Food Research Trends—2003 and Beyond

Thirty-five scientists responsible for peer review of research papers in IFT's journals tell what food research they see—and foresee—happening in their areas of expertise.

Neil H. Mermelstein, Editor

Photo courtesy of Agricultural Research Service, USDA

In the recent past, *Food Technology* published a number of articles in which experts in food science and technology described what they expected to happen in their areas of expertise over the next few years. In "Research Priorities Move Toward Healthy and Safe" (December 2000, p. 42), 38 chief research officers of major food companies discussed the research areas that their departments are involved in, and in "A Look Into the Future of Food Science & Technology" (January 2002, p. 46), representatives of each of IFT's 26 Divisions told what they foresee happening in their respective Division's area of expertise over the next few years.

To vary the source of experts even further this year, I asked the scientific editors responsible for peer review of research papers in the Institute of Food Technologists' journals—*Journal of Food Science*, *Journal of Food Science Education*, and *Comprehensive Reviews in Food Science and Food Safety*—to tell what food research they see—and foresee—in their areas of expertise. In this article, 34 of the editors provide their views (arranged alphabetically by author and journal), and Owen Fennema, IFT's Editor-in-Chief, IFT Scientific Journals, provides an introduction. The result is a comprehensive overview of the state of research in all aspects of food science and technology—including education, which is obviously the starting point for all food research. I hope you find it interesting and stimulating.

Forecasting the Future

By Owen R. Fennema

When considering discussion of this topic, it seems appropriate to ask: Is this discussion worthwhile? and, Is speculation of this type likely to be reliable?

The answer to the first question is clearly yes. Food companies spend millions of dollars annually on research and development, and the results can be highly pleasing or sadly disappointing, depending on whether the funds are wisely allocated. Wise allocations are based on company strengths, careful analysis of exist-

ing trends, and accurate forecasts regarding the firm's future capabilities and consumer preferences. Company strengths and future capabilities can, of course, be assessed by company personnel; however, outside help is highly beneficial for acquiring the other kinds of information. One source of outside help, but obviously not the only one, is articles of the kind presented here.

The second question is more complicated, since it entails two sub-questions. First, what specifically are we speculating about? Products? Processes? Modes of product delivery? Modes of marketing? Threats? Consumer behavior? It is desirable, of course, to consider all of these, because to focus on but one or two entails the risk of missing what might be most important. Second, speculation involves the future, but the time frame has not been specified. It is one thing to speculate about what is likely to happen next year but quite another to do the same for the next decade. Longer, of course is better, provided that the speculation is reasonably reliable—but the more distant the forecast, the more unreliable predictions usually are.

Those participating in this article will, I believe, offer predictions that are quite reliable because each is highly competent in his or her field of specialization. So I suggest that their comments are worthy of your careful attention.

I would like to mention two points of overriding importance for the food industry in general. One is the historical pattern of advances in food technology, and the other is the impact of company mergers.

Unlike in the electronics industry, where mind-boggling innovations are almost a daily occurrence, changes in foods and food processing are typically evolutionary. Abundant evidence clearly indicates the difficulty (impossibility?) of persuading consumers to adopt revolutionary changes in the food they consume. A few examples provide conclusive support for this statement:

• The ability to preserve food by ionizing radiation was developed more than a half century ago, yet the process is not widely accepted, even though its ability to greatly inhibit food spoilage and lessen transmission of disease has been clearly demonstrated and its safety has been more rigorously established than those of either thermally sterilized or dehydrated foods.

Unlike in the electronics industry, where mind-boggling innovations are almost a daily occurrence, changes in foods and food processing are typically evolutionary.

• The ability to rapidly improve foods of plant and animal origin by recombinant DNA technology was developed more than a decade ago, but products so modified are still vigorously resisted by many consumers, even though this technology provides many important advantages and extensive research has failed to indicate any risk to humans.

• Consumer acceptance of pasteurized milk was slow, begrudging, and accompanied by many protests, even though this means of processing milk extended its shelf life and freed it of pathogenic organisms, a serious problem with raw milk at the time pasteurization was introduced, and entailed only minor disadvantages. Managers of R&D and marketing who ignore the resolve of consumers to reject modifications in food and food processing save those that are evolutionary imperil the financial well-being of their firms.

Mergers in the food industry have occurred steadily over the past several decades, and there is no reason to suspect a change in this trend. Large companies spend substantial amounts of money on R&D and marketing, skillfully assess consumer preferences, and tailor their products for the mass market. Where does this leave small and medium-sized food enterprises that are less able to support R&D and marketing activities but are extremely valuable to the national economy because of their important role in job creation? They can and do survive and often prosper by identifying local or niche markets too small to be of interest to their larger competitors, by innovating (evolutionarily, of course) in ways that larger firms consider too risky or, in some instances, by becoming low-cost producers. It is important that these small and medium-sized food enterprises focus on these courses of action when administering their modest funds for R&D and marketing.

—Owen R. Fennema is Professor Emeritus of Food Chemistry, University of Wisconsin, Madison.

Journal of Food Science

Realizing the Potential of Nanobiotechnology

By Carl A. Batt

How many angels can dance on the head of a pin? While this vexing question has been the fodder of philosophers and theologians, a practical answer eludes us. Two confounding factors are how small are angels and how small can we make the head of a pin. In medieval times, angels were believed to be the smallest possible physical object. A more approachable challenge came in 1959, when Richard Feynman asked, "Why cannot we write the entire 24 volumes of the *Encyclopedia Britannica* on the head of a pin?" (http://nano.xerox.com/nanotech/feynman.html). The challenge of moving around single atoms has been met, but the issue of making it practical remains (D.M. Eigler and E.K. Schweizer, www.almaden.ibm.com/vis/stm/atomo.html).

The average computer chip carries a series of electrical circuits that are so small thousands can fit on the head of pin. Advances in nanotechnology now allow wires to be built that are literally a

few atoms wide. Eventually, practical circuits will be created with a series of individual atoms strung together like beads serving as switches and information storage devices.

Nanobiotechnology seeks to develop devices using the very same tools and processes that are being exploited by the micro- and nanofabrication industry to study biology at the nanometer scale. There are three compelling reasons to predict that nanobiotechnology will have an impact in the future:

1. The development of more portable, more robust devices that can be deployed in the field. Sensors can be developed and deployed that will be small enough to be distributed and collect data from a wide area. Given the state-of-the-art in micro and nanofabrication, sensors as small as a particle of dust could be created. The challenges are in powering these devices and the effective distance that they can transmit their signal. Applications in food safety are in the area of hand-held pathogen detectors.

2. The creation of novel analytical devices capable of interrogating single molecules. These devices will have unprecedented sensitivity and specificity by virtue of their ability to isolate single molecules in an exceedingly small volume. Novel approaches to optical or electromagnetic interrogation schemes will be a key factor. We will be able to characterize even smaller quantities of chemicals that are of value to the flavor industry.

3. The fabrication of separation modules that force molecules into confined environments. Unique separation effects can be realized that afford a more rapid and in some cases a more specific separation based on the behavior of molecules in a microfluidic environment. Novel separations of chemicals that are important to the food ingredient industry will be possible.

All of these developments will have an impact on food science and the design of the next decade's food systems. One would still hope, however, that food will still be what it should be—a gastronomical experience of the senses, something that we enjoy from preparation to consumption.

—Carl A. Batt is Director, Ludwig Institute for Cancer Research Partnership, and Co-director, Nanobiotechnology Center, Project Leader, Alliance for Nanomedical Technologies, Cornell University, Ithaca, N.Y.

Studying Food Structure

By H. Douglas Goff

The field of food physics as a specific discipline or curriculum subject has not received the attention in North America that food chemistry has, although many important interactions in foods, dictating structure, texture, stability, etc., are determined by physical interactions. In contrast, the biennial Food Colloids meeting in Europe, under the auspices of the Royal Society of Chemistry, receives hundreds of abstracts per year, and the published proceedings are an important part of the library of any researcher in this field.

However, there is a well-developed and increasingly important research discipline that studies physical properties at the macromolecular and particle scale in complex food structures. We have much to learn from physical property studies that are solidly built on principles of physics. Most of the time, foods that are characterized, for example, as multicomponent or particulate dispersions are not in equilibrium, and it is the kinetics of structural change that dictates success in the marketplace.

Recent research papers have focused on such topics as the properties of edible films and gels, the glass transition in carbohydrate-based dried or frozen foods, formation and stability of emulsions and foams, etc. The effects of novel processing techniques such as high-pressure processing on structural features of processed foods have also been recently studied.

Research techniques are also getting more sophisticated, including increasing use of oscillatory rheometry for viscoelasticity measurements, a wide range of microscopy and light-scattering techniques for quantitative structural analyses, and complex calorimetric analyses for thermal properties and glass transitions, to name a few. I believe we will see an increasing appreciation of the discipline of food physics in the next few years and that it will mature to be recognized as a distinct field of study.

