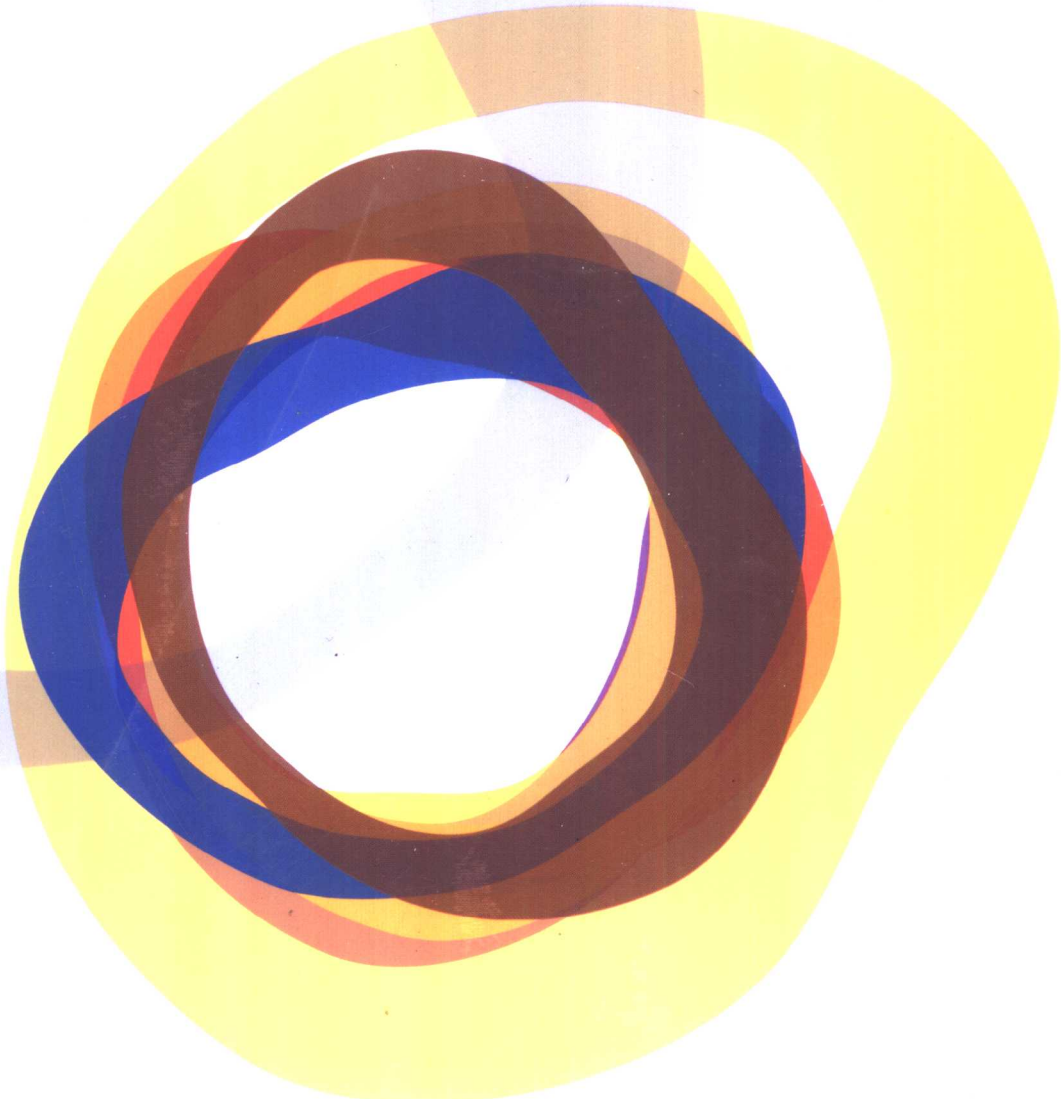
功能性食品生物技术

BIOTECHNOLOGY IN FUNCTIONAL FOODS

郑建仙　主编



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袁隆平院士（中）、单杨研究员（左）和郑建仙教授（右）在一起

