Title
Processed foods: contributions to nutrition 1 , 2 , 3

Journal
American Journal of Clinical Nutrition, 99(6)

ISSN
0002-9165

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Publication Date
2014-06-01

DOI
10.3945/ajcn.114.089284

Peer reviewed

SCIENTIFIC STATEMENT

Processed foods: contributions to nutrition[1,2]

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ABSTRACT

Both fresh and processed foods make up vital parts of the food supply. Processed food contributes to both food security (ensuring that sufficient food is available) and nutrition security (ensuring that food quality meets human nutrient needs). This ASN scientific statement focuses on one aspect of processed foods: their nutritional impacts. Specifically, this scientific statement *1*) provides an introduction to how processed foods contribute to the health of populations, *2*) analyzes the contribution of processed foods to "nutrients to encourage" and "constituents to limit" in the American diet as recommended by the *Dietary Guidelines for Americans*, *3*) identifies the responsibilities of various stakeholders in improving the American diet, and *4*) reviews emerging technologies and the research needed for a better understanding of the role of processed foods in a healthy diet. Analyses of the NHANES 2003–2008 show that processed foods provide both nutrients to encourage and constituents to limit as specified in the 2010 *Dietary Guidelines for Americans*. Of the nutrients to encourage, processed foods contributed 55% of dietary fiber, 48% of calcium, 43% of potassium, 34% of vitamin D, 64% of iron, 65% of folate, and 46% of vitamin B-12. Of the constituents to limit, processed foods contributed 57% of energy, 52% of saturated fat, 75% of added sugars, and 57% of sodium. Diets are more likely to meet food guidance recommendations if nutrient-dense foods, either processed or not, are selected. Nutrition and food science professionals, the food industry, and other stakeholders can help to improve the diets of Americans by providing a nutritious food supply that is safe, enjoyable, affordable, and sustainable by communicating effectively and accurately with each other and by working together to improve the overall knowledge of consumers.
Am J Clin Nutr 2014;99:1525–42.

INTRODUCTION

Food processing is the alteration of foods from the state in which they are harvested or raised to better preserve them and feed consumers (1). As the 2007 World Food Prize Laureate Philip E Nelson said, "If you teach a person how to process food, you can feed a village" (P Nelson, personal communication, 2013). Processing began in prehistoric times. As agriculture and animal husbandry spread, it was essential to preserve foods to avoid losses because of spoilage and to survive during times of scarcity. Food processing was probably the first "technology" that was sufficiently successful such that it led to a segregation of societies into discrete artisan industries. As such, food processing as an industry was likely the stepping stone to urbanization. A brief sketch of the timeline of the broad shifts in food preparation and processing is given in **Figure 1**.

[1] This statement was peer reviewed and approved by the Reviews, Papers, and Guidelines Committee of the American Society for Nutrition (ASN) and approved by ASN's Board of Directors. The statement did not undergo a separate editorial peer review by the editors of *The American Journal of Clinical Nutrition* (*AJCN*). ASN's journals feature a section called "From the American Society for Nutrition," which is devoted to content that originates from the Society rather than the journals. This statement is being published in this section because of its broad interest to the nutrition community and the need to widely disseminate the information contained in the statement. Correspondence about published ASN scientific statements should be addressed directly to ASN (info@nutrition.org) rather than to the *AJCN* Editor-in-Chief.

[2] Author disclosures: JC King, RS MacDonald, J Ordovas, and D Schnakenberg, no conflicts of interest. CM Weaver, serves as an unpaid board member for the International Life Sciences Institute of North America and serves on a scientific advisory board for Pharmavite and her university has received research grants from the Dairy Research Institute, Nestlé, and Tate & Lyle. J Dwyer, serves as an unpaid board member for the International Life Sciences Institute of North America; serves on scientific advisory boards for ConAgra Foods Inc, McCormick Inc, Bay State Milling, and Nestle; performed speaking engagements for Ocean Spray and the Alliance for Potato Research and Education; and owns stock in ConAgra Foods Inc, McCormick Inc, and Hershey. VL Fulgoni III, performs consulting and database analyses for various food and beverage companies and related entities. GA Leveille, serves on scientific advisory boards for Hillshire Brands and the McCormick Science Institute.

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First published online April 23, 2014; doi: 10.3945/ajcn.114.089284.

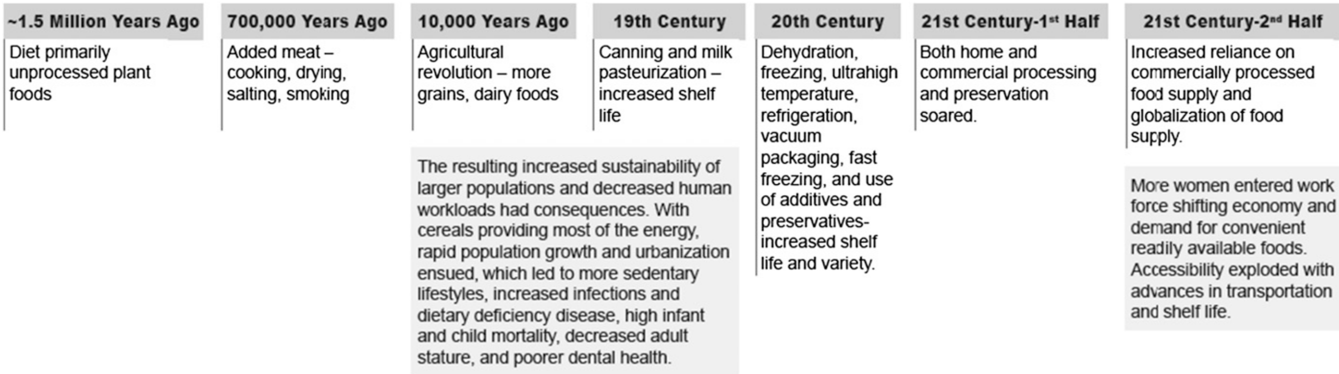

FIGURE 1. Evolution of food processing.

Until recently, much preservation and processing of food were done at home; only within the past 100 y has large-scale food processing become an industrial process. The basic steps involved in preservation and processing and their consequences on food quality, nourishment, and safety are largely the same, however, regardless of whether food is processed at home or commercially (**Figure 2**).

Processed foods contribute to the health of populations

Food security is increasingly challenged by land, water, and energy scarcity (2). The 2012 Global Hunger Index report claimed that "the progress in reducing the proportion of hungry people in the world has been tragically slow" (3). The report concluded that more food needs to be produced with fewer resources and that wasteful practices and policies should be eliminated. With >1 billion people worldwide considered to be food insecure, the need to use technology to efficiently produce an abundance of safe and affordable food was not disputed by 95% of survey respondents in the International Consumer Attitudes Study (4).

People live longer today than they ever have in human history. In the United States, life expectancy is at an all-time high, albeit lower than in many other industrialized countries, and racial and ethnic diversity is increasing. The shortfalls of Americans in meeting the nation's health objectives related to nutrition remain a matter of concern, however. For example, of the 20 objectives related to nutrition and overweight that could be measured in Healthy People 2010, the goal of only 2 objectives was met, exceeded, or moved in the right direction; for 3 objectives no change was shown; and for 15 objectives the outcome moved away from the target (5). Moreover, success in alleviating health disparities was poor, and little progress was made by race-ethnicity, sex, or education from a decade earlier. Obesity, sedentary lifestyles, and chronic, degenerative noncommunicable diseases are especially troubling health problems.

Trends in the health status of the world's population are similar to those in the United States. Global life expectancy at birth (a measure of the mortality pattern that prevails across all age groups in a given year) was 68 y in 2009, ranging from 57 y in low-income countries to 80 y in high-income countries (6, 7). Worldwide, the number of undernourished people has continued to increase, and the recent deterioration in economic conditions does not bode well for a change in that trend. Indeed, one-sixth of the human beings in the world are under- or malnourished. The impact of noncommunicable diseases, such as cardiovascular disease, diabetes, certain cancers, and chronic respiratory diseases, is growing. In fact, since 2006 the prevalence of overnutrition-related diseases has surpassed that of undernutrition, and obesity rates are growing rapidly. The challenge for food science and nutrition is to continue to make progress against poverty-related under- and malnutrition while acting to decrease risks of diet-related noncommunicable diseases and obesity. Success in meeting this challenge requires increasing nutritional security.

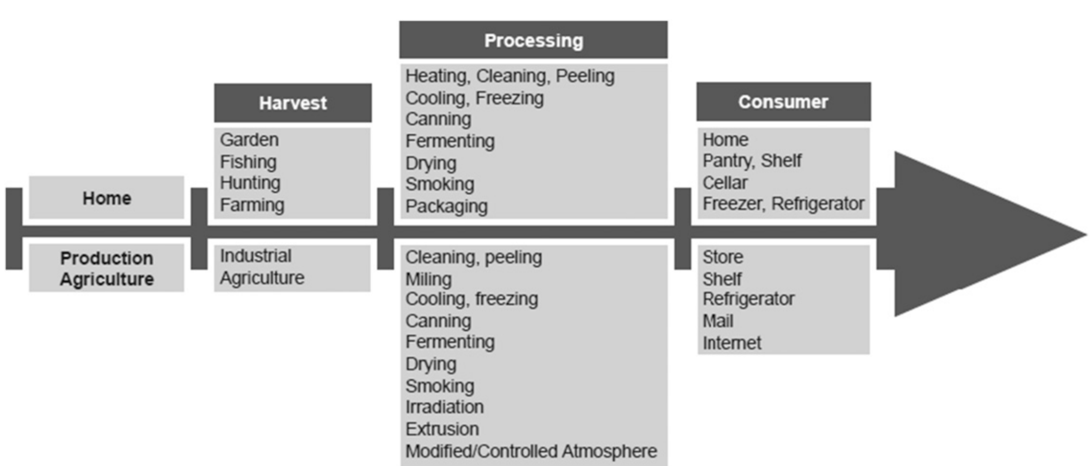

FIGURE 2. Processing of foods is similar whether at home or in the factory.

TABLE 1
Factors affecting the future food supply

Factor	Description
Population growth	The US population is expected to reach 352 million in 2025, up from 304 million in 2011. By 2050, the world population is expected to reach 10 billion, up from 7 billion in 2011.
Food insecurity	Environmental disasters, climate change, and the global recession have sorely tried the food security system. Food prices have risen in many countries, including the United States.
Globalization of the food supply	Today, the American food supply comes in part from other countries and travels long distances to reach consumers. This globalization poses transportation, storage, and food safety challenges that must be managed, especially for raw foods such as fruit and vegetables and seafood. Traditional methods used by regulators to ensure product safety have proven insufficient to deal with a global food supply with much food production and processing being done in remote parts of the world and imported into the United States (8–10).
Food-borne illness	Better surveillance and detection techniques in the United States and globally have increased the capacity to monitor the cause of food-borne illnesses such as *Campylobacter*, *Salmonella*, *Escherichia coli* O157, and others as well as *Listeria monocytogenes* (11).
Aging population and increased noncommunicable chronic degenerative diseases	As populations throughout the world live to older ages, the influence of diet-related chronic degenerative diseases also increases, and these changes have given rise to new dietary needs. The leading causes of preventable death worldwide include several conditions that are associated with diet, including hypertension, high cholesterol, malnutrition and poor diet, overweight and obesity, alcohol abuse, and physical inactivity (12). The links between these diseases and diet are complex, but it is clear that simply getting enough food is no longer the sole criterion for a "good" diet. Balance between different nutrients, moderation, and avoidance of excess are also important. The challenge confronting food and nutrition scientists today is how best to provide foods that fit well with human nutritional needs and promote health while preventing both the diseases of insufficiency and those of excess.
Economic recession	Economic growth has been slow in the United States for several years, increases in real income have been very modest for several decades, and food prices are increasing. These trends exert price pressures on consumers.
Women in the workforce and time constraints	As women spend more time outside the home, home food processing and food preparation have declined and Americans are eating out more (13).
Consumer demands	People buy foods for the benefits they provide, particularly taste, safety, quality, availability, convenience, price, healthfulness, and nutrition, and how the foods fit into personal and societal values such as sustainability and environmental concerns. People appear to care more about these benefits than about the technologies that were used to achieve them, but this issue needs further research. However, consumers need and want to understand why new processing approaches are needed if they are being used, why they are necessary, and what, if any, risks are involved.
Competition	The US food system has become increasingly competitive at the retail level, with the increased presence of nontraditional grocery retailers, including drugstores and supercenters, and the need for food marketers to develop unique product characteristics. These may include developing brands that incorporate such characteristics as corporate responsibility and highly tailored food product offerings (14).

