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Food safety considerations for innovative nutrition solutions

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Failure to secure safe and affordable food to the growing global population leads far too often to disastrous consequences. Among specialists and other individuals, food scientists have a key responsibility to improve and use science-based tools to address risk and advise food handlers and manufacturers with best-practice recommendations. With collaboration from production agriculture, food processors, state and federal agencies, and consumers, it is critical to implement science-based strategies that address food safety and that have been evaluated for effectiveness in controlling and/or eliminating hazards. It is an open question whether future food safety concerns will shift in priority given the imperatives to supply sufficient food. This report brings together leading food safety experts to address these issues with a focus on three areas: economic, social, and policy aspects of food safety; production and postharvest technology for safe food; and innovative public communication for food safety and nutrition.

Keywords: foodborne illness; *Salmonella*; *E. coli*; cooking; food handling; food science

Introduction

Despite significant advances in food science and technology, and in consumer knowledge of safe food preparation, foodborne diseases continue to have harmful health and economic consequences in both developed and developing countries.[1–3] In the United States, the incidence of most foodborne diseases has either remained unchanged or increased over the past decade,[4] and it is estimated that each year approximately one in six individuals become ill (47.8 million annually), ∼128,000 are hospitalized, and ∼3000 die of foodborne diseases.[5] In recent years, a few highly publicized outbreaks of foodborne illness caused by pathogens have attracted the attention of the media, food scientists, policy makers, and consumers and damaged the reputation of the food industry. However, the reported outbreaks of food-associated illness for which a specific source was identified are a small fraction of all foodborne illnesses (0.05%).[6] Among other things, this means that the public is minimally aware of the true magnitude of the foodborne illness problem and the human illness costs to society.

To address several perspectives on food safety issues, experts from academia, government agencies, and the food industry convened at the conference "Food safety considerations for innovative nutrition solutions" held on November 6, 2014, and sponsored by the Sackler Institute for Nutrition Science at the New York Academy of Sciences.[a] The report below provides a detailed overview of the topics discussed at the conference with a focus on three areas: (1) economic, social, and policy aspects of food safety; (2) production and postharvest technology for safe food; and (3) innovative public communication for food safety and nutrition.

[a]http://www.nyas.org/WhatWeDo/Nutrition.aspx

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Global trends in food safety

In the opening keynote address, Frank Yiannas (Walmart) discussed global food safety trends and emerging food system issues from the vantage point of a large global retailer. He began by providing an overview of the history of obtaining, preserving, and processing food, starting with hunter/gatherer societies in 2000 B.C.E., when, as Yiannas speculated, the primary concern was likely to obtain food and consume it quickly rather than to avoid foodborne illness. The beginnings of food preservation techniques emerged in 500 B.C.E. with the process of preserving food with salt, and progressed much later in the mid-19th century with the placement of food on ice blocks and in units containing ice, an early form of refrigeration. In 1864, the advancement of science-based food preservation took a significant leap with the development of pasteurization, and almost 100 years later, the process of irradiation extended the life of food even longer than did pasteurization, allowing food to be shelf stable for several decades. Near the end of the 20th century, however, many consumers deemed irradiated food to be unhealthy, and consumer demand increased for natural, minimally processed, fresh foods, such as raw milk and unpasteurized juices, bringing with it challenges to food safety.

Yiannas presented data from a 2013 food safety progress report from the U.S. Centers for Disease Control and Prevention (CDC) looking at foodborne disease in selected sites where cases of specific pathogens were recorded.[4] The report showed that over a 6-year period, the number of *Campylobacter* cases per 100,000 population increased by 13% and *Vibrio* cases increased by 75%, while there was no change in the numbers of *Escherichia coli*, *Listeria*, *Salmonella*, or *Yersinia* cases (Fig. 1). Posing the question of why foodborne illness has not abated and pointing to five trends that present challenges to food safety in the 21st century, Yiannas discussed in more depth below: (1) a changing food system, (2) enhanced foodborne surveillance, (3) globalization of food, (4) the ingredients in food products, and (5) the use of online social media.

With regard to the first trend, there has been a transformation in food production over time, progressing from the domestication of plants and animals to the industrial farming revolution in the early 1900s, with farmers able to produce more food than ever before to feed the growing world population. Yiannas contrasted the small scale of the first retail food establishment from the early 1900s—for example, a small store in Chicago with roughly 25 shelf-stable products—with the magnitude of modern supermarkets, offering thousands of different food products: fresh fruits and vegetables year-round; locally sourced products; fresh meat, poultry, and seafood; and home meal-replacement solutions. Furthermore, the number of foods available to consumers has progressively grown with the advent of digital commerce—consumers in many countries can purchase any food online, from anywhere in the world, at nearly any time. According to Yiannas, the benefits of year-round availability of affordable, nutritious foods to a large number of people outweigh most downsides; however, managing food safety in this type of system remains challenging.

The second trend Yiannas discussed involves improvement in foodborne surveillance techniques. He pointed out that major headline news of foodborne illness outbreaks were relatively rare until recently (e.g., *Listeria* in cheese in the 1980s, contaminated meat at the fast-food retailer Jack in the Box in the 1990s). The frequency of such headlines has, however, increased from approximately once per decade to once per quarter, in line with reported estimates of foodborne disease per year in the United States and globally.[3,7] One explanation for this is that the ability to detect foodborne illnesses has improved with the increasing use of scientific techniques, online tools such as data from popular searches by consumers in online search engines, and credit card records to track consumer purchases. In 2009, for example, an initially small number of cases of *Salmonella typhimurium* in peanut paste manufactured by the Peanut Corporation of America was detected by pulsed-field gel electrophoresis (PFGE), a scientific technique that allows genetic fingerprinting of a microbial isolate; this laboratory finding led to the discovery of more than 800 related cases of foodborne illness, several ending in death. This specific case ultimately served as a catalyst for the U.S. Food and Drug Administration (FDA) to enact the Food Safety Modernization Act (FSMA) of 2011. Yiannas explained that without scientific techniques such as PFGE (and several others), this seriousness and extent of the outbreak 15 years ago would likely have remained unknown.

Disease Agents	Percentage change in 2013 compared with 2006–2008	2013 rate per 100,000 Population	2020 target rate per 100,000 Population	CDC estimates that...
Campylobacter	13% increase	13.82	8.5	For every *Campylobacter* case reported, there are 30 cases not diagnosed
Escherichia coli O157	No change	1.15	0.6	For every *E. coli* O157 case reported, there are 26 cases not diagnosed
Listeria	No change	0.26	0.2	For every *Listeria* case reported, there are 2 cases not diagnosed
Salmonella	No change	15.19	11.4	For every *Salmonella* case reported, there are 29 cases not diagnosed
Vibrio	75% increase	0.51	0.2	For every *Vibrio parahaemolyticus* case reported, there are 142 cases not diagnosed
Yersinia	No change	0.36	0.3	For every *Yersinia* case reported, there are 123 cases not diagnosed

Figure 1. Food safety progress report. Data are shown from a food safety progress report from the U.S. Centers for Disease Control and Prevention (CDC) looking at foodborne disease in the United States from 2006–2008 to 2013.

Indeed, today, the landscape has changed considerably with the ability to detect foodborne illnesses now outpacing the ability of the food industry to prevent them. Yiannia stressed that introduction of prevention strategies must be accelerated.