—H. Douglas Goff is Professor, Dept. of Food Science, University of Guelph, Guelph, Ontario, Canada.

continued on page 34 ▶

Food Research Trends–2003 and Beyond

Fighting Food Safety Problems

By Mansel W. Griffiths

The Centers for Disease Control and Prevention has estimated that about one-third of the inhabitants of the United States acquire a foodborne infection annually. The World Health Organization has reported that globally 2.1 million people died from enteric diseases in 2000, with diarrhea being a major cause of malnutrition in infants and young children. This high prevalence of diarrheal diseases in many developing countries suggests that there are significant food safety problems in those parts of the world.

In developed countries, changes in agricultural practices and food processing have resulted in large foodborne disease outbreaks. For example, in 1994, an outbreak of salmonellosis in the U.S. caused by contaminated ice cream affected about 224,000 people. The aging populations in most industrialized countries means that a greater number of people are at risk of contracting infectious diseases. Thus, problems related to food safety will remain with us for some time to come.

There have been several consultation exercises conducted to prioritize food safety research (e.g., www.asmusa.org/acasrc/pdfs/Colloquia/Foodsafetyreport.pdf). Many of these have recognized the importance of research on microbial adaptation. Certainly, to effectively combat food- and waterborne illness, more needs to be known about the way that microorganisms interact with each other and their environments. We know that bacteria "communicate" with each other through the production of molecules called pheromones. This conversation allows bacteria to respond to their immediate environment. These responses may include triggering the formation of biofilms to protect them from adverse environments or promoting the expression of virulence factors so that, for example, they can effectively adhere to and colonize the intestinal tract of their host. As well as intraspecies communication, signaling pathways that allow interspecies communication are being identified through which nonpathogenic bacteria can control gene expression by potential pathogens. By interrupting the conversation between microorganisms, it may be possible to limit spread in the environment and prevent infection.

To help reduce contamination at all points in the food chain, we need a better understanding of how microorganisms interact with their environment. We need to better understand the processes that allow microorganisms to survive stress, whether it is starvation induced by a nutrient-limited environment such as water, or acid- and temperature-induced stress in foods. We are now beginning to build a picture of how microorganisms interact with food matrices. Using fluorescent or luminescent labeling, it is possible to track bacteria in plants, food, and even live animals. This enables the identification of niches that promote survival of the organism and will ultimately lead to better intervention strategies to reduce incidence of foodborne pathogens.

> To help reduce contamination at all points in the food chain, we need a better understanding of how microorganisms interact with their environment.

Much of the information that we require will come through the utilization of technologies such as DNA and protein arrays so that we can gain an understanding of how foodborne pathogens work at the molecular level.

—Mansel W. Griffiths is Chair in Dairy Microbiology and Director, Canadian Research Institute for Food Safety, Dept. of Food Science, University of Guelph, Guelph, Ontario, Canada.

Optimizing Hurdles

By Dallas G. Hoover

Areas such as nanotechnology and proteomics have real futuristic potential, but the question is how far into the 21st century will it take for research productivity and resultant applications to be realized in these areas? Certainly, I have yet to see any manuscripts for publication in these basic areas of research applied to some aspect of food production in the commercial realm.

Currently, research trends involving the development of nonthermal processing technologies and active, antimicrobial food packaging are more-mature areas that have evolved to a point shown by manuscript flow and preliminary commercial evidence (and in the case of high-pressure processing, an expanding segment of actual products). Consumer interest continues to supply justification for research involving new-generation processed foods that are flavorful and safe, with fresh-like sensory qualities and appealing nutritional value. Research that optimizes the hurdle approach by incorporation of multiple nonthermal processing technologies, minimal applications of heat, and preservative components such as bacteriocins (i.e., the so-called natural preservatives), in accompaniment with packaging possessing enhanced functional traits, can be expected to continue for the next several decades.

In step with these nonthermal processing developments will be the necessity to compare the nonthermal processing control measures with traditional thermal processes to confidently predict safety requirements for these new-generation foods. Additional science-based review of the safety of these new products is required to deal with regulatory issues of international trade. This process review, along with the competitive search for improved minimally processed foods, will drive a substantial portion of food research efforts beyond 2003.

—Dallas G. Hoover is Professor, Dept. of Animal and Food Sciences, University of Delaware, Newark.

Shifting to Nontraditional Processes

By Fu-hung Hsieh

Food engineering will continue to evolve. Traditional food processing research such as baking, blanching, canning, drying, extrusion, evaporation, frying, and pasteurization, etc., will continue to be conducted and find new applications. However, more and more food engineering research will be shifted

to nontraditional processing and nonthermal processing, such as microwave and radiofrequency processing, ohmic and inductive heating, high-pressure processing, pulsed electric fields, high-voltage arc discharge, pulsed-light technology, oscillating fields, ultraviolet light, ultrasound, and pulsed X-rays. This shift will accelerate, in particular, with the recent discovery that high levels of the possible carcinogen acrylamide are detected in many carbohydrate foods that are fried or baked at high temperatures.

New and innovative extraction, separation, and purification processes will be developed by food engineers for phytochemicals and for biologically active components from genetically engineered plants and animals. They will also contribute to the characterization of the pharmacokinetic and pharmacodynamic properties of functional foods and nutraceuticals.

Finally, food engineers will explore new applications of microelectromechanical systems (MEMS) and nanotechnology, such as in the design of biosensors for detecting pathogens, spores, meat tenderness, food spoilage, and food adulteration.

—Fu-hung Hsieh is Professor, Biological Engineering and Food Science, University of Missouri, Columbia.

Synergizing Emerging Technologies

By Vijay K. Juneja

Current food safety issues demonstrate the need for continued research and re-evaluation of intervention strategies through the farm-to-table continuum for the quantitative reduction/control of pathogens. Research in the area of packaging hurdles, as well as emerging thermal and nonthermal technologies for the destruction of pathogens, will gain momentum. The ultimate aim is to introduce these technologies in the food processing industry, thereby improving the safety and shelf life of foods.

Synergistic effects of emerging technologies, in combination with complex multifactorial experiments and analyses to quantify the efficacy of both intrinsic and extrinsic factors such as the prior history of pathogens, storage conditions, potential temperature abuse, etc., as well as the development of "enhanced" predictive models, will be attempted. Inactivation kinetics models to predict microbial reductions on the surface of foods during surface pasteurization processes will also be developed. To assist in identifying potential new approaches for safer production of foods, studies will be aimed at providing insight into the physiological and molecular mechanisms of microbial inactivation, microbial stress responses and associated enhanced virulence, and pathogen emergence and interactions with food production processes.

For the purpose of identifying critical control points, developing intervention strategies, and constructing accurate models for risk assessments, research efforts will be aimed at gaining knowledge on microbial ecology throughout the food chain, the epidemiology of specific pathogens, and strain-to-strain variations within bacterial species concerning their growth and resistance kinetics. Emphasis will be on the use of molecular biology to understand the response of food pathogens to food environments, including the role of signaling molecules produced by pathogenic and spoilage bacteria in food on the regulation of growth, survival, and virulence of pathogens.

> Approaches relying on the tools of genomics and proteomics will lead to new understandings of physiological responses of pathogens in food environments.

Approaches relying on the tools of genomics and proteomics will lead to new understandings of physiological responses of pathogens in food environments. This information will provide the basis for the development of new detection techniques and more-effective control strategies for bacterial pathogens. While research on the polymerase chain reaction (PCR), molecular subtyping (DNA fingerprinting), impedance/conductance, and enzyme-linked immunosorbent assay (ELISA) tests has made significant strides in diagnostic microbiology with regard to concentration, enrichment, amplification, and detection of low levels of pathogens, development of real-time detection systems for verification and validation of intervention technologies used in Hazard Analysis and Critical Control Points (HACCP) systems remains a task for the future.

With certain pathogens, such as *Escherichia coli* O157:H7, that are declared as an adulterant and with concerns associated with individuals susceptible to low infectious doses, research efforts will be focused on developing technologies that not only reduce or inhibit pathogens, but also destroy or eliminate pathogenic organisms to ensure a safer global food supply.

—Vijay K. Juneja is Lead Scientist/Supervisory Microbiologist, Microbial Food Safety Research Unit, Eastern Regional Research Center, U.S. Dept. of Agriculture, Agricultural Research Service, Wyndmoor, Pa.

Developing New Technologies

By Manfred Kroger

It is now generally accepted that robotics, genetic engineering, and nanotechnology will be the key areas of human developmental creativity to lead us into and through the 21st century. Food research already shows signs of activity in these new disciplines, as reflected by published studies and research position announcements. But nevertheless, traditional food investigations as we know them will continue to be conducted. After all, despite the many decades of systematically delving into the riddles of nature and describing her phenomena, we know so little about what we eat and what happens when we do.

