Innovations in Agricultural & Biological Engineering

Food Technology

Applied Research and Production Techniques




Editors Murlidhar Meghwal
Megh R. Goyal
Mital J. Kaneria

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FOOD TECHNOLOGY

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Edited by
Murlidhar Meghwal, PhD
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LIST OF ABBREVIATIONS

AA	ascorbic acid
AACC	American Association of Cereal Chemists
ABTS	2,2-azino-bis-(3-ethylbenzothiazoline-6-sulfonic acid)
AC	acetone
AICTE	All India Council for Technical Education
ALL	*Aerva lanata* leaf
ALS	*Aerva lanata* stem
AOAC	Association of Official Analytical Chemists
AQ	aqueous
ASAE	American Society of Agricultural Engineers
ASBI	American Shea Butter Institute
AYUSH	Ayurveda, Unani, Siddha and Homeopathy System of Medicines
BARD	Binational Agricultural Research and Development Fund
BC	*Bacillus cereus* ATCC29737
BDR	*Boerhaavia diffusa* root
Bo	bond number
BS	*Bacillus subtilis* ATCC6833
CA	*Candida albicans* ATCC2091
CCl_4	carbon tetrachloride
CE	*Candida epicola* NCIM3102
CF	*Citrobacter freundii* ATCC10787
CF	*Citrobacter freundii* NCIM2489
Cfu	colony forming unit
CG	*Candida glabrata* NCIM3448
CH	chloramphenicol
CN	*Cryptococcus neoformans* ATCC34664
CR	*Corynebacterium rubrum* ATCC14898
CS	cefotaxime sodium
CSIR	Council for Scientific and Industrial Research
DAE	Department of Atomic Energy

DBT	Department of Biotechnology
DFPI	Department of Food Processing Industries
DHA	docosahexaenoic acids
DHA-Et	docosahexaenoic acids–ethyl ester
DMSO	dimethyl sulfoxide
DNA	deoxyribonucleic acid
DOE	Department of Education
DPPH	2,2-diphenyl-1-picrylhydrazyl
DRDO	Defense Research and Development Organization
DSC	differential scanning calorimeter
DST	Department of Science and Technology
DTA	differential thermal analysis
DTG	derivative thermo gravimetry
EA	*Enterobacter aerogenes* ATCC13048
EA	ethyl acetate
EC	*Escherichia coli* ATCC25922
EC	*Escherichia coli* NCIM2931
EPA	eicosapentaenoic acids
EPA-Et	eicosapentaenoic acid-ethyl ester
FAO	Food and Agriculture Organization
FRAP	ferric reducing antioxidant power
GA	gallic acid
GEN	gentamycin
GMPs	Good Manufacturing Practices
HACCP	Hazard Analysis and Critical Control Points
HCl	hydrochloric acid
HPLC	high performance liquid chromatography
HPTLC	high performance thin layer chromatography
ICAR	Indian Council of Agricultural Research
ICMR	Indian Council of Medical Research
IEEE	Institute of Electrical and Electronics Engineers
INSA	Indian National Science Academy
ISO	International Organization for Standardization
KA	*Klebsiella aerogenes* NCIM2098
KP	*Klebsiella pneumonia* NCIM2719
LC-MS	liquid chromatography-mass spectrometry

LDL	low density lipoprotein
LLE	liquid–liquid extraction
LM	*Listeria monocytogenes* ATCC19112
MBC	minimum bactericidal concentrations
ME	methanol
MF	*Micrococcus flavus* ATCC10240
MFCS	Ministry of Food and Civil Supplies
MIC	minimum inhibitory concentrations
ML	*Micrococcus luteus* ATCC10240
MNRE	Ministry of New and Renewable Energy
MRSA	methicillin-resistant *Staphylococcus aureus*
NA	not applicable
NAAS	National Academy of Agricultural Sciences
NADH	nicotinamide adenine dinucleotide reduced
NBT	nitroblue tetrazolium
NDDB	National Dairy Development Board
NOSVODB	National Oil seeds and Vegetable Oils Development Board
OCH	old corn hair
OH	hydroxyl radical scavenging activity
OPEC	Organization of the Petroleum Exporting Countries
OX	oxacillin
PA	*Pseudomonas aeruginosa* ATCC27853
PA	*Pseudomonas aeruginosa* ATCC9027
PAE	acetone extract
PCE	chloroform extract
PCR	crude powder
PE	petroleum ether
PHE	hexane extract
PME	methanol extract
PMS	phenazine methosulfate
PQSS	Product Quality, Safety and Standards
PS	*P. syrigae* NCIM5102
PT	*P. testosterone* NCIM5098
PTE	toluene extract
QMS	Quality Management System
ROS	reactive oxygen species

