nanotechnology research methods for foods and bioproducts

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WILEY-BLACKWELL
A John Wiley & Sons, Ltd., Publication

Wiley-Blackwell is an imprint of John Wiley & Sons, formed by the merger of Wiley's global Scientific, Technical and Medical business with Blackwell Publishing.

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2121 State Avenue, Ames, Iowa 50014-8300, USA
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9600 Garsington Road, Oxford, OX4 2DQ, UK

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Library of Congress Cataloging-in-Publication Data

Nanotechnology research methods for foods and bioproducts / edited by Graciela W. Padua, Qin Wang.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-8138-1731-6 (hardcover : alk. paper)
1. Food–Biotechnology. 2. Nanotechnology. I. Padua, Graciela W. II. Wang, Qin, 1973-
TP248.65.F66N36 2012
664–dc23

2011039277

A catalogue record for this book is available from the British Library.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books.

Set in 10/12pt Times by SPi Publisher Services, Pondicherry, India
Printed and bound in Malaysia by Vivar Printing Sdn Bhd

1 2012

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Foreword

Ample Opportunities for Nanotechnology in Foods and Bio-based Products to Benefit Society

Food, like clean water and fresh air, is essentially important to human living. However, the current global agricultural production and food security are facing serious long-term sustainability challenges, exacerbated by population growth and climate changes. It has been estimated by authority that more than 1 billion people experienced food insecurity in 2011 – a daunting image of one out of every seven people suffering hunger and malnutrition. Yet the world population is expected to increase from 7 billion today to more than 9 billion by 2050. The Food and Agriculture Organization (FAO) of the United Nations predicts that food production will need to increase by 70% over the next four decades to meet the anticipated demand. Given the fact that new land resources for cultivation are extremely limited, the majority of the production increase will have to come from technological innovations and new approaches. Nanotechnology has been actively pursued for about 10 years to enhance our capabilities to address the grand challenges facing agriculture and food systems, and its momentum is continuing.

Nanoscale science, engineering, and technology, often simply referred to as nanotechnology, emerged around the year 2000 as a new distinctive frontier for scientific research and development in broad fields including physics, chemistry, biology, engineering, materials sciences, social sciences, and in almost all industry sectors from semiconductors and electronics, energy, space, medicine and pharmaceutics, food and nutrition, agriculture and forestry, to natural resources and the environment, and many others. The recognition of novel properties of matter at the nanoscale and the newly developed capabilities to precisely study and manipulate such properties was necessary, but not sufficient, to champion for a national R&D initiative. Visionary scholars and government leaders articulated a long-term vision for the transformative potential of nanotechnology R&D to benefit society, and thus ignited the establishment of national nanotechnology initiatives first in the USA, followed by major research powerhouse countries, and now by most countries in the world. Substantial investments in nanotechnology R&D by governments and the private sector have sustained steady advancement of new solutions and products over the last decade. The US National Nanotechnology Initiative (NNI) has contributed a cumulative $14 billion, including about $1.8 billion in 2011, in nanotechnology R&D. Many nanotechnology breakthroughs have begun to impact the marketplace. The current value of nanotechnology-enabled products in the USA is estimated at about $91 billion. Current trends suggest the market impact of nanotechnology-enabled products will achieve $3 trillion worldwide by 2020.

Nanotechnology has been touted to have the potential to revolutionize agriculture and food in the 21st century. Numerous exploratory research projects and publications have clearly shown ample evidence of this in a broad range of critical challenges and opportunities facing agriculture and food systems. Innovative ideas have emerged to develop nanotechnology-enabled solutions for global food security through improving productivity and quality, adaptation and mitigation of agricultural production systems to climate changes, improving nutritional quality of foods, enhancing food safety and biosecurity through better detection of pathogens and contaminants as well as novel intervention technologies, and development of biobased products and bioenergy alternatives. Some examples include novel uses and high value-added products of nano-biomaterials of agricultural origins for food and non-food applications, nanoscale-based sensing mechanisms and devices for reliable early detection of diseases and monitoring of physiological biomarkers for optimal agricultural production, precision agriculture technologies including ones to efficiently manage applications of agricultural chemicals and water resources, and water quality improvements. Persistent investment and support will bring these pioneer work and many other creative ideas to fruition in the near future.