Food research will also be stimulated by local and global attention to these threats looming at the horizon: increasing world population, availability and cost of usable water, disappearance of arable land, a widening gap between the rich and the poor, deforestation, desertification, environmental pollution, species extinction, climate change, exhaustion of nonrenewable energy resources, and incidents of terrorism—or even

war—in their many forms. It takes little imagination to tie each of these jeremiads to food. And it behooves us all to see food as the focal point in all this and to work toward an assurance of having enough food at all times in all places.

Since its beginnings, practical food research has been devoted to postharvest crop protection, i.e., food preservation. Since the onset of public health consciousness about 100 years ago, considerable research attention has been paid to food as a source of infectious diseases and intoxications. Only since the 1920s has there been much research emphasis on the nutritional properties of food components, and lately this physiological aspect of food has been extended into nutraceutical directions. A marriage of the food and pharmaceutical industries is imminent.

And then there is research into the sensory properties of food, which is extremely valuable and has great popular appeal (because we prefer to eat what we like), but which is also driven by new product research, which might range from subtle modifications in an existing food brand to the introduction of a totally new food (or underutilized species), such as the mycoprotein quorn.

All this constitutes a brief overview of current food research. There will be more of it. And researchers will constantly avail themselves of innovations in analytical methodology and borrow from the advances made in other sciences and technologies, increasingly so in robotics, genetic engineering, and nanotechnology.

These areas will see much activity in the next few decades: probiotic and prebiotic products (which all started with yogurt four decades ago); functional foods, which includes anything that has a benign physiological effect beyond that of traditional nutrients; convenience foods formulated according to the most recent nutritional insights, unfortunately often based on misconceptions rather than scientific consensus; and "ecologically correct" agricultural products, as reflected in the recently adopted U.S. regulations for "organic" foods. The latter is a rapidly growing segment of food sales and still awaiting evidence of its claimed sensory and nutritional superiority.

—Manfred Kroger is Professor Emeritus, Dept. of Food Science, The Pennsylvania State University, University Park.

Achieving Real-Time Analyses

By Daryl B. Lund

The most immediate research needs in food engineering are for real-time analyses of constituents of foods. This is in response to the perceived vulnerability of the food supply to terrorist activity. Federal funding agencies are receiving resources from the omnibus U.S. Dept. of Defense National Homeland Security bill that was passed this past summer by Congress and signed by President Bush. Some of the more important constituents which threaten safety of food include toxins, microbiological infections, and poisons (including pesticides).

Other research trends in food engi-

neering include continued development of nonthermal preservation technology. Pulsed-electric-field, high-intensity-light, high-pressure, and aseptic processing of fluids with particulates all require additional research so that the processes are sufficiently characterized for regulation. The body of research includes the development of sensors for on-line, real-time control of processing variables such as residence time and first-in, first-out control. With the recent recall of chicken, there will be renewed research efforts in sanitation and cleaning, including the application of irradiation to food products and a reexamination of the protocols for HACCP.

Further research efforts will expand the application of probability models to describe the effect of processing on reduction of microorganisms in foods. This is especially important to the further development of nonthermal methods of food preservation.

—Daryl B. Lund is Executive Director, North Central Regional Association of State Agricultural Experiment Station Directors, University of Wisconsin, Madison.

Addressing Diet-Related Health Problems

By Dennis D. Miller

Our understanding of relationships between diet and health has grown exponentially over the past century. Discovery of the essential nutrients, fortification of the food supply, and government-sponsored dietary guidance for the public have nearly eliminated most of the nutrient deficiency diseases that were so prevalent in the U.S. in the early 20th century.

These impressive improvements in health were possible because food and nutrition scientists conducted visionary, mission-oriented basic and applied research that produced the knowledge on which government nutrition policy and food manufacturing practices were and are based.

As we look to 2003 and beyond, we must continue to focus our research agendas on the major diet-related health problems that plague our nation and world. Today in the U.S., total cardiovascular disease and cancer cause more than 1.5 million deaths annually; more than 30% of the U.S. adult population is obese, up from 22.9% in 1988–94; and worldwide, an estimated 2 billion people are iron deficient.

There is compelling evidence that modifications in foods and diets can prevent or delay these diseases, but our understanding of the health effects of specific dietary components (nutrient and nonnutrient), interactions among these components, and human genetic variability is limited.

Six broad areas of research will be important: Designing foods and diets to promote weight loss; identifying and evaluating foods and food components that improve blood lipid profiles and glycemic responses; developing improved methods for identifying and evaluating components in "functional foods" that reduce risk for heart disease, cancer, and other chronic diseases; improving nutrient bioavailabilities and densities through genetic modification of crops; evaluating the effects of processing, storage, and genetic modification on nutrients and other bioactive compounds in foods; and developing improved strategies to assist consumers in choosing healthy diets.

Future research pertaining to the isolation, biochemical production, and application of nutraceuticals, as well as their biological effects, will greatly increase.

Multidisciplinary approaches involving nutritionists, food scientists, social scientists, plant and animal breeders, basic biologists, and government and industry policy makers will be required. New tools, including functional genomics, recombinant DNA technology, advanced analytical instrumentation, and computer information technologies, will be key. Substantial increases in funding from government and industry will be critical.

—Dennis D. Miller is Professor, Dept. of Food Science, Cornell University, Ithaca, N.Y.

Producing and Using Phytochemicals

By David B. Min

Recently, food scientists and consumers have recognized the importance of phytochemicals to health. The food industry has experienced an increasing consumer demand for "healthy" foods, which may include nutraceutical or medical foods. The number of publications on the isolation, separation, and identification of phytochemicals from natural products and biochemical production of phytochemicals has increased. Future research pertaining to the isolation, biochemical production, and application of nutraceuticals, as well as their biological effects, will greatly increase.

The chemical mechanisms responsible for the formation of sunlight flavor in dairy products, reversion flavor in soybean oils, and light sensitivity of riboflavin and vitamin C have been extensively studied for the past 70 years. Recently, the detailed chemical reaction mechanisms leading to these phenomena have been revealed to be due to singlet oxygen oxidation. Further basic research to better understand chemical reactions in foods is greatly needed.

The safety of compounds formed during processing and storage should be actively investigated. Acrylamide, which can be formed from starch in food during the heating or frying process, appears to be present in a wide variety of fried or roasted foods such as potato chips and cereals. This substance has been known to cause cancer and nervous system damage in animals.

The identification of toxic compounds formed during processing and storage and a risk assessment should be thoroughly conducted to better understand the public health implications, with the support of federal funding. Research on methods to remove naturally occurring toxin contaminants and to prevent the formation of toxic compounds during processing and storage is essential for food safety.

The effects of nonthermal processes such as pulsed electric fields, high pressure, and irradiation on the chemical stability and safety of foods should be conducted before these processes become widely used by the food industry.

Further research on the chemical

modification of food ingredients such as proteins, carbohydrate, and lipids should be continued to improve the specific functionality and nutritional quality of foods.

—David B. Min is Professor, Dept. of Food Science and Technology, The Ohio State University, Columbus.

Determining Safety

By Patricia A. Murphy

Research trends in food toxicology encompass food allergen determination and detection; novel toxicants produced by food processing; improved discrimination between natural and terrorism-driven toxicant introduction into the food system; and evaluation of the safety of nutraceuticals.We need data from humans in double-blind placebo-controlled trials to establish food allergen thresholds. Human data are preferable in that they do not require animal safety factors, especially in the case of allergens, where there are no good animal models.

Another trend is the push to lower detection limits for analytical chemistry methods for toxicants that may have a significant impact on health. Toxicants produced by processing, such as acrylamide and the Alar breakdown product UDMH, are critical issues. Detection of acrylamide levels and evaluation of its scope in foods are needed. Toxicity and carcinogenicity of acrylamide at levels found in foods must be assessed. The ability to make the "best educated guess" about novel toxicants produced by food processing would be inspired.

Improvement in our abilities to differentiate between natural occurrence and terrorism tampering with natural and synthetic chemical toxins is a critical need. Analytical systems using microarray and DNA/RNA chip technologies may be the future wave to enable us to increase speed and volume of analyses to complement existing analytical technologies.

Food toxicology studies are critical in determining the safety factors and thresholds for the huge array of chemicals in nutraceuticals, especially those being used in foods. The National Academy of Sciences has begun a process that may lead to setting Upper Tolerable Intake Levels for nutraceuticals/dietary supplement components. There are very limited data on toxicity of such components, and both extrapolating from animal studies appropriately and deriving acceptable strategies for human toxicity testing of nutraceuticals are key concerns.