The third trend Yiannas highlighted concerns the rapid rate of globalization of food. As one example, he discussed the 2008 case of the toxic chemical melamine discovered in infant formula in China, and the identification, within days, by the World Health Organization (WHO) of numerous other countries that received dairy products contaminated with melamine.[8] This one example highlights the important fact today that a single food product may (and often does) contain ingredients from many different parts of the world—a single serving of tiramisu, for example, may contain cocoa powder from Switzerland, espresso beans from Columbia, chocolate from Belgium, Kahlua from Mexico, mascarpone cheese from Italy, vanilla beans from Madagascar, cinnamon powder from India, and mint leaves from the United States. In a case of foodborne illness in particular, such diversity makes tracing the exact source of contamination even more challenging.

The fourth trend Yiannas covered concerns the challenges to food safety related to the ingredients used in the manufacturing of food products. To illustrate this trend, the example of peanut paste contamination was revisited. *S. typhimurium* contamination of a single ingredient (the peanut paste) led to the recall of 3913 other food products, including crackers, granola bars, ice cream, and dog treats. More generally, one estimate puts the number of ingredient-driven causes at approximately half of all large multistate foodborne illnesses in the United States.[9] What can be done to address this issue? Yiannas suggested improving risk assessments of sensitive ingredients; extending investigation beyond traceability to determine not only what and where, but also how, the ingredients were contaminated; reformulation of products; and interventions by the manufacturer (e.g., heat treatment of flour by the manufacturer to prevent illness from consumption of raw cookie dough).

The fifth and last trend Yiannas highlighted concerns the use of online social media, which can rapidly disseminate food safety concerns among large numbers of consumers. Yiannas gave the example of lean, finely textured beef, which, in 2011, was labeled as "pink slime" on Twitter by an increasing number of individuals, leading food retailers and manufacturers to decide to omit this type of beef in their beef products. Social media can change the discourse on food safety very quickly, often leading consumers to become polarized on a given food safety issue; once determined one way or the other, consumer views rarely shift back to the center. One positive use of online social media, Yiannas continued, is that it can help detect foodborne illness long before traditional health reporting. In the normal sequence of events in foodborne illness surveillance, an ill individual seeks care from a health professional, submits a specimen for lab testing, and a culture-confirmed case is reported to a local health department or the CDC. Social media changes this sequence; rather than looking for one reported case, health department workers can survey the activities of a larger population through structured and unstructured online data (e.g., from Yelp, YouTube, Twitter, and Facebook), from which insight can be gained about dining experiences, eating patterns, and symptoms of illness that leads to detection of foodborne illness earlier.[10]

In closing, Yiannas listed several ways to reduce foodborne illness and to help ensure that consumers worldwide have access to an abundant supply of safe food:

- accelerate prevention (disease outbreaks cost more than preventative measures);
- emphasize science- and risk-based strategies rather than politically motivated or population-driven ones;
- develop specific, rather than generic, priorities and strategies that are pathogen and product specific;
- collaborate on, and develop innovations in, food prevention strategies;
- recruit more food safety leadership (working at the system level) rather than food safety management (working at the case level); and
- improve food safety performance and create a broad food safety culture that can influence consumer behavior, rather than relying on testing, training, and inspection programs.

Assuring the safety of food: understanding risks

Delivering the second keynote address, Robert E. Brackett (Illinois Institute of Technology) discussed the concept of *risk* in the context of food safety. In recent years, the term *risk based* has routinely been used when determining food testing strategies, product and ingredient sourcing, and which food facilities should be inspected and at what frequency. Despite this common usage, however, Brackett pointed out that a broad understanding of what is entailed by risk in the context of food safety, as well as an appreciation of the multitude of the factors that must be considered when making food safety decisions on the basis of risk, are lacking.

There are several ways to evaluate the risk associated with foodborne illness, including statistical, temporal, and categorical assessments. In statistical assessments, a type-1 assessment indicates a false-positive risk; for example, when a test for a microorganism in food yields a positive result for a food that does not, in fact, contain the microorganism. In contrast, a type-2 assessment indicates a false-negative risk; for example, when a test fails to detect a microorganism in food even though it is, in fact, present—this type of risk is particularly problematic since consumers demand more testing and simply assume, when tests results are negative, that the food is safe when that may not be the case.

Temporal assessments of food safety examine acute risks, such as those associated with pathogens (e.g., *Salmonella*) and acute toxins (e.g., cyanide), which occur over a short period of time; and chronic risks, such as those associated with consumption of unhealthy dietary ingredients (e.g., saturated fat, salt) and toxic food components (e.g., methylmercury, arsenic), which develop over a longer period of time.

Categorical assessments of foodborne illness include such things as the *type* of illness or physical injury (e.g., Salmonellosis versus intestinal lesion due to glass fragments); nutritional risk (e.g., consumer avoidance of entire classes of nutritional food following an isolated outbreak of foodborne illness); economic risk (e.g., increased food costs); societal risk (e.g., impact on local versus distant food providers); and political risk (e.g., consumer perception of overreach by regulatory agencies, potentially influencing consumer voting behavior).

Perceived risk, such as that associated with consumption of, for example, genetically modified or nonorganic foods, must also be considered, as such risk significantly influences food choices of consumers, despite the lack of scientific evidence for risk.

Brackett posed the question of why it is necessary to study food safety risk. In some cases, there are legal mandates to do so. For example, the 2011 FSMA preventive controls for human and animal foods (Section 103) direct the FDA to conduct science-based risk analyses; and economic regulations require the Office of Management and Budget to conduct regulatory impact analyses (RIA), which assess the economic impact of food safety rules to society. On the corporate side, ethical considerations or responsibility to shareholders can drive the development of effective risk management strategies.

Traditionally, food safety risk has been assessed using the Codex risk analysis[11] developed by the Food and Agriculture Organization (FAO) of the United Nations and the WHO. Codex risk analysis emphasizes the interplay between risk assessment (science based), risk management (policy based), and risk communication (interactive exchange of information and opinions concerning risks). Brackett stressed, however, that Codex risk analysis is not the only approach to assess food safety risk, and that there are several variations in risk assessment models.[12] Risk assessment typically involves four components: hazard identification, hazard characterization, exposure assessment, and risk characterization. Traditionally, risk characterization by the Environmental Protection Agency, the WHO, or the International Life Sciences Institute (ILSI) is not conducted until after the risk assessment has been completed.

The effectiveness of these traditional risk characterization approaches was assessed by a 1996 National Academy of Sciences (NAS) report,[13] which concluded that traditional risk characterization may provide scientific and technical information that is often *not* useful for informing policy-related decisions. The report also concluded that science alone is not an adequate basis for a risk decision, and that broader information should be used to design and inform risk assessment before the assessment begins. Attaining this broader information involves identifying the interested parties that would be affected by the risk assessment (e.g., legislators, FDA and related agencies, food industry, consumer interest groups), providing them with targeted information that is relevant to them, and obtaining their input. Also necessary are considerations of alternative sets of assumptions about a perceived risk that may lead to divergent estimates of risk (e.g., consideration of certain subpopulations not previously considered to be at risk). Also, broader information on codependent risks should be considered (e.g., risk assessments of produce safety may affect the environment in related farming regions), and risk assessments may also have effects at social, economic, and ethical levels. From characterizing risk and considering relevant information, the NAS report recommended an analytic-deliberative process that involves using the appropriate science(s)—not only biological, but also economics and social sciences—to provide data for the analysis and soliciting participation from interested and affected parties.

