Abstract

Food science is the application of basic science and engineering principles to the creation and maintenance of a safe, abundant and wholesome food supply. Evolution of food science, particularly over the past century, has been punctuated by the intersection of many basic science and engineering disciplines that has advanced our knowledge of food, and how to transform food into a myriad of safe, convenient, nutritious, healthy and tasty products. In the future, food science will be called upon to address a number of challenges for mankind, including sustainability and nutrition security, longevity and health, food safety and defense, and an ever changing ‘farm-to-fork’ continuum. Embracing transformational and disruptive science and technology will provide some of the solutions, as food science further evolves into a 21st century discipline. In meeting these challenges, ready access to reference material will be essential to the modern food scientist. The *Reference Module in Food Science* represents the next generation in publishing, sourcing and accessing reference material in food science.

Keywords

food science origins, history and evolution; intersection of basic science and engineering disciplines; sustainability and nutrition security; longevity and health; transformational science; food safety and defense; consumer and retailer power.

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1. Introduction

In simple terms, food science is the applied scientific discipline devoted to the study of food. Food science is a meld of many and varied disciplines, including but not limited to chemistry, physics, biochemistry, engineering, biology, microbiology, molecular biology and genetics, statistics, and nutritional and health science, directed at a better understanding of food materials and components, their transformation into safe and nutritious products, and the delivery of these products to the consumer.

One of the world’s leading professional organizations for food scientists and technologists, the Institute for Food Technologists (IFT) in the USA\(^1\), defines food science as an integration of “...several basic sciences which together focus on the unique challenges associated with foods and the systems needed to deliver food products to the consumer” (Heldman, 2006). The applied nature of the food science discipline is exemplified by the definition of Potter and Hotchkiss (1998) as the “application of basic sciences and engineering to study the physical, chemical, and biochemical nature of foods and the principles of food processing”. Similarly, the University of California-Davis describes food science as “...the application of scientific principles to create and maintain a wholesome food supply\(^2\).” These definitions highlight two important features of food science, namely it is an applied discipline and thus is closely associated with everyday practice; and it encompasses many basic sciences and engineering principles thus making it attractive to those wanting to practice the basic sciences in an everyday setting. These features make food science an exciting discipline and explain why practitioners of food science are so passionate about their craft. Ground-breaking developments within the basic science and engineering disciplines can be quickly translated and applied to food systems, thus allowing for a rapid demonstration of these developments in everyday systems we can all relate to. Indeed, the IFT has recognized that “innovative changes within the basic sciences exemplify a natural and ongoing evolution of food science . . . as molecular biology has recently illustrated” (Heldman, 2006).

The evolution of food science has taken place certainly over hundreds, if not thousands of years, but has gained momentum over the past 50 years influenced by the remarkable developments that have taken place over this period in chemistry, biochemistry, physics, medicine, information technology, molecular biology, and the other science and engineering disciplines. These developments and their application have transformed our planet, our lifestyle, and our future more so than at any other time in mankind’s history. The transformation of the food science discipline

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from one sometimes equated to ‘home economics’ to a serious scientific pursuit for our best and brightest bodes well for the challenges that the agro-food industry faces over the foreseeable future.

Modern day practitioners of food science need ready access to the vast array of available reference information and data, both in relation to food science but also those other science and engineering disciplines applied to food systems. This content must be authoritative, it must be current and topical, and it must be easily accessible, searchable and downloadable. The Reference Module in Food Science (Module) addresses all these demands of the modern food scientist. The content has been organized in a hierarchical database around the 12 major themes comprising the food science discipline (Table 1), and has been edited and currency-checked by leading experts in these fields. The section headings shown in Table 1 reflect the rich meld of basic sciences and engineering disciplines that are encompassed within food science. The content is also accessible, searchable and downloadable from any computer or mobile device with internet connectivity from anywhere in the world. The Module represents a huge step forward in making food science reference material readily available to stewards of the discipline.

This introductory article on food science has been crafted to provide the reader with background to the discipline and the Module, including origins and history of the profession, evolution to and features of modern day practice, and the important role that food science and scientists will play in addressing the challenges facing mankind in the 21st century and beyond.
2. **Origins of food science and evolution into a modern scientific discipline**

Food science (and associated technology) has been practiced, sometimes inadvertently, for at least thousands of years and probably before recorded history. Wraghnam (2009) argues that food science, by way of food processing, probably started about 2 million years ago when man discovered fire and its usefulness in cooking food. Since that time, heat treatment for the purposes of processing and preserving food has formed an integral part of food science and the foundation of the modern food processing industry (Henry, 1997; Floros et al., 2010). Cooking was soon supplemented with salting, sun drying, and fermentation that all allowed food to be primitively preserved and stored, and to thus provide sustenance to tribes and small communities particularly during lean times (Tannahill, 1973; Floros et al., 2010). As such, the food science discipline was born and started to flourish, although unknowingly to the practitioners at the time.