利用生物技术
开发功能性食品

袁隆平 二〇〇三.2.廿

序

数万年以来，人类一直在了解、开发和利用我们周围的自然界，同时也不断地认识和改造自己。人类的文明进程已有6000多年的历史，地球上各个民族的共同努力，创造了人类文明的灿烂之花。科学技术从一开始，就随人类生存的需要而产生并持续发展着。我们周边的这个世界正在发生着深刻的变化，这种变化是20世纪以来科学技术革命不断深入的必然结果。生产力的发展是社会发展与文明进步的根本动力，而科学技术是第一生产力。因此，科学技术是推动社会发展和文明进步的革命性力量。人类社会已经走过了农业经济时代和工业经济时代，正在步入知识经济时代，科学技术发挥着越来越重要的作用。

时令已进入了21世纪，展现在人类面前的是一幅比过去任何时候更为美好的前景。以生物技术、信息技术、新材料技术、海洋技术、新能源技术等为代表的高技术革命浪潮，正席卷着全球。而以基因工程、细胞工程、酶工程、发酵工程为代表的生物技术，是世界高技术革命浪潮的一个重要组成部分。这是一场正在蓬勃发展的高技术革命，它不仅推动着工业革命的进程，而且还以前所未有的速度冲击着人类固有的传统观念。由于生物技术的经济潜力极大，它的发展水平已成为一个国家经济科技实力的象征。在发达国家之间、发展中国家之间、发展中国家与发达国家之间，上演了一幕幕你争我夺的好戏。生物技术，受到了世界各国政府和社会各界的重视，形成了全球性的生物技术热潮。各国政府竞相制定发展计划，投入巨额资金，实行优惠政策，促进生物技术的发展。以生物技术产品为开发对象的大中型公司，正在世界各国如雨后春笋般地建立起来，一个新兴的高技术生物产业正在形成。

遗传、营养和教育是决定一个民族整体素质的三大要素。食品工业，是一个与人类共存的永恒产业，是影响我国国民经济建设的支柱产业，关系着中华民族的生存和健康，意义重大。功能性食品，是新时代对食品工业的深层次要求。开发功能性食品的根本目的，就是要最大限度地满足人类自身的健康需求。

开发功能性食品，要对其“安全性”和“功能性”进行科学评价。这就需要明确其中起关键作用的功效成分，并用高新技术（包括生物技术）来生产这些功效成分，再研制生产出相应的功能性食品。这项工作十分重要，同时也是我们与国际先进水平的差距之所在。因此，尽管我国几千年的传统中医药理论和养生康复理论，能为发展有我国特色的功能性食品工业提供宝库。但我们绝不能只停留在几千年的传统理论、躺在老祖宗的功劳簿上自鸣得意，我们应加强基础理论和应用技术的研究，用生物技术及其他高新技术来改造传统产业，以跟上世界发展的潮流，并保留和发展自己的特色。

利用生物技术开发生产功能性食品，任重而道远，前景十分光明。生物技术可代替传统的提取分离技术或化学合成技术，在生产各种具有特定生理功效的配料上发挥重要作用。生物技术在生产功能性低聚糖、功能性单双糖、活性多糖、多不饱和脂肪酸、活性肽、功能性酶蛋白、维生素和维生素类似物、益生菌以及低能量食品成分等重要功效配料上发挥重要作用。

青年教授郑建仙博士10多年来一直从事功能性食品和食品生物技术领域的研究开发工作，近年来先后主持国家、省市和企业委托的有关功能性食品及其功效成分的研发项目共15

项，其中有很多项目已实现了工业化生产，成绩喜人。在这些工作基础上，还编著或主编出版了我国本领域研究的首版大型专著《功能性食品》（第一、二、三卷）、《低能量食品》、《功能性食品学》和《功能性食品甜味剂》等，在国内很有影响。《功能性食品》（第一、二、三卷）还通过版权贸易，由我国台湾省的华香园出版社出版了中文繁体字版。