RSM	ripe seed methanol extract
RTE	ready-to-eat
SA	*Staphylococcus aureus* ATCC29737
SA-1	*Staphylococcus aureus* ATCC25923-1
SA-2	*Staphylococcus aureus* ATCC29737-2
SE	*S. epidermidis* ATCC12228
SE	*Staphylococcus epidermidis* NCIM2493
SEM	scanning electron microscope
SEM	standard error of mean
SERC	Science and Engineering Research Council
SI	self inspection
SICE	The Society of Instrument and Control Engineers
SO	superoxide
SOP	Safety Operation Process
SSOP	Sanitation Standard Operating Procedures
ST	*Salmonella typhimurium* ATCC23564
TBF	*T. bellerica* fruit rind
TBL	*Terminalia bellirica* leaf
TBS	*Terminalia bellirica* stem
TCF	*T. chebula* fruit rind
TCL	*Terminalia catappa* leaf
TCS	*Terminalia chebula* stem
TG	thermo gravimetry
TGA	thermogravimetric analysis
TLC	thin layer chromatography
TPC	total phenol content
TPTZ	2,4,6-tri(2-pyridyl)-s-triazine
TTF	*Tribulus terrestris* fruit
UGC	University Grants Commission
USAID	United States Agriculture International Aid
USDA	United states department of Agriculture
UV	ultra violet
VAN	Vancomycin
WHO	World Health Organization
WS	woody stem
YCH	Young corn hair
YS	young stem

LIST OF SYMBOLS

Aqua	aqueous phase
Bo	Bond Number
Ca	Capillary Number
CCl_4	carbon tetrachloride
Cfu	colony forming unit
$FeCl_3$	ferric chloride
$FeSO_4$	ferrous sulfate
Fish Oil EE	fish oil ethyl ester
H_2SO_4	sulfuric acid
IC_{50}	50% inhibitory concentration
K_2CO_3	potassium carbonate
$K_2S_2O_8$	potassium persulfate
NaCl	sodium chloride
Omega 3 PUFA	omega 3 poly unsaturated fatty acids
Orga.	organic phase
PMi	*Proteus mirabilis* NCIM2241
PMo	*P. morganii* NCIM2040
PPi	*P. pictorum* NCIB9152
PPu	*P. putida* NCIM2872
Re	Reynolds Number
R_f	refractive index
Sal	*Staphylococcus albus* NCIM2178
Q	volumetric flow rate (ml/min)
We	Weber Number
M	fluid dynamic viscosity (Pa.s)
P	fluid density (Kg/m^3)
U	velocity of fluids in mini-channel (m/sec)
ρH	density of heavy phase (Kg/m^3)
ρL	density of light phase (Kg/m^3)
σAB	interfacial tension (mN/m)

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FOREWORD BY T. K. GOSWAMI

I feel very delighted and honored to write this foreword for the book on *Food Technology: Applied Research and Production Techniques* under the book series *Innovations in Agricultural and Biological Engineering.* This book is edited by Murlidhar Meghwal, Megh R. Goyal, and Mital J. Kaneria.

Food technology is the applied science dedicated to the study of food, edible oils, herbs and spices, nutrition, their health effect, and various processing parameter and changes. It is a discipline in which the engineering, biological, and chemical principles of food processing and physical sciences are used to study the nature of foods, the causes of deterioration, packaging, storage, the principles underlying food processing, and the improvement of foods for the consuming public.

In this book, first four sections cover important topics on "Food Technology and Processing and Food Science." They are namely principles and practical applications in good manufacturing practices for food processing industries, research funding agencies around the globe in the food engineering, use of plastics in the twenty-first century food industry, latest trends in thermal processing in food technology, nondestructive technique of soft X-ray for evaluation of internal quality of agricultural produce, *in vitro* antioxidant efficacy of selected medicinal plants, antioxidant activities of some marine algae, omega-3 PUFA from fish oil of silver-based solvent extraction, antioxidant and antibacterial properties of extracts, *in vitro* antimicrobial activity, and antimicrobial properties of leaf extract.