Many of our modern day food transformations, based on enzyme-mediated reactions during fermentations, were born thousands of years ago. Food science practitioners at the time were, in fact, food enzymologists and fermentation engineers, albeit unknowingly and without our current understanding of the molecular processes involved. For example, bread dates back to about 30,000 BC or earlier when the first flatbreads were prepared, likely from a ‘paste’ made from cooked grain and water, and perhaps oil, and then baked into a biscuit-like product (Tannahill, 1973). Versions of these flatbreads are still made today in parts of Europe, the Middle East, North America, and Egypt. The use of yeast to make leavened breads came later and likely the result of airborne yeast spores ‘contaminating’ the ‘grain paste’ (dough) (McGee, 2007). Further, beer is an ancient fermented beverage that dates back to at least 7,000 BC and, like leavened bread, was probably discovered through spontaneous fermentation of sugars in cooked grain following ‘contamination’ from airborne yeast spores (Mirskey, 2007). Similarly, wine dates back to about 6,000 BC. The production of beer and wine represent some of the oldest fermentation-based biological transformation and engineering processes. Chemical analytical evidence of beer-making reveals barley-derived ‘beerstone’, a byproduct of fermentation, on pots that were used in its manufacture some 7,000 years ago in the central region of what is now modern day Iran (Michel et al., 1993). The history of cheese, another fermented food product, in this case derived from milk, can be traced back to about 6,000 BC (Subbaraman, 2012; Salque et al., 2013). The casein curd that forms the base material for cheese products was likely accidently discovered following the storage/transport of milk in calves’ stomachs containing the naturally-occurring protease enzyme chymosin, the action of which led to casein protein coagulation and curd formation. Essentially the same coagulation process, albeit more controlled, is used today in the production of many cheeses.
(Mistry, 2006). Written accounts of cheese making, including illustrations of manufacture and consumption (Figure 1), can be found in the *Tacuinum Sanitatis* that dates back to the 14th century (Forbes et al., 2013).

These brief accounts of the ancient history of food cooking, fermentation, processing and transformation illustrate the rich heritage that is food science. Indeed, some have argued that mankind’s ability to elaborately transform food raw materials into products like beer, wine, cheese and bread, all based around food science principles, has provided a foundation for the development of science and technology more broadly, and to help build civilization and an innovation culture (Dornbusch, 2006; Farhat-Holzman, 2014).

![Figure 1](image-url): Pictorial illustration of cheese making and consumption in the 14th century. Reproduced from the *Tacuinum Sanitatis* (Forbes et al., 2013) with permission of ???.

As mankind moved from foraging to domesticated agriculture starting some 10,000 years ago (Figure 2), and also started to gather more in communities, townships and cities, and thereby to establish societies, the need for a more sophisticated food production and supply chain became important (Henry, 1997; Floros et al., 2010). A critical element of these dramatic changes in
demographics was the need to process or otherwise treat food in order to preserve it for transport and storage (Floris et al., 2010). Prior to refrigeration, these processes included salting, sun and oven drying, smoking, pickling, fermenting, and during winter, freezing the food (Henry, 1997). All these processes resulted in a reduction of the water activity ($a_w$) and/or pH of the processed food, and thereby prevented or at least delayed microbial spoilage and outgrowth of pathogens, both very sound food science principles.

**Figure 2:** From foraging to farming to sophisticated food science and technology (labelled ‘food technology’) – ancestry and evolution of the food science and technology discipline. Reproduced from Henry (1997) with permission of ???.

The industrial and agricultural revolutions during the 18th and 19th centuries changed society and how we live and eat forever. Primarily through improved public health, better sanitation and medical advances, the world’s population grew from less than 10 million in 10,000 BC to about 1 billion in 1800 (**Figure 2**), and continued to urbanize growing cities. These ‘masses of mouths’ needed to be fed and some at the time made dire predictions that rapid population growth would outpace the planet’s ability to produce food. Thomas Malthus predicted that the 19th century would witness mass hunger and starvation because the world’s population would quickly outstrip the required food production to adequately feed this population (Malthus, 1803). All things being equal, Malthus was correct, but he did not factor in science and technology advances that underpinned the agricultural and industrial revolutions, and allowed for dramatic increases in farming productivity and mechanisation that supported mass food production and processing.
These developments allowed mankind to feed the world’s population through the 19th and 20th centuries, and to produce enough food for a planet with more than 7 billion people today, all supported by elements of food science and technology.

Mass production of food was an important element in feeding a growing world population, but the ability to transform food raw materials into desirable products, and to transport and store them were equally important, and critical in delivering safe food to an increasingly urbanized society. To these ends, the pioneering work of Nicolas Appert in heat-based food preservation and canning, Louis Pasteur in thermal treatment of liquids to reduce microbiological loads (pasteurization), and Oliver Evans, John Gorrie and James Harrison in refrigeration and freezing to extend the shelf-life and freshness of foods, all during the 19th century, deserve special mention (Henry, 1997; Floros et al., 2010). The principles established by these pioneering food scientists form the foundation of the modern food processing industry.

