating and flavouring methods enhance sensory masking using natural food-grade materials. The review further discusses key process parameters, characterization techniques, and sensory threshold evaluation methods (such as serial dilution) used to assess masking efficiency. Overall, integrating molecular, matrix, and sensory-based masking techniques presents a sustainable, consumer-acceptable strategy for transforming traditionally bitter phytoconstituents of *M. charantia* into functional food and nutraceutical products.

Keywords: Bitter Gourd (*Momordica charantia*), Taste Masking, Functional Foods, Bioactive Compounds, Sensory Evaluation

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1. Introduction

Bitter gourd (*Momordica charantia* L.) is a cucurbitaceous vegetable that has attracted attention for its medicinal potential, especially in managing oxidative stress, diabetes, and other metabolic disorders. Some of the bioactive chemicals present in bitter gourd include charantin, triterpenoid glycosides, saponins, phenolics, among others; these are believed to contribute to the medicinal and nutraceutical value of bitter gourd (Kaur et al., 2022; Prakash et al., 2024; Singh et al., 2018; Singh et al., 2017). However, despite these benefits, the main limitation to the vegetable's application in functional foods is its intense bitterness. Momordicoside K and L, and extra cucurbitane-type triterpenoids, are mostly responsible for the bitter taste, which often leads to poor palatability and low consumer acceptance of the construct (Repka et al., 2007). Coherent taste-masking methods are necessary for further use in food and nutraceutical products. These methods need to neutralize bitterness without dropping the bioactivity and integrity of key constituents. The pharmaceutical industry has long studied taste masking, but its application to bitter botanical extracts such as *M. charantia* is relatively new. This paper highlights recent advances in de-bittering methods for bitter gourd and outlines approaches to formulating stable, palatable functional food products.



Fig. 1 Bitter gourd

2. Bitter Principles: Causes of Bitterness

Developing successful masking techniques requires figuring out the molecular sources of bitterness. Momordicoside L, momordicine IV, charantoside B, and other cucurbitane-type triterpenoids were identified from the dichloromethane fraction of bitter gourd extract by a additional detailed phytochemical and sensomics analysis (Pierson et al., 2014). Approximately

6. Conclusion

The bitter taste gives the impression to be a key blockade towards inclusive custom of *Momordica charantia*. Nevertheless, since the fruit possesses significant nutraceutical value, it is being added to various functional food systems. Current taste-masking approaches, such as β-cyclodextrin inclusion complexation, microencapsulation by spray drying using appropriate wall materials, and application of film-forming coatings, can drastically reduce perceived bitterness, with reductions often higher than 70-90%, while maintaining the antioxidant and antidiabetic properties of the extract. The final product type (liquid, powder, tablet), processing specifications and regulatory considerations, together with the expected release and stability characteristics of the formulation, are all critical factors in the selection of the best masking approach. Molecular complexation, encapsulation, food-grade coating, and hydrocolloid systems represent integrated techniques offering a systematic way to produce a stable and efficient taste-masked product. Detailed bitterness profiling, assessment of bioavailability, stability studies under storage conditions, and incorporation into real food matrices will all be advantageous for further development. Further, all these processes are required to effectively produce functional foods and nutraceuticals from bitter gourd that are economically feasible.

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Quality Evaluation of Jute Leaves Dried by Open Sun Drying (OSD) and Solar Tunnel Dryer (STD) Methods

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Abstract. This research investigates the quality of dried jute leaves (*Corchorus olitorius*) using two drying methods: open sun drying (OSD) and solar tunnel drying (STD). Jute leaves are a good source of minerals, proteins, vitamins, and macronutrients necessary for human nutrition. Because jute leaves are seasonal, prone to microbial degradation, and spoil easily due to high moisture content, drying is an effective way to prolong shelf life and preserve them. The initial moisture content of fresh jute leaves was $82 \pm 0.5\%$ (wb). The final moisture content of jute leaves achieved after drying with OSD and STD was $10 \pm 0.2\%$ (db) in 9 hours and $4.8 \pm 0.07\%$ (db) in 6 hrs. The findings showed that, compared with OSD, drying in STD maintained better nutritional quality and significantly reduced drying time, making STD a more effective and hygienic technique for preserving jute leaves. Besides improving product quality, it helps sustainably preserve seasonal green veggies after harvest. The quality parameters such as crude fat and ash content of jute leaves dried in STD were $2.43 \pm 0.04\%$ (db), $14.54 \pm 0.10\%$ (db).

