Feeding the World Today and Tomorrow—A Look into Our Future Food System[1]

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Scientific advances and technological developments over the last century have completely transformed our food system. Today, the food system is global, enormously complex, and extremely sophisticated, and a safe, nutritious, abundant, and sustainable food supply has been achieved successfully for healthier people everywhere. Nevertheless, projected increases in the human population, together with greater urbanization and an improved diet, indicate that current food production levels must be increased substantially and that processing methods must be improved significantly over the next few decades. In addition, our food system faces other serious challenges, including global environmental changes, air and water pollution, soil erosion and nutrient depletion, water shortages, energy availability and prices, limited food accessibility, malnutrition in some areas but overconsumption and obesity in others, a longer human life span and an aging population, food safety concerns, and threats from terrorism. This article briefly reviews such challenges and looks into the past, present, and future, when food scientists and technologists will have to work closely with animal and meat scientists, agronomists, horticulturists, molecular biologists, toxicologists, materials scientists, nanotechnologists, bioengineers, biophysicists, and many other experts in informatics, nutrigenomics, medicine, and the health sciences to improve the reliability, robustness, flexibility and responsiveness of the food system to make life better for everyone.

INTRODUCTION

In recent years, our modern food system has come under attack by people who may mean well but who may lack the scientific and technical knowledge, experience, foresight, or historical perspective to understand its complexity and importance. Numerous articles in the popular press, books, movies, TV series, and web blogs use compelling arguments, with some truths, some imagination, and seductively simplistic—sometimes even misleading—approaches to give advice. Mostly, they blame “industrial agriculture” and the “industrial food system” for many of the problems that afflict our society today (obesity, diabetes, cardiovascular diseases, allergies, foodborne pathogens, antibiotic resistance, energy shortages, environmental degradation, and climate change), and they ask people to change their food consumption patterns. From a scientific perspective, my belief is that although our modern food system is not perfect, it has served us well, and before we dispose of it, we had better design the new one very carefully, with creativity, innovation, knowledge, and the responsibility of making life better for present and future generations. As a scientist, I trust science and the progress and solutions it brings, but I also know that science alone will not solve all our problems (Floros, 2009).

In response to these issues, about 3 yr ago, the Institute of Food Technologists appointed a scientific task force to look into such concerns and produce a white paper. As a result, last year the Institute of Food Technologists published a comprehensive scientific review (Floros et al., 2010) that describes the scientific and technological achievements that made possible our modern production-to-consumption food system, a system capable of feeding almost 7 billion people today. The review also discusses the promising potential of ongoing technological advances that will continue to enhance the food supply in the future and increase the health and wellness of the growing global population. I used this comprehensive review extensively to prepare the present article, and readers that need additional information should consult the original paper (Floros et al., 2010).

The following few pages first provide a historical perspective of the development of food processing, agriculture, and modern food science and technology. Discussions of population growth, controversies surrounding processed foods, and food manufacturing then explain why food is processed, and I conclude that various food-processing methods can ensure food safety,

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preserve the quality of food products, and feed a growing population. Finally, a section on potential solutions to future challenges briefly discusses some ways by which scientists, members of the food industry, and policy makers are striving to improve our food supply for a better fed and healthier population in the future.

LESSONS FROM HISTORY

According to Harvard University biological anthropologist Richard Wrangham, food processing was launched approximately 2 million years ago by a distant ancestor who discovered cooking, the original form of food processing (Wrangham, 2009). Later, but still during prehistoric times, cooking was augmented by fermenting, drying, preserving with salt, and other primitive forms of food processing, which allowed groups and communities to form and survive. Humans thus first learned how to cook food, and then how to transform, preserve, and store it safely. This experience-based technology eventually led to modern food processing (Hall, 1989; Floros, 2008).

In July 2009, an important discovery added further evidence that food security was of paramount importance even during prehistoric times. Kuijt and Finlayson (2009) reported their discovery of several granaries in Jordan dating back to about 11,000 years ago. This suggests that populations knew the importance of food processing and of having a dependable food supply before the domestication of plants and the beginning of agriculture.