—Patricia A. Murphy is Professor, Dept. of Food Science and Human Nutrition, Iowa State University, Ames.

Approaching Real-Time Microbial Detection

By Samuel A. Palumbo

Four areas where food microbiology research needs to be done are rapid methods, new technologies, foodborne viruses, and emerging pathogens.

• **Rapid Methods.** Many years ago, a

well-known food microbiologist commented that one of the single major impediments to the development of rapid microbiological methods was the arrival of the plastic Petri dish. That was then. Now there is an absolute and almost critical need for them. Essentially all areas of food microbiology, from quality control and food safety to monitoring critical control points as part of a plant's HACCP plan, would benefit from real-time rapid methods.

Many methods are starting to approach real-time detection of microorganisms in foods; these include PCR and ELISA methods, as well as various biosensors. Most of these "rapid" methods still suffer from three current problems: there is a need for some sort of enrichment step to increase the number of microorganisms to the lower limit of detection; these methods are unable to yield quantitative estimates of the number of microorganisms sought; and, for legal purposes, the regulatory agencies require the isolation of an actual culture in cases of foodborne disease outbreaks, and most current rapid methods do not yield the needed culture.

• **New Technologies.** Perhaps one of the most exciting and challenging areas of food science is the introduction of new technologies to process and preserve foods. While thermal processing still represents our most-utilized and well-studied method of preserving foods, the consumer, especially in the U.S., is demanding foods with better color, nutrient retention, flavor, and texture. Food engineers are working with food microbiologists to develop and bring to market the use of new techniques to inactivate microorganisms to yield a safe food with an extended shelf life. Some of these "new" techniques include high-pressure processing, pulsed electric fields, irradiation, UV light, and others.

Food microbiologists are now faced with the task of demonstrating the safety of these techniques; i.e., will they yield a safe product or even a shelf-stable product? One of the major problems to be solved is the choice of target microorganism for use in inoculated pack studies.

• **Foodborne Viruses.** According to a 1999 article in *Emerging Infectious Diseases*, about 80% of the foodborne illness in the U.S., based on epidemiological evidence, is caused by viruses. Yet, because of lack of methods, relatively little is known about the properties of viruses in foods. This should prove to be a very fertile area and an area where much research is needed.

• **Emerging Pathogens.** When I began studying food microbiology, there were three major foodborne pathogens; now that number has increased several fold and also includes viral and protozoan agents, as well as bacterial. Whether this list will keep increasing is not known, but we may arrive at the point where most of the agents will have been identified and their behaviors in foods known.

Often, research is dedicated by what is fundable. Today, we are fortunate in that what is fundable and what is needed are essentially the same. These are exciting times to be a food microbiologist, and while a lot of good research has been done, much more needs to be done.

—Samuel A. Palumbo is Senior Technical Editor and Acting Safety Assurance Manager, National Center for Food Safety and Technology, Summit-Argo, Ill.

About 80% of the foodborne illness in the U.S. . . . is caused by viruses. Yet, because of lack of methods, relatively little is known about the properties of viruses in foods.

Studying Structural Mechanisms

By M. Anandha Rao

New, especially nonthermal, methods and well-known processing technologies, alone and in combination, are receiving attention. Breakthrough studies to understand mechanisms involved at the cellular level are needed. Reliable values of properties of foods relevant to the new processing techniques need to be studied.

In rheological properties of foods, increased use of nondestructive techniques, such as magnetic resonance imaging (MRI) and ultrasonic velocity, is anticipated. The role of structure and microstructure on tribological and small- and large-deformation rheological properties will continue to be studied. The effects of new processes, such as ultra-high-pressure homogenization, will be investigated.

It would be desirable to either explain or relate properties, especially physical and rheological, of a food in terms of its chemical composition or structure. Reasonable attention should be paid, in selecting a raw food, to the variety/origin and storage history and to characterizing its composition. The same can be said when studying the effect of a processing technique, however innovative it may be.

Physical and functional properties of edible packaging films, made from different food polymers with and without low-molecular-weight components, and their application to foods are receiving considerable attention. Standardization of film preparation, with due regard to the composition of polymers, and physical/chemical measurement techniques should facilitate evaluation of the polymers and results from different laboratories. In addition, interpretation of results in relation to film structure will be valuable.

With continued development of sophisticated computational fluid dynamics (CFD) programs, mathematical modeling dealing with complex phenomena will flourish, such as accounting for anisotropy and capillarity of foods, reactions in foods, and momentum, heat, and mass transfer from fluid and solid food interfaces.

—M. Anandha Rao is Professor, Dept. of Food Science and Technology, Cornell University, Geneva , N.Y.

Conducting Faster Microbial Testing

By Elliot T. Ryser

Food microbiology and safety research has taken on added importance in light of recent terrorist activity, with the security of the U.S. food supply now of major concern. While many types of rapid testing methods and biosensors were already in place well before September 2001 to detect microbial pathogens and their related toxins, federal agencies have increased funding levels to further refine these methods into "real-time" detection strategies.

Aside from issues related to national security, the U.S. is still plagued by massive product recalls involving both *Listeria monocytogenes* and *E. coli* O157:H7. In response, the government has developed a series of risk assessments targeted at these and other organisms, with additional research targeted at filling some of the more important data gaps related to infectious dose and the means by which ready-to-eat meat products and fresh produce become contaminated and are handled at the producer, retail, and consumer levels. Such efforts will be of key importance in developing proper food safety legislation that will protect consumers and, at the same time, not economically cripple the food industry.

The efficacy of various sanitizer formulations and nonthermal processing methods such as high-pressure processing, pulsed electric fields, and high intensity light is being assessed in conjunction with HACCP for reduction of pathogens on raw products, with thermal pasteurization now commonly used to safeguard ready-to-eat meat products against post-processing contaminants such as *Listeria*. Irradiation has been similarly introduced to eliminate *Escherichia coli* O157:H7 from raw ground beef.

Remaining food safety issues of current concern include the continuing emergence of multi-antibiotic-resistant strains of *Salmonella* and other foodborne pathogens and the safety of genetically engineered foods in terms of food allergens and other potentially toxic chemicals.

—Elliot T. Ryser is Assistant Professor, Dept. of Food Science and Human Nutrition, Michigan State University, East Lansing.

Expanding Nutrient Knowledge

By Barbara O. Schneeman

A primary imperative influencing research in food, nutrition, and health in 2003 and beyond is the ever-rising cost of health care coupled with the increasing proportion of the population over the age of 60 and the burden of lifestyle diseases such as cancer and cardiovascular disease.

In the 1990s, the concept of functional foods was introduced, essentially targeting foods for improvement in their nutritional profile. Our efforts in this area have illustrated that a single-nutrient approach is too simplistic and having foods that comply with nutritional recommendations does little to improve health if behavior change among consumers does not occur. Additionally, we are beginning to explore the socioeconomic dimensions of food and nutrition behavior and the related consequences of health disparity among low-income households. Research on behavior that encompasses the physiology of taste and food choice as well as the psychology of food selection and consumption is essential to motivate consumers to shift behavior to achieve health and well-being.

As seen in the past decade, we are still discovering new functions of nutrients, as well as properties of foods that have physiological activity. Although many of the known essential nutrients were discovered in the first half of the 20th century, research on nutrient metabolism has led to new discoveries regarding the role of vitamins and minerals in the prevention of chronic disease. Coupled with the growing sciences of genomics and proteomics, this expanded knowledge of nutrient function is likely to continue at an even faster pace.

To realize the full potential of genomics and nutrition in improving health, new knowledge of the composition of foods as well as improved data on consumption patterns will be essential. Such analyses must go beyond the traditional nutrients to develop reliable databases on the various physiologically active compounds in foods. Likewise, methodology must become more rapid, accurate, and precise. Nutrition will benefit from the emerging field of bioinformatics, given the complexity in food composition and interactions that must be considered.

We can look back to a century of progress in nutrition, moving from correcting deficiencies to maintaining health. The next century is equally promising and will demonstrate the multiple properties of foods that are important in promoting well-being.

—Barbara O. Schneeman is Professor, Dept. of Nutrition, University of California, Davis.

Developing New Dairy Foods

By Harjinder Singh

Growing consumer demands for better taste, nutrition and health, product safety, convenience, and value will continue to drive the need for research into the development of new dairy foods and processing technologies. To develop dairy foods with novel textures and flavors, major advances will be required in further understanding dairy component interactions and flavor binding/release phenomena in complex dairy foods. The long-term goal will be to identify

those properties (e.g., microstructures and rheological properties) that make up the sensory attributes of dairy foods, and find ways to control sensory properties thorough manipulation of chemical and physical properties.