Keywords: Jute leaves, Sun drying, Solar drying, Quality analysis

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1. Introduction

Corchorus capsularis (white jute) and *Corchorus olitorius* (tossa or nalta jute) are two main species utilized as leafy vegetables and belong to the Malvaceae family. Jute is grown in hot, humid tropical climates across most continents, particularly in Asia and Africa. On the Indo-Bangladesh region, commercial jute cultivation is primarily located between 80◦180 E–92◦ E and 21◦240 N–26◦300 N. Other significant producers of kenaf and jute include China, Thailand, Myanmar, Indonesia, Brazil, and Nepal. The Indo-Myanmar region, which includes South China, is considered to be the centre of origin of jute, although Africa and the Indo-Myanmar region are its primary and secondary centres of origin, respectively (Haghdan and Smith, 2015; Mahapatra et al., 2009). Jute leaves are especially rich in important minerals and amino acids. Leaves are used as a natural treatment for malaria and typhoid. Dried leaves are used to make tea and thicken soup, and the seeds are edible. The seeds of *Corchorus olitorius*, a good source of several cardiac glycosides, contain corchorin, corchorgenin, capsularin, corchoritin, olitoriside, and corchortoxin. The plant also shows antioxidant activity and contains a significant level of readily absorbed tocopherol (Gupta et al., 2023; Kaur et al., 2022; Prakash et al., 2024). Rich in active diterpenoids, jute leaves can help in the development of novel medications and strengthen the immune system. Its anti-inflammatory, anti-tumour, antihypertensive, anti-diabetic, cytotoxic, antipyretic, and immune-stimulating qualities make it widely utilized in the cure of various ailments (Ahmed and Sarkar, 2022; Singh et al., 2017). It is valued for its high fibre content and for being high in potassium, calcium, phosphorus, and iron. It contains vitamin C, which supports smooth skin and a strong immune system, and beta-carotene, which supports eyesight. Other research suggests jute may help manage diabetes and heal liver problems, including jaundice (Castro et al., 2018). Many items, such as clothing, bags, ropes, and packaging, are made from the fibre derived from plant stems. Its fibre is good for the environment because it may decompose naturally (Gupta et al., 2023). Therefore, plant sources are given top priority when seeking economically viable solutions that are also more effective and less hazardous (Ahmed and Sarkar, 2022). "Narzi" is a dish from the Bodo community in northeastern India (Assam) and was granted a Geographical Indication (GI) designation in 2024. It is made with dried jute leaves and Khar (filter water through banana fruit skin, corm, and pseudo

Table 2 Bioactive compound content of jute leaves

Bioactive compound	Fresh sample	OSD	STD
TPC (mg GAE/gm)	$52.4 \pm 0.8\%$ (wb)	$31.5 \pm 0.4\%$ (db)	$38.9 \pm 0.5\%$ (db)
TFC (mg QAE/gm)	$28.3 \pm 0.6\%$ (wb)	$15.7 \pm 0.3\%$ (db)	$20.4 \pm 0.4\%$ (db)
TTA (%)	$0.52 \pm 0.02\%$ (wb)	$0.29 \pm 0.01\%$ (db)	$0.39 \pm 0.01\%$ (db)
Antioxidant (DPPH %)	$68.2 \pm 0.7\%$ (wb)	$42.5 \pm 0.5\%$ (db)	$55.1 \pm 0.6\%$ (db)

Table 3 Chlorophyll of jute leaves

Parameter	Fresh sample	OSD	STD
Chlorophyll (mg/gm)	$1.62 \pm 0.03\%$ (wb)	$1.05 \pm 0.02\%$ (db)	$1.28 \pm 0.02\%$ (db)

The findings clearly show that fresh jute leaves had the highest concentrations of bioactive chemicals and chlorophyll, which progressively dropped during drying, with the degree of loss varying by drying technique. Because there was no oxidative deterioration or heat stress, fresh samples had the highest levels of TPC, TFC, TTC (0.52%), antioxidant activity, and chlorophyll. STD consistently retained more nutrients than OSD under both drying techniques. TPC, TFC, TTC (0.39%), antioxidant activity, and chlorophyll (1.28 mg/g) were all higher in STD samples than in OSD samples, which had the lowest values due to increased degradation of sensitive compounds caused by prolonged exposure to direct sunlight, temperature fluctuations, and environmental contamination. Overall, the evolution is Fresh > STD > OSD, indicating that controlled drying in a solar tunnel dryer preserves the nutritional and functional qualities of jute leaves more effectively than OSD.

