Introduction

The obvious but often neglected goal of food production and manufacture is to provide mankind with ample food supplies and adequate nutrition to allow each person not only to survive but also to reach their full intellectual and physical potential (Weiler et al., 2006). However, in practice the two most important drivers of food production are optimal yield and minimum cost in order to achieve maximum profit. Because of these contrasting objectives, the global food system is currently experiencing increasing pressure both on the demand side (from growing population and consumer demands) and on the supply side (from greater competition for inputs and from climate change). Despite the commendable but isolated efforts, announcements, and even signed agreements of governments, international organizations, and agencies, effective and coordinated initiatives aimed at improving food sustainability and security are still at an early stage.

This article on Food Sustainability, Security, and Effects of Global Change deals with the new and dramatic scenarios facing food science in this century. It was timely that the theme of the Universal Exposition held in Milan in 2015 (Expo 2015) was ‘Feeding the Planet.’ Expo 2015 focused on the urgency of providing sufficient food and nutrition to a population likely to reach about 8 billion in 2020 and nearly 10 billion by the middle of the century, all in a sustainable and eco-friendly manner, and through the respectful use of food and water resources. However, if valuable initiatives like Expo 2015 are not followed up by both international policies and coordinated proposals built on sound science, then the task of sustainable food security in a rapidly, and sometimes unpredictably, changing world will become more difficult.

In addressing the challenges of a rapidly increasing global population and depletion of nonrenewable natural resources, recent research efforts have focused on approaches involving integrated molecular technologies. For example, successful engineering of edible plants and crops results in higher yield of biomass material for primary food sources, biofuel, feedstocks, and other benefits (e.g., pharmaceuticals). However, in order to achieve a comprehensive view of plant, animal, and marine responses to climate change; to develop molecular engineering strategies to enhance tolerance to different stresses; and to preserve genetic variability, it will be important to integrate novel ‘-omics’ techniques with bioinformatics and systems biology strategies. Further, there is also a strong need for investment in capacity building and development of agrobiotechnology infrastructure in developing countries, and to set up communication and related strategies to address the education and potential concerns of consumers. This article will focus on all these critical aspects of a modern sustainable food production and manufacturing system.

Scientific interest in food sustainability, security, and global change is exploding as reflected in the exponential increase in publications and citations over the past 20 years (Figure 1). This area thus represents an important element in the food science reference module and has been organized into five main topic areas, each of which is outlined below.

Politics, Economics, and Demographics of Food Sustainability and Security

According to the FAO, undernourishment means that a person is not able to acquire enough food to meet the daily minimum dietary energy requirements, over a period of 1 year, and that hunger is synonymous with chronic undernourishment (http://www.fao.org/hunger/en/ (accessed 23.07.15.)). The most recent figures from the FAO indicate that about 800 million people are undernourished in the world (FAO, IFAD, and WFP, 2015). While this figure represents an improvement in the situation over the past 20 years, 800 million undernourished mouths is still too high a number. Indeed, if global food and water resources were rationally and democratically distributed among nations, every man, woman, and child would have access to adequate nutrition! Addressing the situation of undernourishment is becoming more challenging because of rapidly changing socioeconomic conditions (e.g., increasing world population, urbanization, and dietary changes) and climate change. For these reasons, policies aimed at improving the processes of food production and manufacture, sale, and transport and distribution will play an increasingly important role in ensuring sustainable food security in the modern world.
Several scientific and social developments are currently influencing food security policies, and these include (1) advances in agricultural biotechnologies, including transgenic crops, that offer new hope for agricultural sustainability and nutrition security; (2) concerns that biotechnology multinationals will overly commercialize genetic advances, monopolize the market, and potentially lock out developing nations that have the most need for these technologies; (3) concerns by consumers about the safety of transgenic and cisgenic crops, many of which are still banned in the EU (Paarlberg, 2009) (an inconsistent issue, as evidenced by the recent finding that all natural potato varieties contain transgenes from *Agrobacterium* integrated and expressed within the potato genome (Kyndt et al., 2015)); and (4) the scarce investment made by Western countries in developing nations because of the anticipated small profits. A potential ‘game-changer’ in this area of sustainable food security is the rising economic power of China and India. Both these countries are considered developing nations, but they are increasingly influencing global food trade and policy, not the least of which because they house a large proportion of the world’s population (Chen and Ravallion, 2008).