There is now strong evidence that dairy foods contain a wide variety of bioactive components that can impart health and medical benefits. These include enhancement of immune system, anti-inflammatory, anti-thrombotic, and anticancer activities, protection from hypertension, and maintenance of healthy gut and bones. However, most of these claimed benefits are based on in-vitro and in-vivo animal studies. In the near future, there will be a need to demonstrate real benefits in humans through clinical testing, and further knowledge on absorption and metabolism of bioactive milk components in humans will be required to substantiate the claimed benefits.

To fully capture the health potential of dairy foods, it will be essential to develop new analytical techniques that can precisely determine the low levels of bioactive components in dairy foods and monitor any changes that may occur during processing, storage, and distribution. The emergence of genomics will provide new gene-based approaches to identify the bioactive molecules. Research will also continue to further develop the use of membrane technology and ion-exchange processes to concentrate and isolate the desired bioactive milk components.

On the processing side, there will be further development in the area of low-temperature processes, such as high pressure and pulsed electric fields, which will retain "freshness," flavor, and biological activity. Technologies that are able to process heat-sensitive materials and give a longer shelf life while ensuring food safety are likely to be important in the future. To meet consumer requirements for product safety, advanced techniques to trace the products to the source cow will need to be developed. There will be a need for techniques that can detect quickly and reliably minimal levels of contaminants at every step of the process. The challenge will be to produce sterile products without compromising sensory properties and biological activity.

—Harjinder Singh is Professor and Chair in Dairy Science and Technology, Institute of Food, Nutrition and Human Health, Massey University, Palmerston North, New Zealand.

Developing Actionable Sensory Data

By Herbert Stone

In the field of sensory evaluation, much attention has been focused on two areas: use of specialized software for multivariate analyses of sensory information, and describing the characteristics of various foods and beverages. From a scientific perspective, the former is interesting and holds promise for greater application. The latter is interesting but not critical from a field-advancing perspective.

While more companies look for rapid feedback in terms of the actions to be taken and identify early markers of success, use of real-time analyses has been and will continue to be a valuable tool. However, the input side is being neglected, as sensory professionals have not done enough research to know whether current methods are applicable or the data they are collecting are relevant for the specific algorithm being used. Methods are being modified in ways that are not fully understood, and results are being analyzed without a full appreciation of the risks.

> Sensory professionals need a better understanding of the relationship between technology and the marketplace if they expect to be a significant part of the decision-making process.

As industry moves into new technologies, the need for actionable sensory information becomes even more important. Companies continue to make substantial investments in sensory resources because their importance in assessing market potential is recognized. However, the field needs more research into the methodologies that are being used. Sensory professionals need a better understanding of the relationship between technology and the marketplace if they expect to be a significant part of the decision-making process. Further research efforts also will be needed in the use of electronic sensing systems and their relationship with sensory characteristics of foods, especially as they relate to food security.

—Herbert Stone is President, Tragon Corp., Redwood City, Calif.

Controlling Microorganisms

By Richard Whiting

Controlling spoilage and extending shelf life remain a primary objective of food processing and have a continuing need for basic and applied knowledge. Providing tools with which to reduce the number of illnesses from foodborne microbial pathogens is a major public health objective. Additional improvements need to be made in strains and processes where microorganisms are an intrinsic part of the process, such as in fermented dairy and meat products.

A comprehensive understanding of the interactions among the spoilage flora, bacterial pathogens, and the food environment is needed to predict the lag times, growth rates, maximum growth, inactivation, and survival of the spoilage flora and pathogens. Factors about which further knowledge is needed include the impact of initial population levels, physiological state of the cells, strain variations, and evidence that bacteria do not always behave as independent cells (quorum sensing).

Effective processes that avoid contamination, prevent growth, or kill pathogens are needed. Methods to kill microorganisms, such as pulsed electrical fields, high pressure, irradiation, and ultraviolet light, need further development and commercial implementation. In addition, there are new biological controls (bacteriocins) and chemical inhibitors with potential for use in food formulations to prevent or slow growth.

Significant virulence differences exist among hazardous strains of pathogens. These differences, which are not recognized by the current nomenclature and serological systems, need to be identified and the biochemical mechanisms underlying them elucidated.

Rapid and inexpensive test methods will permit more comprehensive environmental, process, and product testing in real time to identify and correct prob-

lems. Development of polymerase chain reaction (PCR) and immunologically based tests—enzyme linked immunosorbent assays (ELISAs)—promise to reduce time to definitive identifications of species and strains and need to be linked to virulence factors to identify strains of greater concern. Development of genomic and proteomic techniques have great potential for understanding virulence and devising appropriate test methodologies. Improved methods for growing, detecting and enumerating viruses and parasites are needed to facilitate research and control of these emerging microorganisms.

Knowledge of new technologies, microbial ecology, and variations between strains needs to be developed and presented in a mathematical format. Models for individual processes and steps then can be linked to model an entire production line, permitting calculation of the level of risk for a process. This directs mitigation and regulatory efforts toward effective actions and defines the choices in cost, nutritional value, product quality, convenience, and shelf life that must be made in determining how to meet the appropriate level of public health protection. Tools and protocols for making the societal choices of the degree of control to be achieved must be acquired. Once the appropriate level of protection and the corresponding frequency/level of pathogen are agreed on, the food formulations, processes, and HACCP plans can be designed to achieve the necessary degree of control.

—Richard Whiting is Senior Scientist, Center for Food Safety & Applied Nutrition, Food and Drug Administration, College Park, Md.

Developing Nutraceuticals

By James Swi-Bea Wu

Much effort has been spent to make nutraceuticals from individual food materials. The material is usually purified to some extent, and assumes the appearance of medicine. However, in daily life, different food materials are usually formulated together and processed into one single food item for human consumption. The materials can be of plant, animal, or mineral origin. The interactions among various food ingredients in the formulation occur readily. Ingredients may be synergistic or antagonistic in their health effects. They may even compensate one another and generate a new health function.

The processing conditions—e.g., heating time and temperature, degree of aeration, and pH—may also affect the nature and/or rate of interaction. Ancient Chinese people recognized these interactions, used them to prepare foods claimed to have specific health or therapeutic functions, and proposed theories to explain them. Unfortunately, most parts of their theories are too obscure to be understood by modern food scientists.

The research work to establish efficient and reliable methods for screening and accessing the functionality, investigate the mechanism for each type of interaction, evaluate the influential factors, and develop workable hypotheses in modern scientific language to account for the functionality will be heavy, difficult, and sometimes tedious, but challenging and valuable. The health food prepared following the principles of interaction will look the same and taste as palatable as any common food. Consumers will not associate it with any unpleasant experience in taking medicine.

—James Swi-Bea Wu is Director, Institute of Food Technology, National Taiwan University, Taipei City.

Ensuring Water Safety and Quality

By Ahmed E. Yousef

Water safety and quality is an area that deserves great research efforts in the future. Demand for clean and safe drinking and processing water is on the rise, while water supplies, in many parts of the world, are limited. Improving the reusability of water in food processing facilities is becoming a necessity for economic and ecological reasons. Disposal of cold, lightly used processing water is a waste of energy, particularly when the technology for cleaning and reusing this water is becoming feasible. Recent waterborne disease outbreaks in the U.S. and Canada raised public concern about the safety of our water supply. The market for bottled water is booming, and this trend will likely continue for many years to come. To cope with these developments, intensified research is needed to ensure water safety, quality, and availability for future generations.

Detection of foodborne pathogens is a rapidly evolving discipline, and new time-saving methods are appearing in the literature in large numbers. This trend is likely to continue for many years to come. However, there is a genuine need for methods that detect hazardous microorganisms based on their ability to cause diseases. It is ironic that enterohemorrhagic *Escherichia coli* is detected using the antigens O157 and H7, while they have nothing to do with its virulence. Linking detection methods with virulence genes or proteins is a logical approach, and regulatory agencies should consider this link when new detection methods are approved.

—Ahmed E. Yousef is Professor, Dept. of Food Science and Technology, The Ohio State University, Columbus.

Comprehensive Reviews in Food Science and Food Safety

Understanding Carbohydrate Properties

By James N. BeMiller

Food industry trends are driven by the consumer, and research directions are driven by industry needs and trends. Consumers want safety, convenience, and quality, as they define them. Quality includes pleasure. Consumers would also like assurance that the food is nutritious and healthful.

With regard to carbohydrates, the talk is about slow-digesting starch (something between normal starch and resistant starch) that reduces the postprandial hyperglycemic spike. Some will want the food to be natural, and some will be concerned about macro- and micronutrients that will maintain health and prolong life and antigenicity. Consumer desires affect processors as demands for authenticity of ingredients and a desire for minimal processing. The industry is also interested in

continuous processes, waste management, and new textural properties, i.e., making the food more fun to consume.