The fifth section covers isolation, validation and characterization of major bioactive constituents from mango ripe seed, isolation and characterization of lycopene from tomato and its biological activity, and food processing using microbial control system.

I congratulate the editors for their timely decision of bringing out this book for use by scientists, engineers, professionals, and students. I am sure that it will be a very useful reference book for professionals working in food technology, food science, food processing, and nutrition.

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FOREWORD BY G. S. DAVE

I take this auspicious opportunity to congratulate the editorial team of Dr. Murlidhar Meghwal, Dr. Megh R. Goyal, and Dr. Mital J. Kaneria for their extensive input in this book volume. I have been personally enriched while glancing through this compendium.

We are living in the era of global warming—climate change, food, water and natural resource crises—along with advancements in food, environmental and agricultural technologies. Current advancements in technology have made both pros and cons for humanity and the environment. Recent developments and sustainable technologies are combined in this book. I personally feel that this book will be a great resource in the updating and development of agricultural and food technologies in near future.

Advanced topics on food processing, preservation, nutritional analysis, quality checks and maintenance as well as good manufacturing practices in food industries are covered in this book. The editors and the contributing authors have generated highly focused reports to direct development of food and agriculture based on current knowledge into promising technologies.

Readers and stakeholders in agricultural technologies will gain a tremendous amount of information on (i) gaps of interdisciplinary approaches, (ii) food science and technology, and (iii) possible research groups for collaboration. Moreover, this book targets audiences from academia, a wide range of researchers, undergraduate/graduate and postgraduate students, postdoctoral researchers, medical staff, food/pharmaceutical companies, dieticians, private producers, and farmer-innovators. Institutes of higher learning and universities are the main academic sector contributing in teaching and research on various subjects, which are covered in this book.

I give my best compliments to editors, authors, and readers of this book.

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PREFACE 1

The food technologies and industries include various activities, such as good manufacturing practices (GMP), research, isolation and characterization, extraction, expression, antimicrobial activity, thermal processing, food production, transportation, packaging and distribution. This book volume provides information on the technology and suggests devices, standardization, packaging, ingredients, laws and regulatory guidelines and information on infrastructure to transform technology into highly value- added products.

The targeted audience for this book is food technologists, practicing food engineers, researchers, lecturers, teachers, professors, food professionals, those in the dairy industry, and food industries, students of these fields and all those who have inclination for food science and processing sector.

Part I on "*Good Manufacturing Practices and Research in Food Technology*" covers chapters on good manufacturing practices for food processing industries: principles and practical applications, and food engineering research funding agencies around the globe. Part II is focused on "*Latest Food Technologies*," which includes have chapters on use of plastics in the twenty-first in the food industry, latest trends on thermal processing in food technology, and nondestructive technique of soft X-ray for evaluation of internal quality of agricultural produce. Part III covers "*Role of Antioxidants in Foods*", such as *in vitro* antioxidant efficacy of selected medicinal plants of Gujarat, antioxidant activities of some Marine algae as a case study from India, omega-3 PUFA from fish oil by silver-based solvent extraction, and antioxidant and antibacterial properties of extracts *Terminalia chebula* and *Terminalia bellerica*. Part IV focuses on "*Antimicrobials Activities in Food*" and presents an *in vitro* antimicrobial activity study, and antimicrobial properties of leaf extract: *polyalthialongi foliavar pendula* under *in-vitro* conditions. The last section on active constituents of foods provides details about isolation, validation and characterization of major bioactive constituents from mango ripe seed isolation

and characterization of lycopene from tomato and its biological activity food processing using microbial control system.

The coverage of each topic is comprehensive and can serve as an overview of the most recent and relevant research and technology. Numerous references are included at the end of each chapter.

My own training and work experience as a dairy and food process engineer and teacher was crucial in conceiving this book, *Food Technology: Applied Research and Production Techniques*. I wish to thank the contributors, who did the real great work, for their time and energy to create scholarly and practical chapters. Their professionalism is appreciable, and they have my utmost appreciation and admiration.