Responsible development and deployment of nanotechnology is critically important to nanotechnology R&D not only because it will impact the ultimate success in propelling economic growth and job creation, but also the environment, human health and consumer safety. The food science community has a long tradition of ensuring food safety. Agriculture production and allied industries are fully aware of the importance of safety and the environmental implications of agricultural chemical applications. Investigations in risk assessment and characterization of nanosized materials and their uses in agricultural production and foods have been, and will continue to be, a high priority in nanotechnology R&D. Analytical instrumentation, test standards and experimental protocols, both *in vitro* and *in vivo*, will be further developed and used.

This book is among the first covering the intersection of foods and nanotechnology. It is unique in presenting two interrelated but also independent sections, namely materials and analytical techniques, in one combined volume to give the reader a convenient access of references. The material section deals with common food components, nanostructure formation, processes and mechanisms, macromolecular and supramolecular structures and functionality, food and nutrition applications, and nanocomposites in food packaging. The analytical section details seven instrumentations that are among the most important characterization tools in nanoscale science research and technology development. The reader will find rich information detailed by experts in the fields of food science and nanotechnology from some of the most prominent research institutes in the USA. Researchers and students may be inspired and empowered to eagerly engage in addressing the key challenges in securing the supply and availability of food to all, improving human health and wellbeing through better foods, and developing high value-added bioproducts of agricultural origin. The potential of nanotechnology to significantly advance technical solutions for sustainability, vulnerability and human health can be clearly envisioned. These chapters may crystallize new visions and innovative approaches to advance food science and technology in the future. The book editors, Drs Padua and Wang, being two active practitioners and front runners in this field, have indeed made a valuable contribution to the professionals of food and biomaterials nanotechnology, and broadly, to food and agricultural sciences.

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1 Introduction

Graciela W. Padua

Nanoscale-sized particles are not new – they exist naturally. However, our ability to visualize, understand and control matter at the nanoscale is new. Recent recognition of the impact of nanoscale materials on the overall structure and functionality of foods and biological tissues is driving new interest in their study. This new body of knowledge, along with the methodology used to create it, is the subject matter of nanoscale science and technology for food and biological materials. Novel structures and new functionalities are expected to be the product of this new knowledge.

It is increasingly recognized that many of the structure-building elements in foods are the result of self-assembly of nanosized molecules into particles or at interfaces. Thus, the ability to control the assembly of biomacromolecules in a matrix spanning several length scales (the size of a large protein molecule is ~5–10 nm) will become an integral part of food product design.

The next wave of food innovation will require a shift of focus from macroscopic properties to those at the nanoscale. Future development of food products will require an understanding of the relations between nano- and higher length scale structures and their impact on functionality, including physicochemical, nutritional and sensorial.

Examples of structures being examined at the nanoscale are liposomes, micelles, nanotubes, hydrogels, dendrimers and nanocomposites. Such structures are used or proposed to be used for enhancement of nutritional value of foods, improving flavor profiles, preserving freshness, improving packaging and preventing disease.

Nanotechnology has high potential in food science and technology. Major impacts are foreseen in nutrition, food quality, food packaging and food safety assurance.

- **Nutrition:** Controlled delivery of bioactive compounds by micro- and nanoencapsulation is foreseen to yield significant benefits in nutrition and wellness. A goal is the development of more effective delivery systems, able to deliver bioactive compounds directly to the appropriate sites, maintain their concentration at

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suitable levels for long periods of time, and prevent their premature degradation. Nanostructured materials, such as liposomes, micelles and nanospheres, could be used to develop high-performance delivery vehicles for biologically active substances, such as nutraceuticals.
- **Food quality:** Nanostructured systems for the design of novel food matrices are being studied. Another area of development is the use of nanostructured carriers for enhanced delivery of flavors in foods.
- **Food packaging:** Nanocomposites for improving properties of packaging materials are in development. The addition of natural nanosized materials can render plastics lighter, stronger, more heat-resistant, with improved oxygen, carbon dioxide, moisture and volatile barrier properties. Such materials could enhance considerably the shelf-life and safety of packaged foods. With the emphasis on sustainability, nanocomposite technology may be applied to the development of biopolymers as viable packaging materials.
- **Food safety assurance:** Nanotechnology is helping design antigen-detecting biosensors to facilitate early identification of pathogen contamination.