进入新世纪，全球经济一体化的进程明显加快，知识与经济的结合更趋紧密。世界各国竞争的焦点不仅表现在新技术、新产品的研发方面，还表现在科技成果向生产力的转化方面。古老而又年轻的功能性食品工业，由于生物技术等高技术的注入，而呈现出一派勃勃生机的景象。在这种新形势下，郑建仙教授又主持编著了这部全新的《功能性食品生物技术》。该书在郑建仙教授主持的15项科研项目基础上，利用国际互联网技术广泛吸收国外最新的研究成果，系当前国内外功能性食品生物技术领域最具权威的专著之一，对今后相当长时间内功能性食品生物技术的发展都具有重要的指导价值。

《功能性食品生物技术》对各种功效成分或功效配料的生物技术生产方法作了非常详细的论述，这些内容往往都是作为核心技术加以严格保密，而科研和生产单位却又是十分需要的。最后，还着眼全球范围内分析功能性食品产业的发展趋势，以及美国、欧洲功能性食品市场的发展动态，这些信息都是非常有用的。因此，本书的出版有望为食品工业，尤其是功能性食品工业的高新技术改造或产业结构优化重组，提供具体的现实的指导作用。综观全书，内容新颖全面，论述科学严谨，文笔简洁流畅，时代气息浓，科学性强，实用性大，确是一部难得的学术专著。

值本专著即将出版之际，我乐以为序。

2003年6月26日

PREFACE

Over thousands of years, while human beings have been endeavoring to cognize, explore, and utilize our surrounding nature, we persevere in understanding and improving ourselves at the same time. The human civilization blossoms along with its more than 6000 years history under a joint effort of all peoples on the earth. Science and technology have emerged and kept developing accompanied with the human needs to survive and live a better life. The revolution of science and technology in the 20th century has resulted in an inevitable, profound change upon our surrounding world. Productivity growth is the fundamental force for the evolution of society and the progress of civilization, whereas science and technology are the First Productivity. Hence, science and technology are the revolutionary force that drives the evolution of society and the progress of civilization. After walking through the agricultural economy and the industrial economy, we are now running into the information and technology economy as science and technology are playing more and more important roles.

As we are entering the 21st century, human beings are facing a much more promising prospect than ever before. The wave of high－tech revolution, represented by biological technology, information technology, new material technology, ocean technology, and new energy technology, are sweeping throughout the world. Biological technology, as exemplified by genetic engineering, cell engineering, enzyme engineering, and fermentation engineering, is an important component of the world high－tech revolution. Not only the revolution flourishes in driving the progress in industry, it also strikes the deep－rooted traditional concepts with a faster－than－ever speed. Because of the great economic potential of biological technology, the depth and breadth of its development has become an indicator of a nation's economic and technological strength. Intensive competitions are now taking place among developed countries, developing countries, and between developed and developing countries. Biological technology has increasingly received more and more attentions from governments and different social classes, which has formed the global upsurge of biological technology. Governments of various countries have reacted quickly to this opportunity, including roadmapping plans, investing capitals, and offering priority policies in order to promote the biological technology. As a result, a great number of medium or large size biotech companies were founded in a short time. A new high－tech industry is being formed up.

Gene, nutrition and education are the three key elements that determine a nation's overall quality. Food industry is an eternal industry that has existed as long as human beings have come into being. As the pillar of our country's civil economy construction, food industry is tremendously significant to the whole nation's well being. Functional foods, as a demand from the new era, are coming up with goals to maximize the satisfaction upon the needs towards human beings' health.

To develop functional foods, scientific evaluation on their safety and functionality must be employed. It requires us to identify the active ingredient, produce the active ingredient by using high/new technologies (including biotechnology), and develop and produce the corresponding functional food. This is a very important work, which leaves us falling behind the world's leading level. Although we have inherited the treasure of the traditional Chinese medicine, health-care and recovery theories that are greatly beneficial to developing our own functional foods, there is no way we should stagnate on the traditional theories and hug ourselves on our ancestors' accomplishment. We should enhance our research on the basic theories and practical technologies, use bio- and other high/new technologies to transform traditional industries so as to follow the global trend while reserving and developing our own characteristics.