4 Conclusion

The quality evaluation of jute leaves dried with the STD and OSD shows that the choice of drying technique is important for maintaining the leaves' functional and nutritional qualities. The STD method outperformed OSD in preserving overall quality, even though drying typically raises nutrient concentration by lowering moisture. Compared with OSD, STD's controlled temperature, shorter drying time, and protection against environmental pollutants improved retention of proximate nutrients like ash and crude fibre,

as well as bioactive substances, antioxidant activity, and chlorophyll. In contrast, OSD showed higher nutrient losses due to direct sunlight exposure, temperature fluctuations, and longer drying times. As a result, the study clearly demonstrates that STD is a more effective and dependable way to produce dried jute leaves of superior quality, ensuring higher nutritional content and better preservation of health-promoting elements.

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Development and Characterization of Composite Maize Flatbread Fortified with Asparagus Bean Flour: Studies on Enhancement in Nutritional and Quality Attributes

Tajamul Rouf Shah, Pallavi Sharma, Pramod Kumar, Pradyuman Kumar and Kamlesh Prasad

Abstract. Maize flatbreads, a widely consumed staple food, are nutritionally inadequate, as they are low in protein and have limiting essential amino acids. Asparagus bean flour (ABF) supplemented, nutritionally enriched maize flatbread was prepared and investigated. Proximate analysis revealed ABF contained 22.57% protein compared to 8.84% in maize flour (MF), with water absorption index (2.71 g/g vs. 1.80 g/g) and foaming capacity (34.67% vs. 13.25%). ABF was found to be rich in lysine (4.80 g/100g vs 0.17 g in MF). Sensory evaluation for optimal addition of 15% ABF achieved sensory color (8.2), flavor (8.7), and overall acceptability (8.1). The optimized composite flour showed significantly different ($p \leq 0.05$) pasting properties with peak viscosity 1609.00 cP and final viscosity 2326.00 cP. The optimized flatbread exhibited significantly enhanced protein, fiber, and ash content, with in vitro protein digestibility of 85.11%. Texture analysis showed a higher shear value (13.00 N vs 11.50 N). Total phenolic content was 0.81 mg GAE/g, with antioxidant activity of 28.10%. 15% ABF supplementation enhanced nutrition and functionality without significant sensory loss.

Keywords: Asparagus bean flour; Composite flour; Maize flat bread; Nutritional supplementation; Protein enrichment

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1. Introduction

Cereal and pulse combinations in staple foods have been prevalent since ancient times (Kaur and Prasad, 2023; Kaur et al., 2024). Cereal-based baked goods are major dietary staples worldwide (Bhol and John Don Bosco, 2014; Dar et al., 2016). Flatbreads are among the oldest forms of bread and are consumed by major populations across regions. Unleavened flatbreads, or chapattis, are a staple food for most people in the Indian subcontinent (Sandhu and Singh, 2007). When freshly consumed, chapattis provide nearly 90% of dietary energy and offer economical sources of protein and dietary fibre, helping prevent constipation, diverticular disease, and bowel disorders (Gujral and Gaur, 2002; Wani et al., 2016). As consumer demand for nutritious products rises, composite flours from grains, legumes, and other ingredients are increasingly used in flatbread formulations (Bhat and Karim, 2009; Thongram et al., 2016). Cereal grains form the backbone of human nutrition (Sharma et al., 2016). Maize (*Zea mays L.*), the third most important food crop after rice and wheat, yields 1.242 billion tonnes globally and about 42.3 million tonnes in India (FAOSTAT, 2024). Major maize-producing states include Bihar, Punjab, and Madhya Pradesh, contributing over 95% of production. Around 35% of maize is consumed as flatbreads, especially in northern India. Maize is nutritionally rich in vitamins A, C, E, K, and B-complex, selenium, potassium, and phytochemicals such as carotenoids and phenolics, which reduce the risk of chronic diseases (Kerstin, 2006). It contains GNA-maize lectin, which has reported anti-HIV activity (Hoorelbeke et al., 2011). Resistant starch from maize alleviates conditions such as diarrhea, obesity, and atherosclerosis (McCarthy et al., 2005). As a gluten-free grain, maize is suitable for celiac patients (Barada, 2010), though it is low in lysine but rich in sulfur-containing amino acids. Legumes complement cereals nutritionally by being rich in lysine but deficient in sulfur-containing amino acids (Abdelghafor et al., 2013). Their regular consumption reduces chronic disease risk (Anderson and Major, 2002). The asparagus bean (*Vigna unguiculata* subsp. sesquipedalis), locally known as “loung” in Kashmir, is a valuable protein

