Edited by Monique A.V. Axelos and Marcel Van de Voorde

Nanotechnology in Agriculture and Food Science

WILEY-VCH
Verlag GmbH & Co. KGaA

Volume Editors

Dr. Monique A.V. Axelos
INRA
Science & Engineering of Agricultural Products
Rue de la Géraudière
44316 Nantes cedex 03
France

Prof. Dr. Dr. h.c. Marcel H. Van de Voorde
Member of the Science Council
of the French Senate and National Assembly, Paris
Rue du Rhodania, 5
BRISTOL A, Appartement 31
3963 Crans-Montana
Switzerland

Series Editor

Prof. Dr. Dr. h.c. Marcel H. Van de Voorde
Member of the Science Council
of the French Senate and National Assembly, Paris
Rue du Rhodania, 5
BRISTOL A, Appartement 31
3963 Crans-Montana
Switzerland

Cover credits: Glasware: fotolia_© kasto
Orange: fotolia_© Olga Kovalenko
Nanostructure: fotolia_© psdesign1

Library of Congress Card No.: applied for

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library.

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available on the Internet at http://dnb.d-nb.de.

Print ISBN: 978-3-527-33989-1
ePDF ISBN: 978-3-527-69771-7
ePub ISBN: 978-3-527-69773-1
Mobi ISBN: 978-3-527-69774-8
oBook ISBN: 978-3-527-69772-4

Cover Design Adam Design
Typesetting Thomson Digital, Noida, India
Printing and Binding

Printed on acid-free paper

Series Editor Preface

Since years, nanoscience and nanotechnology have become particularly an important technology areas worldwide. As a result, there are many universities that offer courses as well as degrees in nanotechnology. Many governments including European institutions and research agencies have vast nanotechnology programmes and many companies file nanotechnology-related patents to protect their innovations. In short, nanoscience is a hot topic!

Nanoscience started in the physics field with electronics as a forerunner, quickly followed by the chemical and pharmacy industries. Today, nanotechnology finds interests in all branches of research and industry worldwide. In addition, governments and consumers are also keen to follow the developments, particularly from a safety and security point of view.

This books series fills the gap between books that are available on various specific topics and the encyclopedias on nanoscience. This well-selected series of books consists of volumes that are all edited by experts in the field from all over the world and assemble top-class contributions. The topical scope of the book is broad, ranging from nanoelectronics and nanocatalysis to nanometrology. Common to all the books in the series is that they represent top-notch research and are highly application-oriented, innovative, and relevant for industry. Finally they collect a valuable source of information on safety aspects for governments, consumer agencies and the society.

The titles of the volumes in the series are as follows:

Human-related nanoscience and nanotechnology

- *Nanoscience and Nanotechnology for Human Health*
- *Pharmaceutical Nanotechnology*
- *Nanotechnology in Agriculture and Food Science*

Nanoscience and nanotechnology in information and communication

- *Nanoelectronics*
- *Micro- and Nanophotonic Technologies*
- *Nanomagnetism: Perspectives and Applications*

Nanoscience and nanotechnology in industry

- Nanotechnology for Energy Sustainability
- Metrology and Standardization of Nanomaterials
- Nanotechnology in Catalysis: Applications in the Chemical Industry, Energy Development, and Environmental Protection

The book series appeals to a wide range of readers with backgrounds in physics, chemistry, biology, and medicine, from students at universities to scientists at institutes, in industrial companies and government agencies and ministries.

Ever since nanoscience was introduced many years ago, it has greatly changed our lives – and will continue to do so!

March 2016 *Marcel Van de Voorde*

Contents

Foreword

As defined by the European Commission in 2005,[1] "Nanosciences and nanotechnologies are new approaches to research and development that concern the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale."

Over the last three to four decades, these approaches have emerged as a very fast expanding research area at the confluence of physics and chemistry, with a wide range of interactions with other scientific fields, such as life sciences, optics, electronics, and a broad spectrum of potential applications in many areas, such as information and communication technologies, manufacturing of materials, transportation, instruments, energy, medicine and healthcare, security, food, agriculture, water, and the environment.

However, the wide breadth and sharp growth of this key emerging scientific and technological area have resulted in debates about the very definition of nanotechnology and nanomaterials. Ten years ago, the difficulty to reach a consensual definition of nanoscience and nanotechnology was indeed well illustrated by the inaugural issue of *Nature Nanotechnology*.[2] Nevertheless, across the variety of perspectives reflected by the 13 recognized scientists, industrialists, and stakeholders who contributed to the "Feature" section of this issue, a few common points appear: (i) the size of the studied objects, typically 1–100 nm in one or the other of their dimensions; (ii) the very close links between science and technology, that is, between understanding and modeling the specific and often unexpected physical, chemical, or biological properties of nano-objects and the capacity to manipulate individual atoms and molecules and to manufacture nanostructures, nanodevices, and nanosystems; (iii) the broad spectrum and the magnitude of the potential applications and the subsequent need to consider and assess the diversity of impacts of nanotechnology.

1) EU Commission (2005) *Nanosciences and Nanotechnologies: An Action Plan for Europe 2005–2009*. Communication from the Commission to the Council, the European Parliament, and the Economic and Social Committee, 12 pp.
2) T. Feith *et al.* 2005. Feature: Naño·tech·nolo·gy n. *Nat. Nanotechnol.*, **1**, 8–10.