However, the utilization of biotechnology to develop and produce functional foods is a remote, laborious yet prospective way to go. Biotechnology can replace the traditional extraction and separation technology or chemical synthesis technology; therefore it plays a very important role in the production of bioactive ingredients for functional foods, such as functional oligosaccharides, functional mono/di-saccharides, bioactive polysaccharides, polyunsaturated fatty acid, bioactive peptides, functional enzyme proteins, vitamins and their analogues, probiotics, and low-calorie food ingredients.

Dr. Jianxian Zheng (Jackson Zein), a young professor, has been dedicated to the research of functional food and food biotechnology for more than 10 years. He has successively led 15 research projects on functional foods and their active ingredients that were sponsored by the state, the province, the municipality or corporate units, with many of the projects being industrialized. His outstanding accomplishments have received recognitions and praises. In addition, Dr. Jianxian Zheng has served the chief editor or editor on several books that have great impact on the area of functional food in China, including the first monograph in this area written in Chinese, the *Functional Foods* (volume Ⅰ, Ⅱ, Ⅲ), *Low-Calorie Foods*, *The Science of Functional Foods*, *Functional Food Sweeteners* etc. The book of *Functional Foods* (volume Ⅰ, Ⅱ, Ⅲ) was also printed in traditional Chinese and published by Huaxiangyuan Publishing House in Taiwan through copyright exchange.

Upon the arrival of the new century, the procession of economy globalization has been significantly accelerated and the economy has been more closely synchronized with the development of science and technology. The competitions between different nations are not only occurring on the R&D of new technologies and products, but also on the transformation from research harvests to the real productivity. The traditional yet promising functional food industry is thriving with the input of biotechnology and other high/new technology. Under this new situation, Dr. Jianxian Zheng took charge of editing the most updated *Biotechnology in Functional Foods*. This book summarizes the fruits of the 15 research projects led by Dr. Jianxian Zheng, and assembles the latest research results worldwide by utilizing the Internet resources. It is one of the most authoritative monographs in the area of functional foods and biotechnology within and outside China, and will serve as the guidance for the development of functional food and biotechnology in the foresee-

able future.

Biotechnology in Functional Foods intensively expounds the biotech production methods for a large variety of bioactive ingredients. The book helps the general research and production units by providing the detailed information that were usually kept confidential as core technologies by the business corporations. In the end, the book sets its foot on analyzing the global trends of functional foods, as well as its market movement in the United States and Europe. These are all valuable information. Therefore, the publication of the book will provide a concrete and practical guidance for the food industry, especially for transforming, re－structuring, and optimizing the functional food industry by high/new technology. This is an outstanding composition with the up－to－date and comprehensive contents, scientific and precise elucidation, concise and mellifluence writing, strong scientificity, and great practicability.

It is my great pleasure to preface the book at the time of its publication.

Longping Yuan
June 26, 2003

内 容 提 要

利用生物技术生产功能性食品，系当今国际食品科学和食品生物技术领域的前沿阵地，有巨大的市场潜力和广阔的发展空间。本书是国内本领域的第一部专著，内容新颖，论述严谨，科学性强，实用性大。

全书分五篇共十八章。第一篇第一至六章，详细论述酶工程在功能性食品产业中的典型应用范例。内容包括：甜菊糖、三氯蔗糖、天门冬酰苯丙氨酸甲酯（又称阿斯巴甜）等强力甜味剂的酶法改性或酶法合成；低聚果糖、低聚半乳糖、低聚异麦芽糖、低聚乳果糖、低聚木糖、低聚壳聚糖、偶合糖等功能性低聚糖的酶法生产；结晶果糖、L－糖、异麦芽酮糖、海藻糖等功能性单双糖的酶法生产；大豆肽、降压肽、酪蛋白磷肽、糖巨肽、高 F 值低聚肽、含低聚糖肽等活性肽的酶法生产；β－呋喃果糖苷酶、菊粉酶、β－半乳糖苷酶、α－葡萄糖苷酶、木聚糖酶、壳聚糖酶、环糊精葡糖基转移酶、淀粉酶、葡萄糖异构酶、甘露聚糖酶等糖苷酶的性质和生产；超氧化物歧化酶、谷胱甘肽过氧化物酶、溶菌酶等功能性酶蛋白的性质和生产。