The development of food materials through nanoscience involves understanding of the precise assembly and ordering of structures at a molecular scale that subsequently control the organization and integration of structures over several length scales. Food scientists and technologists will find themselves increasingly engaged in nanoscience and nanotechnology.[1]

This book covers nanoscale materials and structures (Part One), where the properties of food materials and biological components are described, self-assembly is explained, and the formation and applications of nanocomposites and nanocolloids are reviewed.

Food nanotechnology is an expanding field. This expansion is based on the advent of new technologies for nanostructure characterization, visualization and construction. Indeed, nanotechnology is possible due to various techniques and instruments for detection and imaging that have only recently become available to researchers and engineers. They are expected to provide insights into meso- and nanostructural changes in food and biological systems and their relationship with their macroscopic properties.[2,3]

This book introduces the reader to a selection of the most widely used techniques in food and bioproducts nanotechnology. It is intended as a quick reference and a guide in the selection of research tools. The focus is on state-of-the-art equipment; thus, it contains a description of the tool kit of a nanotechnologist. The book will provide concise explanations for the technical basis of the methods being described, will highlight research opportunities and will point out methods' pitfalls and limitations. Part Two covers nanostructure characterization techniques, starting with scanning electron microscopy (SEM), then transmission electron microscopy (TEM), dynamic light scattering(DLS), X-ray diffraction (XRD), Quartz crystal microbalance with dissipation (QCM-D) and focused ion beam, through to micro-computer tomography.

This book is addressed to workers new in the field of nanotechnology. It is meant to inform students in formal and informal settings, new researchers and product development teams in the expanding field of food and bioproducts nanotechnology.

The rapid implementation of nanotechnology concepts in industry and academia creates the need for information on instruments and methods among researchers and product development teams. Also, the advent of new structures had led to regulatory reexamination of materials involved. The selection of appropriate characterization instruments and methods is critical to this endeavor.

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2 Material components for nanostructures

Graciela W. Padua and Panadda Nonthanum

Abstract: Nanosized structures are commonly found in foods and biological products. They may be natural formations, such as casein micelles, or the result of processing, such as nanosized fat globules in homogenized milk. Nanotechnology is not involved in their formation; however, it is involved in their characterization and analysis. Nanoscience is involved in the formation of novel products, for example whey protein nanotubes, which are prepared by a combination of enzymatic and chemical treatments. The induced formation of nanostructures by provision of the correct environmental conditions involves nanoscale science. This chapter presents some of the most frequently used materials in nanoscale developments for foods and bioproducts.

Keywords: nanostructure; micelle; liposome; self-assembly; supramolecular; length-scale; amyloidogenic protein; cyclodextrin; amphiphile; montmorillonite

2.1 Introduction

Food products naturally contain nanosize ingredients. Globular proteins may vary between 10 and several hundred nanometers in diameter. Milk naturally contains nanostructures, such as casein micelles. Many polysaccharides are ribbon-shaped polymers that are less than 1 nm thick. Also, nanostructures may be produced during routine food processing operations, such as homogenization. When milk is homogenized, fat globules are reduced to about 100 nm in size. The natural or fortuitous formation of such structures does not involve nanotechnology; however, their characterization does. Novel nanotubes from whey proteins are formed by combinations of enzymatic, chemical and physical treatments. The induced formation of nanostructures by providing the right environmental conditions involves nanoscale science. This chapter will present some of the most frequently used materials involved in food and bioproducts nanoscale developments.

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