Much later, the domestication of plants and land cultivation became widespread, and at the end of the last Ice Age, humans revolutionized meat eating by domesticating animals for food. Thus, plant and animal agriculture also contributed to improving the human condition (Floros et al., 2010). Studies of every ancient civilization clearly show that throughout history, humans overcame hunger and disease not only by harvesting food from a cultivated land, but also by processing it with sophisticated methods. For example, the 3 most important foods in Ancient Greece—bread, olive oil, and wine—were all products of complicated processing that transformed perishable, unpalatable, or hardly edible raw materials into safe, flavorful, nutritious, stable, and enjoyable foods (Floros, 2004).

Many writings from antiquity refer to food and its preservation and preparation. Major advances in food preservation accelerated with the development of canning, which resulted from the investigations of Nicolas Appert in France and the subsequent activities of Peter Durand in England in the early 19th century. Appert used corked glass bottles to preserve food, and Durand introduced the concept of metal cans. This led to increased scientific emphasis on the quantity and quality of food, and to the beginning of contemporary food science and technology. However, the reason for the effectiveness of canning as a food preservation method was not discovered until almost 50 yr later, when Louis Pasteur reported to the French Academy of Sciences in 1864 on the lethal effect of heat on microorganisms. Later, in 1895 to 1896, several researchers in US universities proved the need for both time and temperature control (Labuza and Sloan, 1981).

No time period has seen such rapid advances in food processing as the 20th century (Welch and Mitchell, 2000). Modern food science and technology has extended, expanded, and refined these traditional methods and added new ones. Simple cooking, although still the most common process, evolved into canning. Dehydration, once restricted to less sanitary sun drying, is now usually a highly mechanized and sanitized process. Refrigeration has evolved from simple cool storage to sophisticated refrigerators and freezers, and to the industrial techniques of blast freezing and individual quick freezing that are less detrimental to nutritional and sensory quality. All these developments, and many others, contributed to an increased nutritional quality, safety, variety, acceptability, and availability of foods and beverages (Floros et al., 2010). Many of these techniques are now combined into more effective preservation technologies through the concept of "hurdle technology," which combines techniques to create conditions that bacteria cannot overcome, such as using drying with chemical preservatives and packaging, or mild heat treatment followed by packaging and refrigerated storage (Leistner and Gould, 2002).

THE CHALLENGE OF A GROWING POPULATION

As a result of better agricultural and food-processing methods, improved public health measures, and advances in modern medicine, the population mushroomed from an estimated 1 to 10 million in 10,000 BC to an estimated 600 to 900 million in 1750 AD, and to an estimated 7.0 billion today. Some have authors predicted that over time, population growth will inevitably outpace resource production, and that misery (hunger and starvation) will therefore endure. Undoubtedly, the application of science and technology in agriculture and food manufacturing has negated these predictions and fed the population growth (Floros et al., 2010).

Recently, during the 2009 World Summit on Food Security, it was recognized that by 2050, food production must increase by approximately 70% to feed the anticipated 9 billion people (FAO, 2009). This projected population increase is expected to involve an additional annual consumption of almost 1 billion metric tons of cereals for food and feed and 200 million metric tons of meat.

Another challenge is the large and growing food security gap in many places around the world. As much as one-half of the food grown and harvested in underdeveloped and developing countries never gets consumed, partly because proper handling, processing, packaging, and distribution methods are lacking. Starvation and nutritional deficiencies in vitamins, minerals, protein, and calories are still prevalent in all regions of the world, including the United States. As a consequence, science-based improvements in agricultural production, food science and technology, and food distribution systems are critically important to decreasing this gap (Floros et al., 2010).

In addition, energy and resource conservation are becoming increasingly critical. To provide sufficient food for everyone in a sustainable and environmentally responsible manner, without compromising our precious natural resources, agricultural production must increase significantly from today's levels, and food manufacturing systems must become more efficient, use less energy, generate less waste, and produce more food with an extended shelf life.

Although scientific and technological achievements in the 20th century made it possible to solve nutritional deficiencies, address food safety and quality, and feed almost 7 billion people, further advances are needed to resolve the challenges of sustainably feeding the growing future population in industrialized and developing nations alike. In fact, to meet the food needs of the future, it is critically important that scientific and technological advances be accelerated and applied in both the agricultural and food manufacturing sectors (Smith et al., 2008).