Since 2006, the number of programmes, projects, and publications in nanoscience and nanotechnology has continued to increase at a very fast pace. For example, the number of papers that fall under the category *Nanoscience & Nanotechnology* of the *Core Collection* of the *Web of Science* has nearly quadrupled between 2005 (9,445 papers) and 2015 (37,751 papers). During the same period, the number of these publications that also refer to agriculture, agronomy, food, and veterinary sciences has even grown faster, by more than 10×. However, it should be noted (i) that the latter number remains fairly low (about 2–3%), compared to the total number of publications in nanoscience and nanotechnology or to the total number of papers in food, agriculture, and veterinary sciences and technologies; and (ii) that the rise of publications in nanotechnology applied to the agrifood sector started in the late 1990s, about 10 years later than in most other sectors.

The potential applications of nanotechnology in the agriculture and food sectors are manifold: from the development of sensors for monitoring the environment to the treatment of wastewater and the remediation of contaminated soils; from increasing crop yield (e.g., nanopesticides or nanofertilizers) to biosecurity (e.g., sensors for detecting pathogens along the whole food chain from the farm to fork); from cellulose-derived nanoparticles and new biomaterials to functional packaging; and from food processing to the delivery of specific food additives and ingredients. Some applications have existed for the last several years, but most of them are still under development, and it remains to be seen which will have a real economic impact. Moreover, natural nanoparticles have been existing for ever and natural nanomaterials are part of conventional food and conventional food processing.

Nanoscience and nanotechnology thus generate plenty of new opportunities for the agrifood sector and more widely for bioeconomy. Simultaneously they raise concerns about their potential impacts on environment and human health. These concerns are especially critical for the agrifood sector, because of the strong environmental footprint of agriculture and because food, along with water and air, is one of the major sources of exposition of humans to their environment. There is thus a strong need to develop nanotoxicology and nanoecotoxicology as new research areas, for example, by investigating the uptake and translocation of nanomaterials by the gastrointestinal tract. As for other technologies that have the potential to generate disruptive innovations, it is also worth assessing and monitoring the impacts of nanotechnology on the economic and social organization of the agrifood sector.

As underlined by the Joint Ethics Committee of Inra and Cirad in 2012,[3)] agricultural and food scientists should not only contribute to understanding and predicting the specific properties of agricultural and food products related to their nanoscale structure, to exploring the potential applications of nanotechnology in the bioeconomy, including the assessment of their environmental,

3) Comité d'éthique Comité consultatif commun d'éthique pour la recherche agronomique (2012) *Avis n°4 sur les nanosciences et les nanotechnologies*, Inra & Cirad, Paris, 33 pp.

health, social, and economic impacts, and to informing the agencies in charge of the regulation of new agrifood nanomaterials and nanoproducts. They should also more broadly inform the society and interact with the citizens. This book is therefore most welcome, as it brings together various sources of expertise on the different aspects related to the application of nanoscience and nanotechnology in the agrifood sector.

Chairman of French AllEnvi Alliance
and former President and CEO of INRA
Montpellier, August 21, 2016

François Houllier

Introduction

Due to the growing world population and increasingly varying climate change, leading to lower yields and increasing harvest losses, feeding global population has become an international major issue. The food resources from the field to fork need to be used wisely, with minimum waste and maximum nutritional efficiency.

For this purpose nanotechnologies can play an important role. It is envisaged that the convergence between nanotechnology, plant science and agriculture will lead to revolutionary developments and advances in the next decades to improve food security and sustainability through, for examples, the re-engineering of crops at cellular level, the precision agriculture leading to water and nutrient control for more sustainable farming, the identification systems for tracking plants from origin to consumption or through the precise and the controlled release of fertilizers and pesticides, etc. In the domain of food technology, nanobiosensors will contribute to the identification of harmful molecules such as toxins or pesticides and to quick identification of spoilage processes in food. The development of nanoscience-based food with improved nutritional and palatable benefits will allow to increase food nutritional efficiency and the addition of nanoscale materials for food packaging will extend shelf life and retain quality, both contributing to waste reduction.

As for all new technologies, their application offers great potential but raise ethical questions, and when food is concerned, issues on food safety, risk and benefits, and consumer mistrust become the key ones.

This book provides detailed coverage on the state of the art and the importance of nanoscience in agriculture and food and highlights the perspectives of a science-based nanotechnology in these domains in the future. Through concrete examples, it points out the major role of nanotechnology in the improvement of food supply and in studies and applications ranging from agricultural processes and productivity to nutritional improved foodstuffs, including packaging materials for more effective storage and for secure tracking from source to the consumer to reduce spoilage. It details means to ensure safety for human and for the environment to address the current evolution of the European science policy.

The book will be of interest to students of agriculture and food sciences, physics, chemistry, and biosciences, as well as those working or planning to work in the restaurant and hospitality sectors. It will be of value to food scientists, policy makers, agrochemists and industrialists, and those with a role in consumer bodies, associations, and government agencies. Nanofoods has a global dimension, of particular importance for Europe, Japan, and the United States, but also becoming important for highly populated countries such as China, India, and South America. "Nanofoods" is becoming a hot topic and this book provides clarity and confidence.

Monique Axelos
Marcel Van de Voorde