My thanks also to Almighty God, whose love and blessings help us immensely.

—Murlidhar Meghwal, PhD
March 31, 2017

PREFACE 2

Deep in our refrigerator,
there's a special place
for food that's been around awhile…
we keep it, just in case.
'It's probably too old to eat,'
my mother likes to say.
'But I don't think it's old enough
for me to throw away.'

It stays there for a month or more
to ripen in the cold,
and soon we notice fuzzy clumps
of multicolored mold.
The clumps are larger every day,
we notice this as well,
but mostly what we notice
is a certain special smell.

When finally it all becomes
a nasty mass of slime,
my mother takes it out, and says,
'Apparently, it's time.'
She dumps it in the garbage can,
though not without regret,
then fills the space with other food
that's not so ancient yet

—Deep In Our Refrigerator by Jack Prelutsky
http://poemhunter.com/poems/food/page-1/37365112/

We all know food is essential for our survival. The increasing world population and the continuous climate change result in reduction of agricultural lands for food production. Subsequently this urges modern food science and technology to develop sustainable food production systems and improve nutritional value of food products, while keeping the cost as low as possible. Quality and nutritional value of foods are highly dependent on environment, agricultural practices, production conditions, and consumer preferences, which all may provide different effects for human health. One of the main challenges of food science and technology is to optimize food production to have minimum environmental footprint, lower production costs, and improving quality and nutritional value.

Analysis of foods is continuously requesting the development of more robust, efficient, sensitive, and cost-effective analytical methodologies to guarantee the safety, quality, and traceability of foods in compliance with legislation and consumers' demands. A large number of works have directly focused on the analytical technique used in food technology, while others have focused on the types of food, compound, or process investigated. Regarding specific analytical techniques applied to solve different problems in food analysis, one of the more active areas is the development of food processing techniques, in good agreement with the complex nature of foods. Food processing is one of the key steps for the development of any new analytical methodology; as a result, research on new procedures is one of the most active areas in food technology.

Therefore, we introduce this book volume on *Food Technology: Applied Research and Production Techniques* under book series *Innovations in Agricultural and Biological Engineering* by http://www.appleacademicpress.com. This book covers mainly current scenario of the research on food technology, food quality, emerging technologies of food processing, antioxidant and antimicrobial potentials, isolation and characterization of bioactive compounds, etc. This book volume sheds light on different technological aspects of Food Science and Technology; and it contributes to the ocean of knowledge on Food Science. We hope that this compendium will be useful for the students and researchers of academia as well as the persons working with the food, nutraceutical and herbal industries.

We like to share the views by our cooperating authors on this book. Dr. Kalpna Rakholiya comments: *This book provides exhaustive guidance for*

Agricultural and Biosciences researchers, carrying out research in this direction and useful for society. I know that it has taken a lot of hard work by all authors to get your book to the stage it is at now. According to Dr. Rajesh A. Dave, *food problem is the most vexing problem throughout the world. It is the most insulting problem too. The Governments are trying their best to increase the food-production through block development projects, national extension projects, community projects, package programs, and grow more food campaigns. In that way, our book will be very useful for scientific community as reference, academic, professional, and guidebook*. "*This book provides novel and thought-provoking insights into the fundamental issues involved in food sciences and technology. This book includes the informative chapters regarding funding agencies for research in food technology, principles and practical applications of good manufacturing practices for food processing industries, modern technologies, medicinal properties and characterization of pharmaceutically important active constituents of food*," comments Dr. Yogesh K. Baravalia.

The contribution by all cooperating authors to this book volume has been most valuable in the compilation. Their names are mentioned in each chapter and in the list of contributors. We appreciate you all for having patience with our editorial skills. This book would not have been written without the valuable cooperation of these investigators, many of them are renowned scientists who have worked in the field of food engineering throughout their professional careers. We are glad to introduce Dr. Murlidhar Meghwal (Lead Editor of this book), who is an Assistant Professor in the Food Technology, Center for Emerging Technologies at Jain University – Jain Global Campus in District Karnataka, India. With several awards and recognitions including from President of India, Dr. Meghwal brings his expertise and innovative ideas in this book series. Without his support, leadership qualities as editors of the book volume and extraordinary work on food technology applications, readers will not have this quality publication.

