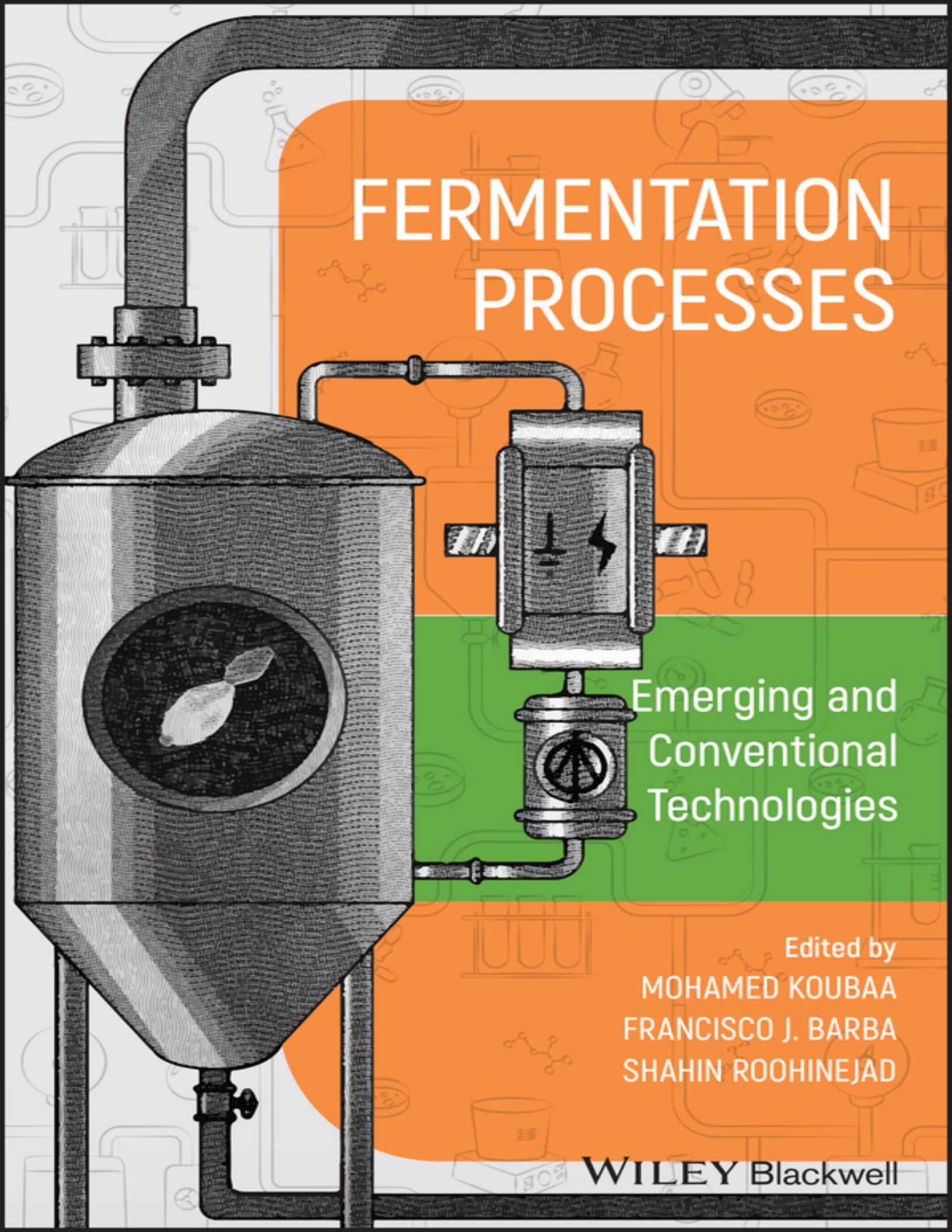


The background of the cover features a detailed illustration of industrial fermentation equipment. On the left is a large, vertical stainless steel fermenter with a conical bottom and a circular viewing window showing a white, foamy substance. To its right is a smaller, vertical cylindrical vessel with a lightning bolt symbol on its side, connected by various pipes and valves. The entire scene is set against a background of faint, light-colored line art depicting various laboratory and industrial equipment like flasks, beakers, and test tubes. The cover is divided into three horizontal color bands: orange at the top, green in the middle, and orange at the bottom.