Brackett highlighted examples of notable risk assessments, including one conducted by the FDA to determine the risk of methylmercury exposure from fish consumption. Specifically, the agency issued a warning to at-risk consumers to limit their consumption of certain types of fish, which inadvertently led to many consumers avoiding all categories of fish products. This prompted the FDA to carry out another risk assessment looking at the net effect of avoiding consumption of fish on fetal neurodevelopment (among other parameters), and they consequently revised the initial recommendation to urge consumers to eat a variety of fish that have known lower mercury levels. This example demonstrates how careful risk assessment can reveal (potential) unintended consequences of recommendations made on the basis of prior risk analysis; it also serves as an example for risk assessors of the potential of confounding factors that need to be uncovered in providing risk assessments.

Concluding his comments, Brackett said that classical risk assessment can provide valuable quantitative and qualitative information about hazards in question, and that such efforts are critical for improving food safety. However, discussions of food safety risk assessment often only focus on the *mechanics* of how to conduct a risk assessment, while ignoring the broader context of how a risk assessment can inform decisions. Brackett recommended that risk assessment strategies evolve to include broader considerations of risk and both science and nonscience impacts of a given target issue.

Economic, social, and policy aspects of food safety

Economics of public and private incentives to control foodborne pathogens

Tanya Roberts (Center for Foodborne Illness Research and Prevention) outlined concrete steps to

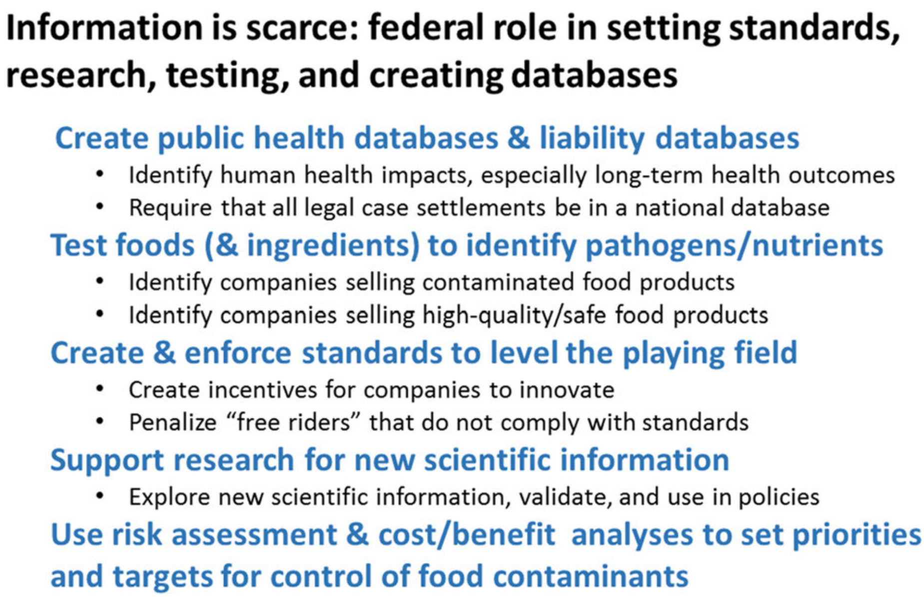

Figure 2. Food safety and the role of the federal government. Shown are steps for the federal government to ensure food safety by setting safety standards, supporting scientific research, pathogen testing, and creating databases.

provide incentives for food companies to improve pathogen-control methods (Fig. 2). Private-market incentives for improving food safety are relatively weak, primarily because it is difficult to link the causative pathogen and human illness to a specific food company.[14] The CDC estimates that each year 47.8 million Americans become ill from acute foodborne illnesses, 138,000 are hospitalized, and 3000 die.[1] Economists have estimated that long-term health outcomes (LTHOs) (such as kidney failure, arthritis, mental retardation, and paralysis) cost societies more than do acute illness caused by several foodborne pathogens.[15] A conservative estimate—conservative because most LTHOs have not been evaluated—of the annual costs of foodborne illness is $78 billion in the United States.[16] Benefit/cost analyses suggest that preventing acute and long-term foodborne illnesses may be significantly less costly than the current annual public health costs (in the United States).[17,18]

Over the last decade, while scientific innovations to test and control pathogens from "farm to fork" have been developed, they have not been uniformly adopted by either private companies or federal regulators. Regulatory programs at the U.S. Department of Agriculture (USDA) and the FDA, for example, have not addressed the basic problem of linking the majority of foodborne illnesses to a contaminated food product and its supplying company. Roberts stated that the cornerstones of such a system are: (1) requiring pathogen tests from farm to fork; (2) requiring government access to these pathogen test results in order to ensure that the prevention systems are working as planned in each food company location; (3) setting strict pathogen performance standards that require improvement from one year to the next; (4) requiring mandatory reporting of legal liability cases and out-of-court settlements involving foodborne pathogens; (5) increasing funding of epidemiologic research identifying and enumerating LTHOs; and (6) critically, creating an integrated nationwide database to link pathogens to specific food products and to the companies that supply contaminated foods.[19,20] Implementing and enforcing these six steps, Roberts continued, will give food companies strong incentives to improve their pathogen-control methods.

Additionally, strict pathogen monitoring in foods from farm to fork may level the playing field for all food providers. Currently, some companies that minimize their role in causing foodborne illness are not held accountable for their actions and the health-related damage that results.[19] This ultimately hurts other companies that adhere to strict safety standards. Roberts stressed that the costs of implementing these six steps may be a fraction of the estimated annual burden of $78 billion currently imposed on U.S. food consumers.

Increased food costs and perceptions related to safety

Victoria Salin (Texas A&M University) discussed perceptions of consumers and producers on the value and costs of avoiding foodborne illness.

Food price inflation in general is linked with a scarcity of raw materials, a failure of crops due to drought or flood, or demand rising faster than production. Over the last decade (specifically in 2008 and 2011), there have been two major shocks in world food commodity prices;[21] in addition, the lingering impact of recent U.S. droughts is still being felt by meat buyers. As a contrast, in 2014, supplies of grain crops were plentiful enough that, after accounting for pass-through of commodity costs to value-added food, inflation in grain-based foods was predicted to be modest (1–2%). The all-food price index, however, was forecasted to be higher by 3% in 2014, led by double-digit price increases of beef. Thus, raw material costs alone do not fully account for these changes in food prices.

Salin explained that it is complex and costly to manage the many processes and market transactions that are necessary to supply the variety of foods offered to consumers, which includes choices in sizes, flavors, preparations, and provenance of foods at different price points. Such variety is accompanied by features such as 24 h/day shopping access; year-round availability; availability of single-serve packages and ready-made meals; and information on origin, location throughout the supply chain, species, and method of production. Approximately 80% of the final food dollar is due to contributions to processing, packaging, transportation, and retailing services, while 20% consists of primary agricultural goods (these figures are from the USDA). Food safety protocols are required at all points in the food system—from production and distribution of staple goods to running the finest restaurants.

Consumers obviously expect foods that are not harmful. But because consumers cannot easily detect pathogen-laden foods (except by sight and smell), government regulations are required for ensuring safety,[19] though food companies also implement a variety of safety protections (still, these are often regulated by government). Consumer response (e.g., complaint) is an incentive for companies to prevent safety lapses. Of interest is the finding that food safety lapses for a specific food (brand) do not necessarily lead to generalized consumer complaints about, or avoidance of, an entire category of food[22–24]—a finding based on an incident involving one brand of peanut butter for which market share comprised only three national brands. In a 27-week period in which the affected brand of peanut butter was taken off the market, there was no significant decline in consumer demand for the other brands of peanut butter. During the period of recall of the one brand of peanut butter, the leading competitor reduced prices, while the other competitor raised prices. Surprisingly, a larger number of households bought peanut butter (on a weekly basis) during the recall period than before, presumably because consumers replaced the discarded recalled brand. Strategic marketing and promotion after the food safety incident allowed the company to recover its market share.

