

Contemporary Food
Engineering Series

Da-Wen Sun, Series Editor



ADVANCES in FOOD DEHYDRATION

**Edited by
Cristina Ratti**



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ADVANCES in FOOD DEHYDRATION

Contemporary Food Engineering

Series Editor

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To my patient husband and dear family

Series Preface

CONTEMPORARY FOOD ENGINEERING

Food engineering is the multidisciplinary field of applied physical sciences combined with the knowledge of product properties. Food engineers provide the technological knowledge transfer essential to the cost-effective production and commercialization of food products and services. In particular, food engineers develop and design processes and equipment in order to convert raw agricultural materials and ingredients into safe, convenient, and nutritious consumer food products. However, food engineering topics are continuously undergoing changes to meet diverse consumer demands, and the subject is being rapidly developed to reflect the market needs.

In the development of food engineering, one of the many challenges is to employ modern tools and knowledge, such as computational materials science and nanotechnology, to develop new products and processes. Simultaneously, improving food quality, safety, and security remain critical issues in food engineering study. New packaging materials and techniques are being developed to provide more protection to foods, and novel preservation technologies are emerging to enhance food security and defense. Additionally, process control and automation regularly appear among the top priorities identified in food engineering. Advanced monitoring and control systems are developed to facilitate automation and flexible food manufacturing. Furthermore, energy saving and minimization of environmental problems continue to be an important food engineering issue, and significant progresses are being made in waste management, efficient utilization of energy, and reduction of effluents and emissions in food production.

Consisting of edited books, the *Contemporary Food Engineering* book series attempts to address some of the recent developments in food engineering. Advances in classical unit operations in engineering applied to food manufacturing are covered as well as such topics as progress in the transport and storage of liquid and solid foods; heating, chilling, and freezing of foods; mass transfer in foods; chemical and biochemical aspects of food engineering and the use of kinetic analysis; dehydration, thermal processing, nonthermal processing, extrusion, liquid food concentration, membrane processes and applications of membranes in food processing; shelf-life, electronic indicators in inventory management, and sustainable technologies in food processing; and packaging, cleaning, and sanitation. The books aim at professional food scientists, academics researching food engineering problems, and graduate level students.

The editors of the books are leading engineers and scientists from many parts of the world. All the editors were asked to present their books in a manner that will address the market need and pinpoint the cutting-edge technologies in food engineering. Furthermore, all contributions are written by internationally renowned experts

who have both academic and professional credentials. All authors have attempted to provide critical, comprehensive and readily accessible information on the art and science of a relevant topic in each chapter, with reference lists to be used by readers for further information. Therefore, each book can serve as an essential reference source to students and researchers in universities and research institutions.

Da-Wen Sun

Series Editor

Series Editor



Born in Southern China, Professor Da-Wen Sun is a world authority in food engineering research and education. His main research activities include cooling, drying and refrigeration processes and systems, quality and safety of food products, bioprocess simulation and optimization, and computer vision technology. Especially, his innovative studies on vacuum cooling of cooked meats, pizza quality inspection by computer vision, and edible films for shelf-life extension of fruit and vegetables have been widely reported in national

and international media. Results of his work have been published in over 180 peer reviewed journal papers and more than 200 conference papers.

He received a first class BSc Honours and MSc in mechanical engineering, and a PhD in chemical engineering in China before working in various universities in Europe. He became the first Chinese national to be permanently employed in an Irish university when he was appointed college lecturer at National University of Ireland, Dublin (University College Dublin) in 1995, and was then continuously promoted in the shortest possible time to senior lecturer, associate professor and full professor. Dr. Sun is now professor of Food Biosystems Engineering and director of the Food Refrigeration and Computerized Food Technology Research Group at University College Dublin.