FERMENTATION PROCESSES

Emerging and
Conventional
Technologies

Edited by
MOHAMED KOUBAA
FRANCISCO J. BARBA
SHAHIN ROOHINEJAD

WILEY Blackwell

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Fermentation Processes

Emerging and Conventional Technologies

Edited by

Mohamed Koubaa

ESCOM, UTC, EA 4297 TIMR, Compiègne, France

Francisco J. Barba

Faculty of Pharmacy, Preventive Medicine and Public Health, Food Science, Toxicology and Forensic Medicine Department, Universitat de València, València, Spain

Shahin Roohinejad

Burn & Wound Healing Research Center, Shiraz University of Medical Science, Shiraz, Iran

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About the Editors

Mohamed Koubaa

Dr. Mohamed Koubaa is an assistant professor in process and chemical engineering at ESCOM Chimie (Ecole Supérieure de Chimie Organique et Minérale) in Compiègne (France). He obtained an engineering diploma in biological sciences in 2007 from the National School of Engineers of Sfax (Tunisia), followed by a master's degree from the University of Technology of Compiègne (France). In July 2008, he received a full doctoral scholarship award from the Ministry of Higher Education, Research, and Innovation (France), and graduated in February 2012. He has performed different postdoctoral research stays as a research assistant in the Department of Industrial Process Engineering, University of Technology of Compiègne (France), the Department of Biological Engineering, National School of Engineers of Sfax (Tunisia), and as a postdoctoral research assistant in the prestigious Department of Molecular Genetics, The Ohio State University, Columbus, Ohio (USA). His research focus is on the use of nonconventional processing for the preservation and/or the extraction of bioactive compounds from liquid and solid foods and more recently in microbial growth stimulation by using emerging technologies. He has more than 100 publications (book chapters and articles in peer-reviewed international journals) to his credit.

Francisco J. Barba

Dr. Francisco J. Barba is an associate professor in Nutrition and Food Science and Technology, Faculty of Pharmacy, University of Valencia, Spain. He holds a European PhD (with distinction) from the University of Valencia and has

obtained degrees in Pharmacy, Food and Technology. He performed postdoctoral stays in the Université de Technologie de Compiègne (UTC), Département de Génie des Procédés Industriels, Laboratoire Transformations Intégrées de la Matière Renouvelable (Compiègne, France), and Marie Curie IEF in the Department of Food Chemistry (University of Copenhagen) to explore different non-thermal applications for preserving and extracting bioactive compounds from plant food materials and by-products. Prior to his current appointment, he was also engaged as a visiting researcher in the Department of Food Biotechnology and Food Process Engineering in Technological University of Berlin, Germany. His research focus is on innovative food processing technologies such as high-pressure processing, supercritical fluids, electrotechnologies, ultrasound, and microwaves for preservation and/or extraction of bioactive compounds from liquid and solid food. He has more than 300 publications to his credit, including more than 250 published or accepted peer-reviewed papers in international journals in the food science and technology area (h-index = 53, SCOPUS). He has been included in the Highly Cited Researchers 2019, 2020 list, the latest classification of the Clarivate Analytics bibliometric data provider. Dr. Barba currently serves as associate editor for prestigious journals such as *Food Research International*, *Journal of Food Composition and Analysis*, *Journal of Food Processing and Preservation*, *Antioxidants*, *Foods*, *Molecules*, and *Frontiers in Nutrition*, among others.

Shahin Roohinejad

Dr. Shahin Roohinejad obtained his BSc in 2000 in the field of food science and technology from the Islamic Azad University, Iran. He completed his MSc in food biotechnology at the University Putra Malaysia (UPM) in 2009. In July 2011, he received a full doctoral scholarship

award from the Department of Food Science at the University of Otago in New Zealand and graduated in December 2014. In 2015, he received the Georg Forster Research Fellowship Award granted by the Alexander von Humboldt Foundation to pursue his postdoctoral research at the Department of Food Technology and Bioprocess Engineering, Max Rubner-Institut (MRI), the German Federal Research Institute of Nutrition and Food. He joined the Department of Food Science and Nutrition, University of Minnesota as a Postdoctoral Research Associate in 2017. Followingly he started to work as a Research Scientist at Tillamook County Creamery Association in Oregon, USA in 2018. Currently, he is a Senior Scientist - Next Generation Oral Products at Reynolds American Inc., USA. He is a professional member of the Institute of Food Technologists (IFT), a member of IFT Press Advisory Group, and a Global Harmonization Initiative Ambassador in the USA. In the last 15 years, he has been working on different food areas such as fermentation, emerging food processing, emulsion-based systems, nanotechnology, and functional foods. His research activities have resulted in more than 100 original papers in peer-reviewed journals, book chapters, abstracts, and short papers in congress proceedings.