CONTROVERSIES ABOUT PROCESSED FOODS

Today, the public generally embraces and enjoys key benefits of the modern food supply: value, consistency, safety, quality, abundance, and convenience. Nevertheless, some suggest that the cost to society of obtaining these benefits is too high. Negative perceptions about processed foods also exist, especially among consumers in the United States. A range of factors contribute to these perceptions, including uneasiness with technology, low levels of science literacy, labeling and advertising that have at times taken advantage of food additive or ingredient controversies, influences on perceptions of the voluntary (compared with involuntary) nature of risk, and high levels of food availability (Slovic, 1987; Clydesdale, 1989; Hall, 1989).

Other factors contributing to negative public perceptions about processed foods include the increasing prevalence of obesity in many industrialized or developed countries, the use of chemicals in production or additives in foods, limited personal contact between consumers and the agricultural and food manufacturing sectors, food safety issues, and concern that specific ingredients (particularly salt) may contribute to illnesses or affect childhood development (Schmidt, 2009).

For example, journalist Michael Pollan recently declared in his latest book, *In Defense of Food*, that food has been replaced by nutrients and common sense by confusion. In numerous places in the book he claims that we eat edible food-like substances, which are intricate products of food science (see the book's cover, page 1, 32, 147). He then advises everyone to eat like their great grandmothers did, choosing real, well-grown, unprocessed foods. Unfortunately, this notion, which lacks a scientific and historical perspective, is increasingly appealing to consumers. The misguided belief that raw foods are "natural" and therefore good, whereas processing diminishes nutritional value and is therefore bad is not only a simplistic misperception, but also a dangerous one. Consider, for example, that cassava, the third largest source of carbohydrates for human food and the largest source in the most impoverished regions of the world (Africa), is poisonous unless processed properly (Floros, 2009).

Today, our production-to-consumption food system is complex, but our food is largely safe, tasty, nutritious, abundant, diverse, convenient, and less costly and more readily accessible than ever before. This complex food system includes agricultural production and harvesting, holding and storing of raw materials, food manufacturing (formulation, processing, and packaging), transportation and distribution, retailing, food service, and food preparation in the home. Contemporary food science and technology contributed greatly to the success of this modern food system by integrating biology, chemistry, physics, engineering, materials science, microbiology, nutrition, toxicology, biotechnology, genomics, computer science, and many other disciplines to solve difficult problems, such as resolving nutritional deficiencies and enhancing food safety (Floros et al., 2010).

The impact of modern food manufacturing methods is evident in today's food supply. Food quality can be maintained or even improved, and food safety can be enhanced. Sensitive nutrients can be preserved, important vitamins and minerals can be added, toxins and antinutrients (substances such as phytate that limit the bioavailability of nutrients) can be removed, and foods can be designed to optimize health and reduce the risk of disease. Waste and product loss can be minimized, and distribution around the world can be facilitated to allow seasonal availability of many foods. Modern food manufacturing also often improves the quality of life for individuals with specific health conditions by offering modified foods to meet their needs (for example, sugar-free foods sweetened with alternative sweeteners for people with diabetes; Floros et al., 2010).

PRESERVING THE FOOD SUPPLY AND THE EVOLUTION OF PROCESSING

Postharvest losses occur between harvest and consumption as a result of spoilage of raw agricultural commodities, primarily during storage and transportation, before they can be consumed or stabilized for longer term storage. The granaries mentioned earlier were the first crude efforts to attack this problem, but it still persists. Postharvest losses caused by rodents, insects, and microbial spoilage in some areas amount to 50% or more of the harvested crop. This results in wasted seed, water, fertilizer, energy, and labor. Postharvest losses must be attacked with appropriate improvements in locally available technology (Floros et al., 2010). It is not enough merely to increase the supply of raw food; it must also be conserved against further loss by processing, and must be packaged, distributed to where it is needed, and guaranteed in its safety, nutritional value, and cultural relevance. That is the role of science, technology, and engineering applied to the processing of foods and beverages.

A widely accepted definition of food processing does not exist, and perceptions of processed foods vary widely. From the broadest perspective, food processing may be considered to include any deliberate change in a food occurring between its point of origin and its consumption. The change could be as simple as rinsing and packaging by a food manufacturer to ensure that the food is not damaged before consumption, or as complex as formulating the product with specific additives for controlling microorganisms, maintaining desired quality attributes, or providing a specific health benefit, followed by packaging that may itself play a role in microbial control or quality preservation. Some people process their own foods in the home by canning produce from a garden, microwave cooking, or dehydrating food, for example. Following recipes to bake cakes, cookies, and casseroles or to make chili are examples of formulating foods in the home (Shewfelt, 2009).