We will like to thank editorial staff, Sandy Jones Sickels, Vice President, and Ashish Kumar, Publisher and President at Apple Academic Press, Inc., for making every effort to publish the book when the diminishing water resources are a major issue worldwide. Special thanks are due to the AAP

Production Staff for typesetting the entire manuscript and for the quality production of this book.

I request readers to offer their constructive suggestions that may help to improve the next edition.

We express our admiration to our families and colleagues for their understanding and collaboration during the preparation of this book volume. As an educator, there is a piece of advice to one and all in the world: *Permit that our almighty God, our Creator, provider of all and excellent Teacher, feed our life with Healthy Food Products and His Grace; and Get married to your profession.*

—Megh R. Goyal, PhD, PE
Mital J. Kaneria, PhD
February 1, 2017

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PLEASE READ CAREFULLY

The goal of this book volume is to guide the world community on how to manage efficiently for technology available for different processes in food science and technology. The reader must be aware that dedication, commitment, honesty, and sincerity are important factors for success. This is not a one-time reading of this compendium.

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Dr. Kaneria received his BSc degree in botany from M.D. Science College, Porbandar, Saurashtra University, Gujarat, India, and his MSc degree in botany from Department of Biosciences, Saurashtra University, Rajkot, Gujarat, India. He earned his PhD degree in botany under the guidance of Prof. Sumitra Chanda, from the same Institute. During his PhD training, he was awarded a BSR Fellowship from UGC, New Delhi, India, for three years. His doctoral research is based on the phytochemical and pharmacological potency of a selected medicinal plant from Gujarat region.

BOOK ENDORSEMENTS

A highly informative, value added, well researched interpretation will excite students and researchers and showcase recent advances in major areas in food technology. Insights of highly experienced scientists and experts in this field create diversity in the chapters. "Food Technology: Applied Research and Production Techniques" will have high impact in the universities and research institutions and act as a guideline for the food processing units.

—Arpita Das, PhD
Visiting Faculty
Dept. of Pharmacutical Technology
Jadavpur University

This book provides a comprehensive coverage of the various aspects of food technology. Topics will be very useful to students and professionals. The Increasing awareness of consumers on food technology, food processing and preservation and the growing processed food market make this book an excellent source for reference in these areas.

—Narendra Reddy, PhD
Professor and Ramalingaswami Fellow
Centre for Emerging Technologies,
Jain University, Jain Global Campus, Bangalore, India

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- Engineering Interventions in Foods and Plants

EDITORIAL

Apple Academic Press, Inc., (AAP) is publishing book volumes in the specialty areas as part of *Innovations in Agricultural and Biological Engineering book series*, over a span of 8 to 10 years. These specialty areas have been defined by *American Society of Agricultural and Biological Engineers* (http://asabe.org).

The mission of this series is to provide knowledge and techniques for Agricultural and Biological Engineers (ABEs). The series aims to offer high-quality reference and academic content in Agricultural and Biological Engineering (ABE) that is accessible to academicians, researchers, scientists, university faculty, and university-level students and professionals around the world. The following material has been edited/modified and reproduced below "*Goyal, Megh R., 2006. Agricultural and biomedical engineering: Scope and opportunities. Paper Edu_47 at the Fourth LACCEI International Latin American and Caribbean Conference for Engineering and Technology (LACCEI' 2006): Breaking Frontiers and Barriers in Engineering: Education and Research by LACCEI University of Puerto Rico – Mayaguez Campus, Mayaguez, Puerto Rico, June 21–23."*

WHAT IS AGRICULTURAL AND BIOLOGICAL ENGINEERING (ABE)?

"*Agricultural Engineering (AE) involves application of engineering to production, processing, preservation and handling of food, fiber, and shelter. It also includes transfer of technology for the development and welfare of rural communities*," according to http://isae.in." *ABE is the discipline of engineering that applies engineering principles and the fundamental concepts of biology to agricultural and biological systems and tools, for the safe, efficient and environmentally sensitive production, processing, and management of agricultural, biological, food, and natural resources systems*," according to http://asabe.org.