The 20th century has witnessed huge and rapid advances in food science and technology, building upon developments in the basic science and engineering disciplines, and the sound principles established in the 19th century. Modern biochemistry and medical and nutritional science have allowed for a detailed understanding of the major and minor food components, together with the role played by macro and micro nutrients, and also the dangers of toxicants in foods. Sophisticated analytical chemistry has provided the foundation for detecting adulteration of foods, as evidenced by recent high-profile events (e.g., Ramzy and Yang, 2008). Modern chemical, process and mechanical engineering have facilitated the extension, adaptation, expansion, refinement, and automation of traditional food processing operations, many built around the use of heat for pasteurization, concentration and dehydration, and the development of new food processes many non-thermal (Henry, 1997). Membrane-based technology for mass processing and concentration of liquids, common-place in modern food factories (Coutinho, 2014), has been made possible through developments in organic and inorganic chemistry, polymer science, and process engineering. Modern food packaging materials have been made possible through developments in chemistry, polymer science, and chemical engineering; and modern molecular biology has supported the development of many improved variants of important plant and animal food raw materials (Floros et al., 2010). These advances in food science and technology over the past 100 years represent just a snapshot of the many that have occurred. Further details can be found in the Module.
An important consequence of mankind transitioning from foraging to farming to large-scale and mechanized food production and processing, together with urbanization of the world’s population, has been a large reduction in the number of plant and animal species cultivated for food (Henry, 1997). Hunter-gatherers likely sourced more than 100 different plant, animal and insect species for food, but with the advent of farming and eventually broad-acre agriculture, this number reduced to perhaps 20, and in more developed regions of the world to less than 10 (Henry, 1997). Intuitively, this dramatic reduction in species variety would suggest that the number of different foods able to be prepared from these raw materials would be quite limited. In fact, the opposite is the case, and the reason is that food science (and technology) provides a strong practical foundation for the almost unlimited transformation of even a limited number of raw materials into a myriad of tasty, nutritious and safe modern day foods (Henry, 1997; Floros et al., 2010). Harking back to the mediaeval origins of food science, Henry (1997) notes “...the food technologist (scientist) is the modern day alchemist ... (creating) foods of unimaginable complexity and taste.” Indeed, the more than 30,000 food products available in modern supermarkets today are there, in large part, because of a world filled with food science and technology.

The modern food science professional could be a chemist, biochemist, physicist, molecular biologist, chemical engineer, nutritionist, or even a mathematician, not to mention the many other science and engineering pursuits that form the meld that is food science. The evolution of food science, particularly over the past century, has been punctuated by the exciting intersection of the many basic science and engineering disciplines. Food science has transitioned from a very empirical pursuit to one that’s dominated by a strong fundamental science base that has underpinned the research and development responsible for the myriad of successful food products and ingredients available today.

In terms of evolution of the food science discipline, Philip Nelson has noted “...just as society has evolved over time, our food system has also evolved over centuries into a global system of immense size and complexity. The commitment of food science and technology professionals to advancing the science of food, ensuring a safe and abundant food supply, and contributing to healthier people everywhere is integral to that evolution. Food scientists and technologists are versatile, interdisciplinary, and collaborative practitioners in a profession at the crossroads of scientific and technological developments ...” (Floros et al., 2010).
Content in the Module reflects the rich history that is food science, the meld of basic science and engineering disciplines that intersect as food science, and the many features of modern day practice of the food science discipline (Table 1).
3. Challenges and opportunities for food science tomorrow

Mankind faces huge challenges over the next 30-40 years, not the least of which will be pressures resulting from a rapidly growing population, notably in the least developed regions of the planet, and one that’s ageing at a rapid rate (United Nations, 2009; 2013; Australian Government, 2015). The meld of scientific and engineering disciplines that constitute modern food science, and the practitioners of this discipline, will be called upon to address the challenges and capture the opportunities in order to secure mankind’s future. Food science thus represents a critical pursuit over the foreseeable future. Some of the key challenges, opportunities and possible scenarios for the ‘food science of tomorrow’ are outlined below.

**Sustainability and security**

It is not hyperbole to describe the world’s population as exploding! Currently the global population stands at about 7.3 billion people and is showing a net increase of more than 230,000 persons/day[^1]. If mortality rates continue to decline and fertility rates remain at current levels then the world’s population will exceed 10 billion people by 2055 (United Nations, 2009). These staggering figures highlight the immense challenges the agro-food industry faces to sustainably feed these billions of people, the majority of whom live in underdeveloped regions; to provide them with food, but perhaps more importantly, nutrition security; and to achieve all of this as the world goes through unprecedented global changes (economic, social, demographic, climate, and environmental).

The addition to the planet of ~2.7 billion mouths to feed over the next 40 years will require a huge increase in food production and manufacture, almost unprecedented in human history. Currently, the average per capita daily food consumption across the world is ~11,600 kJ/person/day, with 20% higher intake in developed countries and 20% lower in underdeveloped/developing regions (Alexandratos and Bruinsma, 2012). If this level of consumption remains the same through mid-century, then the planet will need an additional ~3.1 x 10^{13} kJ/day by 2055 in order to feed the additional mouths! World agricultural output will need to expand ~60-70% by the middle of the century to meet this increased demand for food (Floros et al., 2010; Alexandratos and Bruinsma, 2012). To address this formidable challenge, the agro-food industry must undergo a 21st century revolution, much like the agricultural revolution of the 18th century, but in a sustainable manner. The term ‘sustainable’ is often used in reference to the environment and natural resources, but the

term has greater plurality than just ecology. In summary, the World Bank defines sustainability as management of activities and resources to ensure that the average quality of life we enjoy will be shared by all future generations\(^4\). The term thus encompasses environmental, social, behavioral, economic, demographic and geo-political aspects. As the agro-food industry enters a 21st century revolution in a world experiencing massive change, including unpredictable and dramatic climatic events, it must develop approaches that recognize the plurality of sustainability, and food science will play a critical role.