The factors that affect the future food supply are outlined in **Table 1** (8–14). Although adequate food for all and global food security continue to be major goals worldwide, in recent years, global food production has outpaced population growth, such that there has been an increase in food energy available per person (15, 16). Distribution injustice remains a problem, however, and some still do not receive enough to eat (17, 18). In addition to economic, political, and social reform, more widespread use of methods to preserve, store, and distribute foods in developing countries can help to alleviate some problems of under- and malnutrition due poor food distribution (2, 19). Also, improvements in the capacity to process foods (eg, to safely preserve, store, and transport food) are needed to reduce food wastage and to better ensure an adequate food supply as the world's population grows (17, 20). Nutrition scientists, public health professionals, agricultural economists, food scientists, and other professionals dedicated to meeting the food and nutritional needs of people around the globe recognize that fresh, local foods cannot meet all nutritional requirements. Food processing is necessary (1). National and global goals for nutrition and health can only be accomplished by incorporating attention to food processing into social and economic reforms.

Although nutritional security (quality) and food security (quantity) both depend on food processing, in recent years there has been considerable public controversy over the nutritional contribution that processed foods make to the American diet. Consumer research by the International Food Information Council (IFIC)[11] shows that 43% of consumers are concerned about some aspects of processed foods (21). The many issues currently being debated include views on nutritional quality, freshness, safety, origin (locally grown compared with grown elsewhere), healthfulness, sustainability, techniques used for raising them (organic compared with nonorganic and genetically modified organisms), and perceived ethical aspects of production. This ASN scientific statement focuses on the role of processed foods in one area of these concerns only: the nutritional value of processed foods. Specifically, this scientific statement *1*) provides an introduction to how processed foods contribute to the health of populations, *2*) addresses the role of processed foods in providing "nutrients to encourage" (ie, dietary fiber, vitamin D, calcium, and potassium, and, for some, iron, folate, and vitamin B-12) and "constituents to limit" [ie, energy, sodium, added sugars, and saturated fat, as specified in the 2010 *Dietary Guidelines for Americans* (22)],

[11]Abbreviations used: HPP, high-pressure processing; IFIC, International Food Information Council; IR, ionizing radiation; PEF, pulsed electric field processing.

3) identifies the responsibilities of various stakeholders in improving the American diet, and 4) reviews emerging technologies and the research needed for a better understanding of the role of processed foods in a healthy diet.

Definitions of processed foods

Perhaps some of the confusion surrounding processed foods can be clarified by stating some simple operational definitions at the outset. To process food means to use a series of mechanical or chemical operations to change or preserve it. An Institute of Food Technologists scientific review (1) described processing as "one or more of a range of operations, including washing, grinding, mixing, cooling, storing, heating, freezing, filtering, fermenting, extracting, extruding, centrifuging, frying, drying, concentrating, pressurizing, irradiating, microwaving, and packaging." Many staples in the diet, such as bread, cheese, and wine, bear little or no resemblance to their starting commodities and are highly processed and prepared but are often not regarded as "processed" by consumers.

Efforts have been made to describe foods by distinguishing between different levels of processing, which has led to terms such as "unprocessed" or "minimally processed" foods, "processed culinary ingredients," "food industry ingredients," and "ultraprocessed foods" (23). Admittedly, all classification schemes are somewhat arbitrary, but a subjective definition based on extent of processing is value-laden and does not characterize foods in a helpful manner. Rather, a reproducible and useful scheme for assessing the role of processed foods in the diet is to define the characteristics of the food by use of objective, government-determined nutritional terms for dietary standards (eg, amount of fat, fiber, or sodium in comparison with dietary standards or some other criterion) or by criteria that address some specific attribute of the food, such as degree of convenience, resulting in prolonged shelf life, use of food additives, use of organically grown ingredients, or types of processing techniques used. After conducting focus groups with consumers, the IFIC developed a set of definitions for processed foods (**Table 2**; 24). Although further work is necessary to more fully define the nutritional and other characteristics of processed foods in the diet, the IFIC definitions provide one scheme for evaluating the nutritional contribution of processed foods to the US diet. The present statement is based on an analysis conducted by use of the IFIC definitions.

AN ANALYSIS OF THE ROLE OF PROCESSED FOODS IN THE AMERICAN DIET

A direct comparison of nutrient and nonnutrient constituents in processed compared with fresh foods would not be useful in an analysis of the role of processed foods in the American diet because of the wide range of composition of each. Instead, this committee evaluated the contribution of processed foods to the nutrients to encourage and the constituents to limit as recommended by the 2010 *Dietary Guidelines for Americans* (22). We examined intakes from energy and selected nutrients over the past ≥30 y in the 1976–1980, 1988–1994, and 2001–2008 NHANES (**Figure 3**). The analysis included persons aged ≥2 y with reliable records and excluded pregnant and lactating women. The numbers of subjects included were 19,170, 27,953, and 33,207 for the 1976–1980, 1988–1994, and 2001–2008 NHANES, respectively. All analyses were adjusted for the relevant complex sample design of each NHANES sample period. To assess changes over time, Z-tests were used to compare population means with a Bonferroni-corrected P value <0.0167 considered as significant. These data provide directional information about intakes in America, but the reader should keep in mind that considerable improvements in dietary assessment procedures and probably changes in the nutrient content of the food supply (especially fat amounts) have occurred over this time frame.

As shown in Figure 3, energy and sodium intakes have increased significantly since the 1970s but have remained rather constant since the 1980s to 1990s. In contrast, saturated fat, either as grams per day or as a percentage of calories declined significantly from the late 1970s through the 2000s. Whereas calcium increased significantly since the 1970s, potassium intake was more variable, with intakes increasing in the 1980s and then declining somewhat in the 2000s. The intake of added sugars (for which information was available for only the 2000s because of database limitations) declined somewhat in the past few years compared with earlier years.

Although numerous efforts have characterized the sources of nutrients in the diets of Americans (25–27), few have focused specifically on processed foods. One effort evaluated the contribution of fresh and processed fruit and vegetables to nutrient intakes in America by using data from NHANES 2003–2006 (28). As expected, consumption of all types of fruit and vegetables (fresh and "processed") provided large percentages of

TABLE 2
Categories of processed foods as proposed by the International Food Information Council[1]

Type of food	Examples
Foods that require processing or production (also called "minimally processed")	Washed and packaged fruit and vegetables; bagged salads; roasted and ground nuts and coffee beans
Foods processed to help preserve and enhance nutrients and freshness of foods at their peak	Canned tuna, beans, and tomatoes; frozen fruits and vegetables; puréed and jarred baby foods
Foods that combine ingredients such as sweeteners, spices, oils, flavors, colors, and preservatives to improve safety and taste and/or add visual appeal; does not include "ready-to-eat" foods listed below	Some packaged foods, such as instant potato mix, rice, cake mix, jarred tomato sauce, spice mixes, dressings and sauces, and gelatin
"Ready-to-eat" foods needing minimal or no preparation	Breakfast cereal, flavored oatmeal, crackers, jams and jellies, nut butters, ice cream, yogurt, garlic bread, granola bars, cookies, fruit chews, rotisserie chicken, luncheon meats, honey-baked ham, cheese spreads, fruit drinks, and carbonated beverages
Foods packaged to stay fresh and save time	Prepared deli foods and frozen meats, entrées, pot pies, and pizzas

[1] Reproduced with permission from reference 24 (www.foodinsight.org/understandingourfood.aspx).

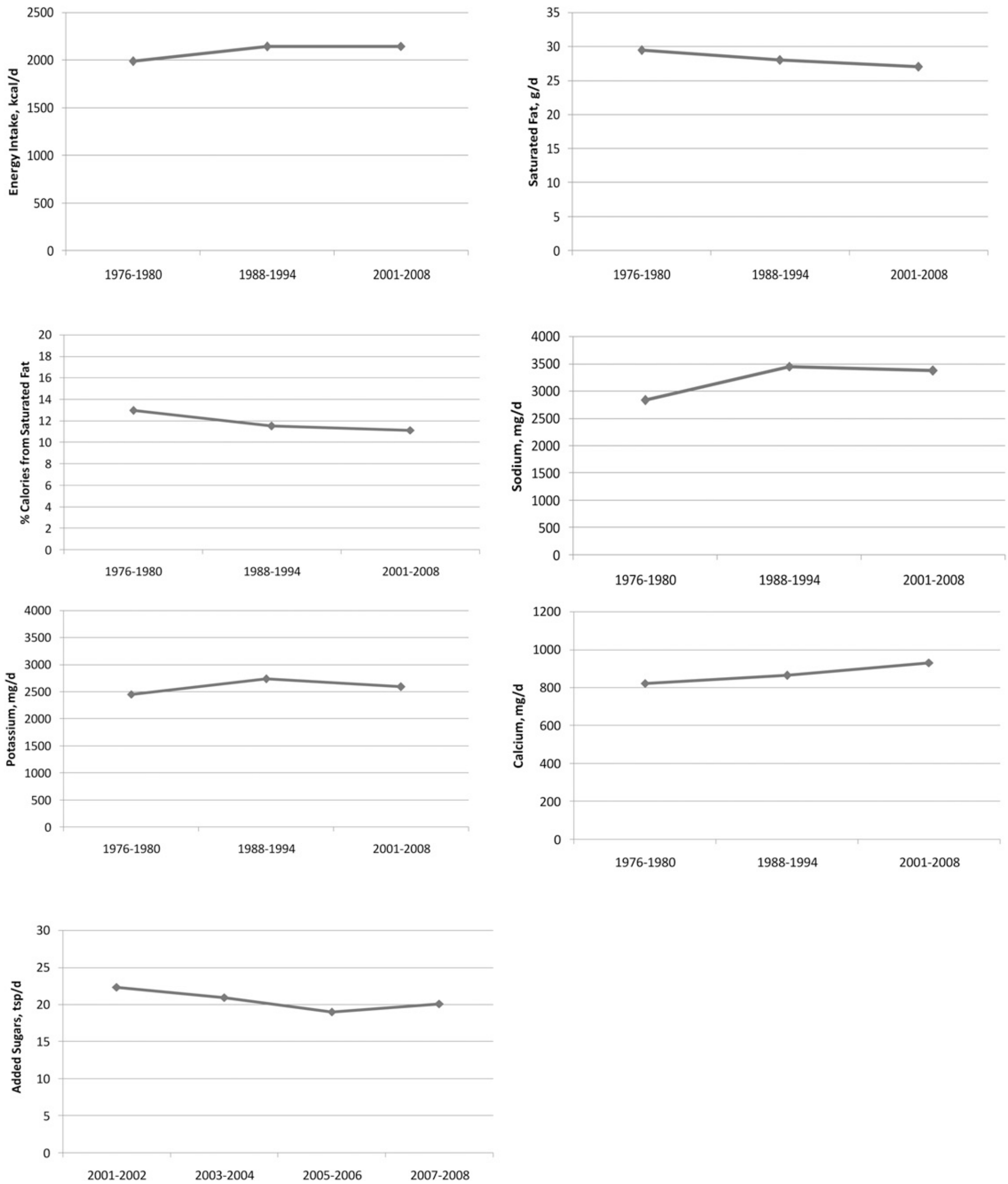

FIGURE 3. Intakes over time as reported in the 1976–1980, 1988–1994, and 2001–2008 NHANES.

dietary fiber (36%), vitamin A (24%), vitamin C (73%), vitamin E (20%), and potassium (31%) in the diet and <10% of calories (and sodium) and <2% of added sugars. Fruit and vegetables that were processed by being frozen, canned, or dried provided ∼33% of the dietary fiber, ∼50% of the vitamin C, ∼45% of the potassium, and approximately two-thirds of the sodium provided by all forms (including fresh) of these foods (∼220 mg/d) (**Figure 4**).