Commenting further on these findings, Salin referred to distinct consumer segments with respect to risk taking on food safety.[25] Although empirical studies that quantify the size of segments of consumers who are resilient to food safety concerns are scarce, one study[26] found that approximately one-third of consumers expressed high concern about the safety of produce after a national outbreak of foodborne illness, and that the most common consumer response was to examine products closely (a nonscientific approach to selecting a safer product, to be sure). Salin concluded by pointing out that market researchers who are interested in understanding the connection between consumer perceptions of food safety and market incentives that lead businesses to enhance safety protocols face the challenge that incidents of product harm are relatively rare. This keeps attitudes of consumers influenced by the idea of there being a safe food system. In addition, quantitative market research methods often fail to distinguish intentional risk taking by consumers from lack of awareness of the foodborne illness by consumers.

Why food safety requirements should be science based

William H. Sperber (The Friendly Microbiologist LLC) provided a brief history of modern food safety management, stressing the importance of the scientific method as the basis for strengthening food safety requirements. Sperber stressed the importance of maintaining a scientific basis for food safety efforts; indeed, work in this area has become a worldwide collaborative effort among many scientists. He also argued that some of those who are responsible for developing science-based requirements are insufficiently educated about or experienced in the procedures necessary to produce safe foods.[27]

In the 1960s, the Pillsbury Company, the National Aeronautics and Space Administration (NASA), and the U.S. Army pioneered modern food safety management by developing the hazard analysis and critical control point (HACCP) system to assure the safety of military and space foods. Pillsbury's HACCP system for its consumer food products was fully operational by 1975, and, gradually, other food producers nationally, and then globally, adopted it. In 1992, HACCP was codified by the U.S. National Advisory Committee on Microbiological Criteria for Foods (NACMCF) and the United Nations Codex Alimentarius Commission. By this time, it was recognized that HACCP systems needed additional practices to assure sanitation throughout the farm-to-table supply chain—practices such as good agricultural and manufacturing practices.[28]

Sperber explained that the HACCP system works well for those foods that can be processed with a critical control point (CCP) to assure that pathogenic microorganisms will be killed or prevented from growing. These are foods (e.g., pasteurized dairy products and canned foods) that can be sterilized, pasteurized, frozen, dehydrated, or modified by the use of preservatives or by the reduction of pH or water activity.

While HACCP works well for processed foods, where CCPs are available, its early success created the false expectation that all foods could be produced and marketed free of pathogens.[29] Particularly for foods that are consumed raw or undercooked, it is unscientific to expect that they can be pathogen free when no CCP is available. In such cases, Sperber continued, the product or process should be altered to create a CCP, and if this is not possible, the food should not be produced. Nevertheless, common consumption of fresh produce and undercooked meats will continue without the protection of a CCP, especially when the use of electronic irradiation for pasteurization is not supported or permitted. Good consumer practices are required to educate consumers about avoiding potential hazards; such recommendations were made by the National Research Council but ignored by food regulators for over 30 years.[30]

Numerous science-based advancements have improved the safety of the food supply in much of the world; however, more work is needed. Sperber concluded that science-based food safety requirements would best protect consumers when an effective audit system can be created and reliably used to prevent practices that are unethical or criminal (such as economic deception, product adulteration, and falsification of food safety records). One industry-driven initiative—the Global Food Safety Initiative (www.mygfsi.com)—working to advance food safety management through collaboration between industry, government, and academia, may fill this need for effective audits.[31]

Who is responsible for food safety?

Dane Bernard (Bold Bear Food Safety) explored the question of who is responsible for food safety in the United States. According to Bernard, considering food safety to be an equally shared responsibility among government, industry, and consumers is a significant oversimplification of the current system, as the boundaries, expectations, limitations, and overlap between these three groups are often obscure. Bernard discussed different perspectives on what the respective roles of these groups should be in ensuring food safety.

He cited a 2014 report by the Congressional Research Service (CRS)[32] stating that federal laws give food manufacturers, distributors, and retailers the basic responsibility for assuring that foods are wholesome, safe, and handled under sanitary conditions, ultimately placing primary responsibility for food safety on the food industry. However, numerous federal, state, and local agencies also share responsibilities for regulating the safety of the U.S. food supply, with approximately 15 federal agencies administering at least 30 food safety–related laws, and state and local food safety agencies regulating retail food establishments and some manufacturing. The FDA is responsible for overseeing 80–90% of all foods, including domestic and imported food products sold in interstate commerce (except for most meats and poultry), as well as all seafood, fish, and shellfish products, in-shell eggs, wild game, exotic species, bottled water, dietary supplements, and milk in interstate commerce. In addition to the FDA, the USDA Food Safety and Inspection Service (FSIS) is responsible for oversight of 10–20% of foods, including domestic and imported meat, poultry, some egg products, and catfish. In Bernard's view, the main function of these government agencies is to provide a regulatory framework, driven by risk assessment targeting acceptable levels of protection (ALOP), which outlines the performance expectations for all segments of the food industry and which provides uniform oversight and appropriate verification of compliance.

Bernard next elaborated on the role of the food industry, a vast interconnected system consisting of three main sectors: the agricultural sector (e.g., farmers, fertilizer and equipment manufacturers, distribution warehouses), which is minimally regulated; the food processing industry; and wholesale and retail trade, all of which are extensively regulated. Although Bernard agrees with the CRS in that the food industry is primarily responsible for food safety and providing foods that, at a minimum, meet ALOP, he pointed out that a clear definition of ALOP, and the levels of protection that the food industry is capable of providing, is not currently agreed upon.

Despite adherence by the food industry to current regulations, there are hazards that remain in the food supply, which consumers need to be aware of to minimize risk. Bernard discussed an example of an uncooked packaged poultry product, whose manufacturer clearly labeled the product as raw and provided validated cooking instructions, in accordance with FSIS labeling policies. However, in 2006, a *Salmonella* outbreak was traced to this poultry product, leading to a recall and suggesting that the affected consumers may not have followed the labeling guidance. Bernard asserted that consumers and food preparers need to make reasonable food choices and extend ALOP by understanding and applying safe practices of food preparation. He cited a 2010 FDA food safety survey that found an increase between 2006 and 2010 in eating raw foods, such as eggs and fish, which should be cooked before eating[33] and pointed out the increasing consumption of unpasteurized (raw) milk, for which foodborne illness is 150 times greater on an individual serving basis than illness associated with pasteurized milk. He also discussed the increasing consumer preference for poultry from farmers' markets—often not subject to USDA inspections—and showed evidence of a greater number of confirmed *Salmonella* and *Campylobacter* cases in farmers' market chicken compared to regulated conventional or organic chicken.[34] In addition to government, industry, and consumers, Bernard also briefly discussed the significant and expanding role of "influencers"—individuals (often with no background in food safety or food science) communicating about food safety issues through online social media and significantly influencing public perceptions of food safety.