Feeding billions of additional mouths by the middle of the century is only part of the challenge for the agro-food industry. Consumers, notably those in developing regions of Asia, are increasingly demanding more high quality protein in their diets and for protein to meet a higher proportion of their daily energy needs (Cao and Li, 2014). Calculations by the author indicate that with the projected population increase and consumer demands for more protein in their diets, the agro-food industry will need to produce an additional \(\sim 40\) billion kg of edible protein by 2055! In addition, consumption of animal protein products (beef, pork, dairy) has been on the increase over the recent past, notably in fast developing regions of the world where many consumers have newfound prosperity (e.g., China, India) (Cao and Li, 2014). Consumers in these regions are demanding Western-style diets that are dominated by animal proteins, thus creating pressure on prime agricultural grazing land, greater demand for feed crops and water, and environmental impact from livestock production (e.g., greenhouse gases). While it could be argued that meat/animal-based diets represent an excellent choice from a nutrition perspective (Hoffman and Falvo, 2004), they represent a very poor choice from the position of sustainability (Pimentel and Pimentel, 2003).

Food science and related disciplines will be at the forefront in addressing the challenges posed by food sustainability and nutrition security over the next 40 years. Technological innovations will be critical in securing the global economy and the future of the planet. Possible scenarios include (i) more productive farms through increased yields of crops and livestock, and enhancing productivity on poor quality land; (ii) more efficient and effective use of agricultural and food processing ‘inputs’ (e.g., water, chemicals) with less damage to the ecosystem; (iii) shifting diets away from the focus on animal proteins to nutritious and more sustainable sources; and (iv) reducing food waste, noting that more than 30% of food produced at present is either lost through the food chain or thrown away in homes or restaurants (Smith, 2015). The role of food science in sustainability and security is an important aspect of content found in the Module, notably in the

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sections on *Food Sustainability, Security and Effects of Global Change, Food Quality, Storage and Transport, Food Biosciences, Food Process Engineering, and Food Packaging.*

**Longevity and health**

Consumers are ageing rapidly, the result of declining mortality and fertility rates (United Nations, 2013). Life expectancies at birth and later in life have increased dramatically since the latter part of the 19th century. Figure 3 shows human life expectancy data at birth for various developed and developing nations during the 20th century, together with a representation of total population. These data illustrate that for developed and even developing nations, life expectancy at birth has on average nearly doubled since 1900. Further, it is projected that babies born in 2055 in Australia, and presumably other developed countries, will live on average until the middle of the 22nd century (i.e., life expectancy ~96 years) (Australian Government, 2015). Over the next 40 years, the proportion of the Australian population aged 65 years and over will substantially increase from 15% in 2015 to a projected 23% in 2055, reflecting an increased “greying” of the population (Australian Government, 2015), data that mirrors the situation in other developed and developing nations (Käferstein and Abdussalam, 1999) (Figure 4).

Advances in medicine, biomedical science, disease control and treatment (e.g., antibiotics, vaccines), and improvements in diet, nutrition and lifestyle choices (e.g., dramatic reduction in smoking rates\(^5\)), particularly since World War II, have been largely responsible for improvements in life expectancy and healthy ageing of the population. However, as the population ages, pressure on healthcare spending and aged care services will increase. Indeed, a recent Intergenerational Report (Australian Government, 2015) projects that in current currency terms healthcare spending will more than double over the next 40 years from $2,800 (2014) to ~$6,500 per person, and increase from the current 4% of GDP to potentially more than 7% of GDP in 2055. Considering there will be proportionally fewer tax payers in 2055 to support this spending, these increases are unsustainable.

The dramatic changes in population demographics, and the consequent pressure on healthcare and aged services spending, highlight the need to move from a health system built primarily on treating disease to one that’s balanced with a preventative approach. In essence, to move the focus from ‘therapeutics’ to ‘prophylactics’, and to ensure that as consumers age that they

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maintain active, healthy, productive and fulfilling lives. In this quest, food science will play a critical role.

**Figure 3:** Dramatic rise in life expectancy in both developed and developing nations during the 20th century. Reproduced with permission from the German Association of Research-Based Pharmaceutical Companies (http://www.vfa.de/en/imprint). Accessed July 27, 2015.

**Figure 4:** Percentage of the world’s population aged over 65 years (1950 – 2050). Reproduced from United Nations (2009) with permission of???.

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Foods and beverages will be important in moving the focus from treating disease to reducing the risk and even preventing illness. Some 2,500 years ago, Hippocrates espoused “let food be thy medicine and medicine be thy food”, and this tenet forms the basis for modern day functional foods and nutraceuticals designed to provide consumers with both nutritive value and a specific health benefit (Siro et al., 2008; Goldberg, 2012). Some well known and successful examples of functional foods include table spreads incorporating plant sterol esters\(^6\) to lower the absorption of cholesterol (Richelle et al., 2004), and fermented dairy drinks\(^7\) containing peptides that clinically lower hypertension by inhibiting angiotensin-converting enzyme (EC 3.4.15.1) (ACE) (Jauhiainen, 2003; Pihlanto et al., 2010). Both these products have been designed to serve as prophylactic agents in addressing the issue of cardiovascular disease (CVD), and food science played a central role in their development. Other functional ingredients and products will be needed to address 21st century lifestyle and age-related issues, including obesity, diabetes, muscle health, and osteoporosis. As the world’s population ages rapidly (Figure 4), food scientists will be called upon to develop new, novel and attractive foods and beverages for the elderly. These foods will need to address geriatric health challenges like osteoporosis and sarcopenia, for example, and also take account of xerostomia (dry mouth) that often afflicts aged consumers (Ben-Aryeh et al., 1985).