Another effort evaluated the contribution of processed foods in which nutrients were added by either enrichment or fortification to mean nutrient intakes in America (29). Those researchers defined "enrichment" as replacing nutrients lost in processing and "fortification" as adding nutrients at higher amounts than naturally occur in the food. Examples of enriched foods were grain products, especially breads, whereas examples of fortified foods included ready-to-eat cereals (fortified with B vitamins including folate, iron, and other nutrients) and milk (fortified with vitamins A and D). With the use of data from NHANES 2003–2006, these researchers reported the percentage of the population with nutrient intakes below recommended levels [estimated adequate requirement] and above the upper tolerable levels from foods assuming intake of only naturally occurring nutrients and then intake from foods with additional nutrients from enrichment and fortification. If enrichment and fortification were not present, large percentages of the population would have had inadequate intakes of vitamins A, vitamin C, vitamins D, vitamin E, thiamin, folate, calcium, magnesium, and iron. When nutrients from enrichment and fortification were included, the percentages of the population with inadequate intakes decreased substantially for vitamin A, vitamin D, folate, and iron.

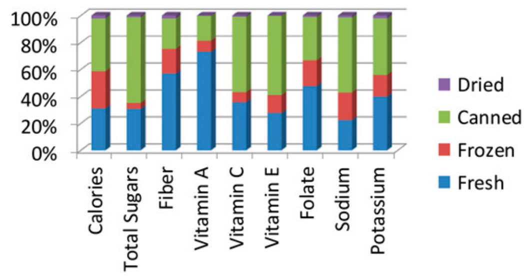

FIGURE 4. Contribution of fresh, frozen, canned, and dried fruit and vegetables to nutrient intakes from these foods in the US population (≥2 y of age) according to the NHANES 2003–2006. Adapted from reference 28.

A smaller reduction was noted for inadequate intakes of vitamin C, vitamin D, and vitamin B-6 (**Figures 5** and **6**). Clearly, this type of food processing, of adding nutrients to foods, has greatly benefitted nutrient intakes in the United States. In addition, the percentage of the population with intakes exceeding the upper level as a result of enrichment and fortification was minimal; only zinc was of possible concern. However, when distributions for individual subgroups were examined and total dietary intakes including dietary supplements were considered, some groups did exceed the upper levels for certain nutrients.

In another analysis of the contribution of processed foods to the nutrient intakes of Americans, data from NHANES 2003–2008 were combined (30), providing 25,351 subjects aged ≥2 y with reliable dietary records (10,298 children aged 2–18 y and 15,053 persons aged ≥19 y; pregnant or lactating females were not excluded). With the use of the IFIC definitions of processed food, every food code was placed into one and only one definition of processed foods. All foods that were obtained from "restaurants, schools, dining halls, or other eating establishments" were classified as a separate group. Details of the methods used are described elsewhere (30). For the purposes of this discussion, the data were combined for the 4 degrees of processing (foods processed for preservation, mixtures of combined ingredients, ready-to-eat processed foods, and prepared foods/meals). The calories and nutrients provided by the foods in each group (ie, minimally processed,

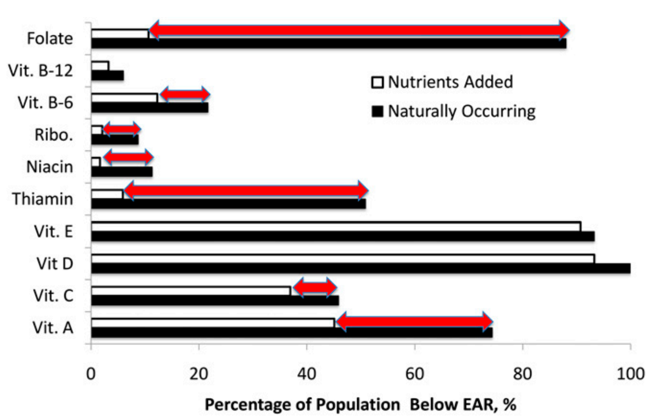

FIGURE 5. Impact of added nutrients from enrichment and fortification in the US population (≥2 y of age) on inadequate intake of certain vitamins according to the NHANES 2003–2006. The red arrows emphasize the gap. Adapted from reference 29. EAR, estimated average requirement; Ribo., riboflavin; Vit., vitamin.

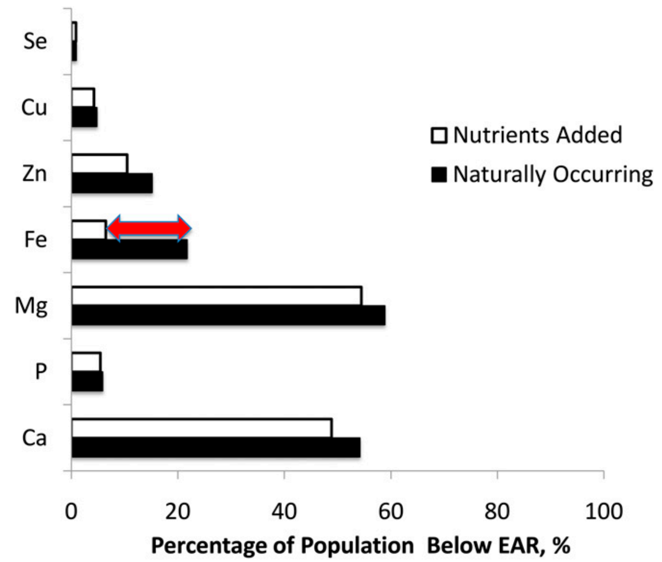

FIGURE 6. Impact of added nutrients from enrichment and fortification in the US population (≥2 y of age) on inadequate intake of certain minerals according to the NHANES 2003–2006. The red arrows emphasize the gap. Adapted from reference 29. EAR, estimated average requirement.

processed foods, and restaurants/dining halls) were summed by person and were then summarized across relevant populations.

Some key findings were as follows (**Figure 7**):

- There was considerable consistency across the age groups studied, namely >2 y, 2–18 y, and ≥19 y.
- "Minimally processed foods" accounted for only ∼300 kcal/d and provided considerable amounts (>20%) of dietary fiber, vitamin D, calcium, potassium, and vitamin B-12 to the American diet.
- "Processed foods" provided ∼1200 kcal/d and the majority of saturated fat, sodium, added sugars, dietary fiber, iron, and folate and considerable amounts (>20%) of vitamin D, calcium, potassium, and vitamin B-12 in the American diet.
- "Foods from restaurants/dining halls" provided ∼600 kcal/d and provided considerable amounts (>20%) of dietary fiber, calcium, potassium, vitamin B-12, folate, and iron to the American diet but also considerable saturated fat, added sugars, and sodium.

Another way to examine the contribution of processed food to the American diet is in the context of their energy contribution (**Figure 8**A–C). This approach allows assessment of the relative contribution of constituents to limit and nutrients to encourage expressed as a percentage of their energy contribution. Some key findings were as follows:

- "Minimally processed foods": compared with their contribution to energy (∼14%), these foods provided a higher percentage of dietary fiber, vitamin D, calcium, potassium, and vitamin B-12 to the diet. Compared with their calorie contribution, these foods also provided a lower percentage of sodium and added sugars to the diet.
- "Processed foods": compared with their contribution to energy (∼57%), these foods provided a higher percentage of sodium, added sugars, iron, and folate to the diet.
- "Foods from restaurants/dining halls": compared with their contribution to energy (∼29%), these foods provided a higher percentage of sodium and added sugars to the diet.

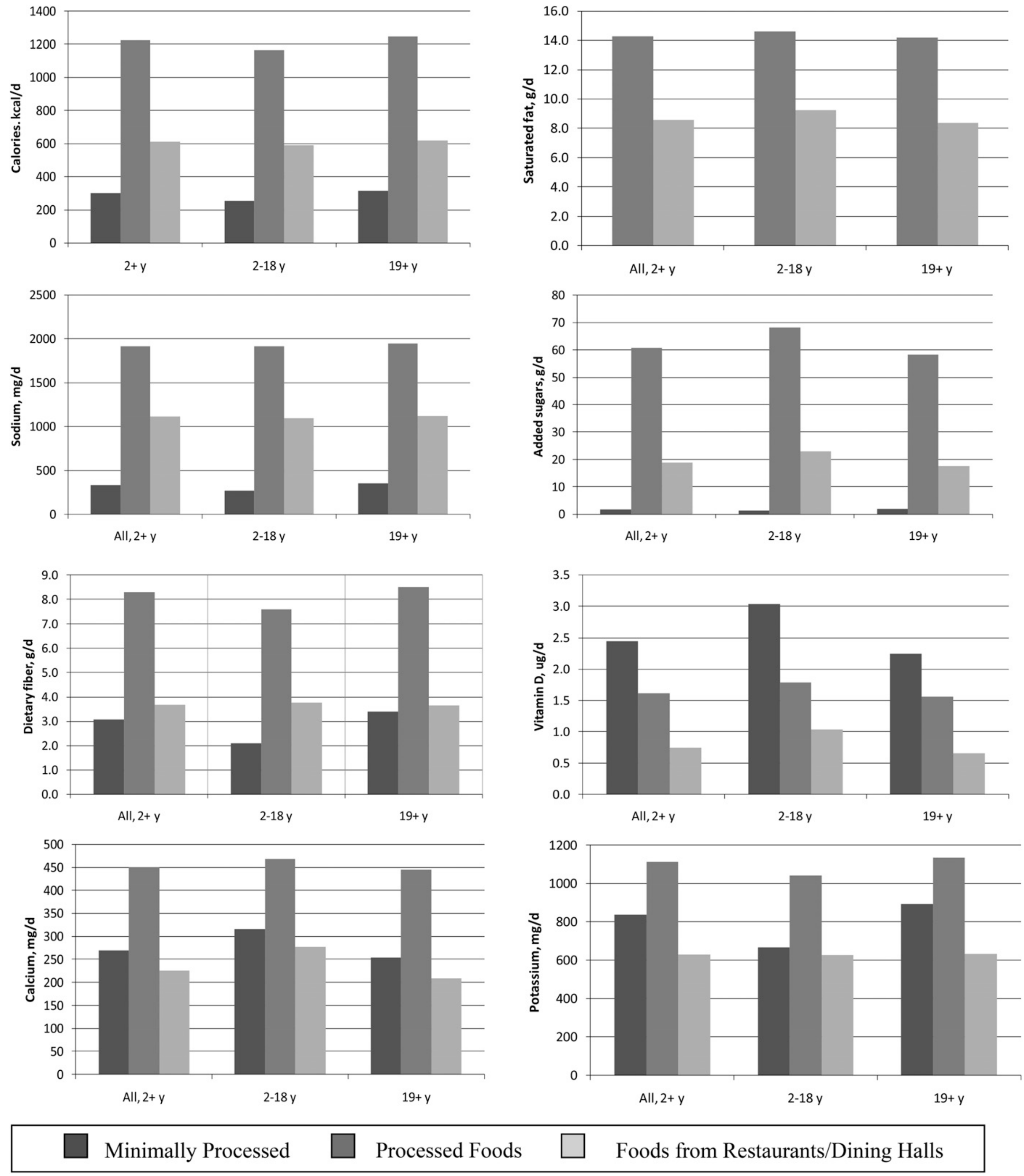

FIGURE 7. Amount of energy and selected nutrients contributed to the American diet from minimally processed food, processed foods, and foods from restaurants and dining halls. Source: NHANES 2003–2008, day 1, ages ≥2 y. Covariates with age group included energy (kcal), sex, race-ethnicity, and poverty-income ratio.