List of Contributors

Marina Al Daccache

Faculté des Sciences, Centre d'Analyses et de Recherche,
UR TVA, Laboratoire CTA, Université Saint-Joseph,
Beyrouth, Lebanon

Francisco J. Barba

Faculty of Pharmacy, Preventive Medicine and Public
Health, Food Science, Toxicology and Forensic Medicine
Department, Universitat de València, València, Spain

Ivonne Delgadillo

Escola Superior de Biotecnologia, Universidade Católica
Portuguesa, Porto, Portugal

LAQV-REQUIMTE, Department of Chemistry, University of
Aveiro, Aveiro, Portugal

Ana M. Gomes

Escola Superior de Biotecnologia, Universidade Católica
Portuguesa, Porto, Portugal

Seyedeh-Sara Hashemi

Burn & Wound Healing Research Center, Shiraz University
of Medical Science, Shiraz, Iran

Mahdi Irani

Department of Food Science and Technology, Ferdowsi
University of Mashhad (FUM), Mashhad, Iran

Sucheta Khubber

Food Engineering and Nutrition, Center of Innovative and
Applied Bioprocessing, Mohali, India

Mohamed Koubaa

ESCOM, UTC, EA 4297 TIMR, Compiègne, France

Rita P. Lopes

LAQV-REQUIMTE, Department of Chemistry, University of Aveiro, Aveiro, Portugal

Jose M. Lorenzo

Centro Tecnológico de la Carne, Parque Tecnológico de Galicia, Ourense, Spain

Nicolas Louka

Faculté des Sciences, Centre d'Analyses et de Recherche, UR TVA, Laboratoire CTA, Université Saint-Joseph, Beyrouth, Lebanon

Richard G. Maroun

Faculté des Sciences, Centre d'Analyses et de Recherche, UR TVA, Laboratoire CTA, Université Saint-Joseph, Beyrouth, Lebanon

Krystian Marszałek

Department of Fruit and Vegetable Product Technology, Prof. Waław Dąbrowski Institute of Agricultural and Food Biotechnology, Warsaw, Poland

Department of Food Technology and Human Nutrition, Institute of Food Technology and Nutrition, College of Natural Science, University of Rzeszow, Rzeszow, Poland

Francisco J. Marti-Quijal

Faculty of Pharmacy, Preventive Medicine and Public Health, Food Sciences, Toxicology and Forensic Medicine Department, Universitat de València, València, Spain

Maria J. Mota

LAQV-REQUIMTE, Department of Chemistry, University of Aveiro, Aveiro, Portugal

Maryam Nejadmansouri

Department of Food Science and Technology, College of Agriculture, Shiraz University, Shiraz, Iran

Mehrdad Niakousari

Department of Food Science and Technology, College of Agriculture, Shiraz University, Shiraz, Iran

Alireza Rafati

Division of Pharmacology & Pharmaceutical Chemistry, Sarvestan Branch, Islamic Azad University, Sarvestan, Iran

Maryam Razmjooei

Department of Food Science and Technology, College of Agriculture, Shiraz University, Shiraz, Iran

Fabienne Remize

UMR QualiSud, Université de La Réunion, CIRAD, Université Montpellier, Institut Agro, Université d'Avignon, Sainte Clotilde, France

Shahin Roohinejad

Burn & Wound Healing Research Center, Shiraz University of Medical Science, Shiraz, Iran

Dominique Salameh

Faculté des Sciences, Centre d'Analyses et de Recherche, UR - EGP, Laboratoire E2D, Université Saint-Joseph, Beyrouth, Lebanon

dominique.salameh@usj.edu.lb

Faculté des Sciences, Centre d'Analyses et de Recherche, UR - EGP, Laboratoire E2D, Université Saint-Joseph, Beyrouth, Lebanon