Much more needs to be understood about the fundamental properties of the complex, heterogeneous, biological systems we call food—from the molecular- through the nano- and micro- to the macroscale biopolymer systems. But this is where the fly gets in the ointment. The trend is to depend on university and government laboratories for the technical expertise required to fulfill this need. However, there has not been a similar trend in the U.S. toward increasing research support from either government or industry, so progress is slow.

For example, it is agreed that dietary fiber is a plus for human health, that the average diet contains too little fiber, and that not all components of dietary fiber have equal efficacy, but there is a long way to go before specific components can be categorized with respect to degrees of specific health benefits. In attempts to get more fiber into foods, both health benefits and eating quality must be considered for acceptance by the consuming public. And neither is much known about the effects that the biotechnology used to modify crops has on their cell walls, the principal component of dietary fiber.

The bottom line is that there is need for application of higher-level scientific principles and techniques. Without a concurrent trend in the U.S. toward support from either government or industry, developments in fundamental knowledge that will allow application of new processes, improvement of current processes, development of new products, and introduction of new ingredients, perhaps from genetically modified organisms, may be slow.

—James N. BeMiller is Professor and Director, Whistler Center for Carbohydrate Research, Purdue University, West Lafayette, Ind.

Understanding Consumer Perceptions

By Colin Dennis

Because the ultimate success of products is of course reflected by satisfying consumer needs and expectations, it is paramount that food scientists and technologists should more fully appreciate consumer attitudes, perceptions, and preferences which collectively influence behavior in relation to food choice. Thus, an enhanced understanding of consumer perceptions of product quality and safety and the physiology of sensory perception is crucial.

The increased importance of the link between diet and health warrants continued research effort on consumer behavior with respect to foods, diet, and health and enhanced scientific knowledge of the links among disease, nutrition, and genetics.

There is a clear need for research which will lead to more-effective assurance of quality, including functionality and integrity, of raw materials and ingredients for both the fresh and processed food markets. Fundamental to this is the need for an increased ability to identify key components or properties which allow the prediction of functionality of ingredients in final products and an ability to define authentic and detect nonauthentic materials.

Fundamental . . . is the need for an increased ability to identify key components or properties which allow the prediction of functionality of ingredients in final products and an ability to define authentic and detect nonauthentic materials.

Within manufacturing, the key research needs should lead to an improvement in the product development process and cost optimization by improved control of current methods of manufacturing or the adoption of innovative methods. Emphasis should be placed on enhancing product quality by understanding the interaction of physical, chemical, and biological properties of food processing operations (i.e., machine impact on materials), better simulation and modeling of food processes, and the development of novel packaging materials and systems.

In relation to food safety, emphasis should be on research which leads to a reduction in hazards and risks along the food supply chain and thus results in better assurance of the safety of raw materials, ingredients, and final products. This should focus on risk analysis (assessment, management, and communication) along the whole agri-food chain, resulting in enhanced food safety management systems in food production, manufacturing, and distribution and the establishment of realistic food safety objectives as part of public policy. Continued effort is also required to develop further rapid, reliable, robust and cost-effective methods for the detection and/or identification of microbiological, chemical, and physical contaminants.

—Colin Dennis is Professor and Director-General, Campden & Chorleywood Food Research Association, Chipping Campden, UK.

Controlling Foodborne Pathogens

By Michael P. Doyle

The challenges associated with reducing the occurrence of foodborne illnesses of microbial origin continue to grow as advanced foodborne disease surveillance and bacterial genetic fingerprinting techniques continue to be implemented, new detection technologies for foodborne pathogens such as microarray gene chips are introduced, and importation of foods from countries having minimal sanitary practices continues to increase.

Furthermore, the threat of intentional contamination of foods with microbial pathogens and toxins, including those about which little is known regarding their stability in foods, provides an additional challenge to maintaining safe foods. With these and many additional untold challenges confronting food producers and processors, there are ample opportunities for research to provide much-needed solutions.

The following are several research areas from which critical findings could lead to major advances in protecting public health:

• **Developing alternative nonthermal processes** and innovative product formulations to inactivate or control foodborne pathogens, especially *Listeria monocytogenes* in ready-to-eat foods.

• **Differentiating highly virulent from avirulent or weakly virulent foodborne pathogens**, especially *L. monocytogenes*, *Salmonella*, and enterohemorrhagic *E. coli*. Microarray DNA microchip technology could be an important contributor to unraveling this knotty issue.

• **Developing alternatives to antibiotics** for animal production as well as for human wellness. Examples include prebiotics, probiotics, and competitive-exclusion microorganisms. A better understanding of factors influencing antibiotic resistance which may differ among antibiotics will be useful for well-founded regulatory decision making and for developing product-use strategies that prolong the effectiveness of antibiotics for therapeutic purposes.

• **Addressing data gaps in microbial quantitative risk assessments of foods.** This is critical for sound regulatory decision making based on risk analysis.

• **Achieving real-time detection of foodborne pathogens.** Biosensors and nucleic acid–based assays may be the answers to sensitive methods for the rapid detection of pathogens in foods and the food processing environment.

• **Developing on-farm critical control points/intervention strategies to reduce foodborne pathogens at food production facilities.** Since manure is a principal vehicle for disseminating *E. coli* O157:H7, *Campylobacter*, and *Salmonella*, controls are needed to reduce pathogen carriage by food-producing animals, and processes are needed to inactivate pathogens in animal waste.

• **Developing counter-bioterrorism approaches to reduce the risk of intentional microbiological contamination of foods.** We need to determine survival characteristics of nonfoodborne pathogens considered potential biological threats, such as *Franciscella tularensis*, to determine the effectiveness of traditional food processing intervention strategies to inactivate nonfoodborne biological threats and newly identified biological agents; to develop innovative treatments to kill pathogens in minimally processed foods that are sensitive to thermal processing; and to develop rapid methods that can detect in foods "nonfoodborne" human pathogens, including those that have been genetically modified.

—Michael P. Doyle is Regents Professor of Food Microbiology and Director, Center for Food Safety, University of Georgia, Griffin.

Focusing Food Science Research

By Felix E. Escher

If food science is to meet the future challenges from both those who produce and process food and those who consume foods, an interdisciplinary and system-oriented approach over the whole agri-food chain is necessary. On the other hand, interdisciplinary research cannot be promoted without creating and maintaining a solid fundament by advancing disciplinary research in basic science and engineering.

Three key areas are proposed to summarize the orientation food science research should take: food safety, diet, and health; food material science; and biomaterial engineering.

Finding the proper balance between system and discipline is of particular importance in a time in which the pace for setting new research priorities and strategies by economic, social, and political pressure is ever increasing. Three key areas are proposed to summarize the orientation food science research should take: food safety, diet, and health; food material science; and biomaterial engineering. All three focus on product quality (how a food should be) and production quality (how a food should be produced) as the two central requirements of any food system.

• **Food Safety, Diet, and Health.** These ask not only for the application of human molecular biology, human physiology, microbiology, and toxicology, but also for an increasing commitment to research on the psychology of eating, food acceptance, and risk perception. Since sensory properties play an important role in this context, efforts are necessary to develop understanding of sensory perception and judgment by principles of neuroscience and linguistics.

• **Food Material Science.** Chemical, physical, and structural analyses of many foods have already brought an insight into the individual food components and structural units, so that we now have to move toward studying the interfaces, interphases, and interactions among these components. Much of this research will involve colloid science and soft-condensed-matter physics on the one hand and cell biology of food of plant and animal origin on the other. Thus, the tools for obtaining the full extent of scale from molecular to macroscopic level must be applied.

• **Biomaterial Engineering.** Research in this area should further move from the empiric approach in many process technologies to an understanding of the process on the basis of kinetics, thermodynamics, and fluid dynamics. This requires both experimental tools for process monitoring and control, which will come increasingly in the form of sensors developed by nanotechnology, and theoretical tools for modeling and simulating such processes. The term bioengineering indicates the clear trend that biology and engineering are converging in food research. The principles of both areas must be applied to promote successful research in the future.

—Felix E. Escher is Professor of Food Technology, Institute of Food Science and Nutrition, Swiss Federal Institute of Technology (ETH), Zurich, Switzerland.

Achieving Unprecedented Opportunities

By Todd Klaenhammer

Microorganisms in our food play many roles, some positive, as is the case for starter cultures in fermented foods, bioprocessed ingredients, and probiotics. In contrast, food safety and quality remain among the food industry's most important challenges as we also strive to control the negative aspects of microorganisms in foods, eliminating pathogens that cause foodborne disease and limiting spoilage organisms that destroy quality.

Since Louis Pasteur, food microbiologists have systematically isolated and characterized microorganisms from foods, attempting to understand their physiology and metabolism and ultimately control their growth, survival, and activity. Our views of microorganisms associated with foods are changing

dramatically, as hundreds of genome sequences are now being revealed and analyzed.