The data summarized in this section show that processed foods, at least as defined by using the IFIC definitions, make significant contributions to both constituents to limit and nutrients to encourage. Thus, processed foods are nutritionally important to American diets. How, then, do we enhance the contribution of processed food to nutritional security and food security? In the next 2 sections of this statement, we outline the actions we recommend to enhance the contribution of processed food to nutritional

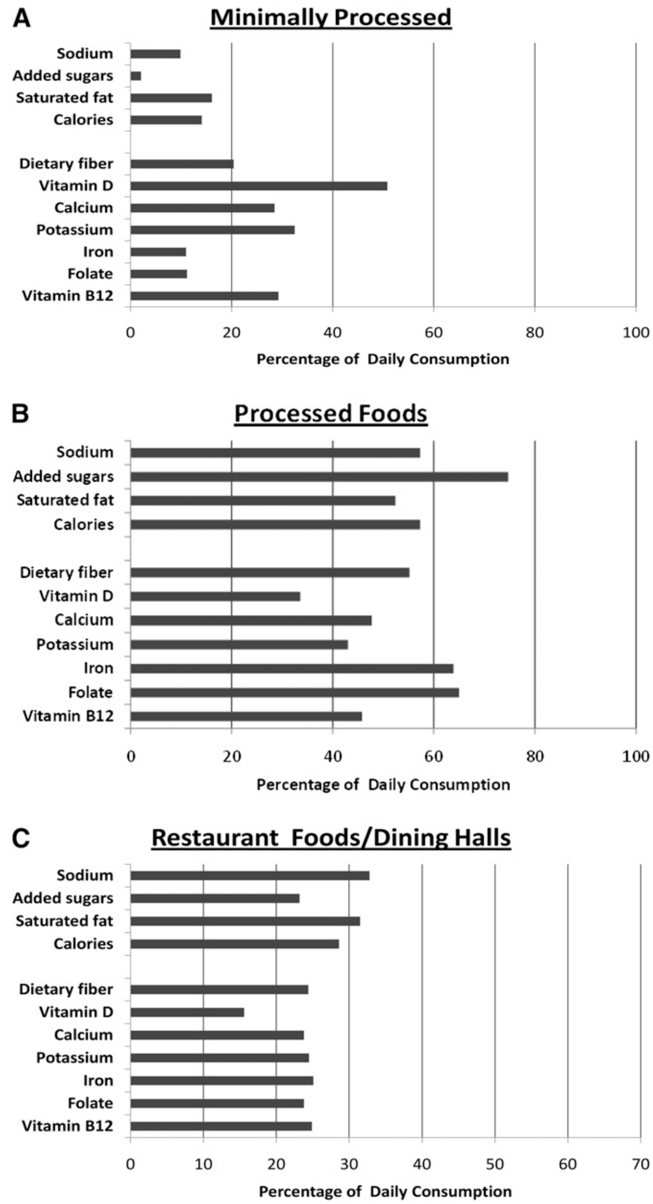

FIGURE 8. Contribution to the US diet of minimally processed foods (A), processed foods (B), and foods obtained from restaurants and dining halls (C). Source: NHANES, 2003–2008, day 1, ages ≥2 y. Covariates with age group included sex, race-ethnicity, and poverty-income ratio.

security and food security and the responsibilities of stakeholders in the food system for providing healthy processed foods.

ACTIONS NEEDED TO ENHANCE THE CONTRIBUTION OF PROCESSED FOOD TO NUTRITIONAL SECURITY AND FOOD SECURITY

Nutritional security ensures an adequate, balanced, varied, and wholesome diet. Food security, or having enough food and a secure, sustainable, and affordable food supply, is essential for all countries and individuals. As outlined in Table 1, factors such as population growth, food insecurity, and the globalization of the food supply will affect the demand for food in the United States and abroad and food security over the next 25–50 y. To enhance the contribution of processed foods in helping to address these challenges, several actions are described below.

Enhance nutritional benefits and decrease undesirable attributes of food processing

Many years ago, Bender (31) suggested some rules of thumb for producing nutritionally favorable processed foods, such as convenience in preparing a complete meal, ease in conforming to human needs, an emphasis on foods with nutrients that are likely to fall short in diets, and a de-emphasis on those with constituents that are in excess. Food processing techniques such as enrichment and fortification can add essential nutrients that might otherwise be in short supply and can alter food profiles to decrease components that may be overconsumed (32, 33). Some examples are iron-fortified infant cereals, the fortification of milk with vitamin D, the fortification of margarine with vitamin A, processed foods prepared with iodized salt (34), enrichment of cereals with B vitamins and iron, and the recent fortification of wheat flour with folic acid. Rather than limiting processed foods in the diet, it may be more productive to encourage the best available food options, namely, those that provide fewer constituents to limit and more nutrients to encourage for the calories consumed. Greater effort needs to be made to choose processed foods with lower amounts of saturated fats, sodium, and added sugars while still consuming nutrients to encourage (suggesting a need for a broader definition of nutrient density). Diets are more likely to meet food guidance recommendations if nutrient-dense foods, either processed or not, are selected.

Diminish perceived and real disadvantages of food processing

Unfamiliar processes

One disadvantage of commercial food processing techniques is that they are poorly understood. Commercial food processing involves techniques that are difficult for the general public to grasp and that are out of their control, thus introducing a lack of transparency and generating suspicion and concerns about safety in some individuals. The understanding of home canning and other food preservation processing has diminished as Americans' reliance on convenience food has grown. Even food preparation skills are diminishing (35). In addition, concerns about the nutritional content and other aspects of the production of processed foods, such as sustainability and cost, have led to criticisms of processed foods as "ultra-processed" and not compatible with good nutrition. However, the type and extent of processing do not necessarily correlate with the nutritional content of the product. For example, high-temperature, short-term pasteurization and ultrahigh temperature sterilization cause less loss of nutrients than do older methods such as pasteurization and sterilization (36).

Food safety

Another concern about food processing involves fears about food safety. In the 19th century, during the transition from farms and subsistence agriculture with home-processed food to urbanization and a commercially processed food supply that was ineffectively regulated, adulteration and other abuses in the manufacture of processed foods were common. Abuses led to a public outcry that drove the passage of the Pure Food and Drug

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Act of 1906 (37). Over the past century, food-borne illness crises have continued to erupt from time to time and their scope and distribution is often large because of today's highly concentrated food processing and distribution system. Thus, a single source of contaminated eggs or beef can lead to food-borne illness in hundreds or thousands rather than tens of consumers. Such problems have led to concerns about the adequacy of hazard identification and risk reduction and have prompted calls for more rigorous regulation to avoid safety risks (9). It is a constant and dynamic challenge to keep pace with the changing food supply and to continue to maintain a safe food supply. Appropriate processing and preparation techniques for foods and a strong regulatory program are 2 essential means of safeguarding health in the face of these safety challenges.

Some progress is being made on these fronts. In the recent Healthy People 2010 report on promoting health and preventing disease in the United States, of the 22 food safety objectives that could be measured, 16 met or exceeded the goal or moved in the right direction and only 6 moved in the wrong direction, away from the target.

Nutritional value

Many Americans are concerned about nutrition, but they may not know how to prepare foods to maintain their nutritional value. Some also have nutritional concerns about food processing that may lead to over- or undercooking of food at home. Processing techniques that involve milling; separating; exposures to air, light, heat, or radiation; changes in acidity or osmolality; or other techniques during freezing, drying, canning, or vacuum packing can and often do alter the content of nutrients and other nonessential bioactive food constituents. Comparisons between the nutrient content of unprocessed and processed products have been reviewed elsewhere (38, 39). Overall, there is no systematic reduction in nutrient content as the result of processing of vegetables, and losses during prolonged storage of fresh produce can be severe (39). For example, the blanching and freezing of peas decreases amounts of vitamin C and riboflavin but not of 9 other nutrients examined (**Figure 9**). The loss of nutritional value must be weighed against other benefits such as convenience. Minimizing nutritional losses should be a goal of processing that is strived for whenever possible.

Food processing can also lead to an increase in dietary components that may need to be limited, such as salt, sugars, and

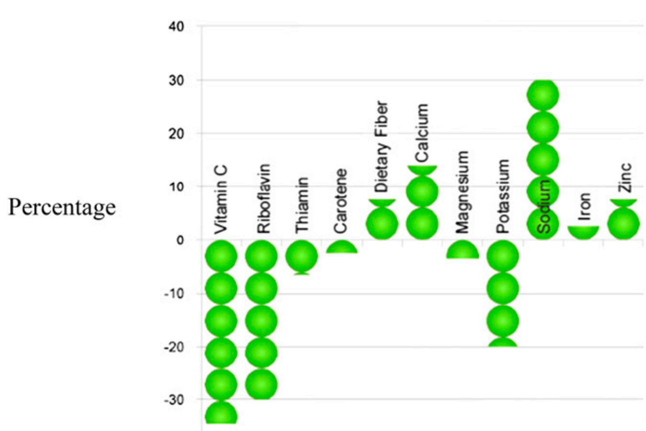

FIGURE 9. Effect of blanching and freezing on the nutrient content of peas.

saturated fats. When products that are high in the dietary constituents to limit make up the majority of foods in the marketplace, it is difficult for consumers to choose diets that meet nutritional profiles that are in line with health. This problem varies with geographic and economic demographic characteristics and is particularly acute for some subsets of the population. New approaches to processing must consider means for reformulating these foods to be lower in these constituents. Fortunately, the great advantage of processing is that techniques are available that can alter food products in a manner that is more in line with nutritional health profiles. Food scientists and nutrition scientists must work together to formulate and produce such products.

Cost

The actual cost of food is a subject on which a great deal of consumer ignorance exists. Relative to virtually all consumer product categories, food costs have increased the least over the past half century (40). Nevertheless, consumers remain highly sensitive to food prices, and price approaches taste as a top concern when purchasing foods and beverages (24, 41). Food prices in the United States increased rapidly and peaked in 2008, although the rate of growth has declined somewhat since then (42). Processing is often blamed for the bulk of the increase. Over the long term, it is true that farm commodity costs now account for less of the food dollar than they did several decades ago. However, it appears that the more dominant factors contributing to these increases today have been higher farm commodity (raw food) prices (because of higher input costs, demand for corn for ethanol, the low global food grain and oilseed supplies, a weak dollar, and rising incomes abroad) and higher energy costs, which increase transportation processing and retail costs (43). The amount of a typical food dollar that goes to various aspects of the food supply chain is shown in **Figure 10**; ~$0.19 goes to all forms of processing (44). This $0.19 might be better appreciated by highlighting within these costs those costs associated with food safety and nutrition.

Lack of fit with food preferences or other values

Some consumers have ethical or cultural beliefs or philosophical concerns about processed foods. They hold values or preferences that cause them to object to various aspects of processing (eg, food colors, food additives, bioengineered foods, irradiated foods, foods processed in unsustainable ways, or foods with high carbon footprints). These values are personal views that nutrition and food scientists must respect and, when possible, provide alternatives in the marketplace that cater to them. Better communication with consumers is needed to modify values and choices that are motivated more by perceptions of a food being unhealthy or perceptions of risk or lack of safety.