Food policies of industrialized countries toward developing nations will be fundamental in designing not only more equal and secure access to food, but also a safer and more peaceful world. In this context, the role of international agencies, often criticized for their static, irrelevant, and politicized positions, will assume increasing importance in a fully globalized society. An important option for ensuring that everyone can enjoy adequate access to food is to create targeted social protection or safety net programs that direct resources to the poor and vulnerable, and also avoid social and gender discrimination. The most important safety net policies include, for example, cash-transfers, school meals, food price subsidies, fee waivers (for health care, schooling, or transport), and food stamps. These options were used successfully by a number of developing countries, including Brazil and Ethiopia, during the 2007/08 food crisis (FAO, 2009).

**Innovation for Sustainable Agriculture and Food Production**

In addressing the challenges of food security and health in a society threatened by population growth and by depletion of nonrenewable natural resources, genetic engineering efforts have shifted from single pathways to holistic approaches involving multiple genes, the latter made possible by the integration of systems biology science with ‘-omics’ technologies (Yoon et al., 2013). In a world experiencing the effects of climate change, environmental stress factors such as drought, elevated temperature, salinity, and rising CO₂ levels affect plant growth and pose a threat to sustainable agriculture. Plant adaptation to stress involves key changes in gene expression and protein synthesis. Therefore, by exploring these pathways, ‘-omics’ analytical approaches are providing clues...
to understanding the physiological and molecular ‘fingerprints’ as plants adapt to stress. Such analysis reveals how genes, proteins, and metabolites change after single and multiple environmental stresses. These ‘-omics’ data may finally support the development of models showing the contribution of different signaling pathways to the plant’s response(s) in relation to climate change events. For example, through a systems biology analysis, the photosynthetic pathway of plants has been shown to be under highly cooperative regulation in changing environments. Systems-level modeling could thus be used to explore options for enhanced photo-synthesis in the context of global climate change (Luo et al., 2009).

The availability of high-throughput ‘-omics’ techniques has enabled the study of crop proteome responses to various stress factors (Jorrín-Novo et al., 2009). Very recently, cereal and legume proteomes have been investigated, using complementary gel-based and gel-free proteomic approaches, in relation to protein expression under unfavorable environmental conditions, and in response to abiotic stress (Kosová et al., 2014; Fercha et al., 2013; Kim et al., 2014; Komatsu et al., 2014a,b). In order to achieve a holistic view of plant responses to climate change, and to develop molecular engineering strategies to enhance plant tolerance to different stresses, it will be important to integrate ‘-omic’ data with bioinformatics-based systems biology and to develop computational models (Shulaev et al., 2008; Fukushima et al., 2009; Dutta et al., 2009; Kanelisa et al., 2008). The ultimate objective is to understand how to deliver increased production and reduced carbon footprint via the plant seed. The latest developments in this topic have been highlighted within this section, together with scientific progress that will make possible new global agricultural systems.

**Preservation of Food Raw Materials**

Global demand for agricultural crops is increasing, and will likely continue for decades, propelled by a 2.3 billion person increase in global population and greater per capita incomes expected through the middle of this century (Godfray et al., 2010). Both land recovery and more intensive use of existing croplands could contribute to the increased crop production needed to meet such demand, but the environmental impacts and trade-offs of these alternative paths of agricultural expansion are unclear (Government Office for Science, 2011). The challenge today is to preserve crop biodiversity in a supply chain requiring massive production to achieve food security for all. Inevitably, there will always be potential conflict between biodiversity protection and human food needs, and the task is how best to plot a route between them. A key issue to consider is how land can optimally be used to achieve both enhanced food production and protection of biodiversity.

Preserving natural genetic variation will be an important requirement for livestock breeding strategies, to match animals to a variety of husbandry systems, and for adaptation to environmental changes. In addition, genetic diversity of livestock species is of considerable scientific interest for understanding phenotypic variation, and for reconstructing the history of livestock (FAO, 2007; Bonfiglio et al., 2010; Groeneveld et al., 2010). Interest in the conservation of local livestock types has increased recently in response to the expansion of highly productive livestock at the expense of local populations (Hall, 2004). Molecular of livestock populations has now become an active field of research. To date, it has been assumed that genetic distinctiveness, as estimated with anonymous markers, is indirectly related to functional diversity, but genome-wide approaches now allow for a more direct study of phenotypic variation. Preservation of genetic diversity will be essential for the management of breeds (Toro et al., 2009). It is also likely, as for plants and crops, that proteomics, lipidomics, and metabolomics will play a critical role in linking livestock genetics with the quality of meat and other animal products (e.g., milk, cheese, etc.) (Picard et al., 2010; Janjanam et al., 2014; Lu et al., 2014).