Development of functional ingredients/nutraceuticals to act as prophylactics in foods and beverages is only part of the story. These ingredients also need to be delivered in products and to the consumer both effectively and efficaciously. Often, these nutraceuticals are chemically and/or biologically labile and lose their efficacy even under mild conditions or during product shelf-life, and/or they can negatively impact the sensory properties of the product thus rendering it unacceptable to consumers. Ideally, the nutraceutical should also be delivered to the consumer in a targeted way at a point in the gastrointestinal tract where it will be most efficacious. The application of food science will thus be critical in developing systems that revolutionize the delivery of nutraceuticals in various food vehicles (e.g., Ying et al., 2012; McClements and Xiao, 2014).

The 21st century will be punctuated by personalized nutrition and health plans, and the application in food settings of modern genetic technologies, such as epigenetics and nutrigenomics. Epigenetics is the overarching study of cellular and physiological changes induced by extraneous factors that can switch genes on/off, and also affect how genes are read. Nutrigenomics is the study of the affect that foods and food constituents have on gene expression. These two specialties of modern genomics are clearly interrelated and their application in food science settings will be

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\(^6\) Pro-Activ® and Logicol®.

\(^7\) Evolus® from Finland and Calpis® from Japan.
critical in the development and widespread application of personalized nutrition (Kussmann and Fay, 2008).

The desire by ageing consumers for healthy and active lives will demand that food scientists aim to better understand those physiological and biochemical issues that impact overall health status, and most importantly the ‘levers’ to influence them. Gut health is increasingly being recognized as an important influencing factor in overall health status, influencing seemingly disconnected physiological functions like brain activity (Claesson et al., 2012; Collins et al., 2012; Cho and Blaser, 2012). The makeup of the ‘gut microbial community’, the so-called microbiome, is critical to gut health, and diet is a major influencing factor (Claesson et al., 2012; Blaser, 2014). Oligosaccharides (so-called prebiotics), for example, play an important role in creating a probiotic-friendly environment in the gut and thereby influence overall health status (Bode, 2012). The unique human milk oligosaccharides play a critical role in the development of babies and toddlers by creating a gut environment conducive to the growth of Bifidobacteria, an important probiotic organism in infancy and later in life (Bode, 2012). Research into the microbiome and the influence of dietary components, including pre/probiotics, will likely dominate the food science literature for the foreseeable future. Some argue that a ‘microbiome revolution’ has started (Cho and Blaser, 2012; Blaser, 2014).

The role of food science in longevity and health is an important aspect of content found in the Module, notably in the sections on Nutrition and Health, Food Biosciences, Food Products and Ingredients, and Food Process Engineering.

**Transformational and disruptive science and technology**

The world is currently witnessing an explosion of new science and supporting technology that has the power to transform and disrupt the agro-food industry, and much of this science and technology comes from outside the food arena. Food scientists will be called upon to embrace, adapt and apply this new science and technology, both in terms of the natural evolution of the food science discipline, but also in addressing many of the challenges the planet faces in the 21st century. While there are many examples of transformational and disruptive science and technology in the early part of the 21st century, some stand out from a food science perspective.

The miracle of stem cell science and its medical applications is familiar to all of us, but the translation of this science into the food arena is less well known. The production of beef without...
cows, pork without pigs, and chicken without poultry would have been considered ‘science fiction’ in only the recent past. However, so-called ‘test-tube meat’ is now a reality and could potentially revolutionize the livestock industry (Hanlon, 2012; van der Weele and Tramper, 2014). The technology relies on either (i) culturing stem cells from an animal in large fermenters or bioreactors akin to the pharmaceutical industry, and then isolating the cultured cells and processing them into products with muscle meat-like features (Figure 5) (van der Weele and Tramper, 2014); or (ii) selecting specific plant proteins, and then formulating and processing them to recreate the taste and texture of meat (and dairy products like cheese) (Hanlon, 2012). The latter technology has been commercialized by a USA-based company8. Producing meat without the need for animals would address the environmental, sustainability and animal welfare challenges of large-scale livestock production, and would also address consumer demands for reduced-fat, and antibiotic, hormone and pathogen-free meat9. Food scientists and engineers will be at the forefront in further researching, developing and commercializing these technologies.

Transgenics is a branch of modern day biology concerned with the introduction of exogenous genetic material from one species into another species in order to express a new or improved trait, and for the new genetically modified organism (GMO) to pass that trait onto progeny. The application of transgenics and the resultant GMOs in the food chain has been a very emotive and controversial subject, eliciting strong debate including arguments for and against genetically-modified food10. Some regulatory authorities, such as the European Food Safety Authority (EFSA), have taken strong stands in regard to such foods11.