In general, food processing has evolved from merely a need to preserve foods from the time and location of harvest or assembly until the product reaches the consumer, to possibly complex activities that may include sourcing raw materials and ingredients from different parts of the world, which can improve nutritional and other desirable qualities for the better overall health and wellness of consumers. Therefore, modern food processing is applied for one or more of the following reasons: preservation, extending the harvest in a safe and stable form; safety; quality; availability; convenience; innovation; health and wellness; and sustainability. Although the private sector carries out these processes and delivers the final product to the consumer, public investment in generating the science and engineering base necessary to continue the creativity and ultimate application of new technologies is clearly warranted (Floros et al., 2010).

Drying, canning, chemical preservation, refrigeration (including chilling and freezing), and nutrient conservation and fortification were significant advances of the 19th and 20th centuries that permitted population growth. Such population growth could occur only if there was sufficient food. The Industrial Revolution could not have occurred without a food delivery system that allowed people to leave the farms, migrate to the cities, and engage in the useful production of goods and services for society.

Important developments during the early part of the 20th century include the discovery of vitamins and the realization of the role of other micronutrients, such as iodine, iron, and calcium, in human health. Study of the history of that period brings to mind the bowed legs associated with rickets from vitamin D deficiency and the swollen thyroids related to goiter from iodine deficiency. With the introduction of the draft just before World War II, the army discovered widespread malnutrition among young American males. This led to the foundation of the Food and Nutrition Board at the Institute of Medicine, part of the National Academies, and also the development of the Recommended Dietary Allowances for essential nutrients in 1941. The difficulty of achieving these Recommended Dietary Allowances from available foods, especially among the poor, led manufacturers to fortify common foods with vitamins and other micronutrients, beginning with iodized salt in 1924. Today, fortified foods, defined by Federal Standards of Identity, include such staples as pasta, milk, butter, salt, and flour (Floros et al., 2010).

Advances in agriculture and in food science and technology have led to a reduction in diseases related to nutrient deficiencies; a generally safe food supply with consistent high quality, available independent of the seasons; food choices that do not require preparation time; a wide range of delicious foods; reduced food waste; lower household food costs than ever before; convenience foods requiring much less preparation time than before, a benefit for working families; and efficient global food distribution that can be exploited in times of natural and human-made disasters. However, innovations in food preservation depend on advances in science, especially chemistry and microbiology. How these innovations are applied within each society depends on the economic, cultural, and political context. For example, vegetarian groups require certain technologies, but not others; rice-eating societies may reject, sometimes strongly, foods based on other grains; and slaughtering procedures may vary widely with religious backgrounds (Floros et al., 2010).

During the past 20 to 25 yr, and to meet consumers' growing demands for fresh-like and highly nutritious foods with better safety, several alternative food preservation technologies have been developed. These technologies include novel aseptic processing and packaging methods and thermal processes such as microwave and ohmic heating, which produce shelf-stable foods faster and more efficiently than the currently widespread canning methods. They also include other physical methods that do not use heat as a primary mode of inactivating microorganisms in foods, such as ultra-high pressure, pulsed electric fields, ultrasonic waves, high-intensity pulsed light, and others. Each of these alternative technologies has unique characteristics and potential for expanded applications in different categories of food products (Floros et al., 2010).

Food processing does change some quality attributes of the product. In some cases, these changes are intentional and provide improvements in the nutritive quality, texture, appearance, or flavor of the product. In other cases, the changes may simply make the product different, without improving its quality. Processed foods and beverages may have positive nutrient benefits beyond those of the raw or home-prepared product. Nutrient retention is highly variable, depending on commodity, cultivar, timing of harvesting, storage conditions, nutrient type (for example, sensitivity to heat or oxygen, and water solubility), and processing method. Depending on these variables, processed foods may have more nutritional value than the fresh product (because of greater bioavailability of β-carotene or lycopene, for example). In addition, some processed products (for example, canned and frozen fruits and vegetables) are often a better value for the consumer than the fresh or raw product (Floros et al., 2010).