There are genome sequences already available for many food-relevant organisms, including foodborne pathogens (*E. coli* O157:H7; *Vibrio cholera, L. monocytogenes, Campylobacter jejuni, Staphylococcus aureus*), lactic acid bacteria (*Lactococcus lactis, Bifidobacterium longum, Lactobacillus casei, Lactobacillus gasseri, Lactobacillus plantarum, Leuconostoc mesenteroides, Pediococcus pentosaceus,* and *Oenococcus oeni*), and the most widely used bioprocessing organism on the planet, *Saccharomyces cerevisiae.*

The impact of this information will be multifaceted and dynamic. First, it reveals the genetic content of most of the key microorganisms known to be important in foods. Second, comparisons between these genomes will expose what gene systems are shared and uncover those that are unique, revealing islands of pathogenicity or regions responsible for adaptation to food-relevant environments (e.g., acid tolerance). Third, the influence of the food environment on microorganisms will provide new insights on essential and responsive gene sets that control microbial growth, survival, and activity. Understanding what factors (pH, temperature, inhibitors) induce or negate expression of these gene sets will offer new strategies to control the growth of microorganisms in foods, both positively and negatively. And fourth, DNA cloning, amplification, and sequencing technologies will be used to discover and monitor the viable but nonculturable flora present in our foods and gastrointestinal tract. These organisms likely play pivotal roles in human health, positively as commensals or negatively in promoting disease as foodborne pathogens.

Tomorrow's food microbiologist must be armed with the genetic and bioinformatic tools required to understand, interpret, and functionally analyze DNA sequences and genomic information. There are 700 microbial genomes underway, and the number of sequenced microorganisms, both culturable and nonculturable, will continue to grow as the speed of high-throughput sequencing increases. In the near future, our most insightful view of foodborne microorganisms will be through their genes. This perspective will provide an unprecedented opportunity to investigate, understand, and control microorganisms that are associated with our food supply and, in the process, improve the margin of safety, enhance quality, and expand the many applications for beneficial microbes.

—Todd Klaenhammer is a Distinguished University Professor & William Neal Reynolds Professor of Food Science and Director, Southeast Dairy Foods Research Center, North Carolina State University, Raleigh.

Using Nontraditional Processes

By Dietrich Knorr

Traditional food processing has proven to provide safe products of high quality, but increasing demands on both criteria require a systematic reevaluation of key conventional processes regarding potential improvements in food safety and quality issues. The validity of the currently applied log-linear inactivation concept for microorganisms, the potential of food structure engineering via selected and targeted processing, the targeted process-aided utilization of indigenous food constituents for product improvements, the development of new antimicrobial concepts, process-derived nutritional enhancement, improved retention and delivery of valuable food constituents via food-chain integration, and the use of genomic tools to better identify essential parts of our genetic pool, such as probiotic microorganisms in the human gut, are just a few examples of the needs of future food science research.

> The continuing demand for a safer, fresh-like, minimally or gently processed, and highly convenient food supply with maximum shelf life and constant and consistent food quality is . . . an increasing challenge.

The continuing demand for a safer, fresh-like, minimally or gently processed, and highly convenient food supply with maximum shelf life and constant and consistent food quality is, because of the highly diverse, complex, and perishable nature of most foods, an increasing challenge. New minimal processing technologies are being researched, but more information needs to be developed for each:

• **High Hydrostatic Pressure.** This process has proven to be an effective tool for inactivation of vegetative microorganisms and bacterial spores. However, limited data exist regarding inactivation kinetics of key pathogens. Preliminary data indicate that pressure–temperature combinations are effective in achieving a complete elimination of infectivity of prion protein at temperatures below 100EC, but information regarding pressure effects on toxins, allergens, and viruses is scarce.

• **Pulsed Electric Fields.** High-intensity electric field pulses have been shown to be effective tools for the reversible or irreversible permeabilization of biological membranes, but limited and conflicting data exist on their effects on bacterial spores. Data regarding toxins, viruses, or allergens are practically nonexistent.

• **Ultrasound.** This technology is receiving increasing attention for inactivation of vegetative microorganisms and enhancement of heat transfer and flow behavior of viscous materials. However, limited data exist regarding its potential for the inactivation of food pathogens, toxins, viruses, or allergens.

• **Microwave and Ohmic Heating.** To improve product quality and reduce heating times during thermal processing, microwaves and electric resistance heating have been applied. But little information is available regarding the potential suitability of these rapid-heating methods alone or in combination with other techniques for elimination of key pathogens.

• **Supercritical Fluids.** The effectiveness of supercritical carbon dioxide to permeabilize biological membranes and inactivate microorganisms has been demonstrated. Its advantages include low-temperature application, modest pressure requirements, and minimum reactivity with food materials, but no data are available on its impact on spores, toxins, viruses, or allergens.

—Dietrich Knorr is Professor and Head, Dept. of Food Biotechnology and Food Process Engineering, Berlin Univer-

sity of Technology, Berlin, Germany; Research Professor, University of Delaware, Newark; and Adjunct Professor, Cornell University, Ithaca, N.Y.

Revolutionizing Food Engineering

By Josef L. Kokini

One of the most significant research areas in food science today is nanotechnology, which consists of benefiting from the special properties of materials at the nanoscale. These properties include special luminescence properties, unique conformations to enhance delivery of active compounds, the ability to produce work through biological systems, self-assembly mediated by the unique attractive forces, nanoscale rheological properties, and others. The science and technology of edible food materials at the nanoscale is already beginning to have an impact in delivery of active compounds directly to cells. One company, Biodelivery Sciences Inc., is able to engineer cochleates which are able to deliver various active compounds.

Another new trend is the use of genomics and proteomics to understand how food is effectively delivered within the human body and what components of food turn on and off genes responsible for wellness and disease promotion and trigger the action of protein markers of these genes. This patented know-how at Rutgers University is already leading the revolution in terms of understanding how phytochemicals work and which ones are the most effective.

Nature is full of molecules which have the ability to protect us from disease or at least delay its action. Bioinformatics and computational and combinatorial chemistry will help us to effectively select the best candidate to achieve health promotion and other functionalities through rules of quick selection.

Imaging is giving eyes to food technology. Confocal laser microscopy, atomic force microscopy, and other exciting imaging tools are enabling us to see how functionality develops in biological molecules of food origin.

Food microbiology is undergoing a revolution with the tools of genetics and genomics. The genes of pathogens and spoilage microorganisms are being sequenced, and signaling proteins are being deciphered and understood. The RNA and DNA of these molecules are being utilized through nanotechnology to come up with fast-acting sensors to reduce detection times to minutes and seconds. In an era where biosecurity is becoming so critical, these advances will ensure that the 21st-century consumer will have a safe food supply.

Molecular modeling—numerical simulation—is moving food science and technology to new frontiers. Through dynamic molecular simulation, the functioning of important food molecules is becoming better understood as a function of the environment in which we are functioning. This will lead to better textures, better packaging materials, etc.

Food engineering is revolutionizing itself by looking at the use of new forms of energy, such as pulsed electric fields and high pressure, to sterilize foods while maintaining high quality. Advanced computational techniques are enabling the design of better and more efficient food processes, and the availability of new materials and new technologies is helping the engineering of new packaging materials which encapsulate active substances such as antioxidants, antimicrobials, etc.

—Josef L. Kokini is Professor II and Chair, Dept. of Food Science, and Director, Center for Advanced Food Technology, Rutgers University, New Brunswick, N.J.

---

journal of Food Science EDUCATION

Shifting from Teaching to Learning

By Wayne Iwaoka

Food science education in the U.S. and around the world will evolve more in the next 10 years than it did in the past 50. The change will be a shift from teacher-centered instruction to student-centered learning. One of the driving forces for this change is the development and implementation of the Institute of Food Technologists' new education standards for undergraduate degrees in food science. The standards now require that food science programs develop and implement outcome-based assessments to provide feedback to faculty on student learning. In addition, food science students must now learn and practice more of the "success" skills in their classes—such as interpersonal, critical-thinking, problem-solving, and oral and written communication skills.

Unlike the disciplinary knowledge of food science, these skills cannot be adequately learned through lectures or be memorized as facts. They must be developed through application and practice. Thus, the way food science educators need to facilitate student learning of these skills will have to change, from the traditionally passive teacher-centered mode to a more active-learning, student-centered mode.

Another recent development that is precipitating positive changes within colleges of agriculture across the U.S. is the acceptance of a broader definition of "scholarship"; this has become particularly important to those individuals involved in extension (outreach) and instruction. Previously, all faculty members had to publish their "scholarly" research in a traditional manner—in traditional technical research journals in their discipline. However, it is now becoming acceptable (and even encouraged) for faculty not only to make innovations in their extension and instruction activities, but also to publish their results in peer-reviewed extension and education journals. As a result, there will be an increase in the number of extension and instruction publications in the food science field where there were hardly any before.