Enhance understanding of the role of food processing in meeting nutritional needs as well as societal and consumer wants

Nutrition scientists, food scientists, food manufacturers, and health professionals are having difficulty communicating among themselves and to consumers about the role of processed foods in nutrition and health. In part this is because of the different definitions used by these groups, the different perceptions of

FIGURE 10. Portion of the typical US food dollar contributed by various food supply chain industry groups in 2008. Adapted from reference 44.

these groups, and the difference in the training they have received. For example, an individual who desires a diet that is low in pesticides, hormones, and additives may describe it as one that does not contain "processed" foods, but a food scientist/technologist interprets this request as a desire to omit all foods that are heat-treated, frozen, or otherwise transformed during manufacture. Thus, the two will misunderstand each other and strive for different outcomes. A nutritionist is interested in processed foods from yet a third viewpoint, ie, the nutrient contribution to the diet. Nutrition professionals can play a role in assessing the contributions of processed foods to the intake of both nutrients to encourage and constituents to limit in American diets and in communicating these findings to colleagues and consumers. Food technologists need to work closely with nutrition scientists to design products that are safe, affordable, and replete with appropriate health and nutritional characteristics. A need also exists to communicate the role of food processing in meeting needs for food stability, desires for convenience, and the desires of consumers in specific market segments.

Stability

Napoleon Bonaparte declared that an army marches on its stomach. From the statement in 1778 by Benjamin Rush (45), Surgeon General of the Continental Army, that the "diet of soldiers should consist chiefly of vegetables" to the 2010 Department of Defense menu standards, pressures to serve military service men and women have influenced both advances in preservation of food and interest in nutrient requirements. The development of processed foods specifically designed to meet the needs of soldiers for rations that are shelf stable, convenient, palatable, portable, and nutritious has been a major challenge to the US Department of Defense for >2 centuries (**Table 3**). The need for processed food for the military has not been debated because such foods are necessary for the military to carry out its mission. This same goal has been carried to the US space program, which is now developing foods that can be carried on extensive missions to Mars (46).

Convenience

Even in traditional societies, prepared and packaged convenience foods are popular, although processing techniques may not be sufficient to prevent contamination (47). The scientific challenge is to enhance the healthful nutritional properties of these foods in all countries. Although the concept appears trivial, at its core the convenience of modern foods is the reason that a significant proportion of the population has been freed from the need to process raw commodities at home every day.

Tailoring to food preferences and special needs

Much room still exists for developing food products that cater to specific subgroups of consumers by market segments such as ethnicity, religious preferences, philosophical beliefs (eg, vegan, "organic," "whole food," etc), and medical needs (eg, gluten-free, lactose-free). Medical foods are key therapies for some disorders (10). Some individuals must rely exclusively on processed foods, such as persons receiving total parenteral nutrition or astronauts in space.

Research is needed to fully understand what consumers believe and desire. Definitions of "processed" as commonly used by consumers are much broader than the presence or absence of nutritional contributions. Consumer objections to processing are more complex and nuanced than are definitions based on attributes such as convenience and probably include concerns about risk, artificiality, sustainability, and others. It is important for more sophisticated research on these complex concepts to be carried out if ASN members and other scientists are to have more meaningful and productive dialogue on these concepts with consumers.

Health-related information

Numerous regulations exist in the United States to control and guide what can be said about food products. Regulations developed as part of the Nutrition Labeling and Education Act of 1990 by the Food and Drug Administration established mandatory nutrition labeling of food products and guide the use of nutrient content claims as well as many specific health messages. A summary of currently available claims has been published elsewhere (48). The Food and Drug Administration definition of "healthy" is operationally complicated and slightly different for different food products. Many food producers communicate that their products are part of a healthy diet or claim that they provide specific health benefits to inform the consumer through nutrient labels and front-of-package labeling (49).

TABLE 3
Contributions from military nutrition

Date	Individual or institution	Contributions
1778	Benjamin Rush, Surgeon General, Continental Army	"Diet of soldiers should consist chiefly of vegetables."
1800	Count Rumford	Developed "Rumford's Soup" as an inexpensive but nutritious ration to feed the Bavarian poor and European soldiers.
1810	Nicolas Appert, French chef	Developed a canning method to preserve food in glass jars for French armies on long forays. Napoleon awarded Appert a 12,000 franc prize for the development.
1810	Peter Durand, British inventor	Received patent from King George III for invention of cylindrical canister made of iron coated with tin.
1813	Bryan Donkin, John Hall	Set up first commercial canning factory and produced first canned goods for the British Army and Navy.
1846	Henry Evans	Invented a machine that could manufacture tin cans at a rate of 60 per hour.
1858	John Ordronaux, Army surgeon	Published "Hints on the Preservation of Health in the Armies," which provided the basis for the "Dietary Guidelines for Soldiers," which is similar to today's US Department of Health and Human Services/USDA *Dietary Guidelines for Americans*.
1864	Eben Horsford, professor	Proposed a light-weight, low-volume "marching ration" of roasted wheat or self-rising flour and dried and compressed sausage beef.
1866	J Osterhoudt	Patented the tin can with key opener.
1870	William Lyman	Patented the first easy-to-use household can opener with a wheel that rolls and cuts around the rim of the can.
1870	German Army	Developed *Erbwurst*, a combination of dried pea meal, fat, and bacon compressed into the form of a sausage and used during the Franco-Prussian War. When mixed with hot water, *Erbwurst* made a rich, savory, nourishing soup.
1895	Alonzo E Taylor, member, US Food Administration	Advocated substituting other cereal grains for wheat and the judicious use of mixed flours to make "victory bread" to conserve wheat under WWI conditions.
1919	Samuel C Prescott, food technologist, Army Surgeon General's Office	Developed improved dehydration methods and published "Dried Vegetables for Army Use."
1940	Paul Howe, Chief, Nutrition Division, Army Surgeon General's Office	Suggested to the NAS/NRC Food and Nutrition Board that all flour purchased by the military be enriched with B vitamins. As a result, enriched flour became available everywhere, for civilians as well as for the military.
1941	Ancel Keys, physiologist, University of Minnesota	As an advisor to the US War Department, designed a nonperishable lightweight individual combat ration that could fit in a soldier's pocket and which became widely known as the "K-ration."
1942–1945	Quartermaster Food and Container Institute of the US Armed Forces and the US Army's Medical Nutrition Laboratory, Chicago	Developed individual "D," "K," "C," Survival and Emergency combat rations and the "Ten-in-One" and "B" group rations, consisting of canned and dehydrated components.
1950s	US Department of Defense	Funded research to develop methods to use radiation to lengthen food storage time. In 1958 the FDA classified irradiation as a food additive; thus, irradiated foods had to be proven safe for human consumption. Although the FDA approved the irradiation treatment of some foods (eg, hamburger patties), consumer concerns have limited the availability of irradiated food products in the marketplace.
1950s–1960s	US Army Quartermaster Food and Container Institute	The Meal, Combat, Individual (MCI) replaced the "C" ration as the primary individual ration used by the military. The Long-Range Patrol (LRP) was the first flexible packaged ration to enter the military supply system. The LRP was based on a precooked freeze-dehydrated main dish that could be rehydrated or eaten dry.
1977–1978	David Schnakenberg, Nutritional Physiologist, Letterman Army Institute of Research	Conducted a "Nutritional Evaluation of a Fast Food System Afloat" aboard an aircraft carrier operating in the Mediterranean Sea at the request of the US Navy. Limited refrigerated storage space caused rapid exhaustion of fresh milk supplies and reconstituted nonfat dry milk consumption was very low, resulting in greatly reduced calcium and riboflavin intakes. Introduced UHT milk and the use of vitamin A–fortified milk shakes made from dry base and vitamin C–fortified extruded French fries and vitamin C–fortified dry beverage base. Still in use today, these changes to the Navy Afloat food service system improved nutrient intakes and consumer satisfaction.
1980s	US Army Natick Research and Development Center/US Marine Corps	Introduced a Food Packet Assault (FPA) to meet a US Marine Corps requirement for a lightweight ration with high nutrient content for individuals in nonresupply conditions on the basis of technological advances in freeze-drying and compression. A similar Arctic ration was developed for use in operations requiring heavy exertion under extreme cold conditions.
1980s	US Army Natick Research and Development Center	The Meal, Ready-To-Eat Individual (MRE) ration, packaged in a flexible retort pouch, was introduced as a replacement for the Meal, Combat, Individual "C" ration.

(Continued)

TABLE 3 (*Continued*)

Date	Individual or institution	Contributions
1980s	David Schnakenberg, US Army Research Institute of Environmental Medicine	During a 60-d long-term feeding trial, problems in inadequate nutrient consumption and excessive body weight loss were observed and recommendations were made and implemented to improve the MRE. More acceptable entrée items were substituted, and a new shelf-stable bread packet, individual bottles of mini Tabasco sauce (McIlhenny Company), and flavored carbohydrate electrolyte beverage powders were added.
1990s	US Army Natick Research and Development Center/US Army Research Institute of Environmental Medicine	Developed a Fielded Individual Ration Improvement Program (FIRIP) to improve the variety, acceptability, consumption, and nutritional intake of individual combat rations to enhance performance on the battlefield. A Flameless Ration Heater (FRH) has been included in most MREs since 1993. There are now 24 different menus, including 4 vegetarian menus.
2000s	US Army Natick Soldier RD&E Center/US Army Research Institute of Environmental Medicine	On the basis of recommendations of the NAS/NRC/IOM Committee on Military Nutrition Research, US military began to provide caffeine-delivery systems to maintain cognitive performance and physical endurance, particularly in situations of sleep deprivation. Currently, a caffeine-containing nutrient bar (HOOAH; D'Andrea Brothers LLC) and a caffeine supplement chewing gum "Stay Alert" (Stay with Marketright Inc) are being produced for the military. The development of a new First Strike Ration (FSR) was fielded in 2008 as a restricted-calorie ration for remote areas such as Afghanistan. The FSR takes advantage of major advancements in intermediate moisture foods, glucose optimization, and novel packaging designs.
2010s	US Army Natick Soldier RD&E Center/US Army Research Institute of Environmental Medicine	In development: • A Nutritionally Optimized First Strike Ration (NOFSR) for use under the first 72 h of intense combat; this will contain a balance of enhancements formulated to allow faster recovery of war fighters from physical and mental fatigue Food enhancers being studied: • Anti-inflammatory compounds (eg, quercetin, curcumin) to bolster immune function • Amino acid tyrosine to enhance decision making in extreme and stressful environmental conditions • Probiotics and prebiotics to improve gastrointestinal health • Omega-3 fatty acids to potentially improve cognitive performance, wound healing, and mood state, and to reduce combat symptoms • Bioactive compounds such as curcumin, resveratrol, flavonoids, isoflavones, flavanols, catechins, and theanine on the basis of recommendations contained in a 2011 report from the NAS/NRC/IOM Committee on Military Nutrition Research entitled "Nutrition and Traumatic Brain Injury—Improving Acute and Subacute Health Outcomes in Military Personnel"
2010s	US Air Force/Department of Defense	Initiated the Food Transformation Initiative at 6 US Air Force bases, a pilot program designed to improve the quality, variety, and availability of food operations and to increase the utilization of DFACs by airmen and their families. The First Lady Michelle Obama visited the Hercules Dining Facility at Little Rock Air Force Base on 9 February 2012 to observe the Food Transformation Initiative on base. She was accompanied by Johnathan Woodson, Assistant Secretary of Defense for Health Affairs, who announced the Military Health System's new obesity and nutrition awareness campaign. The campaign will include changes to bring more fruit, vegetables, whole grains, and entrée choices that are lower in fat to 1100 service member dining facilities in the coming months. Healthier foods will become more available in Department of Defense schools and other places where service members and their families purchase food on base, including vending machines and snack bars.
2010s	US Army/US Army Research Institute of Environmental Medicine/Aaron Crombi	The Army incorporated new Department of Defense menu standards into a Soldier Fueling Initiative announced by Mark Hertling in September 2010. The healthy foods offered will include whole-grain breads, cereals, and pasta. Crombi has recently conducted dining facility intervention studies at 10 Fort Bragg, NC, DFACs by using photography and visual estimation to assess food and nutrient intakes of male enlisted soldiers. The energy, fat, and refined grain intakes were significantly reduced while improving customer satisfaction indexes in 5 intervention DFACs compared with 5 control DFACs after 6 mo of intervention. Crombi's next project will test more aggressive interventions at the Camp Mackall DFAC at Fort Bragg.