Finally, food expenditures, as a percentage of household expenditures, in the United States are the lowest in the world: 5.6% compared with 9.1% in Canada, 11.4% in Germany, 24.1% in Mexico, and 44.1% in Indonesia (Economic Research Service, 2008). Cost is an extremely important variable for most consumers when making food purchases, particularly to those with low income. Many of the most economical foods (processed meats, snack foods, soft drinks) have high-calorie contents. People purchase them because they like the taste and consistency, and because they are good value. They have a legitimate role in our food supply, but that role should not be excessively large (Floros et al., 2010).

LOOKING TO THE FUTURE

The future of our food system will be largely determined by the trajectory of 3 major trends: the population growth and its associated demographics; the availability and type of energy resources; and climate change as it influences available land, water, and air quality. Population is by far the most important trend because it drives the other components through its growth rate, standard of living (consumption rate), and other demographic indicators. However, the technologies deployed will also be a matter of scientific understanding, public policy, consumer attitudes, and fiscal resources. Further advances in science and technology are critically needed to successfully meet the daunting challenges ahead in feeding the growing world population, especially in the areas of greatest need.

The new tools of biotechnology hold promise for meeting the needs of our rapidly growing world population more efficiently and cost effectively through improved crop production yields, the ability to grow crops in environmentally stressful conditions, and improved nutrient availability and delivery in an environmentally sustainable manner (Floros et al., 2010).

Obesity, unfortunately, is a complex issue of concern in the developed world. With scientific and technological advancements, food manufacturers have been able to provide many more options than were available just a few years ago to consumers who seek to manage their weight. These options include food and beverage products with reduced caloric density, nutrient-dense foods, and packaging as a component of portion control. Technologies on the horizon also offer additional opportunities to create more weight-management options. Further developments in genomics, metabolomics, and nutrigenomics hold tremendous promise for the development of personalized nutrition and individualistic solutions to obesity. Through nutrigenomics and metabolomics, personalized nutrition for health and wellness will become better understood and a more practical reality for a larger number of people. Such changes will probably lead to changes in regulatory oversight and new approaches to food marketing. Tools in genomics and microbial ecology will allow improved food quality and protection from pathogens, through opportunities ranging from probiotic foods to more precise pathogen interventions (Floros et al., 2010).

Nanotechnology can be expected to have beneficial effects throughout the food system, from agricultural production, where it may enable more precise management of resources, to personalized nutrition, which holds potential for enhancing the delivery and absorption of nutrients and bioactive substances via functional foods. With continued developments in nanotechnology, we can anticipate new mechanisms for detecting and controlling pathogens in the agricultural and food-manufacturing sectors, improved traceability, and better food packaging applications (Floros et al., 2010).

In the future, the food system must be flexible, resilient, consumer driven, and sustainable. It must minimize its environmental impact, use as few natural resources as possible, and ensure the health and wellness of an increasing number of consumers. Food science and technology can help us advance the food system; minimize risks; maximize benefits; and deliver a safe, nutritious, and abundant food supply to all people around the world. However, food science and technology professionals in academia must work together with many others in the food industry and those in the regulatory and public policy communities. In addition, society must invest in basic and applied research, education, and outreach. With science and technology solutions available to address specific issues throughout the food system, our ability to feed a growing population in a sustainable way, while safeguarding both human and planet health, looks not only possible, but also promising. We must, however, remain steadfast and rational about our approach, to help both humanity and nature.

EPILOGUE—A FINAL WORD

Throughout human history, indigenous knowledge and applications of science and technology within the food system have allowed the production of foods in adequate quantities to meet the basic needs of an evolving society. Today, our production-to-consumption food system is complex, and our food is largely safe, tasty, nutritious, abundant, diverse, convenient, and less costly and more readily accessible than ever before (Floros et al., 2010). Scientific and technological advances must be accelerated and applied in developed and developing nations alike if we are to feed a growing world population while addressing the persistent problems of our times: human and planet health, energy and water shortages, and environmental and climate changes.

Food producers and processors in industrialized and developing nations alike require science and technology to ensure a sustainable supply of safe, nutritious, and affordable food, and to satisfy a rapidly growing demand (Floros, 2009). Agriculture, regardless of whether it is traditional or modern, sustainable or organic, small or large scale, will need more science and technology, not less. And people's food, be it fast or slow; local or global; whole, natural, fresh, or processed; industrial or not, will require more food science and technology, not less.

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