Bernard concluded by outlining the following steps that each group can take in sharing the responsibility of ensuring food safety: (1) government and industry should clarify reasonable targets with progressive expectations, particularly with regard to ALOP; (2) industry organizations should stop defending other industry players that violate safety standards and should develop a better understanding of, and address, the evolving role of influencers in online social media; (3) consumers should take a greater interest in safe food preparation and make risk-informed decisions when making food choices; and lastly, (4) influencers in online social media should be conscientious about providing balanced, complete, and accurate food-related information to consumers.

Production and postharvest technology for safe food

Managing food safety risks in produce

Linda J. Harris (University of California, Davis) opened the second session with a focus on safety risks in produce, a broad category that generally includes fruits and vegetables, sprouts, fresh and some processed culinary herbs, and sometimes tree nuts. Produce in all forms are typically considered an important part of a healthy diet, and consumers have been encouraged over the past three decades to consume more fruits and vegetables. In the United

States, consumption of fresh fruits and vegetables has increased significantly during this time. The postharvest processing options for produce cover the spectrum of old and low technology such as drying and fermentation, to new technology such as high-pressure processing. Despite the wide number of options for preserving produce, roughly 50% of the world's produce is never consumed.[35] In developed countries, waste is higher and closer to the point of consumption (retail and final preparation), while in developing economies, the lack of cold-chain and general infrastructure push waste closer to production and processing.

An increase in consumption overall, a shift to consumption of fresh rather than processed or cooked fruits and vegetables, and significant improvements in surveillance and detection methodologies has led to an increased recognition of the contribution of fruits and vegetables to foodborne illness in the United States. In recent years, FDA-inspected foods (except meat and poultry) accounted for approximately 55% of reported cases of foodborne illnesses annually in the United States.[36,37] From 1998 to 2008, sprouts, fruits, and vegetables were linked to nearly 22% of foodborne illness outbreaks from FDA-regulated food, and leafy greens, tomatoes, melons, berries, and herbs have been responsible for 75% of produce-associated outbreaks.[6]

Salmonella outbreaks are often associated with melon and tomato consumption and *E. coli* gastroenteritis outbreaks are frequently linked to consumption of leafy greens; berries are often linked to outbreaks of foodborne viruses or parasitic protozoa.[38] Although the contamination of produce with pathogens can occur anywhere along the food chain, the scope and size of produce-associated outbreaks tend to decrease, the closer the point of contamination is to the time of consumption.

Harris explained that the complexity of produce surfaces makes it extremely difficult to consistently and effectively reduce pathogens once the produce has been contaminated.[39] For fresh produce that is consumed raw, there are few options for reducing pathogens after harvest, and thus food safety management begins at the farm long before harvest begins. Food safety risk–reduction strategies embodied in good agricultural practices focus on the main known sources of foodborne pathogens—water, wildlife, soil amendments, and worker hygiene—and these sources of potential contamination are also the basis on which the produce safety rule of the FSMA was proposed.

Managing food safety risks in foods of animal origin

Manpreet Singh (Purdue University) focused on foods of animal origin. Typically, *E. coli* and enteric pathogens, such as *Salmonella* and *Campylobacter*, are associated with foodborne illness from consumption of raw meats, while *Listeria monocytogenes* is most commonly associated with the consumption of ready-to-eat processed meats and poultry products.[40] Other pathogens, such as *Clostridium perfringens* and *Yersinia enterocolitica,* are also of concern with regard to foods of animal origin. The major foods of animal origin can be categorized into cattle, swine, and poultry, which includes broiler chickens, turkeys, laying hens, and, to a certain extent, game animals in niche markets. Most pathogens are usually harbored in the intestinal tract of healthy animals and end up in the associated food as a result of various production, processing, handling, and consumption events.[41]

Livestock can be considered as a production system, where inputs into animal production consist of live animals, feed, water, and the environment, and the output of the system is usually fresh/raw meat and processed meat and poultry products. During the rearing of animals for human consumption, contamination can occur from animal to animal, and through feed and water, personnel involved with husbandry practices, farm vehicles, and a lack of good biosecurity. During food processing, cross-contamination can occur from one carcass to the other, and from personnel, equipment, and the in-plant environment. Singh stated that the current strategies to address food safety issues in foods of animal origin are critical for food safety but need to be evaluated for their effectiveness in controlling and/or eliminating the hazards. More specifically, intervention technologies and practices need to be robust and effective throughout the production continuum from the farm to the consumer to ensure food safety.

With the increasing diversity in the demographics of the U.S. population and the growing number of working families, time for food preparation is decreasing in many households, generating a need to focus on the safety of convenience foods. According to a 2014 analysis of consumer spending on food away from home, there are approximately 1 million restaurant locations in the United States that account for $683 billion in sales.[42] Although no direct correlation has been reported with respect to where pathogens are acquired, approximately 41% of foodborne outbreaks can be attributed to foods from an animal source,[6] not accounting for protein sources from aquatic animals. Spoilage and pathogenic microorganisms are associated with food animals, and unless interventions are applied throughout the production continuum from the farm to the consumer—during production, processing, retail, and food preparation, along with appropriate controls during distribution—foodborne illnesses are inevitable.[43] Singh concluded that the design and implementation of good agricultural practices on farms, vigilant veterinary monitoring, good manufacturing practices in processing plants, and adequate food preparation can prevent, reduce, or eliminate food safety risks. Such practices, in addition to consumer education, enhance food safety and help consumers to avoid foodborne illnesses from foods of animal origin.

Food safety implications for low-moisture food

Jeffrey M. Farber (Health Canada) discussed the microbial hazards associated with low-moisture foods (LMFs) and the development of international codes of food safety practices. LMFs can be defined as foods that are either naturally low in moisture or are produced from higher moisture foods through drying or dehydration processes. These foods generally have a long shelf life because of their low water activity and are mainly shelf stable. Some major food categories that are classified as LMF include spices and dried herbs, nuts and nut products, dried fruits and vegetables, cereals and grains, as well as confections and snacks. In general, LMFs have been assumed to be safe products in that they do not support the growth of bacterial pathogens, and many are commonly consumed as ready-to-eat products. However, this assumption of safety has been challenged in recent years by the occurrence of a number of outbreaks and recalls associated with contaminated LMF in several countries.[44] In recognition of this, there has been a global acknowledgement of the need to better understand and control the microbiological hazards associated with LMF. For example, the Codex Alimentarius Commission, established by the FAO/WHO, recently agreed that a codex hygienic code of practice for LMFs should be developed.

To support the development of the Codex code and other risk management activities, a risk ranking was initiated by the FAO/WHO. Data from a systematic review of information on the burden of illness, prevalence, and concentration of microbial hazards, and possible interventions related to LMF, fed into the risk ranking.[45] Categories of LMF were evaluated against four criteria: burden of illness, vulnerability of the category during production, vulnerability of the category during consumption, and international trade. The ranking exercise concluded that the categories of LMF posing the greatest risk are in descending order: (1) cereals and grains; (2) dried protein products; (3) spices and dried herbs; (4) nuts and nut products; (5) confections and snacks; (6) dried fruits and vegetables; and (7) seeds for consumption.[45]

Farber explained that the main microbial hazard in LMF is *Salmonella* spp.; however, other pathogens such as *Bacillus cereus* and *E. coli* O157:H7 have also caused illness.[45] The ability of *Salmonella* to cause illness in LMF is facilitated by several factors: its widespread distribution and complex ecology; its prolonged survival and heat resistance in low-moisture and high–fat/sugar products; its prolonged survival in the processing environment; and a low-dose response.[46–49] Bacterial pathogens can be introduced into LMF through contaminated incoming ingredients, inadequate heating or kill steps, recontamination through the addition of contaminated ingredients, cross-contamination through the processing environment, or by the growth and spread of bacteria through the presence of moisture.[44,50] The proposed draft hygienic code of practice for LMFs[51] focuses intervention methods on minimizing the spread of pathogens in the processing environment and preventing the growth of pathogens by maintaining a dry environment. Validation of control measures, including environmental monitoring, is also discussed in the code of practice. With a look to the future, best practices for the production of LMF will be shared with the Codex member countries and the food industry, with the ultimate goal of reducing the number of foodborne illnesses related to the consumption of LMF.