[1] DFAC, Dining Facility Administration Center; FDA, Food and Drug Administration; IOM, Institute of Medicine; NAS, National Academy of Sciences; NRC, National Research Council; RD&E, Research Development & Engineering Center; UHT, ultrahigh temperature; WWI, World War I.

The Institute of Medicine's recent front-of-package labeling report (49) focused solely on constituents to limit and not on nutrients to encourage, leaving the manufacturer responsible for any messages related to the latter. Several efforts have been developed to help to identify nutrient-dense foods: for example, Guiding Stars (50, 51), NuVal (52), Smart Choices (53), and Nutrient Rich Foods (54, 55). None of these labeling programs rank foods on the basis of the level of food processing.

Another important step in the resolution of the disconnect with consumers is transparency. Labeling products with information about perceived risks, such as whether a product contains altered DNA (eg, that it is genetically modified), allows the consumer to make a choice, even if there is no scientific evidence that such a process affects nutrition adversely, is harmful to health, or otherwise adulterates the food product. Consumers are seeking guidance for choosing or avoiding various processed foods. Federal and state government materials provide objective assistance on dietary recommendations. Food selection guidance is also readily available in popular supermarkets such as Giant Foods, Stop and Shop, Hannaford, Whole Foods Market, Wal-Mart, Trader Joe's, and other chains, but it varies in the quality, timeliness, and validity of the information that is provided. Nutrition societies have a role in assisting governments in providing and translating evidence for dietary guidance.

RESPONSIBILITIES OF STAKEHOLDERS IN THE FOOD SYSTEM FOR PROVIDING HEALTHY PROCESSED FOODS

Ensuring that processed foods contribute to a healthy diet requires input from all segments of our food system (agriculture and food scientists, food industry, grocers, restaurants, food service, health care and public health professionals, the media, government, and consumers). Although the general responsibilities of health professionals in each segment differ, the combined, integrative contributions of all determine the composition, quality, accessibility, and safety of our food supply (**Table 4**). In general, agricultural scientists, food scientists, and the food industry should develop and maintain our food supply; grocers, restaurants, and other food services should ensure accessibility to safe, adequate foods; health professionals, along with the media, should provide responsible information; government officials should set standards, monitor, and educate the public; and public health and nutrition scientists should identify health problems stemming from insufficient access to quality food and assess the effect of changes in the food system on population health.

Although each component of our food system is essential for maintaining good nutrition and health, no mechanism is in place for coordinating changes in the system to meet the population's needs. Task forces involving a few components of the food system have worked together in the past. For example, the Food

TABLE 4
Responsibilities of our food system for positioning processed foods in the healthy diet

Food system component	Responsibilities
Agriculture and food scientists	Develop new agriculture procedures for enhancing food quality and evaluating food safety
	Invent new technologies for increasing accessibility to healthy processed foods
Food industry	Develop new technologies for food preservation and enhancing food quality
	Maintain food quality and safety standards
	Provide affordable, accessible, healthy processed foods
	Develop price structures for healthy foods to reduce food insecurity
	Develop and support effective labeling or branding of foods
	Educate the public in processing techniques
	Define and support food processing research
	Develop convenient, tasty alternatives for perishable foods
Grocers, restaurants, food services	Provide healthy, tasty, low-cost processed food menu alternatives
	Create labeling, branding, and marketing strategies to inform consumers
	Educate consumer palates for fresh-tasting processed food items
	Inform consumers about preparation techniques
Health care professionals	Communicate healthy uses of processed foods
	Incorporate healthy processed foods into counseling and educational tools
	Develop partnerships with the food industry to meet patient needs
The media	Create branding or images of processed foods in healthy meals
	Provide information on placing processed foods into a healthy diet pattern or meal
	Provide methods for food purchasing and preparation with the use of healthy processed foods
Government	Define the contribution of processed and nonprocessed foods in a healthy food pattern (eg, MyPlate)
	Show the cost-effectiveness and convenience of incorporating processed foods into the diet pattern
	Provide examples of using processed foods in diet patterns for subpopulations
	Provide funding for developing new food technologies and for testing the nutrition and health effects of foods and food products
Nutrition and public health scientists	Expand telecommunications technologies and social media to educate consumers regarding healthy processed food choices
	Monitor the impact of processed foods on the population's nutrition and health
	Investigate the impact of processed food consumption on biomarkers of health and disease
Consumers	Demand information on food processing and health
	Provide feedback to the food industry and scientists about the adequacy of our food system
	Encourage public and private partnerships to enhance the quality of our food supply and to reduce food waste

and Nutrition Task Force, created in 2007 and consisting of representatives from the Institute of Food Technologists, the IFIC, the Academy of Nutrition and Dietetics (formerly the American Dietetic Association), and the ASN identified several areas of common interest, such as the nutritional contribution of processed foods to the American diet. However, food growers, processors, and grocers were missing from the group along with food service facilities and the media. Representatives from governmental regulatory groups also were not included. Meeting future challenges to provide sufficient, affordable, quality food for our growing population worldwide requires integration of the efforts from all components of our food system. We believe that such a broad-based consortium on all components of the food system is essential to enable balanced, prompt responses to public concerns about the food supply, as has occurred over the past decade with regard to processed foods. None of the efforts of these stakeholders is a substitute for the need for educating our population on basic food skills and the fundamental relation between diet and health at home and at school.

EMERGING TECHNOLOGIES AND FUTURE ROLES OF PROCESSED FOODS

Food processing technologies hold substantial promise to promote the health and wellness of consumers. Looking to the future, a major focus will be on ways to use the technologies and knowledge obtained from years of research to address the chronic diseases facing the population. Combined with advances in clinical, genetic, and metabolic medicine, evolving food processing approaches will encourage and enhance healthy lifestyles. In this section we discuss some approaches that are already in development and speculate on futuristic advances. This information is summarized in **Table 5**.

Reduce calorie intake

Food processing approaches that address the obesity epidemic are critically needed. Overconsumption of calorie-dense foods is one contributor to obesity, typically combined with inadequate physical activity. Food scientists are exploring ways to address this imbalance by, for example, reducing calorie intake while retaining pleasurable food experiences, slowing digestion while enhancing nutrient bioavailability, improving the palatability and acceptability of high-nutrient-dense foods, and enhancing satiety. The main sources of calories in foods are carbohydrates and lipids. Modified starches that resist digestive activity (56, 57) are being developed. The goal of these products is to reduce the rate of starch digestion so that blood glucose concentrations are more evenly maintained, which leads to improved glycemic responses and prolonged satiety, thereby reducing risk of diabetes and cancer

TABLE 5
Examples of current and future food processing technology innovations and their benefits to consumers

Challenge	Innovative technology	Consumer benefits
Reduce calorie intake	Digestion-resistant starches • Changing starch structures in plants • Modifying starch chemistry Naturally derived noncaloric sweeteners Fat-reduction processes for food preparation	Reduce risk of obesity, diabetes, and related morbidities while maintaining diverse and enjoyable diet
Enhance gut health	Novel types of fiber such as water-soluble Development of prebiotics and probiotics and effective biodelivery systems	Optimize digestive tract performance and reduce risk of disease; resist allergens; enhance well-being
Reduce salt intake	Altered salt crystal structures such as microcrystallization Flavor enhancement approaches to replace salt	Provide flavor and food quality while reducing excessive salt intake
Enhance health benefits of foods	Stabilized omega-3 fatty acids and DHA enrichment of foods Targeted biodelivery with the use of nanotechnology of antioxidants and other bioactive compounds Natural colors and flavors derived from plants	Improved dietary quality with enhanced nutrients and bioactive compounds that enhance health and well-being and prevent disease
Improve food safety and reduce food waste	Smart packaging materials Temperature and oxygen sensors Natural antimicrobials Edible packaging	Better information about food handling and safety; means of readily identifying unsafe foods; reduced handling to avoid contamination; reduced landfill waste
Reduce allergy	Nanotechnology approaches to block antigenic agents Plant modifications to reduce antigen exposure	Prevention of allergic responses to foods to enhance quality of life
Promote fresh but stable foods	Nonthermal processing: high-pressure processing, ionizing radiation, pulsed electric field Advanced packaging techniques Improved plant varieties	Access to fresh, high-quality foods year-round at affordable prices to promote enhanced consumption and improve nutrition
Produce age-specific products	Optimize nutrients for • Infants • Children • Pregnancy • Athletes • Midlife • Older adults	Improve growth and development; enhance mental acuity; prevent or treat disease; improve fitness and well-being; prolong quality of life

(58). Several noncaloric, intense sweeteners, such as stevia, that can replace sugar have recently been developed and many others are being investigated (59). In addition, through the use of the advanced tools of nanotechnology and flavor chemistry, future products will have enhanced and nuanced flavors that reduce the need for caloric sweeteners. Reducing the amount of fat consumed while keeping the food enjoyable and fun to eat can be achieved by using novel techniques. For example, making fried potatoes without oil may be possible by using dynamic radiant frying, which uses a high-heat flux to provide the appearance, taste, and texture of fried food without using additional oil (60). This process provides the opportunity to reduce fat by as much as one-third. In addition, the process reduces energy input and eliminates oil waste and associated chemical contaminants, providing a healthier, safer product. Providing specific appetite-suppressing compounds in foods without altering flavor or texture is also being studied (61). Through the use of nanotechnology approaches, flavors and textures may be modified to alter sensory responses to foods, which could be applied to products designed to induce satiety.

Enhance gut health

A major growing consumer interest is in gut health. Characterizing the microbiome of the human gut is currently underway, and this information combined with food technology approaches could affect many aspects of health, including intestinal illness, inflammation, allergenic responses, and cancer (62). Providing the appropriate prebiotics (nondigestible compounds that maintain desirable microorganisms) and populating the intestine with health-promoting probiotics (beneficial bacteria) is an active area of research and product development that will require new process technologies.

Reduce salt intake

Salt in foods has important functional, sensory, and safety roles. However, concern exists that processed foods provide too much salt for consumers, which may be increasing risks of hypertension and possibly cardiovascular disease (63). Reducing salt in foods is being achieved by using innovative technologies and substitutes (64). For example, altering the structure of salt, which can be achieved during the drying process, allows greater salt taste with less salt. In addition, food scientists are developing herb and spice blends that produce the desired flavors and saltiness consumers expect in foods but with less salt.

Enhance health benefits of foods

Nutrition researchers have identified many beneficial bioactive compounds to promote health, reduce disease risk, and treat existing conditions. Providing the means to deliver these compounds effectively to the body through food will require novel approaches. For example, the ratio of omega-6 to omega-3 fatty acids in the Western diet is too high, but finding ways to add more omega-3 to foods has been challenging. Current sources of omega-3 fatty acids are primarily fish, which can convey undesirable flavors, and wild fish sources are both unsustainable and have potential for contamination with mercury. Algae grown in tanks are a renewable and controlled source of omega-3 oils. Omega-3 oils are highly susceptible to oxidation; therefore, new approaches to stabilize oils are being developed (65).

The advent of nanotechnology has allowed the production of microemulsions that capture nutrients or bioactive compounds to enhance their stability, retain their functionality, and define their absorption. Microemulsions may be designed to maintain the functionality of dietary components in a food matrix; in addition, these approaches provide opportunities to control when the dietary component is released (or not) during the digestive process, thereby allowing finely determined dose and exposures to dietary ingredients and nutrients (66). By using nanotechnology-based approaches, food-based multilayered membranes have been produced that are designed to selectively release nutrients along the digestive tract (67). Examples of this approach include microemulsions of phytonutrients that would be protected from degradation in a beverage but have high bioavailability once consumed. Several biotechnology companies are actively engaged in using nanotechnology tools to deliver compounds to the body that scavenge free radicals or affect specific cellular events associated with cancer. Encapsulating key nutrients or bioactive compounds has the potential to make them more bioavailable and functional when consumed. For example, carbohydrate nanoparticles are being used to assemble structures that can stabilize lipid compounds against oxidation and prevent degradation of the bioactivity of labile compounds (68).