Jorge A. Saraiva

QOPNA, Chemistry Department, University of Aveiro, Aveiro, Portugal

LAQV-REQUIMTE, Department of Chemistry, University of Aveiro, Aveiro, Portugal

Sylwia Skąpska

Department of Fruit and Vegetable Product Technology, Institute of Agricultural and Food Biotechnology, Warsaw, Poland

Justyna Szczepańska

Department of Fruit and Vegetable Product Technology,
Institute of Agricultural and Food Biotechnology, Warsaw,
Poland

Igor Tomasevic

Faculty of Agriculture, University of Belgrade, Belgrade,
Serbia

Artur Wiktor

Faculty of Food Sciences, Department of Food Engineering
and Process Management, Warsaw University of Life
Sciences (WULS-SGGW), Warsaw, Poland

Dorota Witrowa-Rajchert

Faculty of Food Sciences, Department of Food Engineering
and Process Management, Warsaw University of Life
Sciences (WULS-SGGW), Warsaw, Poland

Łukasz Woźniak

Department of Fruit and Vegetable Product Technology,
Institute of Agricultural and Food Biotechnology, Warsaw,
Poland

Preface

Bioprocesses find many traditional or new applications in the agri-food, chemical, pharmaceutical, and environmental industries. Enhancing these processes for better production of microbial biomass and/or products has interested many scientists in the last two decades. One of the strategies consists of changing the medium composition or the fermentation parameters (e.g. oxygenation, agitation, temperature, etc.), most of the time via a design of experiment approach. Besides, some emerging technologies (e.g. pulsed electric fields, ultrasounds, high hydrostatic pressure, microwaves, etc.) have shown their efficiency to enhance the fermentation processes. These technologies when applied at high intensities cause cell disintegration and find their applications in bioprocesses, for example, to produce sugar monomers from lignocellulosic biomass. Nonetheless, their application at sublethal levels may induce stress of microorganisms and affect the microbial growth and the formation of the products during fermentation. The beneficial effects of microbial stimulation by emerging technologies include mainly the shortening of the fermentation time, the acceleration of the substrate consumption, and the increase of the microbial biomass.

This book covers the principles of conventional fermentation processes, the major microorganisms used in bioprocesses, their implementation in industrial fermentation processes, the medium condition changes, and the use of emerging technologies for enhancing the fermentation processes. Besides, the mechanisms of action of the above-mentioned emerging technologies are discussed.

This book is designed to assist scientists working on fermentation processes as well as those working in the food, nutraceutical, pharmaceutical, and beverage industries. The topics covered in this book are suitable for teaching in courses such as bioprocess technology, microbiology, new product development, and food processing.

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Mohamed Koubaa, Francisco J. Barba, and Shahin Roohinejad

1

Introduction to Conventional Fermentation Processes

Mohamed Koubaa

ESCOM, UTC, EA 4297 TIMR, Compiègne, France

1.1 Bioprocesses

Bioprocesses represent all the methods and techniques that use microbial, plant, or animal cells or their components (e.g. enzymes, proteins, genes, etc.) for the production of goods and services (Sindhu et al. [2017](#)). Bioprocess technology is, in fact, an extension of the ancestral techniques used at the time to develop useful products (Kalaichelvan and Pandi [2019](#)). Nowadays, microbial cells are not only used in common processes, such as for the production of alcoholic beverages (e.g. wine, beer, etc.) or dairy products (e.g. yogurt, cheese, etc.), but also to produce a wide diversity of complex molecules. In this sense, bioprocesses find many traditional or new applications in the following industries:

- Agri-food industry: production of animal proteins, amino acids, fermented foods and beverages, vitamins, enzymes, etc.
- Chemical industry: production of organic acids, ethanol, solvents, polymers, biogas, etc.
- Pharmaceutical industry: production of antibodies, vaccines, hormones, plasmids, steroids, etc.
- Environmental industry: decontamination of wastewater, air, and soil; development of agricultural

and industrial by-products, etc.

In this respect, bioprocesses are exploited in three specific fields: fermentation processes, animal and plant cell cultures, and environmental bioprocesses. This chapter will mainly focus on conventional fermentation processes.