Innovative public communication for food safety and nutrition

Food handling and consumption knowledge, attitudes, and behaviors of young adults and the impact of a food safety information campaign

Carol Byrd-Bredbenner (Rutgers University) stressed that reaching consumers with a greater tendency for mishandling foods (e.g., young adults) with effective food safety campaigns is one critical way to protect public health. In general, informational campaigns are most effective when messages are tailored to the needs and sensibilities of a specific audience. A limitation of many food safety campaigns is a lack of data describing the cognitions and behaviors of the audience of interest and an inadequate understanding of how this audience prefers to learn about a given topic. Thus, in order to create a campaign with an increased likelihood of success, Byrd-Bredbenner developed a young adult–targeted food safety campaign that took these issues into consideration and proceeded in the following three phases.

In the first phase, a survey instrument to investigate food safety–related cognitions and self-reported behaviors was developed, validated, and administered online to 4343 young adults (college students).[52,53] With regard to food safety knowledge, participants achieved an overall score of 60%, equivalent to a grade of D−.[54] Food safety belief scores indicated a fair to good level of interest in food safety, but the participants were neutral in their perceptions of foodborne illness being a personal threat. In addition, their food safety self-efficacy—or confidence in their ability to handle food safely—was high. In contrast, their stage of change for safe food handling indicated that they were aware of the need to change their food preparation techniques to enhance food safety, but were not yet ready to make these changes. Self-reported food handling practices indicated very poor compliance with safe food-handling practice scores. However, they reported consuming few high-risk foods.[54]

The data from the second phase complemented the self-reported behavioral data from the first phase and were obtained by observing 153 young adults prepare chicken fajita and uncooked salsa recipes as they would at home and by auditing their home kitchens. These observations revealed significant deficits in using safe temperatures for food storage and cooking (i.e., refrigeration, using thermometers to cook animal proteins, reheating temperatures) and hand washing (i.e., how to adequately wash hands and the occasions that warrant hand washing).[55,56]

Table 1. Evaluation of food safety campaign

Measure	Pretest	Posttest
Food safety knowledge total	41%	52%
Safe cooking temperatures	45%	60%
Safe refrigerator temperatures	38%	53%
Safe leftover-reheating temperatures	31%	41%
Stage of change for safe food handling	2.6 ± 1.1	2.8 ± 1.2
Self-report behavioral indicators		
Washed hands w/soap before cooking	49%	60%
Washed hands w/soap after bathroom	50%	67%

The data are from Ref. 57.

The third and last phase involved the development, implementation, and evaluation of a campus-based food safety information campaign and was informed by the first two phases. Focus groups with young adults ($n = 52$) revealed the following: (1) information overload and time constraints were key barriers to receiving food safety messages; (2) a desire for personalized, light-hearted, short messages focusing on a few behaviors; and (3) a preference for messages delivered in a convenient, fun manner. The final campaign messages that were developed were “Clean—Don’t get caught dirty handed,” “Cook—When the temp is right, take a bite,” “Chill—Are you cool enough? Set fridge to 32–40°F,” and “Leftovers help keep you alive, but only if you reheat’em to 165°F.”

The final campaign, implemented on eight university campuses, used myriad communication strategies, including campus newspaper advertisements, messages on dining hall table tents, posters, videos, and events. A comparison of matched pretest and posttest ($n = 607$) results indicated significant increases in food safety knowledge, stage of change, and self-reported behavioral intentions (Table 1).[57] On the basis of these findings, Byrd-Bredbenner concluded that in order to achieve the goals of lowering the incidence of foodborne illness, it is critical to understand the target population’s needs and interests and use this information to target and tailor interventions, and to address the target population in their preferred format.

Communicating food safety risk–reduction messages

Ben Chapman (North Carolina State University) continued the session's focus on food safety communication and education, and emphasized Byrd-Bredbenner's point about the importance of bringing targeted messages to specific populations when communicating about risk. With an estimated 48 million foodborne illnesses in the United States annually, food safety is a societal issue. While microbiology and epidemiology provide tremendous insight into disease acquisition mechanisms and the methods for control, risk management decisions often lie in the hands of the consumer/food handler. Whether amateur (in the home kitchen) or professional (on farms, in processing plants, in commercial kitchens), food handlers are at the front lines of food safety. It is the responsibility of food safety experts to ensure that food handlers, and those who oversee them, are armed with the most current, evidence-based information and practical tools to address risks.

Research on health and related behaviors has suggested that individuals make rational decisions about such behaviors when they are aware of, and have some knowledge about, the risks associated with particular actions. However, Chapman pointed out that simply having the knowledge does not necessarily translate into behavior. Relevant research in psychology has shown that several factors influence the intention to carry out a planned behavior: attitudes toward the behavior, the subjective norm, and perceived behavioral control.[58] Therefore, Chapman pointed out that the typical aim of food safety communication to merely increase efforts toward education is simplistic and needs to consider the spectrum of factors, in addition to education, that influence intentions and behavior. Furthermore, food safety educators should determine whom the target population is, understand the complexity of the target population's views and decision-making processes with respect to food safety risk, and identify whom that population trusts enough to receive risk-related messages from (e.g., food scientists versus trusted individuals in the community).

According to Chapman, messages communicated to food handlers about food safety risks should, above all else, be frank. Although consumers are often led to believe that the food that they are purchasing is guaranteed to be safe, messages to consumers need to honestly convey the uncertainties surrounding food safety and the reality that there is never a complete absence of risk. Traditional risk communication channels, such as brochures, public service announcements, and posters, are being supplemented with engaging discussions online through a variety of social media fora. Combining personal experiences with safe food-handling information can create effective food safety messages, and the use of stories and verbal narratives in message delivery has been demonstrated to be more effective in conveying information than the use of prescriptive messages or numerical statistics alone. By investigating and fostering the combination of food safety, communication, psychology, and risk analysis, the field of communicating food safety risk–reduction messages has seen significant progress.

"Is My Food Safe?"—a mobile app from Home Food Safety

In order to help consumers find reliable, accurate food safety information, the Academy of Nutrition and Dietetics formed an industry–association collaboration with ConAgra Foods to create the Home Food Safety program, a public awareness campaign dedicated to providing simple solutions that allow easy and safe handling of food at home. As part of the Home Food Safety program, a free mobile app—"Is My Food Safe?"—was developed to share important science-based food messages in an easily accessible manner (homefoodsafety.org/app). In her presentation, Marjorie Nolan Cohn (Academy of Nutrition and Dietetics) highlighted the three primary features of this mobile app and the importance of each feature for promoting food safety practices.