Improve food safety and reduce food waste

The field of nanoscience is providing scientists the means to explore foods and their safety at a level of detail not previously possible. Nanotechnology tools are being developed to improve food packaging to resist penetration by oxygen and light, increase strength and durability, inactivate pathogens, and improve tracking of products. This technology has the potential to provide sensors and detection devices on packages that confirm freshness or alert the consumer to spoilage. These sensors may inform consumers if the product has been mishandled or exposed to heat or water. In addition, nanotechnology may allow consumers to be assured that the ingredients in the package are authentic and pure through DNA-based bar codes. Edible films, or nanolaminates, that are made from natural materials derived from polysaccharides and proteins (fruit purée, soy protein, egg albumin, starch, algae, or whey protein) and infused with compounds that have antimicrobial effects are being developed (69). These films may be applied to fresh fruit and vegetables to protect them from spoilage. An emerging research agenda is to identify natural antimicrobials that will convey the same level of pathogen reduction and shelf life that is currently achieved by using chemicals. Natural antimicrobials from plant oils, extracts, and spices, or from egg and milk, have been discovered that are effective in inhibiting the metabolic activity of bacteria, yeasts, and molds. Several are already in use, such as nisin and rosmarinic acid. Food processors are also actively developing combination approaches referred to as "hurdle technologies" that combine natural antimicrobials with light processing approaches that generate safe food with less overall processing (70). Overall, these tools will reduce food contamination, food-borne illness, and food waste, thus increasing the value and sustainability of the entire agricultural system.

Reduce allergy

Another health concern is the increasing incidence of allergic reactions to food components. Nanotechnology approaches are being developed that will block antigens in foods so that reactions are prevented (71). Food technologists are also working with plant geneticists to remove allergens directly from plants. Another approach to dealing with the increasing problem of autoimmunities in general is to create ingredients and food products that replace allergy-inducing ones, such as gluten and dairy for the subset of the population unable to consume traditional products including bread and milk.

Promote fresh but stable foods

Consumers are interested in fresh and less processed foods while also desiring convenient, low-cost, safe, and shelf-stable products. There is also increasing interest from consumers for foods free of synthetic or artificial colors and preservatives. New technologies are emerging that will allow these goals to be achieved. Examples of enabling technologies include ionizing radiation (IR), high-pressure processing (HPP), and pulsed electric field processing (PEF), which can in part replace traditional heat-based processing.

Processing of commodities and foods under high pressure to destroy pathogens and spoilage enzymes and to increase the health benefits of foods is becoming more common. A wide range of products are on the market that have been prepared by HPP, including guacamole, fresh oysters, ready-to-eat meats and prosciutto ham, salsa, and beverages (72). HPP controls pathogenic bacteria without the use of high heat, thereby preventing the cooked flavors associated with canning. During HHP the food matrix is exposed to pressures that destroy hydrophobic bonds and electrostatic interactions that cause denaturation of proteins. These effects of high pressure are desirable in making meat tender and in destroying the enzymes that promote spoilage of foods. HPP technologies are gaining in acceptance and use in the food industry, in part because they provide a means of processing foods to enhance quality and safety without adding chemicals (73). Novel uses of HPP are also being studied, including to process fruit and vegetables to retain their fresh flavor and appearance.

IR has been shown to be effective in destroying pathogens in food without subjecting the food to high temperatures. Spices are routinely irradiated. IR is safe for consumers and as applied to foods does not introduce or produce any dangerous contaminants. It is widely used in several regions of the world with high safety records. IR can be applied to bulk materials such as grains and fresh fruit and vegetables to eliminate pathogens. NASA has accepted irradiated foods for use in the space programs, and numerous IR products are produced for military food programs.

PEF uses short bursts of electricity to destroy pathogens in foods without heat, thereby preventing off flavors resulting from cooking the product. By applying an electrical current to the food, microorganisms are denatured and proteins are inactivated. This process is suitable for liquids and semiliquid foods and may be applied while the product is flowing. Applications for PEF in milk (74), liquid eggs (75), and juice (76) processing are being developed.

Produce age-specific products

At the interface of nutrition and medicine, current research is gaining an understanding of how dietary components influence growth and development and chronic disease across the life span. The future of food will include age-specific products that provide appropriate nutrients and bioactive compounds for each life stage. For example, substantial work has documented that DHA, an omega-3 fatty acid found in fish oils, is important during perinatal brain development. Concentrations of DHA during pregnancy and early life may influence life-long cognition. In addition, short-term DHA supplementation may improve attention and behavior in children (77) and delay age-related dementia in adults (78). These studies have led to the enrichment of infant formulas and baby foods, as well as adult products, with DHA. Future exploration of dietary components and the brain is underway as well, including the use of foods to promote cognitive performance (79) and delay age-related decline (80). Many other examples of age-targeted foods are in development that will lead to improved fitness and quality of life and that may protect consumers from chronic diseases such as osteoporosis, dementia, diabetes, and heart disease.

CONCLUSIONS

In this assessment of the nutritional impacts of processed foods, we conclude that processed foods are nutritionally important to American diets. They contribute to both food security (ensuring that sufficient food is available) and nutrition security (ensuring that food quality meets human nutrient needs).

Research has shown that processed foods provide both nutrients to encourage and constituents to limit as specified in the 2010 *Dietary Guidelines for Americans*. Therefore, although food processing has had positive impacts on human health, some of those successes have produced foods that, when consumed inappropriately or at inordinately high proportions of a total diet, are deleterious to health. Diets are more likely to meet food guidance recommendations if nutrient-dense foods, either processed or not, are selected.

This initial assessment of the role of processed foods in nutrition and health identified many topics for further research, including the need for more complete data collection and refinement of the diverse measures of processed foods, especially to compare foods eaten at home with those consumed away from home. Also, there is a priority to develop new technologies to preserve foods in a manner that increases their nutrient density and simultaneously decreases the constituents that have been identified as dietary components to limit. Finally, consumer definitions of processed foods need more research and education.

Nutrition and food science professionals, the food industry, and other stakeholders can help to improve the diets of Americans by providing a nutritious food supply that is safe, enjoyable, affordable, and sustainable; by communicating effectively and accurately with each other; and by working together to improve the overall knowledge of consumers.

The authors' responsibilities were as follows—All authors contributed to the writing, editing, and revision of the manuscript.

REFERENCES

1. Floros JD, Newsome R, Fisher W, Barbosa-Canovas GV, Chen H, Dunne P, German JB, Hall RL, Heldman DR, Karwe MV, et al. Feeding the world today and tomorrow: the importance of food science and technology. An IFT Scientific Review. Compr Rev Food Sci Food Saf 2010;9:572–99.

2. Conway C. One billion hungry: can we feed the world? Ithaca, NY: Cornell University Press, 2012.
3. Von Grebmer K, Ringler C, Rosegrant MW, Ologinbiyi T, Wiesman D, Fritschel H, Badiane O, Torero M, Yohannes Y, Thompson J, et al. 2012 Global Hunter Index. The challenge of hunger: ensuring sustainable food security under land, water and energy stress. Washington, DC: International Food Policy Research Institute, 2012.
4. Simmons J. Making safe, affordable and abundant food a global reality. Presented at: 19th World Meat Congress, June 4–6, 2010; Paris, France. Available from: http://www.meat-ims.org/wp-content/uploads/2012/06/Simmons-World-Meat-Congress-6June2012verF.pdf (cited 23 August 2013).
5. Polon RH, Stoody EE. Dietary guidelines for Americans, 2010: national nutrition policy. In: Rippe JM, ed. Lifestyle medicine. 2nd ed. Boca Raton, FL: CRC Press, 2013:131–47.
6. World Health Organization. Global Health Observatory. Life tables. Available from: http://www.who.int/gho/mortality_burden_disease/life_tables/life_tables/en/index.html (cited 27 August 2013).
7. World Health Organization. World Health Report. 50 Facts: global health situation and trends 1955-2025. Available from: http://www.who.int/whr/1998/media_centre/50facts/en/ (cited 28 August 2013).
8. US Food and Drug Administration. A special report: pathway to global product safety and quality. Washington, DC: Food and Drug Administration, 2011.
9. Olson ED. Protecting food safety: more needs to be done to keep pace with scientific advances and the changing food supply. Health Aff (Millwood) 2011;30:915–23.
10. Institute of Medicine. Ensuring safe foods and medical products through stronger regulatory systems abroad. Report brief. Washington, DC: The National Academies Press, 2012.
11. Economic Research Service, US Department of Agriculture. Food borne illness cost calculator 2011. Version current 26 May 2012. Available from: http://www.ers.usda.gov/topics/food-safety/foodborne-illness/background.aspx (cited 28 August 2013).
12. Lopez AD, Mathers CD, Ezzati M, Jamison DT, Murray CJ. Global and regional burden of disease and risk factors, 2001: systematic analysis of population health data. Lancet 2006;367:1747–57.
13. Stewart H, Blisard N, Jollife D. Let's eat out: Americans weigh taste, convenience and nutrition. Washington, DC: US Department of Agriculture, Economic Research Service, 2006. (Publication 19.)
14. Martinez S. The U.S. food marketing system: recent developments 1997-2006. Version current 27 May 2012. Washington, DC: US Department of Agriculture, Economic Research Service, 2007. Available from: http://www.ers.usda.gov/publications/ERR42/ (cited 28 August 2013).
15. Food and Agriculture Organization. 2010 Food balance sheets. Rome Statistics Division, Food and Agricultural Organization. Available from: http://faostat.fao.org/ (cited 28 August 2012).
16. Food and Agriculture Organization. The state of food and agriculture 2010-11. Women in agriculture: closing the gender gap for development. Rome, Italy: Food and Agricultural Organization, 2011. Available from: http://www.fao.org/docrep/013/i2050e/i2050e.pdf (cited 28 August 2013).
17. World Summit on Food Security. Feeding the world, eradicating hunger. Rome, Italy: Food and Agricultural Organization, 2009. (Publication WSFS 2990/INF/2.) Available from: http://www.fao.org/fileadmin/templates/wsfs/Summit/WSFS_Issues_papers/WSFS_Background_paper_Feeding_the_world.pdf (cited 28 August 2013).
18. Food and Agriculture Organization. The state of food insecurity in the world: economic growth is necessary but not sufficient to accelerate reduction of hunger and malnutrition. Rome, Italy: Food and Agricultural Organization, 2012.
19. Smil V. Feeding the world: a challenge for the 21st century. Cambridge, MA: MIT Press, 2001.
20. Food and Agriculture Organization. The state of food and agriculture 2000. Part II: world food and agriculture: lessons from the past 50 years. Rome, Italy: Economic and Social Development Department, Food and Agriculture Organization, 2000.
21. International Food Information Council Foundation. 2011 Food and health survey: consumer attitudes toward food safety, nutrition, and health. Washington, DC: International Food Information Council Foundation, 2012.
22. Dietary Guidelines Advisory Committee. Report of the Dietary Guidelines Advisory Committee on the Dietary Guidelines for Americans, 2010. Washington, DC: US Department of Agriculture, Agricultural Research Service, 2011.
23. Monteiro C. Nutrient 'profiling' and 'fortified' soft drinks for Africans. World Nutr 2011;2:8–21 (commentary).
24. International Food Information Council Foundation. Understanding our food communications tool kit: leaders guide. Available from: http://www.foodinsight.org/Default.aspx?tabid=1398 (cited 28 August 2013).
25. Cotton PA, Subar AF, Friday JE, Cook A. Dietary sources of nutrients among U.S. adults, 1994 to 1996. J Am Diet Assoc 2004;104:921–30.
26. National Cancer Institute. Usual dietary intakes: food intakes, US population, 2001-04. Version current 21 December 2010. Available from: http://riskfactor.cancer.gov/diet/usualintakes/pop (cited 28 August 2013).
27. Krebs-Smith SM, Guenther PM, Subar AF, Kirkpatrick SI, Dodd KW. Americans do not meet federal dietary recommendations. J Nutr 2010;140:1832–8.
28. Dwyer JT, Fulgoni VL III, Clemens RA, Schmidt DB, Freedman MR. Is 'processed' a four letter word? The role of processed foods in achieving dietary guidelines and nutrient recommendations. Adv Nutr 2012;3:536–48.
29. Fulgoni VL, Keast DR, Bailey RL, Dwyer JT. Foods, fortificants, and supplements: where do Americans get their nutrients? J Nutr 2011;141:1847–54.
30. Eicher-Miller HA, Fulgoni VL III, Keast DR. Contributions of processed foods to dietary intake in the US from 2003-2008: a report of the Food and Nutrition Science Solutions Joint Task Force of the Academy of Nutrition and Dietetics, American Society for Nutrition, Institute of Food Technologists, and International Food Information Council. J Nutr 2012;142(suppl):2065S–72S.
31. Bender AE. Food processing and nutrition. London, United Kingdom: Academic Press, 1978.
32. Andress EL, Nickols SY, Andress EL, Peek GG, Nickols-Richardson SM. Seeking food security: environmental factors influencing home food preservation and wellness. Part II:1960-2010. Fam Consum Sci Res J 2011;39:233–45.
33. Nickols SY, Andress EL, Peek GG, Nickols-Richardson SM. Seeking food security: environmental factors influencing home food preservation and wellness. Part 1: 1910-1959. Fam Consum Sci Res J 2010;39:122–36.
34. Ohlhorst SD, Slavin M, Bhid JM, Bugusu B, Bhalla S. Use of iodized salt in processed foods in select countries around the world and the role of food processors. Compr Rev Food Sci Food Saf 2012;11:233–84.
35. Lichtenstein AH, Ludwig DS. Bring back home economics education. JAMA 2010;303:1857–8.
36. Fellows PJ. Food processing technology: principles and practice. 3rd ed. Cambridge, United Kingdom: CRC Press and Woodhead Publishing Ltd, 2009.
37. Barkan ID. Industry invites regulation: the passage of the Pure Food and Drug Act of 1906. Am J Public Health 1985;75:18–26.
38. Kyureghian G, Stratton J, Bianchini A, Albrecht J. Nutritional comparison on frozen and non-frozen fruits and vegetables: literature review. Lincoln, NE: The Food Processing Center, University of Nebraska-Lincoln, 2010.
39. Miller S, Knudson B. Nutrition & costs comparisons of select canned, frozen and fresh fruits and vegetables. Ann Arbor, MI: Michigan State University, 2012. Available from: http://expeng.anr.msu.edu/uploads/files/44/TF-CMI-MSUknudsonedits.pdf (cited 28 August 2013).
40. US Department of Agriculture, Economic Research Service. Consumer price index (CPI) homepage. Available from: http://www.ers.usda.gov/topics/food-markets-prices/consumer-price-index-(cpi).aspx (cited 28 August 2013).
41. McCarty R. Economics and food choices: consumer response to food price inflation. Available from: http://www.beefissuesquarterly.com/economicsandfoodchoicesconsumerresponsetofoodpriceinflation.aspx (cited 28 August 2013).
42. US Department of Agriculture, Economic Research Service. Food and expenditures. Available from: http://www.ers.usda.gov/Briefing/CPIFoodAndExpenditures/Data/CPIForecasts.htm (cited 28 August 2013).
43. Capehart T, Richardson J. Food price inflation: causes and impacts. Washington, DC: Congressional Research Service, 2008. ([CRS Report for Congress No. RS22859.]).
44. Canning P. A Revised and Expanded Food Dollar Series: A Better Understanding of Our Food Costs. US Department of Agriculture, Economic Research Service, 2011. Economic Research Report ERR-114. Available from: http://www.ers.usda.gov/publications/err-economic-research-report/err114.aspx (cited 28 August 2013).
45. Rush B. Medical inquiries and observations upon the diseases of the mind. Philadelphia, PA: Grigg and Elliot, 1835:350–1.