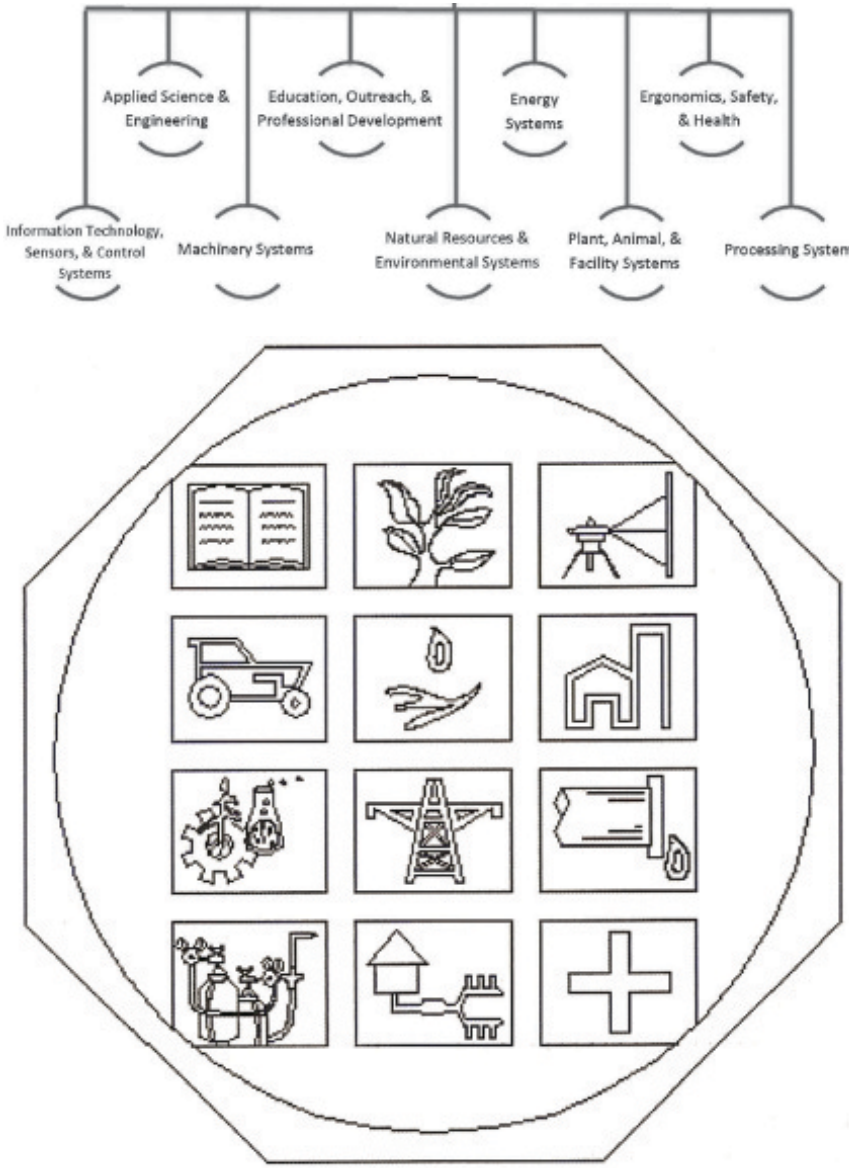
"*AE is the branch of engineering involved with the design of farm machinery, with soil management, land development, and mechanization and automation of livestock farming, and with the efficient planting, harvesting, storage, and processing of farm commodities*," definition by: http://dictionary.reference.com/browse/agricultural+engineering.

"AE incorporates many science disciplines and technology practices to the efficient production and processing of food, feed, fiber and fuels. It involves disciplines like mechanical engineering (agricultural machinery and automated machine systems), soil science (crop nutrient and fertilization, etc.), environmental sciences (drainage and irrigation), plant biology (seeding and plant growth management), animal science (farm animals and housing) etc.," by: http://www.ABE.ncsu.edu/academic/agricultural-engineering.php.

According to https://en.wikipedia.org/wiki/Biological_engineering: "*BE* (*Biological engineering) is a science-based discipline that applies concepts and methods of biology to solve real-world problems related to the life sciences or the application thereof. In this context, while traditional engineering applies physical and mathematical sciences to analyze, design and manufacture inanimate tools, structures and processes, biological engineering uses biology to study and advance applications of living systems*."