Most of the methods and techniques used in bioprocesses are based on fermentation technology. This is not surprising since the first ancestral processes were based on microbial fermentation. For most people, fermentation simply refers to the production of alcohol (beer and wine) or the deterioration of food by microorganisms (curd). Nevertheless, the word fermentation takes on a broader common industrial meaning. It is any process for producing a substance or biomass of cells on a large scale by using the culture of a microorganism, in aerobic or anaerobic conditions.

To be able to carry out these fermentations, it is imperative to cultivate microorganisms in tanks equipped with a certain number of more or less sophisticated systems; these tanks are called *fermenters* or *bioreactors*. Their role is to provide a controlled environment for optimal growth of microbial cells throughout the culture by constantly stirring the medium, infusing sterile air – in the case of aerobic fermentation – and controlling the temperature and pH of the fermentation broth. By using these tanks, contamination by other microorganisms is avoided by constantly maintaining asepsis conditions.

The first modern fermenters were designed in the 1950s to support the industrial production of penicillin and other newly discovered antibiotics. Since then, they have been able to control several other types of crops and to substantially increase the quantity of products marketed in each of the three fields of application of industrial

bioprocesses mentioned above. Six major groups of products could then be obtained by fermentative processes, namely the production of (i) microbial biomass, (ii) microbial metabolites, (iii) microbial enzymes, (iv) recombinant proteins, (v) microbial plasmids, and (vi) bioconversion.

1.1.1 Production of Microbial Biomass

Commercial production of microbial biomass can be divided into two major processes: the production of viable microorganisms used primarily for fermentative applications (Vitorino and Bessa [2017](#)) and the production of microbial cells, usually dead, that can serve as protein-rich supplements (Matassa et al. [2016](#)).

In the first case, we can cite several examples: the production of bakery yeasts for the production of bread, the production of yeasts to perform alcoholic fermentation (e.g. beers, wines, spirits, etc.), and the production of lactic acid bacteria for the manufacturing of cheese, yogurt, fermented meats (i.e. sausages), or fermented vegetables (e.g. sauerkraut, marinated pickles, etc.). Some food supplements composed of live lactic acid bacteria, also called *probiotics*, are produced by fermentation. They can be defined as live microorganisms, and the adequate amounts of them supply a health benefit to the host (Otlés and Ozyurt [2019](#)). Their role is to exert a beneficial effect by improving the quality of the intestinal flora. These microorganisms are usually supplied as a lyophilized powder in hermetically sealed sterile bags or containers. Generally, the name of ferments is given to microorganisms that serve to start a fermentation process (Koutinas [2017](#)). Some microbial strains such as the bacterium *Bacillus thuringiensis*, whose spores produce a very effective toxin against pest larvae (biological insecticide), are also grown.

In the second case, it is a question of producing microbial biomass to exploit the nutritional potential of the proteins that it produces (Matassa et al. [2016](#)). This biomass is incorporated into prepared foods to increase their protein content without significant fat intake, which improves their nutritional quality. The yeast *Candida utilis* is mostly used as a dietary supplement because of its exceptionally high protein content (50–55% of dry weight). This yeast can be used as a valuable raw material to produce various preparations enriched with valuable bioelements (e.g. selenium, magnesium, etc.). The use of such preparations in the human diet provides an interesting alternative to classical, pharmacological supplementation and prevents deficits of important elements, while their addition to feedstock significantly improves the results of animal production (Kieliszek et al. [2017](#)).

1.1.2 Production of Microbial Metabolites

Microorganisms are characterized by a variety of metabolic pathways that allow them to synthesize a host of organic compounds, called *metabolites*, many of which are potentially useful. In this type of fermentation, it is sought to produce by the metabolic activity of a microorganism a substance that is too complex to be chemically synthesized at a reasonable cost (Jeandet et al. [2013](#)).

Metabolites are generally divided into two categories depending on whether they are produced in relation to growth or not. The first ones are called *primary metabolites* and are produced in large enough quantities during the exponential growth phase by essential metabolic pathways that are common to many microorganisms. Several primary metabolites produced by fermentation are the residues of the energetic catabolism of microorganisms. These are mainly alcohols, solvents, and organic acids used in food or the chemical industry. Others are derived from cellular

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