While the long-term safety of genetically-modified foods remains a concern to consumers (Grunert et al., 2004; House et al., 2004), at least some of the controversy about such foods has come from the focus of the technology to date. Application of transgenics to plants and animals has primarily been directed at yield increases, through growth promotion and/or protection against pests, and consequent enhanced profits for the owner of the GMO (Bennett, 2014). However, the power of the technology can be directed at traits beyond just yield. For example, in a world looking for nutrition security, as noted elsewhere in this article, transgenics could be used to enhance the nutritional quality of plant and legume staples to match or exceed the quality of animal proteins, and thus help to address malnutrition in underdeveloped and developing regions of the world. The

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technology could also be used to generate and deliver health-promoting components in various food staples, and thereby help to prevent many lifestyle diseases of the 21st century. Food science will be critical in these pursuits.

*Figure 5*: Schematic illustration of the steps involved in the application of stem-cell science and technology to the manufacture of so-called ‘test-tube meat’. Reproduced with permission from the Genetic Literacy Project (http://www.geneticliteracyproject.org/2015/02/19/wheres-the-beef-and-fat-are-you-ready-for-a-juicy-test-tube-burger/) (Accessed July 28, 2015).

The promise of nanotechnology has yet to be realized in the food arena, and the science of nanotechnology demands greater attention from food scientists (Floros et al., 2010; Rashidi and Khosravi-Darani, 2011). The application of nanotechnology could bring great benefits to 21st century foods and beverages. For example, advances in nanoscale science could include (i) stable nano-emulsions or nano-capsules to provide the means to deliver oil-soluble nutraceuticals in clear water-based drinks; (ii) nano-structured food components (e.g., proteins) to enhance taste, notably for the elderly who have less acute organoleptic senses; (iii) nano-based ‘smart packaging’
materials to keep food fresher and safer for longer; and (iv) nano-based pathogen detection systems for real-time monitoring of food safety.

3D printing science and technology is all pervasive, and is revolutionizing the medical, industrial manufacturing and construction industries (Lipson and Kurman, 2013; Wu et al., 2015). This technology also has the potential to revolutionize the food and related industries (Gross et al., 2014), and food scientists need to be at the forefront in exploring, researching and developing applications for 3D printing in foods. Whilst the 3D printing of complex food products with customized shapes, flavors, textures and colors is an obvious application, other areas also deserve attention. For example, an economical 3D printed ‘smart cap’ for perishable beverages (e.g., milk) would provide the consumer with real-time information about the freshness of the product and perhaps render ‘best-by’ and ‘use-by’ dates obsolete (Figure 6) (Wu et al., 2015).

The 21st century food scientist will need to embrace the basic sciences of mathematics and statistics, among others, to help in the collection, analysis and interpretation of so-called ‘mega data’, including vast amounts of raw data, and huge data sets that are sometimes incompatible (The Economist, 2010). The ability to effectively and efficiently collect, analyze, interrogate and interpret a deluge of data will impact the success or otherwise of the many exciting transformational and disruptive technologies, several of which are noted above.

Content on transformational and disruptive science and technology in the food science of tomorrow can be found in the Module, notably in the sections on Food Biosciences, Food Products and Ingredients, Food Chemistry and Analysis, Food Process Engineering, Food Packaging, Nutrition and Health, and Food Sustainability, Security and Effects of Global Change.

Food safety and defense

One food and beverage characteristic that is non-negotiable and that consumers rightly expect is food safety!

There has been great progress, particularly over the past 50 years, in understanding and controlling foodborne illness (Maki, 2006; Nyachuba, 2010). Advances include (i) detailed understanding of infectious agents and toxins, and their route into the food chain; (ii) sophisticated detection and identification methodologies; (iii) effective control mechanisms, like heat treatment, refrigeration and sanitizers; (iv) education of food processors, handlers and consumers about safe
food practices; (v) sanctioned food production, processing, storage and transport control protocols, like HACCP; and (vi) a strong regulatory environment. However, despite all these advances and control mechanisms, foodborne illness and fatalities are on the rise, even in the developed world (Nyachuba, 2010).

Figure 6: 3D printed ‘smart cap’ for rapid detection of liquid food quality featuring wireless readout: (a) the smart cap with a half-gallon milk package, and the cross-sectional schematic diagram; (b) sensing principle with the equivalent circuit diagram. Reproduced from Wu et al. (2015) with permission of ???.

Reported outbreaks of *Salmonella*, enterohemorrhagic *Escherichia coli*, and Hepatitis A, to name just a few, are now almost a daily occurrence, and usually receive intense media attention (Nyachuba, 2010). Recent high-profile outbreaks of Hepatitis A and *Salmonella* in Australia have
been traced to frozen berries from China\textsuperscript{12}, and likely to undercooked chicken or raw eggs\textsuperscript{13}, respectively. In Australia alone, foodborne illness related to \textit{Salmonella} has increased by 50\% over the past 2 years\textsuperscript{13}, with an average of more than 10 cases per day in 2014, a situation mirrored in other countries\textsuperscript{14}. Although outbreaks of potentially fatal botulism (caused by the spore-forming bacterium \textit{Clostridium botulinum}) were effectively eliminated more than 30 years ago through carefully controlled retorting and other control mechanisms of ‘at-risk’ products, this foodborne illness is now showing a renaissance (Juliano \textit{et al.}, 2013).