The first feature discussed is a section of the app—"Is It Done Yet?"—that provides a list of safe cooking temperatures for many individual food items. Consumption of undercooked foods is a primary cause of food poisoning, and a food thermometer is the only reliable way to ensure that food is thoroughly cooked to a safe minimum internal temperature. For example, Cohn pointed out that one in four beef burgers turns brown during cooking before it has been heated to a safe temperature, indicating that a reliance on sight, smell, or even taste is not sufficient to determine whether food is thoroughly cooked. The "Is It Done Yet?" section provides a simple way to find the safe cooking temperature of individual food items and promotes the importance of using a food thermometer.

Cohn also highlighted a section of the mobile app—"Time To Toss?"—that provides a food storage guide with essential information on the shelf life of common foods. This section may help to eliminate the question of whether food is still safe to eat by providing consumers with information on the specific shelf life of a given food when stored in either the refrigerator or freezer. Freezing, which prevents the growth of bacteria, yeast, and mold that cause food spoilage and food poisoning, can extend the shelf life of food. Thus, if food is nearing its expiration date, one can reduce food waste and freeze the surplus food rather than disposing of it. Ultimately, the list provided by this section of the app may help reduce the risk of food poisoning by ensuring that the average consumer is aware of the shelf life of their foods.

Lastly, the app features an interactive quiz—"Is My Kitchen Safe?"—that challenges consumers to test their food safety knowledge and assesses the safety of their individual kitchens. Even though some consumers understand the risk, they often do not follow recommended food safety guidelines. Cohn stated that this quiz may encourage consumers to fill in the gaps in their food safety knowledge and to abide by these important risk-reduction practices, ultimately reducing their risk of food poisoning.

Summary and conclusion

The discussion above provides several perspectives at the intersection of science and societal imperatives in the provision of safe and adequate food supplies. Specific ways to better address the challenge of preventing harm from food safety lapses were suggested, including the development of a food safety culture within the business organizations that produce and distribute foods, and a strong foundation of food protection in production was deemed crucial to address the food hazards that remain. There was also a call for stronger federal regulations: for example, HACCP implementation has not been scientifically applied to prevent pathogen contamination on food products that are sold raw; and economic incentives have not been fully utilized both to promote adoption of food safety innovations and to punish companies that sell contaminated food.

An overarching theme, risk-based policy addressing potential trade-offs between producing safe food/fewer illnesses and the cost of adopting new pathogen-control systems must be grounded in a broader societal context. This will include essential roles of the private sector and public authorities in risk management and risk assessment, as well as the interaction of risk communication and the range of behaviors exhibited by consumers. Of great importance is communicating risk to the public using credible messages that are appropriate to the consumer niches targeted, and the extent to which these targeted messages induced change. Cultural trends demanding convenience and freshness of produce mitigate some of the traditional concepts of hazard reduction in processed foods. There are additional opportunities for communicating risk by providing even more information related to food handling, preparation, and consumption through online social media.

Much work has been done in identifying the costs, causes, and consequences of foodborne illness, and innovations have been developed to test and control pathogens. However, greater effort is needed to facilitate uniform adoption of these innovations across all food sectors. Accelerated implementation of programs by food companies to prevent product contamination by pathogens, stronger federal regulations, and ongoing dialog that brings together food science and behavioral science offers potential to address some of the challenges of providing a safe and affordable food supply.

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Conflicts of interest

The authors declare no conflicts of interest.

References

1. Scallan, E., *et al.* 2011. Foodborne illnesses acquired in the United States–major pathogens. *Emerg. Infect. Dis.* **17:** 7–15.
2. United States Department of Agriculture (USDA) Economic Research Service. 2014. Cost estimates of foodborne illnesses. November 12, 2014. http://www.ers.usda.gov/data-products/cost-estimates-of-foodborne-illnesses.aspx.

3. Rocourt, J., *et al.* 2003. *The Present State of Foodborne Disease in OECD Countries.* Geneva: World Health Organization.
4. Centers for Disease Control and Prevention. 2014. Food Safety Progress Report for 2013. April 2014. http://www.cdc.gov/media/releases/2014/images/p0417-2013-foodborne-infections.pdf.
5. Centers for Disease Control and Prevention. 2011. CDC estimates of foodborne illness in the United States. January 8, 2014. http://www.cdc.gov/foodborneburden/2011-foodborne-estimates.html.
6. Painter, J.A., R.M. Hoekstra, T. Ayers, *et al.* 2013. Attribution of foodborne illnesses, hospitalizations, and deaths to food commodities by using outbreak data, United States, 1998–2008. *Emerg. Infect. Dis.* **19:** 407–415.
7. Mead, P.S., *et al.* 1999. Food-related illness and death in the United States. *Emerg. Infect. Dis.* **5:** 607–625.
8. World Health Organization. 2008. Melamine-contaminated powdered infant formula in China. Global Alert and Response (GAR). September 18, 2008. http://www.who.int/csr/don/2008˙09˙19/en/.
9. Gould, L.H., *et al.* 2013. Surveillance for foodborne disease outbreaks—United States, 1998–2008. *MMWR* **62:** 1–34.
10. Keller, M., *et al.* 2009. Use of unstructured event-based reports for global infectious disease surveillance. *Emerg. Infect. Dis.* **15:** 689–695.
11. Joint FAO/WHO Food Standards Programme. 2007. *CODEX Alimentarius Commission. Procedural Manual.* Rome: FAO/WHO.
12. Joint Institute for Food Safety and Nutrition. 2015. Risk Assessment Models. Accessed on February 17, 2015. http://foodrisk.org/ramodels/.
13. Stern, P.C. & H.V. Fineberg. 1996. *Understanding Risk: Informing Decisions in a Democratic Society*. P.C. Stern & H.V. Fineberg, Eds.: 1–264. Washington, DC: The National Academies Press.
14. Golan, E., T. Roberts, E. Salay, *et al.* 2004. Food safety innovation in the United States: evidence from the meat industry. U.S. Department of Agriculture (USDA) Economic Research Service (ERS). Agricultural Economic Report No. 831.
15. Buzby, J.C. & T. Roberts. 1996. ERS updates U.S. foodborne disease costs for seven pathogens. *Food Rev.* **19:** 20–25.
16. Scharff, R. 2008. Economic burden from health losses due to foodborne illness in U.S. *J. Food Prot.* **75:** 123–131.
17. Roberts, T., J.C. Buzby & M. Ollinger. 1996. Using benefit and cost information to evaluate a food safety regulation: HACCP for meat and poultry. *Am. J. Agric. Econ.* **78:** 1297–1301.
18. Malcolm, S., T. Roberts, C. Narrod & M. Ollinger. 2004. Evaluating the economic effectiveness of pathogen reduction technology in beef slaughter plants. *Agribusiness* **20:** 109–123.
19. Roberts, T. 2013. Lack of information is the root of U.S. foodborne illness risk. *Choices* **28:** 1–6.
20. Roberts, T. 2005. Economic incentives, public policies, and private strategies to control foodborne pathogens. *Choices* **20:** 95–122.
21. U.S. Department of Agriculture (USDA) Economic Research Service (ERS). 2014. Food price outlook. Accessed on October 1, 2014. http://www.ers.usda.gov/data-products/food-price-outlook.aspx.
22. Bahktavoryan, R., O. Capps, Jr. & V. Salin. 2014. Dynamics of consumer response to food contamination: the 2007 peanut butter recall. *J. Food Distrib. Res.* **44:** 66–81.
23. Bahktavoryan, R., O. Capps, Jr. & V. Salin. 2014. The impact of food safety incidents across brands: the case of the Peter Pan peanut butter recall. *J. Agric. Appl. Econ.* **46:** 559–573.
24. Bahktavoryan, R., O. Capps, Jr. & V. Salin. 2012. Impact of food contamination on brands: a demand systems estimation of peanut butter. *Agric. Resour. Econ. Rev.* **41:** 1–13.
25. Wansink, B. 2004. Consumer reactions to food safety crises. *Adv. Food Nutr. Res.* **48:** 103–150.
26. Pennington, J., K. Rao & D. Ball. 2009. Produce food safety in the marketing channel and the American consumer. Presented at the 64th Annual Conference of the American Association for Public Opinion Research, Hollywood, Florida, May 14–17, 2009.
27. Sperber, W.H. 2005a. HACCP and transparency. *Food Control* **16:** 505–509.
28. Sperber, W.H., K.E. Stevenson, D.T. Bernard, *et al.* 1998. The role of prerequisite programs in managing a HACCP system. *Dairy Food Environ. Sanit.* **18:** 418–423.
29. Sperber, W.H. 2005b. HACCP does not work from farm to table. *Food Control* **16:** 511–514.
30. Subcommittee on Microbiological Criteria, Committee on Food Protection, National Research Council. 1985. *An Evaluation of the Role of Microbiological Criteria for Foods and Food Ingredients.* Washington, DC: National Academies Press.
31. Boisrobert, C.E., A. Stjepanovic, S. Oh & H.L.M. Lelieveld. 2010. *Ensuring Global Food Safety: Exploring Global Harmonization.* C.E. Boisrobert, A. Stjepanovic, S. Oh & H.L.M. Lelieveld, Eds.: 1–452. London: Elsevier.
32. Johnson, R. 2014. The federal food safety system: a primer. Congressional Research Service. January 17, 2014. www.crs.gov.
33. Lando, A. & E. Carlton. 2011. 2010 Food safety survey: key findings and topline frequency report. U.S. Food and Drug Administration. September 2011. http://www.fda.gov/Food/FoodScienceResearch/ConsumerBehaviorResearch/ucm259074.htm.
34. Scheinberg, J., S. Doores & C.N. Cutter. 2013. A microbiological comparison of poultry products obtained from farmers' markets and supermarkets in Pennsylvania. *J. Food Saf.* **33:** 259–264.
35. Gustavsson, J., C. Cederberg, U. Sonesson, *et al.* 2011. Global food losses and food waste: extent, causes and prevention. Rome. Food and Agriculture Organization of the United Nations.
36. Centers for Disease Control and Prevention (CDC). 2014. *Surveillance for Foodborne Disease Outbreaks United States, 2012: Annual Report.* Atlanta: U.S. Department of Health and Human Services.
37. Centers for Disease Control and Prevention (CDC). 2014. *Surveillance for Foodborne Disease Outbreaks United States, 2011: Annual Report.* Atlanta: U.S. Department of Health and Human Services.

