

SUSTAINABLE FOOD INNOVATIONS:

PRODUCT DEVELOPMENT, PACKAGING, AND WASTE VALORIZATION

**Innovations in Sustainable Food Processing,
Functional Foods and Smart Technologies**

Edited by

**Kamlesh Prasad, PhD
Shubhra Shekhar, M. Tech.
Harish Kumar Sharma, PhD**



**Sant Longowal Institute of Engineering and Technology,
Longowal – 148106, Sangrur, Punjab, INDIA**

Sustainable Food Innovations: Product Development, Packaging, and Waste Valorization

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Harish Kumar Sharma, PhD



**Sant Longowal Institute of Engineering and Technology,
Longowal – 148106, Sangrur, Punjab, INDIA**

Editors

Prof. Kamlesh Prasad, SLIET, Longowal
Mr. Shubhra Shekhar, UNSW, Sydney
Prof. Harish Kumar Sharma, SLIET, Longowal

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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.

Shubhra Shekhar, M. Tech.

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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List of Contributors

Akhouri Sanjay Kumar Sinha

Department of Chemical Engineering,
Sant Longowal Institute of Engineering and Technology,
Longowal-148106, Punjab, India

Amisha Gurung

Department of Food Engineering and Technology,
Sant Longowal Institute of Engineering and Technology,
Longowal-148106, Punjab, India

Anisha

Department of Food Science and Technology,
Graphic Era University, Dehradun - 248002, UK, India

Avantika Thakur

Department of Food Science and Technology,
I. K. Gujral Punjab Technical University,
Kapurthala-144603, Punjab, India

Barinderjit Singh

Department of Food Science and Technology,
I. K. Gujral Punjab Technical University,
Kapurthala-144603, Punjab, India

Daimu Basumatary

Department of Instrumentation Engineering,
Central Institute of Technology, Kokrajhar-783370, Assam, India

Dipen Deka

Department of Instrumentation Engineering,
Central Institute of Technology, Kokrajhar-783370, Assam, India

Divyanshi Thakur

Department of Food Engineering and Technology,
Sant Longowal Institute of Engineering and Technology,
Longowal-148106, Punjab, India

Harish Kumar Sharma

Department of Food Engineering and Technology,
Sant Longowal Institute of Engineering and Technology,
Longowal-148106, Punjab, India

Himjyoti Dutta

Department of Food Technology, Mizoram University,
Aizawl – 976 004, Mizoram, India

Jyothi Lakshmi

Traditional Foods & Applied Nutrition Department,
CSIR-Central Food Technological Research Institute,
Mysuru-570020, Karnataka, India

Kamlesh Prasad

Department of Food Engineering and Technology,
Sant Longowal Institute of Engineering and Technology,
Longowal-148106, Punjab, India

Kaushal Kishor Prasad

Department of Gastroenterology; PGIMER, Chandigarh-160 012, India

Lalmangaihi

Department of Food Technology, Mizoram University,
Aizawl – 976 004, Mizoram, India

Makdud Islam

Department of Food Engineering and Technology,
Sant Longowal Institute of Engineering and Technology,
Longowal-148106, Punjab, India

Minijuli Basumatary

Department of Food Engineering and Technology,
Central Institute of Technology, Kokrajhar-783370, Assam, India

Neerja

Department of Food Engineering and Technology,
Sant Longowal Institute of Engineering and Technology,
Longowal-148106, Punjab, India

Pallavi Sharma

Department of Food Engineering and Technology,
Sant Longowal Institute of Engineering and Technology,
Longowal-148106, Punjab, India

Parinitha

Academy of Scientific and Innovative Research (AcSIR),
Ghaziabad-201002, UP, India

Pooja Yadav

Department of Food Technology, HBTU Kanpur-208002, UP, India

Pradyuman Kumar

Department of Food Engineering and Technology,
Sant Longowal Institute of Engineering and Technology,
Longowal-148106, Punjab, India

Pramod Kumar

Department of Food Technology,
NIMS Institute of Engineering & Technology,
NIMS University Rajasthan, Jaipur - 303121, Rajasthan, India

Prasadarao Bobbili

Department of Electronics and Communication Engineering,
Vignan's Institute of Information Technology,
Visakhapatnam-530049, Andhra Pradesh, India

Praveen Saini

Department of Food Engineering and Technology,
Sant Longowal Institute of Engineering and Technology,
Longowal-148106, Punjab, India

Rahul Das

Department of Food Engineering and Technology,
Sant Longowal Institute of Engineering and Technology,
Longowal-148106, Punjab, India

Rajesh Kondareddy

Department of Instrumentation Engineering,
Central Institute of Technology, Kokrajhar-783370, Assam, India

Rishabh Thakur

Department of Food Engineering and Technology,
Sant Longowal Institute of Engineering and Technology,
Longowal-148106, Punjab, India

Shubhra Shekhar

School of Chemical Engineering, UNSW, Sydney 2052, Australia

Simple Sharma

Department of Food Science and Technology,
I. K. Gujral Punjab Technical University,
Kapurthala-144603, Punjab, India

Sumaiya Fatima

Department of Food Technology, HBTU Kanpur-208002, UP, India

Tajamul Rouf Shah

Department of Food Science and Technology,
Govt. Degree College, Baramulla-193101, J&K, India

Titikha Machahary

Department of Instrumentation Engineering,
Central Institute of Technology, Kokrajhar-783370, Assam, India

Vipul Kumar

Department of Food Technology, HBTU Kanpur-208002, UP, India

Vivek Kumar

Department of Food Technology, HBTU Kanpur-208002, UP, India

Yogesh Kumar

Department of Food Science and Technology,
Graphic Era University, Dehradun - 248002, UK, India

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)

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

M. Islam (✉), and K. Prasad (✉)

Department of Food Engineering and Technology, SLIET, Longowal-148106, Punjab, India
email: makubkv96@gmail.com, profkprasad@gmail.com.

A. S. K. Sinha (✉)

Department of Chemical Engineering, Sant Longowal Institute of Engineering and Technology, Longowal-148106, Punjab, India
email: akhourisanjay@gmail.com

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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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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

- Sustainable food product development and functional foods
- Utilization of undervalued crop and food processing by-products
- Agricultural residue conversion and waste valorization
- Sustainable and biodegradable packaging materials
- Food allergen reduction and processing technologies
- Nutritional and bioactive potential of fruits, vegetables and herbs
- Dietary fibre recovery and value-added ingredients
- Techno-economic analysis and scalability
- Innovative drying, extraction and processing methods
- Applications of smart and sustainable technologies in food systems

EDITORS

Prof. Kamlesh Prasad, PhD

SLIET, Longowal

Mr. Shubhra Shekhar, M. Tech.

UNSW, Sydney

Prof. Harish Kumar Sharma, PhD

SLIET, Longowal



Sant Longowal Institute of Engineering
Longowal Technology, Longowal
Longowal – 148106, Sangrur, Punjab, INDIA

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