46. Daneman M. Mars mission to be simulated to find best menus for trip. USA Today [online]. Version current 20 February 2012. Available from: http://www.usatoday.com/tech/science/space/story/2012-02-17/research-mars-food-hawaii/53160760/1 (cited 28 August 2013).
47. Unnevehr LJ. Food safety as a global public good: is there underinvestment? International Association of Agricultural Economists 2006 Annual Meeting; August 12–18, 2006; Queensland, Australia. Available from: http://purl.umn.edu/25733 (cited 28 August 2013).
48. Institute of Medicine. Examination of front-of-package nutrition rating systems and symbols: phase i report. Washington, DC: The National Academies Press, 2010.
49. Institute of Medicine. Front-of-package nutrition rating systems and symbols: promoting healthier choices. Washington, DC: The National Academies Press, 2011.
50. Fischer LM, Sutherland LA, Kaley LA, Fox TA, Hasler CM, Nobel J, Kantor MA, Blumberg J. Development and implementation of the Guiding Stars nutrition guidance program. Am J Health Promot 2011;26:e55–63.
51. Sutherland LA, Kaley LA, Fischer L. Guiding Stars: the effect of a nutrition navigation program on consumer purchases at the supermarket. Am J Clin Nutr 2010;91(suppl):1090S–4S.
52. Katz DL, Njike VY, Rhee LQ, Reingold A, Ayoob KT. Performance characteristics of NuVal and the Overall Nutritional Quality Index (ONQI). Am J Clin Nutr 2010;91(suppl):1102S–8S.
53. Lupton JR, Balentine DA, Black RM, Hildwine R, Ivens BJ, Kennedy ET, Packard PT, Sperber BR, Steffen D, Story M. The Smart Choices front-of-package nutrition labeling program: rationale and development of the nutrition criteria. Am J Clin Nutr 2010;91(suppl): 1078S–89S.
54. Fulgoni VL III, Keast DR, Drewnowski A. Development and validation of the Nutrient-Rich Foods Index: a tool to measure nutritional quality of foods. J Nutr 2009;139:1549–54.
55. Drewnowski A, Fulgoni V III. Comparing the nutrient rich foods index with “Go,” “Slow,” and “Whoa,” foods. J Am Diet Assoc 2011;111:280–4.
56. Zhao Y, Hasjim J, Li L, Jane JL, Hendrich S, Birt DF. Inhibition of azoxymethane-induced preneoplastic lesions in the rat colon by a cooked stearic acid complexed high-amylose cornstarch. J Agric Food Chem 2011;59:9700–8.
57. Zhang B, Huang Q, Luo FX, Fu X, Wang K, Jiang H, Jane JL. Effects of octenylsuccinylation on the structure and properties of high-amylose maize starch. Carbohydr Polym 2011;84:1276–81.
58. Diaz-Sotomayor M, Quezada-Calvillo R, Avery SE, Chacko SK, Yan L, Lin HM, Ao Z, Hamaker BR, Nichols B. Maltase-glucoamylase modulates gluconeogenesis; sucrase-isomaltase dominates starch digestion gluconeogenesis. J Pediatr Gastroenterol Nutr (Epub ahead of print 5 July 2013).
59. Foster RJ. Sweet tomorrows: new and emerging sweeteners [slide show online]. Food Product Design. March 2012. Available from: http://www.foodproductdesign.com/galleries/2012/03/slide-show-sweeteners.aspx?pg=4#gallery (cited 29 August 2013).
60. Lloyd BJ, Farkas BE, Keener KM. Quality comparison of French fry style potatoes produced by oven heating, immersion frying, and controlled dynamic radiant (CDR) heating. J Food Proc Preserv 2004;28:460–72.
61. Van Kleef E, Van Trijp JCM, Van Den Borne JJGC, Zondervan EC. Successful development of satiety enhancing food products: towards a multidisciplinary agenda of research challenges. Crit Rev Food Sci Nutr 2012;52:611–28.
62. Wallace TC, Guarner F, Madsen K, Cabana MD, Gibson G, Hentges E, Sanders ME. Human gut microbiota and its relationship to health and disease. Nutr Rev 2011;69:392–403.
63. Frisoli TM, Schmieder RE, Grodzicki T, Messerli FH. Salt and hypertension: is salt dietary reduction worth the effort? Am J Med 2012; 125:433–9.
64. Dötsch M, Busch J, Batenberg M, Liem G, Tareilus E, Mueller R, Meijer G. Strategies to reduce sodium consumption: a food industry perspective. Crit Rev Food Sci Nutr 2009;49:841–51.
65. Torres-Giner S, Martinez-Abad A, Ocio MJ, Lagaron JM. Stabilization of a nutraceutical omega-3 fatty acid by encapsulation in ultrathin electrosprayed zein prolamine. J Food Sci 2010;75:N69.
66. Parada J, Aguilera JM. Food microstructure affects the bioavailability of several nutrients. J Food Sci 2007;72:R21–32.
67. Gudipati V, Sandra S, McClements DJ, Decker EA. Oxidative stability and in vitro digestibility of fish oil-in-water emulsions containing multilayer membranes. J Agric Food Chem 2010;58:8093–9.
68. Bi L, Yang L, Bhunia AK, Yao Y. Carbohydrate nanoparticle-mediated colloidal assembly for prolonged efficacy of bacteriocin against food pathogen. Biotechnol Bioeng 2011;108:1529–36.
69. Valencia-Chamorro SA, Palou L, del Rio MA, Perez-Gago MB. Antimicrobial edible films and coatings for fresh and minimally processed fruits and vegetables: a review. Crit Rev Food Sci Nutr 2011;51:872–900.
70. Gómez PL, Welti-Chanes J, Alzamora SM. Hurdle technology in fruit processing. Annu Rev Food Sci Technol 2011;2:447–65.
71. Neethirajan S, Jayas DS. Nanotechnology for the food and bioprocessing industries. Food Bioprocess Technol 2011;4:39–47.
72. Balasubramanian VM, Farkas D, Turek EJ. Preserving food through high pressure processing. Food Technol 2008;62:32–8.
73. Jung S, Mahfuz A. Low temperature dry extrusion and high-pressure processing prior to enzyme-assisted aqueous extraction of full fat soybean flakes. Food Chem 2009;114:947–54.
74. Zhang S, Yang R, Zhao W, Hua X, Zhang W, Zhang Z. Influence of pulsed electric field treatments on the volatile compounds of milk in comparison with pasteurized processing. J Food Sci 2011;76:C127–32.
75. Marco-Molés R, Rojas-Graü MA, Hernando I, Pérez-Munuera I, Soliva-Fortuny R, Martín-Belloso O. Physical and structural changes in liquid whole egg treated with high-intensity pulsed electric fields. J Food Sci 2011;76:C257–64.
76. Zhang Y, Hou Y, Zhang Y, Chen J, Chen F, Liao X, Hu X. Reduction of diazinon and dimethoate in apple juice by pulsed electric field treatment. J Sci Food Agric 2012;92:743–50.
77. McNamara RK, Able J, Jandecek R, Rider T, Tso P, Eliassen JC, Alfieri D, Weber W, Jarvis K, DelBello MP, et al. Docosahexaenoic acid supplementation increases prefrontal cortex activation during sustained attention in healthy boys: a placebo-controlled, dose-ranging, functional magnetic resonance imaging study. Am J Clin Nutr 2010;91:1060–7.
78. Cole GM, Frautschy SA. DHA may prevent age-related dementia. J Nutr 2010;140:869–74.
79. Nurk E, Refsum H, Drevon CA, Tell GS, Nygaard HA, Engedal K, Smith AD. Intake of flavonoid-rich wine, tea and chocolate by elderly men and women is associated with better cognitive test performance. J Nutr 2009;139:120–7.
80. Joseph JA, Shukitt-Hale B, Willis LM. Grape juice, berries, and walnuts affect brain aging and behavior. J Nutr 2009;139(suppl):1813S–7S.