**Food Production and Ecosystem Protection**

Modern intensive agriculture has major global environmental impacts, including land clearing and habitat fragmentation that threaten biodiversity (Dirzo and Raven, 2003); greenhouse gas emissions resulting from land clearing, animal production, and use of fertilizers (Burney et al., 2010); and harm to marine, freshwater, and terrestrial ecosystems from run-off containing fertilizers (Vitousek et al., 1997). Understanding the future environmental impacts of global agriculture and how to achieve greater yields with lower impact requires quantitative assessments of future demand and how different production practices affect yields under variable environmental conditions.

Quantification of yield, input, and related ecosystem changes, as well as evaluation of the occupational exposure of food workers will be addressed in this section, as well as the contributions that novel technologies, including nanotechnologies, green technologies, and biofortification of foods, can offer in the future.

High-throughput ‘-omics’ approaches integrated with nanotechnologies are being applied to the study of ecosystems and related issues. Nanomaterials, including quantum dots, gold nanoparticles, carbon nanotubes, and nanowires, have all demonstrated their potential to overcome the challenges of sensitivity for biomarker detection, discovery, and application. On this basis, a framework for assessing the potential of nanotechnology in enhancing food security in India has been recently developed (Sastry et al., 2011). The model has allowed identification and prioritization of potential areas for application of nanotechnology in enhancing food security in the country. Novel approaches to food manufacture are also improving food security in India. For example, the ‘Mindful Milk’ initiative/process, which utilizes a patented liquid photo-purification technology (SurePure (http://www.surepureinc.com/) (accessed 23.07.15.))), is a green and eco-compatible alternative to traditional pasteurization. This approach has broadened access...
to high-quality milk for a large population in northern India and has also improved the livelihood of local dairy farmers (http://strausfamilycreamery.com/news-media/item/mindful-milk-a-collaborative-project-to-improve-milk-quality-for-dairy-farm (accessed 23.07.15.)).

The almost inevitable conflict between securing food and preserving the ecosystem is evidenced by the recent initiatives in aquaculture policies undertaken by countries such as China. This country represents one of the main markets for farmed fish, with a consequent deep negative environmental impact on rivers and lakes. However, nowadays extended aquaculture zones are being created that correspond to entire isles or lakes, where the trophic chain is self-sustainable. These zones include water-filtering organisms, herbivores, and predators. They include algae, shellfish, and small and big fish varieties, each of which is utilized for human nutrition, thus minimizing the impact on the natural ecosystem (Wong et al., 2014). Other studies (Phalan et al., 2011) are exploring whether policies such as ‘land sharing’ or ‘land sparing’ represent the best approach for sustaining the biodiversity of key species, considering the spectrum of land use and environmental conditions across the world.

**Impact of Climate Change on the Food Chain**

Sustainability and security of the food chain are critical issues in the early part of the twenty-first century, and more so as the world grapples with unprecedented variations in climate punctuated by almost daily occurrences of dramatic weather events. This section presents state-of-the-art knowledge of this ‘hot’ area of food science research. Climate adaptation solutions are presented designed to help food production ecosystems and the population to adapt to the inevitable consequences of climate change. In the future, climate change will affect food production by causing changes in temperature, rainfall, and so forth, but also by triggering extreme weather events (McKersie, 2015). Climate change is already telling mankind – either adapt or perish. While much of the current debate around climate change portends the dire consequences for food production, some climate change may in fact benefit food production. For example, secular rises in temperature may mean that land currently unsuitable for agriculture, especially at high latitudes, could now be farmed. By contrast, increased temperature and dramatic rain events may continue to degrade already stressed agricultural soils, further undermining their future capacity to produce food. This scenario will have great economical and social consequences. For example, the area for quality grape and wine production is changing from traditional temperate landscapes to regions that now embrace places like the UK and the American East Coast, thereby opening up new opportunities for wine production but potentially affecting more traditional locations (Hannah et al., 2013). Finally, the impact of climate change on unwanted pests and pathogens in the food chain should not be underestimated. Tackling these pests/pathogens will require close integration of biochemical, biological, agricultural, and technological approaches.

**Conclusions**

This article on *Food Sustainability, Security, and Effects of Global Change* is a synopsis of the path that modern society is currently taking with respect to securing food in a sustainable manner for a growing population, all in an environment of unprecedented global change (climate, social, economic). Sustainability and food security are important elements of modern food science as scientists address the very topical issues of, for example, the impact of climate change on food resources, biodiversity, and global food security. Solving these issues will not be easy and will rely on integration of knowledge from different disciplines in order to strengthen the capacity to generate and share research data, not only within the scientific community but also within the industrial world and society in general. The development, optimization, validation, and application of novel technologies for food production and manufacture will be critical in securing food for all of mankind in a sustainable way.

**References**


