CHAPTER 1
Book overview

Food is an essential component that sustains human life. With the continual increase in the human population and the rarity of self-sustaining communities, the availability of food in sufficient quantities where and when it is needed is of paramount importance. Although there is a resurgence in growing interest to grow local food supplies and in self-reliance through initiatives such as agrihood, complete self-sustainability in terms of year-round food needs is absent in almost all circumstances. Reasons for this could include the need for variety demanded by consumers, inefficiencies, and the lack of required skills as well as the unavailability of necessary resources (e.g., water, land) that are associated with growing one's own food, and issues related to economics.

The food industry addresses this need by providing the infrastructure necessary to grow and deliver food from farm to fork (F2F) when and where it is needed. The food consumed by most people these days passes through the food industry in some form that includes processed and raw material. The food industry therefore directly helps nourish and sustain the world population. In broad terms, the highly diverse food industry comprises a complex network of actors, resources, and processes that add distinct value and facilitate the growth, transportation, retail, and consumption of food products. The food production and distribution process connects all stakeholders from producers to consumers with a global-scale food network that is highly interwoven with culture, economics, environment, politics, and science.

The food industry is associated with and responsible for every detail of food products from farm to fork. A wide variety of activities occurs in the food industry, including research and development (e.g., to develop effective means to address pests and the damage they create), agriculture (e.g., to grow crops, raise livestock), food processing (e.g., transform fresh food products to canned and packaged food products), the creation of regulations for food production and distribution that ensure safe food products, and the packaging, distribution, advertising, and marketing of food products. As our modern world evolves rapidly through environmental changes, technological innovations and population shifts, the global food network is undergoing rapid transformation as it adapts to significant challenges and opportunities.

RFID and Sensor Network Automation in the Food Industry: Ensuring Quality and Safety through Supply Chain Visibility, First Edition. Selwyn Piramuthu and Wei Zhou.

In this book, we embrace technological innovation across the food supply chain as well as the set of perspectives that brings food products from farm to fork. Specifically, we consider RFID (radio-frequency identification) and its use in the food industry. While the extent of RFID use in the food industry in general is not as widespread as it is in the apparel and pharmaceutical industries, there is certainly an increase in interest for RFID in raw material production for use on farms as well as livestock, food-supply chains at least at the pallet level, and for inventory management as well as to address various forms of shrinkage at retail stores. We provide a basic high-level introduction to RFID in Chapter 2 to help understand its general characteristics, what it can and cannot be used for, and some challenges that are associated with RFID adoption. For the remainder of this chapter, we briefly consider some general trends that affect the food industry, some of the challenges it faces, and the need for traceability in the food industry.

1.1 General trends

We now briefly discuss a few general trends that affect the food industry – population growth and the increased interest in food quality and safety.

1.1.1 Population growth

The food industry is generally credited with the provision of relatively affordable food products at locations that are not too inconvenient to a reasonably large proportion of the world's population. While the overall amount of food produced is likely to be enough to feed the world and to eradicate hunger altogether, there are severe constraints that prevent this from realization: the supply of and demand for food products are not necessarily in close physical proximity to each other, the lack of physical infrastructure such as roads at some locations where food products are urgently needed, the perishable nature of food products, unsaleables due to damage and waste at farms and elsewhere, and ultimately economic infeasibility.

As the world population size grows, this imbalance in the ability of food industry to ensure that food product demand is satisfied with at least enough supply in terms of when and where food is needed is only likely to worsen. Most forecasts predict a steady increase in the world's population. For example, the United Nations has forecast, the world's population to increase to 9.15 billion by 2050 and generate about a 60% increased demand for food. Concomitant to this population increase are several directly or indirectly related issues such as the effects of global warming and the increase in the volume of crops that are used for bioenergy and other industrial purposes, which essentially reduces available land for food products for human consumption. According to an estimate by the Intergovernmental Panel on Climate Change (IPCC 2014, Chapter 7), global warming has been reducing agricultural yield by 2% per decade even as global food demand has risen by 14% per decade over the same period. Moreover, uneaten food reduces other scarce resources such as fresh water and oil.

The United Nations Food and Agriculture Organization (FAO) estimates that, each year, about 1.3 billion tons, which is about a third of the food produced in the world for human consumption, is wasted or lost in the food supply chain due to various reasons. In addition to related social and economic implications, there are clearly associated environmental impacts. In the United States, for example, about two thirds of the food waste ends up in landfills with about a quarter in terms of its weight generated as methane gas, which is a major contributor to global warming. With the projected increase in human population and the issues associated with the availability of food products when and where they're required, it is critical for the food industry to meet the food consumption needs of people worldwide so that they can have healthy and active lifestyles with access to high-quality, fresh, and nutritious food.