The global challenge and urgency of food safety in the 21st century has been placed in stark relief by Käferstein and Abdussalam (1999) who noted “... the global importance of food safety is not fully appreciated by many public health authorities despite a constant increase in the prevalence of foodborne illness. Numerous devastating outbreaks of salmonellosis, cholera, enterohaemorrhagic \textit{E. coli} infections, Hepatitis A and other diseases have occurred in both industrialized and developing countries... more foodborne pathogens can be expected because of changing production methods, processes, practices and habits.” These portends of Käferstein and Abdussalam (1999) more than 15 years ago are now showing signs of reality accelerated by growth and ageing of the population (\textbf{Figures 3 and 4}), mass urbanization, lack of effective sanitation in rapidly developing economies, mass tourism and international travel, conflict, and globalization of food trade. These and other factors mean that the occurrence of food poisoning outbreaks will grow and when they occur they’ll likely travel quickly around the world.

In the 21st century, food scientists will be critical in defending the safety of the world’s food supply chain. These scientists will be called upon to develop, validate and exploit new detection and identification technologies to more effectively monitor and evaluate threats to food safety. Food scientists and engineers will need to improve existing technologies for the safe production, processing, storage and transport of food, and to also research, develop and commercialize new technologies designed to assure the food chain. Vigilance will be essential.

The role of food science in the assurance of a safe and wholesome food supply chain is an important aspect of content found in the Module, notably in the sections on \textit{Food Chemistry and Analysis}, \textit{Food Safety, Defense and Microbiology}, \textit{Food Management, Policy and Regulations}, and \textit{Food Process Engineering}.

**Consumer and retailer power**

Consumers are demanding! In 1999, Carol Brookins noted at the Global Food and Agriculture Summit that “…consumers are demanding ‘miracle foods’ that are totally natural, have zero calories, zero fats and cholesterol, delicious taste, total nutrition, low price, environmentally-friendly production, ‘green’ packaging . . . and that guarantee perfect bodies, romance and immortality”! The challenge for food science in aspiring to these demands is that the modern food industry is founded, in the main, on thermal processing to render food safe and to allow it to be readily stored and transported. Unfortunately, heat is detrimental to the texture, flavor, aroma, appearance, and sometimes the nutritional quality of foods (Henry, 1997). Thus, for the past ~20 years food and other scientists have been exploring alternative/novel food processing technologies, many non-thermal, that promise to render the food safe, but to also protect the inherent characteristics of the food thus making it more appealing to the consumer (Henry, 1997; Barbosa-Cánovas *et al*., 2004). Examples include high hydrostatic pressure, pulsed electric field, ultrasonics, pulsed high-intensity light, and cool plasma. While some of these novel techniques are ‘batch processes’ and thereby inherently more costly then continuous processes, some have been commercialized (e.g., high pressure) because of the consumer benefits that they deliver\(^{15}\)\(^{16}\).

Consumers in the 21st century are taking a strong interest in the food that they eat, and their choices are increasingly being influenced by the health-promoting qualities of these foods (Zink, 1997; Siro *et al*., 2008). In developed countries, consumers are also becoming increasingly concerned about lifestyle diseases including obesity (Mela, 2001), and terms like ‘energy density’ (kJ/g) of foods is being used in everyday language (Henry, 1997). Traditional heat-based food processing can lead to a 10-fold increase in the energy density of the processed food due to concentration and dehydration (Henry, 1997). Thus, as consumers seek out low energy density foods, the food industry will need to explore alternative processes that both maintain safety but also render the food low in energy density. The alternative non-thermal processes noted above may provide part of the answer (Zink, 1997; Barbosa-Cánovas *et al*., 2004).

In the early part of the 21st century, consumer advocacy has become vociferous, organized and sophisticated, and governments and food companies are listening. Led by the millennials (‘Generation Y’), these consumers are demanding ‘natural’ and ‘clean label’ foods, and such demands are being answered by some food companies through ‘blanket bans’ on a number of


ingredients, additives and supplements. Unfortunately, many of the banned ingredients and additives are naturally-occurring, nutritious and/or important to the quality and safety of the food. In this important debate, food science will be critical in ensuring that decisions are fact-based and founded in sound science.

The latter part of the 20th century has witnessed an historic shift in ‘power’ along the food production/processing/retailing continuum (‘farm-to-fork’) from the food producers/processors to the mega-retailers/supermarkets (e.g., Milligan and Brown, 2011). These supermarkets now ‘call the tune’ and as such have created immense pressure on their suppliers to reduce costs. While such a situation is good news for consumers reflected in lower food prices, the flow-on effect demands that producers and processors must continue to find cost savings in their operations. The clever application and adaptation of science and engineering will be critical in finding and implementing many of these cost savings. Some examples include (i) robotics for processing efficiency (Perks, 2006); (ii) substituted membranes for more cost-effective concentration and fractionation of food components (Arunkumar and Etzel, 2013; 2015); (iii) substituted stainless steel for improved ‘cleaning-in-place’ effectiveness and efficiency (Barish and Goddard, 2013); and (iv) non-thermal processing options (e.g., ultrasound) for enhanced manufacturing throughput (Muthukumaran et al., 2007).

The changing face of consumers and the food production/processing continuum is an important aspect of content found in the Module, notably in the sections on Consumer Behavior and Food Marketing, Food Science Education, Research and Professional Development, Food Products and Ingredients, and Food Process Engineering.