SPECIALTY AREAS OF ABE

Agricultural and Biological Engineers (ABEs) ensure that the world has the necessities of life including safe and plentiful food, clean air and water, renewable fuel and energy, safe working conditions, and a healthy environment by employing knowledge and expertise of sciences, both pure and applied, and engineering principles. Biological engineering applies engineering practices to problems and opportunities presented by living things and the natural environment in agriculture. BA engineers understand the interrelationships between technology and living systems, have available a wide variety of employment options. "*ABE embraces a variety of following specialty areas*," http://asabe.org. As new technology and information emerge, specialty areas are created, and many overlap with one or more other areas.



1. **Aquacultural Engineering**: ABEs help design farm systems for raising fish and shellfish, as well as ornamental and bait fish. They specialize in water quality, biotechnology, machinery, natural resources, feeding and ventilation systems, and sanitation. They

seek ways to reduce pollution from aquacultural discharges, to reduce excess water use, and to improve farm systems. They also work with aquatic animal harvesting, sorting, and processing.

2. **Biological Engineering** applies engineering practices to problems and opportunities presented by living things and the natural environment.
3. **Energy:** ABEs identify and develop viable energy sources – biomass, methane, and vegetable oil, to name a few – and to make these and other systems cleaner and more efficient. These specialists also develop energy conservation strategies to reduce costs and protect the environment, and they design traditional and alternative energy systems to meet the needs of agricultural operations.
4. **Farm Machinery and Power Engineering**: ABEs in this specialty focus on designing advanced equipment, making it more efficient and less demanding of our natural resources. They develop equipment for food processing, highly precise crop spraying, agricultural commodity and waste transport, and turf and landscape maintenance, as well as equipment for such specialized tasks as removing seaweed from beaches. This is in addition to the tractors, tillage equipment, irrigation equipment, and harvest equipment that have done so much to reduce the drudgery of farming.
5. **Food and Process Engineering:** Food and process engineers combine design expertise with manufacturing methods to develop economical and responsible processing solutions for industry. Also food and process engineers look for ways to reduce waste by devising alternatives for treatment, disposal and utilization.
6. **Forest Engineering**: ABEs apply engineering to solve natural resource and environment problems in forest production systems and related manufacturing industries. Engineering skills and expertise are needed to address problems related to equipment design and manufacturing, forest access systems design and construction; machine-soil interaction and erosion control; forest operations analysis and improvement; decision modeling; and wood product design and manufacturing.
7. **Information and Electrical Technologies Engineering** is one of the most versatile areas of the ABE specialty areas, because it is

applied to virtually all the others, from machinery design to soil testing to food quality and safety control. Geographic information systems, global positioning systems, machine instrumentation and controls, electromagnetics, bioinformatics, biorobotics, machine vision, sensors, spectroscopy: These are some of the exciting information and electrical technologies being used today and being developed for the future.

8. **Natural Resources:** ABEs with environmental expertise work to better understand the complex mechanics of these resources, so that they can be used efficiently and without degradation. ABEs determine crop water requirements and design irrigation systems. They are experts in agricultural hydrology principles, such as controlling drainage, and they implement ways to control soil erosion and study the environmental effects of sediment on stream quality. Natural resources engineers design, build, operate and maintain water control structures for reservoirs, floodways and channels. They also work on water treatment systems, wetlands protection, and other water issues.
9. **Nursery and Greenhouse Engineering**: In many ways, nursery and greenhouse operations are microcosms of large-scale production agriculture, with many similar needs – irrigation, mechanization, disease and pest control, and nutrient application. However, other engineering needs also present themselves in nursery and greenhouse operations: equipment for transplantation; control systems for temperature, humidity, and ventilation; and plant biology issues, such as hydroponics, tissue culture, and seedling propagation methods. And sometimes the challenges are extraterrestrial: ABEs at NASA are designing greenhouse systems to support a manned expedition to Mars!
10. **Safety and Health:** ABEs analyze health and injury data, the use and possible misuse of machines, and equipment compliance with standards and regulation. They constantly look for ways in which the safety of equipment, materials and agricultural practices can be improved and for ways in which safety and health issues can be communicated to the public.
11. **Structures and Environment:** ABEs with expertise in structures and environment design animal housing, storage structures, and