As a leading educator in food engineering, Sun has contributed significantly to the field of food engineering. He has trained many PhD students, who have made their own contributions to the industry and academia. He has also given lectures on advances in food engineering on a regular basis in academic institutions internationally and delivered keynote speeches at international conferences. As a recognized authority in food engineering, he has been conferred adjunct/visiting/consulting professorships from ten top universities in China including Zhejiang University, Shanghai Jiaotong University, Harbin Institute of Technology, China Agricultural University, South China University of Technology, and Jiangnan University. In recognition of his significant contribution to food engineering worldwide and for his outstanding leadership in the field, the International Commission of Agricultural Engineering (CIGR) awarded him the CIGR Merit Award in 2000 and again in 2006. The Institution of Mechanical Engineers (IMechE) based in the United Kingdom named him Food Engineer of the Year 2004. In 2008 he was awarded the CIGR

Recognition Award in honor of his distinguished achievements in the top one percent of agricultural engineering scientists in the world.

He is a fellow of the Institution of Agricultural Engineers. He has also received numerous awards for teaching and research excellence, including the President's Research Fellowship, and he twice received the President's Research Award of University College Dublin. He is a member of CIGR Executive Board and honorary vice-president of CIGR, editor-in-chief of *Food and Bioprocess Technology—An International Journal* (Springer), series editor of the *Contemporary Food Engineering* book series (CRC Press/Taylor & Francis), former editor of *Journal of Food Engineering* (Elsevier), and editorial board member for *Journal of Food Engineering* (Elsevier), *Journal of Food Process Engineering* (Blackwell), *Sensing and Instrumentation for Food Quality and Safety* (Springer) and *Czech Journal of Food Sciences*. He is also a chartered engineer registered in the U.K. Engineering Council.

Preface

Dehydration processes have been known and used in food preservation for centuries. In spite of this, drying of foodstuffs is a complex heat and mass transfer process, which consumes large amounts of energy and unfortunately does not always lead to high-quality final products. Its current understanding is still quite limited because of the following factors: (1) the complex nature of food systems together with the deep structural and physicochemical changes that foodstuffs undergo during processing, (2) the difficulty of defining quality quantitatively and developing appropriate control techniques, and (3) the lack of realistic models and simulations to represent the phenomena. Knowledge of food physicochemical, kinetics, and sorptional properties and their variation with water content and drying conditions is also required to interpret this process correctly. In addition, recently there has been a clear need to optimize natural resources to reduce energy requirements together with an increasing demand for low-cost, high-quality products. This requires practical and advanced knowledge on dehydration in the food processing industry.

Dehydration is a traditional food engineering area that has advanced significantly in the last 20 years. New methods of dehydration have been developed, new sophisticated analytical techniques have been applied to drying to allow a better understanding of the phenomena, mathematical modeling has been improved to simulate the various driers under different conditions, and so forth. This new volume in food dehydration consists of 15 chapters on traditional and novel aspects of food dehydration. Each chapter will introduce the importance of the subject, followed by general concepts and finally by the latest developments in the area.

I sincerely acknowledge the collaboration and hard work of each contributor to this volume, the help of my graduate students and research assistant, and the valuable advice and input from Dr. Tadeusz Kudra.

Editor

Cristina Ratti, who is originally from Bahia Blanca, Argentina, graduated as a chemical engineer from the National University of the South (Bahia Blanca) and began her graduate studies in food engineering at the same institution under the supervision of Enrique Rotstein and Guillermo Crapiste. She obtained a PhD in chemical engineering in 1991 with her thesis on the "Design of batch air dryers for fruit and vegetable products." Her three postdoctoral stages were undertaken at three academic institutions in collaboration with Arun Mujumdar (chemical engineering, McGill University, Canada) from 1991 to 1993, Vijaya Raghavan (bioresource engineering, McGill University) from 1993 to 1995, and Guillermo Crapiste in PLAPIQUI (Bahia Blanca) from 1995 to 1996.

In 1996 she joined the Department of Soils and Agri-Food Engineering at Laval University (Québec, Canada) as a professor of food engineering. She is presently a full professor, the coordinator of the Food Engineering Program at Laval University (since 2001), and a member of the Institute of Nutraceutical and Functional Foods (since 2003). Her research interests have always been related to food dehydration (air drying, freeze-drying, osmotic dehydration) and physicochemical and quality properties of foodstuffs related to drying. She has published numerous scientific manuscripts and contributed to the training of many graduate and undergraduate students on the science of food engineering and dehydration.

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1 Dehydration of Foods: General Concepts

Monica Araya-Farias and Cristina Ratti

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