4. Concluding remarks

Food science has a rich and long heritage, and has evolved into a discipline that nowadays plays a critical role in ensuring a nutritious, safe and abundant food supply. Food science is a meld of many scientific and engineering disciplines, such as chemistry, biology and chemical engineering, applied to better understand food and its transformation, and to use this knowledge to deliver safe and desirable food products to the consumer. As mankind faces challenges in the 21st century and beyond, including sustainability and food security, longevity and health, food safety and defense, and new found consumer power, food science will be called upon to embrace transformational and disruptive science and technology in seeking answers. The modern food science practitioner will need to be well armed with knowledge, and ready access to reference material will be a key element.

Food science practitioners nowadays are looking for the following features in the reference material they source: content from an authoritative and reliable source, current and topical material including real-life examples, and accessibility. The Reference Module in Food Science addresses all these key demands from the modern food scientist. First, the Module is published by Elsevier, the world’s leading technical content publisher with a proven track record in producing authoritative and reliable content. Second, material in the Module will be currency-reviewed, up-to-date, and topical; and all content will be overseen by editors who are leading experts and practitioners in the food science field. Finally, material in the Module will be online, searchable, and downloadable, and thereby easily accessible by researchers from anywhere in the world. The Reference Module in Food Science represents the next generation in publishing, sourcing and accessing reference material in food science and related disciplines.
References


Figure legends

**Figure 1**: Pictorial illustration of cheese making and consumption in the 14th century. Reproduced from the *Tacuinum Sanitatis* (Forbes *et al.*, 2013) with permission of ????.

**Figure 2**: From foraging to farming to sophisticated food science and technology (labelled ‘food technology’) – ancestry and evolution of the food science and technology discipline. Reproduced from Henry (1997) with permission of ????.

**Figure 3**: Dramatic rise in life expectancy in both developed and developing nations during the 20th century. Reproduced with permission from the *German Association of Research-Based Pharmaceutical Companies* (http://www.vfa.de/en/imprint). Accessed July 27, 2015.

**Figure 4**: Percentage of the world’s population aged over 65 years (1950 – 2050). Reproduced from United Nations (2009) with permission of ????.

**Figure 5**: Schematic illustration of the steps involved in the application of stem-cell science and technology to the manufacture of so-called ‘test-tube meat’. Reproduced with permission from the *Genetic Literacy Project* (http://www.geneticliteracyproject.org/2015/02/19/wheres-the-beef-and-fat-are-you-ready-for-a-juicy-test-tube-burger/) (Accessed July 28, 2015).

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Table 1: Organization of the Elsevier Reference Module in Food Science

<table>
<thead>
<tr>
<th>Section name</th>
<th>Synopsis of content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food Chemistry and Analysis</td>
<td>Proximate and more sophisticated food component analysis; major and minor food chemicals and their determination; sensory analysis; and statistical techniques used in food analysis.</td>
</tr>
<tr>
<td>Food Process Engineering</td>
<td>Engineering properties of food; traditional and modern unit food processing technologies; non-thermal and innovative processes; food process modeling; and food plant and process design and optimization.</td>
</tr>
<tr>
<td>Food Packaging</td>
<td>Definition and function of food packaging; food packaging materials and formats; biodegradable, intelligent and active packaging; controlled and modified atmosphere packaging; and packaging systems for different processing applications and food products.</td>
</tr>
<tr>
<td>Food Safety, Defense and Microbiology</td>
<td>Pathogenic and spoilage microorganisms; virulence; food defense and food safety assurance; microbiology of fermentation; the microbiome; and chemical and physical hazards in food.</td>
</tr>
<tr>
<td>Food Quality, Storage and Transport</td>
<td>Definition and measurement of food quality; impact of storage on food quality; storage and transport requirements; traceability; cool and cold store design, construction and operation; and refrigerated and non-refrigerated transport.</td>
</tr>
<tr>
<td>Food Management, Policy and Regulations</td>
<td>Management and economics of food production and processing; local and international trade in food; government food policy; and the regulatory environment and enforcement.</td>
</tr>
<tr>
<td>Nutrition and Health</td>
<td>Specific macro and micro nutrients and health; diet and disease; in borne errors and metabolic diseases; epidemiology and public health; molecular nutrition; clinical nutrition; and human physiology and health.</td>
</tr>
<tr>
<td>Food Products and Ingredients</td>
<td>Primary food production; dairy, cereal and legume, meat, seafood and horticultural products and ingredients; confectionery; food structure, rheology and texture; and molecular gastronomy.</td>
</tr>
<tr>
<td>Food Biosciences</td>
<td>Food-omics; biomaterials; traditional breeding and genetics; transgenics; food biotechnology; food bioscience intellectual property and consumer issues; and food sensory parameters modifying consumer perception and choice.</td>
</tr>
<tr>
<td>Consumer Behavior and Food Marketing</td>
<td>Evaluation of consumer behavior and food market opportunities; marketing food products and brands; and consumer research and marketing strategies.</td>
</tr>
<tr>
<td>Food Sustainability, Security and Effects of Global Change</td>
<td>Politics, economics and demographics; sustainable agriculture and food production; preservation of food raw materials; ecosystem protection; and impact of climate change on the food chain.</td>
</tr>
<tr>
<td>Food Science Education, Research and Professional Development</td>
<td>Approaches to food science education; research protocols and strategies; continuing professional development for food scientists; and role of professional institutes/agencies.</td>
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</tbody>
</table>