4. Conclusion

The study successfully developed a nutritionally enriched maize flatbread with 15% added asparagus bean flour. The composite formulation significantly improved protein, lysine, and fiber content while enhancing functional properties such as water absorption, dough stability, and protein digestibility. Sensory evaluation confirmed high acceptability with no compromise in product quality. The optimized baking conditions (225°C, 120 and 116 s sequential baking) and suitable packaging ensured extended storage stability. Overall, ABF supplementation effectively addressed the nutritional limitations of traditional maize flatbread, offering a promising approach for producing functional, protein-enhanced staple foods suitable for large-scale application and further development. There is still underutilization of maize and asparagus bean flour in Indian food sector. Therefore they should be utilized for the development of new food products. They are easily available in the market and least expensive. The resulted product can be easily afforded by common people. Moreover they are loaded with nutrients and bioactive compounds. Hence can improve the nutritional and health standard of population.

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Hydrothermal treatment for the recovery of dietary fiber

Rishabh Thakur and Harish Kumar Sharma

Abstract. Hydrothermal treatment has emerged as a green and versatile technology to recover DF from food and food by-products. This chapter critically examines the application of hot-water, subcritical water, steam-explosion, saturated steam, and autoclaving for the recovery of DF. The use of high temperature and pressure facilitates matrix hydration and swelling, improves heat and mass transfer, disrupts non-covalent interactions, and cleavage of glycosidic/ ester linkages. Studies showed that the severity of hydrothermal treatment governs the fiber recovery, conversion of insoluble fiber into soluble fraction, and degradation into oligosaccharides. The mild hydrothermal treatment (hot-water) promotes dissolution and diffusion, whereas subcritical water and steam explosion induce extensive depolymerization and microstructural disruption in the polysaccharide matrix. On the other hand, autoclaving emerged as an intermediate treatment that combines moist heat, moderate pressure, and partial hydrolysis. In the present chapter, we summarize the research performed so far and compare the extraction yield, compositional change, and functional outcomes of the DF obtained after different hydrothermal treatments. Future studies should be performed on matrix-specific optimization of hydrothermal process conditions and its integration with other DF extraction techniques.

Keywords: Hydrothermal treatment; dietary fiber extraction; subcritical water; steam-explosion; autoclaving.

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1. Introduction

The complex carbohydrates (polymers) associated with plants, which exhibit resistance to digestion in the small intestine, are referred to as dietary fiber (DF). Essentially, DF are the plant cell wall polysaccharides (Thakur and Sharma, 2026a). Industries and researchers have shown increasing interest in developing DF-enriched functional foods due to a recent surge in demand for DF. Although most horticultural produce (fruits and vegetables) is rich in DF, people rarely meet the recommended daily DF intake. Despite high recommended DF intake (men: 38 g and women: 25 g/day), average daily intake is around 15 g/day (USDA, 2010). Therefore, interventions in existing food formulations, incorporating DF into processed foods, or supplementing existing foods with DF have become the need of the hour. Apart from horticultural produce, cereals, and grains, the processing by-products of fruit and vegetables, legumes, cereal grains, tuber crops, and oilseeds are also very rich in DF (Cui et al., 2019; Hussain et al., 2020; Islam et al., 2023; Nevara et al., 2021; Pathania and Kaur, 2022; Saini et al., 2023). Household and processing by-products generated from fruits and vegetables (peel, pomace, pods, seed, husk, or residues) and cereal grains (bran, husk, straw) make up 40-50% and 30% of total food waste, respectively (Plakantonaki et al., 2023). Therefore, the extraction of high-value compounds, viz. polyphenols, pigments, or dietary fiber from these wastes is of great significance (Kaur et al., 2022; Prakash et al., 2024; Prakash et al., 2023; Prasad et al., 2022). Various conventional and modern (physical, chemical, and biological) extraction techniques are used to recover DF. Among physical approaches, ultrasound, microwave, pulse electric field, cold plasma, hot-water extraction, subcritical water, etc. are primarily used to extract DF (Chen et al., 2019; Ibrahim et al., 2024; Mehta et al., 2022; Shekhar et al., 2023; Thakur and Sharma, 2026b; Yan et al., 2019). Hydrothermal treatment involves exposure to elevated temperatures, with or without pressure, to physically disrupt plant cell wall polysaccharides. This approach ranges from simple hot water to hot-compressed water (HCW), subcritical water (SW), steam explosion, or autoclaving. Studies on hydrothermal treatment for DF extraction are fewer. Nonetheless, hydrothermal treatment has been shown to yield good DF yields; however, studies on DF extraction using hydrothermal techniques remain far fewer than those on phenolics extraction.