第二篇第七至十五章，系统阐述发酵工程在功能性食品产业中的典型应用范例。内容包括：木糖醇、甘露醇、赤藓糖醇等多元糖醇的发酵法生产；灵芝、冬虫夏草、蜜环菌、银耳、云芝菌、猴头菇、香菇、金针菇、双孢蘑菇等大型真菌菌丝体的发酵法生产；螺旋藻、小球藻的发酵法生产；维生素C、维生素 B_2、泛酸、辅酶A、烟酸、烟酰胺、维生素 B_{12}、生物素、β－胡萝卜素、辅酶 Q_{10}、L－肉碱等维生素和维生素类似物的发酵法生产；EPA、DHA、γ－亚麻酸、花生四烯酸等多不饱和脂肪酸的发酵法生产；乳链球菌、曲酸、纳他霉素等生物防腐剂的发酵法生产；硒、锗、铬等微量元素的生物有机化；透明质酸、谷胱甘肽、1,6－二磷酸果糖、功能性乳制品的发酵法生产。

第三、四篇第十六、十七章，分别讨论基因工程和细胞工程生产高甜蛋白、人参细胞、超氧化物歧化酶的典型范例。

第五篇第十八章，着眼全球范围内分析功能性食品产业的发展趋势，以及美国、欧洲功能性食品市场的发展动态。

本书利用国际互联网技术广泛吸收国外最新的研究成果，系当前国内外功能性食品生物技术领域最具权威的专著之一，对今后相当长时间内功能性食品生物技术的发展都具有重要的指导价值。可供生物工程、食品工程、医药工程、化学工程等领域科研、生产单位从业人员和管理决策人员参考，对相关学科的院校师生也有重要的参考价值。

ABSTRACT

The utilization of biotechnology in the production of functional foods represents the world's leading cutting－edge area of food science & food biotechnology, which possesses great market potential and growth prospect. This book is the first Chinese monograph specialized in this area, with the up－to－date development, scientific and precise elucidation and strong practicability.

The book consists of 5 parts in 18 chapters. Part 1 (Chapter 1～6) details the typical applications of enzyme engineering in the production of functional food, including enzymatic modification or synthesis of stevia, sucralose and aspartame; enzymatic production of functional oligosaccharides, such as fructooligosaccharide, galactooligosaccharide, isomaltooligosaccharide, lactosucrose, xylooligosaccharide, chitooligosaccharide, coupling sugar etc.; enzymatic production of functional mono/di－saccharides, such as crystalline fructose, L－sugars, isomaltulose and trehalose; enzymatic production of bioactive peptides, such as soybean peptide, antihypertensive peptide, casein phosphopeptide, glycomacropeptide, high F value peptides and peptides containing oligosaccharides; the properties and production of glycosidases, such as β－fructofurnosidase, inulinase, β－galactosidase, α－glucosidase, xylanase, chitosanase, cyclodextrin glucanotransferase, amylase, glucose isomerase and mannase; the properties and production of functional enzymes, such as superoxide dismutase, glutathione peroxidase, and lysozyme.

Part 2 (Chapter 7～15) systematically illustrate the typical applications of fermentation engineering in the production of functional food, including the fermentation production of sugar polyols, such as xylitol, mannitol and erythritol; the fermentation production of macrofungus such as *Ganoderma lucidum*, *Cordyceps sinensis*, *Armillaria mellea*, *Tremella fuciformis*, *Hedgehog hydnum* etc.; the fermentation production of microalgaes such as *Spirulin* and *Chlorella*; the fermentation production of vitamins and their analogues, such as vitamin C, vitamin B_2, vitamin B_{12}, pantothenic acid, coenzyme, nicotinic acid, nicotinic amide, biotin, β－carotene, coenzyme Q_{10} and L－carnitine; the fermentation production of polyunsaturated fatty acids, such as EPA, DHA and γ－linolenic acid and arachidonic acid; the fermentation production of biopreservatives, such as nisin, kojic acid and natamycin; the bio－organization of the minerals, such as selenium, germanium and chromium; the fermentation production of hyaluronic acid, glutathione, fructose－1,6－diphosphate and functional diary products. Part 3 and Part 4 (Chapter 16～17) discuss the typical applications of gene engineering and cell engineering in the production of sweet proteins, ginseng cell and superoxide dismutase, respectively. Part 5 (Chapter 18) focuses on the global trends of functional food, especially the trend in America and Europe markets.