The paradigm shift in the way faculty help students learn content and skills and their publishing of innovative learning techniques will ultimately result in greater numbers of quality food science programs.

—Wayne Iwaoka is with the College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa, Honolulu.

continued on page 48 ▶

Food Research Trends–2003 and Beyond

Providing Internships and Work Experiences

By Grady W. Chism III

Changes in undergraduate education in food science are driven by three major factors: who our students are, where our students will work, and funding for education. Today's students are more likely to be female, work more than 20 hours per week at a job during the school year, and have oral communication skills superior to those of previous students. This trend is likely to continue.

Recently, there has been a trend toward forcing students to work in teams and focus on problem solving. Students of tomorrow will have better team and problem-solving skills, but will have less of the fundamentals at their fingertips. Declines in educational funding will continue to drive down the extent and quality of laboratory experiences students receive. Pilot-plant experiences will become more "show and tell" and less hands-on, and will increasingly utilize outdated equipment. This will likely be offset some by internships and work experience.

The same trend will occur in analytical laboratories, where the students will have few opportunities to actually operate state-of-the-art equipment and most will have had only limited experiences with modern analytical equipment. Some of this decline may be offset by increased emphasis on internships. The students of tomorrow are much more likely to have multiple internships than today's students. However, increasing pressure to have undergraduates complete a bachelor of science degree in four years may lead to a reduction in internship experiences.

—Grady W. Chism III is Professor, Dept. of Food Science and Technology, The Ohio State University, Columbus.

Sharing Approaches to Education

By Faye M. Dong

Food science education takes place in a variety of settings such as in companies, food science and human nutrition programs at universities, government regulatory agencies, community colleges, continuing education programs, commodity councils, K-12 schools, and professional organizations. One of the many benefits of belonging to the Institute of Food Technologists is that it gathers together people with varying degrees of experience and diverse perspectives to examine, discuss, assess, and evaluate topics in food science education.

Certainly, it is much easier for us to openly talk about food science education today than it was 15–20 years ago. Our conversations have evolved from listing what courses should be required in curricula to articulating the knowledge, skill sets, and competencies that learners should acquire during their educational experience. We should be continually asking ourselves if we are using the best means to assess and improve the health of all of our programs in food science education (broadly defined), so that students and employees are well prepared to meet the current and future challenges of the food industry in feeding people throughout the world.

> Declines in educational funding will continue to drive down the extent and quality of laboratory experiences students receive. Pilot-plant experiences will become more "show and tell" and less hands-on. . . .

I predict that we will be hearing about many topics in food science education in the next 10 years: effective techniques for teaching and learning; the tailoring of delivery systems to meet the needs and learning styles of the students; ways to integrate development of professional and interpersonal skills into the learning environment; the importance of familiarity with the languages of other disciplines such as accounting, marketing, and business; defining of graduate education competencies and proficiencies; increased applications of distance education methods; development of more extramural programs for employees in industry and regulatory agencies; more integration of food science into science education in grades K-12; and continuing globalization of education.

Through IFT's Annual Meeting, Section and Division activities, and *Journal of Food Science Education*, IFT is providing multiple venues for publicly sharing and evaluating approaches, ideas, and techniques in food science education.

—Faye M. Dong is Professor and Head, Dept. of Food Science and Human Nutrition, University of Illinois, Urbana.

Utilizing Creative Educational Approaches

By Richard Hartel

With the development of IFT's *Journal of Food Science Education* this year, food scientists now have an outlet to publish research on instructional practices. The increased importance placed on student learning in the new IFT Education Standards for Undergraduate Food Science Programs stresses the importance of using good research practices to improve teaching and learning. Development of methods for assessing student learning in individual courses as well as for the entire undergraduate food science program is needed to meet the new education standards.

In each individual course, instructors must develop specific learning outcomes based on the needs of their graduates (industry, academia, etc.) and develop instructional methods that ensure that students meet those learning outcomes. Assessment techniques must be developed that ascertain the level reached by each student. Any new teaching technique should undergo a rigorous evaluation to determine whether student learning is truly enhanced.

There are numerous challenges to performing this rigorous evaluation of student learning. For example, the low student enrollments often found in food science courses mean that statistical measures of student learning are difficult to obtain. The applied nature of the discipline may also impose certain restrictions on the use of existing assessment tools. In addition, food science instructors are typically not trained in education practices and must learn these

methods of research before meaningful results can be obtained. Such efforts take up valuable time and resources from other important activities of the academic.

Despite these limitations, it is imperative that food science instructors use sound educational practices to research teaching and learning. Creative approaches are needed to overcome the challenges imposed by the nature of the field. This may require collaboration with education experts to ensure that rigorous and well-tested approaches are used.

—Richard Hartel is Professor of Food Engineering, Dept. of Food Science, University of Wisconsin, Madison.

Developing Well-Rounded Professionals

By Cheryll Reitmeier

We have been very good at helping students become technically competent food scientists, but we have often neglected to help them succeed in business. The most recent trend in higher education is the establishment of environments for the development of well-rounded professionals.

A learning community is an example of this type of environment. It is an organized group of students who take some courses together, work with peer mentors, create their own study groups, and live on the same residence floor. Learning communities help students be more involved and connected with each other and with faculty, which is often difficult in large universities. Students who participate in learning communities are more satisfied with their college experiences and are more likely to complete their education than students who are not in learning communities.

Classroom efforts to create a supportive environment include active-learning strategies, group and team activities, and communication (oral, written, visual, and electronic) instruction within the discipline. Service learning, internships, undergraduate research projects, and study-abroad courses have been developed to help students learn about "real world" problems. These innovative, interdisciplinary experiences can help students become successful food science professionals.

—Cheryll Reitmeier is Associate Professor, Dept. of Food Science and Human Nutrition, Iowa State University, Ames.

Providing Active Learning Opportunities

By Shelly J. Schmidt

Students entering today's workforce must solve complex, multidisciplinary problems, work successfully in teams, manage and keep pace with an ever-growing amount of information, exhibit effective oral and written communication skills, and practice good interpersonal skills. To successfully prepare our students for the workplace, we need a framework for shaping the educational experiences we provide to our students. One of the fundamental elements of this framework is the generous use of active-learning activities in and outside the classroom.

Students, just like the rest of us, learn best by doing. A.W. Chickering and Z.F. Gamson in 1987 aptly stated that "Learning is not a spectator sport. Students do not learn much just sitting in class listening to teachers, memorizing pre-packaged assignments, and spitting out answers. They must talk about they are learning, write about it, relate it to past experiences, apply it to their daily lives. They must make what they learn part of themselves."

What does this mean for food science education? We need food science educators to develop and employ effective active-learning activities and to share these activities with other educators. These activities can be as simple as asking students to reflect on the lecture material presented during a class period and write a paragraph summarizing the main points, or they can be as complex as a multiphase, semester-long group research project. Regardless of the length of the activity, the underlying theme remains the same—our students are actively doing things and thinking about what they are doing.

—Shelly J. Schmidt is Professor of Food Chemistry, Dept. of Food Science and Human Nutrition, University of Illinois at Champaign-Urbana.

Improving Food Science Education

By Ronald E. Wrolstad

When food chemistry students would ask Al Anglemier, now Professor Emeritus at Oregon State University, what would be on his final exam, he would respond, "The questions will be the same as those on previous exams, but I've changed the answers." The same could be said for food chemistry education. While the same basic principles will continue to provide the core, there will be new insights, examples, and applications.

For example, Maillard browning reactions will always be a section of any comprehensive food chemistry course, but the formation of acrylamide from asparagine and glucose will be today's example. Food analysis will always be critical to a food science curriculum, but the laboratory exercises will be updated to accommodate more-sensitive analytical procedures and new instrumental methods, and give more emphasis to data interpretation. More importance will be placed on developing students who can work effectively as members of teams. Partnerships of academia with industry and government through internships and other training programs will be recognized as an essential component of food science education.

I am presently on sabbatical leave at Massey University in New Zealand and have been impressed with their required Food Science Project. Food Technology majors spend 25% of their fourth year on a product/process development or food science research project integrating food processing, food chemistry, food microbiology, and sensory analysis. Projects are sponsored by industry and government agencies, and the student is mentored by a faculty member and representative from the funding organization. Students are much better equipped to enter the marketplace having had this intensive experience.

—Ronald E. Wrolstad is Distinguished Professor of Food Science & Technology, Oregon State University, Corvallis.

Summit Conferences to Define Research Needs

Two conferences designed to facilitate the interchange of information among scientists conducting basic research and those conducting applied research will be presented in Orlando, Fla., in January 2003. Sponsored by the Institute of Food Technologists, the Summit Conferences are designed to define research needs in the field of food science and technology. For more information, see p. 68.