5. Conclusion

Hydrothermal treatments are versatile and comparatively green techniques that can extract DF from food materials and agro-industrial by-products. The studies conclude that hydrothermal treatment can improve the accessibility & recovery of DF, loosen compact polysaccharide structure, and improve the techno-functionality of the fiber. Nevertheless, the outcome of the applied treatment depends on the matrix and processing conditions. Under severe hydrothermal conditions, as in SWE and steam explosion, polysaccharides are more extensively degraded and IDF is more fully converted to SDF. The treated DF exhibited a lower molecular weight, increasing its solubility. The chapter also highlights the application potential of hydrothermal treatments as a pretreatment to recover greater yields of DF.

Future research should be performed to optimize the hydrothermal processing conditions. Matrix-specific processing conditions should be standardized, and mass-balance analysis should be performed to experimentally distinguish extraction, solubilization, conversion, and degradation of DF. Moreover, the integration of hydrothermal techniques with other techniques like ultrasonication, enzymes, acid hydrolysis, membrane concentration, etc. needs to be explored in depth.

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Influence of extraction techniques on the bioactive profile of stinging nettle (*Urtica dioica*) and potential applications

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Abstract. *Urtica dioica*, known as stinging nettle, is well-known for its valuable nutrients and bioactive compounds. The aerial part (leaves and stem) is rich in phenolic acids and flavonoids, while the root contains phytosterols. UD has been studied for its biological and therapeutic activities. Additionally, the bioactive profile makes it an excellent functional food ingredient. Bioactive compound recovery may vary depending on the technique used. Modern techniques improve bioactive compound recovery and reduce extraction time and solvent use. Based on recent studies, UD extract can modulate oxidative stress and inflammatory mediators; however, its efficiency may depend on plant part, extraction parameters, and technique. Many researchers have developed functional food products incorporating UD flour. Overall, UD is a good source of valuable compounds, and detailed studies on bioaccessibility and clinical research are needed to establish it as a functional and nutraceutical product. However, the available information is quite dispersed and needs a comprehensive study to bridge the gap between bioactive compounds, therapeutic potential and application in food systems. Therefore, this chapter examines the nutritional and bioactive composition of *U. dioica* leaves based on various extraction techniques and the potential application of leaf extract as a therapeutic agent.

Keywords: *Urtica dioica*, bioactive compounds, extraction technique, functional ingredient.