By utilizing the internet resources, this book has assembled an impressive collection of the

latest researches worldwide on the biotechnology in functional foods, which makes it one of the most authoritative monographs in this area within and outside China. It will serve as the guidance for the future development of biotechnology in functional foods for quite some time, and as an important reference for the professionals or students working in such areas as biology engineering, food engineering, pharmaceutical engineering, and chemistry engineering etc.

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第六章　功能性酶蛋白的范例

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前　言

生物技术(Biotechnology),是应用自然科学及工程学原理,依靠微生物、动物、植物细胞及其产生的活性物质,作为某种化学反应的执行者,将原料进行加工成某种产品来为社会服务的技术。它是利用生物体系,应用先进的生物学和工程技术,加工或不加工底物原料,以提供所需的各种产品,或达到某种目的。

功能性食品(Functional food),是强调其成分对人体能充分显示机体防御功能、调节生理节律、预防疾病和促进康复等功能的工业化食品。功能性食品,是新时代对传统食品的深层次要求。开发功能性食品的最终目的,就是要最大限度地满足人类自身的健康需要。

功能性食品中真正起生理作用的成分,称为功效成分(Functional composition),或称活性成分、功能因子等。很显然,功效成分是生产功能性食品的关键。随着科学研究的不断深入,更新更好的功效成分将会不断被发现。就目前而言,业已确认的功效成分,主要包括以下8类:

(1) 功能性碳水化合物:例如真菌多糖、功能性低聚糖、功能性单双糖等。

(2) 功能性脂类:例如 $\omega-3$ 多不饱和脂肪酸、$\omega-6$ 多不饱和脂肪酸、磷脂等。

(3) 氨基酸、肽与蛋白质:例如牛磺酸、酪蛋白磷肽、降压肽、免疫球蛋白、酶蛋白等。

(4) 维生素和维生素类似物:包括水溶性维生素、油溶性维生素、生物类黄酮等。

(5) 矿物元素:包括常量元素、微量元素等。

(6) 植物活性成分:例如皂苷、生物碱、萜类化合物、有机硫化合物等。

(7) 益生菌:主要是乳酸菌类,尤其是双歧杆菌。

(8) 低能量食品成分:包括蔗糖替代品、脂肪替代品等。

功能性食品的出现,标志着作为食品中的关键组分,开始从重点要求大量的传统营养素,转向重点要求微量的功效成分。由于功效成分普遍具有的"微量"、"高效"和"不稳定",应用传统的工程技术,已不能适应微量成分的制造工程,不能开发出高科技的功能性食品。现代食品工程高新技术的出现,将有力地促进这个问题的圆满解决。高新技术在功能性食品生产中所占的比重不断增大,特别是生物技术的应用得以长足的发展,尤其是用在功能性食品配料(功效成分)的生产上,这将有力地推动食品工业发生革命性的变化。

这是一个令人振奋的高新技术领域,是当今国际食品生物技术领域的前沿阵地,有广阔的发展空间和巨大的市场潜力。就目前而言,生物技术已在功能性食品生产上得到有效应用,就上述提到的8类功效成分中,除植物活性成分一般采用提取分离法外,其余的均可用生物技术来高效生产。例如:

(1) 利用生物技术生产低聚果糖、低聚乳果糖、低聚半乳糖和低聚木糖等功能性低聚糖,结晶果糖、L-糖、异麦芽酮糖和海藻糖等功能性单双糖,以及灵芝、冬虫夏草、蜜环菌等真菌菌丝体,参见第二、三、四、八章。

(2) 利用生物技术生产 EPA、DHA、γ-亚麻酸、花生四烯酸等,参见第十一章。

(3) 利用生物技术生产降压肽、酪蛋白磷肽、糖巨肽、高 F 值低聚肽、谷胱甘肽和酶蛋白