38. U.S. Food and Drug Administration. 2013. Outbreaks associated with fresh and fresh-cut produce. Incidence, growth, and survival of pathogens in fresh and fresh-cut produce. April 24, 2013. http://www.fda.gov/Food/FoodScienceResearch/SafePracticesforFoodProcesses/ucm091265.htm.
39. Palumbo, M.S., J.R. Gorny, D.E. Gombas, *et al.* 2007. Recommendations for handling fresh-cut leafy green salads by consumers and retail foodservice operators. *Food Prot. Trends* **27:** 892–898.
40. Sofos, J.N. 2008. Challenges to meat safety in the 21st century. *J. Meat Sci.* **78:** 3–13.
41. Norrung, B. & S. Buncic. 2008. Microbial safety of meat in the European Union. *J. Meat Sci.* **78:** 14–24.
42. National Restaurant Association. 2014. Consumer spending in restaurants 2014 reports.
43. Doyle, M.P., G.R. Acuff, D. Bernard, *et al.* 2004. Intervention strategies for the microbial safety of foods of animal origin. Council for Agricultural Science and Technology (CAST), Issue Paper No. **25:** 1–24.
44. Beuchat, L.R., E. Komitopoulou, H. Beckers, *et al.* 2013. Low-water activity foods: increased concern as vehicles of foodborne pathogens. *J. Food Prot.* **76:** 150–172.
45. Food and Agriculture Organization of the United Nations (FAO)/World Health Organization (WHO). 2014. Ranking of low-moisture foods in support of microbiological risk management. Draft preliminary report. Accessed on November 12, 2014. ftp://ftp.fao.org/codex/meetings/CCFH/CCFH46/LMF%20Part%201-3%2030Oct%202014.pdf.
46. Finn, S., O. Condell, P. McClure, *et al.* 2013. Mechanisms of survival, responses, and sources of *Salmonella* in low-moisture environments. *Front. Microbiol.* **4:** 331.
47. Russo, E.T., G. Biggerstaff, R.M. Hoekstra, *et al.* 2013. A recurrent, multistate outbreak of *Salmonella* serotype Agona infections associated with dry, unsweetened cereal consumption, United States, 2008. *J. Food Prot.* **76:** 227–230.
48. Werber, D., J. Dreesman, F. Feil, *et al.* 2005. International outbreak of *Salmonella* Oranienburg due to German chocolate. *BMC Infect. Dis.* **5:** 7.
49. Aviles, B., C. Klotz, T. Smith, *et al.* 2013. Survival of *Salmonella enterica* serotype Tennessee during simulated gastric passage is improved by low water activity and high fat content. *J. Food Prot.* **76:** 333–337.
50. Podolak, R., E. Enache, W. Stone, *et al.* 2010. Sources and risk factors for contamination, survival, persistence, and heat resistance of *Salmonella* in low-moisture foods. *J Food Prot.* **73:** 1919–1936.
51. Codex Committee on Food Hygiene. Joint FAO/WHO Food Standards Programme. 2014. Proposed draft hygienic code of practice for low-moisture foods. The 46th Session of the Codex Alimentarius Commission. Lima, Peru. November 17–21, 2014.
52. Byrd-Bredbenner, C., V. Wheatley, D. Schaffner, *et al.* 2007. Development of food safety psychosocial questionnaires for young adults. *J. Food Sci. Educ.* **6:** 30–37.
53. Byrd-Bredbenner, C., V. Wheatley, D. Schaffner, *et al.* 2007. Development and implementation of a food safety knowledge instrument. *J. Food Sci. Educ.* **6:** 46–55.
54. Byrd-Bredbenner, C., J. Maurer, V. Wheatley, *et al.* 2007. Food safety self-reported behaviors and cognitions of young adults: results of a national study. *J. Food Prot.* **70:** 1917–1926.
55. Byrd-Bredbenner, C., J. Maurer, V. Wheatley, *et al.* 2007. Observed food safety behaviors and skills of young adults. *Br. Food J.* **109:** 519–530.
56. Byrd-Bredbenner, C., J. Maurer, V. Wheatley, *et al.* 2007. Food safety hazards lurk in the kitchens of young adults. *J. Food Prot.* **70:** 991–996.
57. Abbot, J.M., P. Policastro, C. Bruhn, *et al.* 2012. Development and evaluation of a university campus-based food safety media campaign for young adults. *J. Food Prot.* **75:** 1117–1124.
58. Ajzen, I. 1991. The theory of planned behavior. *Organ. Behav. Hum. Decis. Process.* **50:** 179–211.