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1. Introduction

Urtica dioica, which is generally referred to as stinging nettle, is from *Urticaceae* family. The aerial part of the plant is covered with tiny needle-like structures called trichomes. Each trichome releases neurotransmitters like histamine and acetylcholine when touched (Devkota et al., 2022). There is increasing interest in plant research because of their rich bioactive profile and health benefits. Plants have been used for ages to treat and prevent diseases because they contain significant nutrients and active compounds (phenolic acids, flavonoids, vitamins, and minerals). Due to the growing demand for natural products, researchers are focusing on finding the potential uses of therapeutic plants. Because of its rich nutritional profile, researchers have incorporated *U. dioica* into food systems. Leaf extract, leaf powder, seed flour etc., have been used to improve the nutritional characteristics of food products such as cake, bread, pasta, cookies, and milk-based products (Mohammadi et al., 2016). Researchers have also explored using *U. dioica* leaf extract in packaging systems. The leaves are often consumed as a side dish or in soup, stew etc. It is a powerhouse of many active compounds like phenols, flavonoids, sterols, fatty acids and vitamins, which provide significant health benefits like antioxidant, anti-hypertensive, anti-analgesic, anti-inflammatory and cardiovascular-related activity (Devkota et al., 2022). In some cultural practices, the leaves and stems of stinging nettle are topically applied to relieve joint pain (Randall et al., 1999). In recent decades, research has reported recovering valuable compounds from *U. dioica* leaves using both conventional and modern techniques. Repajić et al. (2021) reported the presence of benzoic acid, cinnamic acid, flavonols, flavones, isoflavones, coumarins, etc., with chlorophyll as the most abundant natural pigment in the leaves and stalks of *U. dioica*. Different extraction techniques (UAE, MAE and conventional extraction) and concentrations of solvents (ethanol, methanol, water) were varied to extract bioactive compounds from *U. dioica*. 60% methanol (v/v) with UAE resulted in the highest antioxidant activities (Naqash et al., 2025). The presence of valuable compounds also contributes to the therapeutic potential of *U. dioica*. Researchers have identified phenolic acids, flavonoids, and tannins that have shown antioxidant effects (Naqash et al., 2025).

increasing UD concentration, significant decrease in yeast, mold and Enterobacteriaceae counts was observed during storage (14 days), suggesting the potential of UD in contributing towards microbial stability and extended shelf life. Fish is highly susceptible to spoilage; therefore, research is required to overcome the challenges faced during the storage or transportation of fish. To control fish spoilage by psychotrophic bacteria such as *Pseudomonas* and *Shewanella,* ethanolic extract of oregano and UD was used. Results indicated that the UD extract had better antimicrobial activity for both bacterial strains. UD nano-emulsion (1-4%) has been employed to increase the shelf life of fish meat. Storage study (14 days) of fish with 4% UD nano-emulsion resulted in optimal quality (Sterniša et al., 2020).

6. Conclusion

Urtica dioica has a significant content of nutrients and valuable compounds for application in the food nutraceutical industry. Concisely, UD leaf contains phytochemicals, such as phenolic acids, flavonoids, carotenoids, mineral and vitamins, which contributes to its bioactivity or health benefits. Advancement in extraction technologies, results in efficient recovery of bioactive compounds. However, variation in bioactive compounds in UD is related to processing condition, extraction techniques and solvents. Among conventional techniques, Soxhlet extraction provided highest recovery of bioactive compounds. Whereas, in modern extraction techniques, MAE was successful to recover maximum bioactive compounds present in UD. Further, health benefits of UD are widely reported, with evidence from in-vivo and in-vitro studies. UD leaf flour, extract and seed flour has been used to develop functional bakery, dairy, extruded and meat products. All the results indicate that use of UD enhances the biological and functional properties of the food product.

Future research may focus on the acceptability of UD food products. Scalability and regulatory considerations are also needed before the commercialization of product. Overall, the present study demonstrates the potential of UD as a functional formulation due to its rich polyphenolic profile, while detailed clinical study is required to validate the application of UD in food and pharmaceutical sectors. The extraction of different bioactive compounds and their application for the different functional benefits also require the attention of the researchers.

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SUSTAINABLE FOOD INNOVATIONS:

PRODUCT DEVELOPMENT, PACKAGING, AND WASTE VALORIZATION

Innovations in Sustainable Food Processing, Functional Foods and Smart Technologies

This book presents recent research and innovative applications in sustainable food product development, packaging and waste valorization. It explores the utilization of biodegradable crops, food processing by-products and agricultural residues, development of functional and specialized food products, sustainable packaging materials, and emerging processing technologies. The chapters highlight multidisciplinary approaches integrating food science, food engineering, nutrition, biotechnology and materials science for resource-efficient, environmentally sustainable and value-added food systems. The volume serves as a useful reference for researchers, academics, students, industry professionals and Policymakers working towards innovations in sustainable food processing, functional foods and smart technologies.

KEY TOPICS COVERED

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- Utilization of undervalued crop and food processing by-products
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- Techno-economic analysis and scalability
- Innovative drying, extraction and processing methods
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