Clearly, with the steady increase in competition for agricultural land between products that are and that are not meant for human consumption, it is becoming necessary to adapt our ways so that more people are fed with output from less land. Moreover, there is also widespread realization that raising production levels alone will not necessarily address the issues facing the food industry because inadequate storage and distribution is the major cause of food loss in developing countries and wastage at the retail and consumer level is the major cause in affluent countries (www.sustainablefoodssummit.com, accessed October 2, 2015). The changing diets in the developing world also require appropriate responses from the food industry. There is also a need to protect existing natural resources because agriculture already consumes around 70% of all fresh water that is used and accounts for about a third of the greenhouse gas emissions while utilizing about 40% of the available land area. The challenge, therefore, is to improve sustainable food production that minimizes its environmental impact and takes into account societal preferences and needs as well as its economic impact on the overall food industry.

Despite the gloomy projections by forecasters around the world on the availability of food to sustain the population in the immediately foreseeable future, not all hope is lost yet. When we look at history, there is a strong precedent for the ability of humans to step up to the plate and do what is necessary. For example, agricultural production across the world doubled four times between 1820 and 1975 to feed a global population that increased from one billion human beings in 1800 to 6.5 billion in 2002 (Scully 2003). Given current levels of inefficiencies in the food supply chain, as evidenced by the amount of wastage, surely there are ways to improve the food supply chain efficiency and to increase the *effective* amount of food that is available for human consumption (Oxfam 2014). We discuss some of these issues in Chapters 5 and 8.

1.1.2 Food quality and safety

As demand for food products has increased, developments in food product technology have extensively modified the processes involved in the production and distribution of food products. The science of food production evolves in response to continual pressure from population growth, arable land shrinkage, species vulnerability, and environmental disruptions. To ensure safe and animal-friendly production, restricted pollution, and use of natural resources, governments have responded through new legislation and regulation. Examples of this include the *Codex Alimentarius* standards, the General Food Law (European Union 2002/178), and the EU-BSE (bovine spongiform encephalopathy) regulations.

Since the first session, held in Rome in October 1963, the primary goals of the Codex Alimentarius Commission have been to ensure food safety and fair practices in the international food trade. Jointly administered by FAO and WHO, the commission sets standards related to food products in terms of guidelines, codes of practice and recommendations, on hygiene, food labels, food safety, and risk assessment, contaminants in food, limits on pesticide residues, food additive provisions, limits on veterinary drugs in human food, among others. Some of the well known safeguard concepts such as "best if used before" were established by this commission. The commission evolves with food trends, and has guidelines for labels and associated standards for low-fat, light food, and organic, genetically modified ingredients, among others.

As per *Codex Alimentarius* (FAO/WHO, 2001), "food safety is the assurance that food will not cause harm to the consumer when it is prepared and/or eaten according to its intended use." Numerous opportunities exist for food safety violations during the processes, procedures, or stages that any given food product passes through on its way from farm to fork. The onus is placed on the food industry to provide food products that are safe for consumption in line with *Codex Alimentarius*.

With increasingly frequent cases of food contamination reported in the news, today's consumer is inevitably rather circumspect when it comes to the quality and safety of food products as well as the possible negative effects of bioindustrial food production. In general, food safety signifies various chemical and microbiological elements in food products. While some of these chemicals and microbiological organisms are safe for human consumption, it is important to identify and eliminate the harmful ones.

The quality of a food product depends to a large extent on its specific characteristics and its production process. Its own characteristics can vary and depend on weather conditions, biological variations, seasonality, storage, transportation, cooling facilities, and hygienic measures, as well as its producer. Based on these characteristics, specific hazards may be introduced such as cross contamination of batches when different batches are mixed as well as when the same resource is used for the production of different intermediate products, as well as the challenges associated with quality assurance when raw materials are sourced from different suppliers.

Human food safety is relatively easy to define based on these considerations. On the other hand, food quality is difficult to define because it also depends on context and point of reference. In this sense, food quality can include organoleptic characteristics, functional and physical properties, nutrient content, consumer protection from fraud, geographical characteristics such as controlled appellations, political and social issues such as farm-worker wages, and religious dietary restrictions (for example halal and kosher food). The scope of both food quality and food safety increases with the globalization of food supply chains. We consider this topic in detail in Chapter 9, along with discussions on how RFID can help ensure food quality and safety.

1.2 Challenges faced by the food industry

Despite the advances in knowledge and efficiency related to various facets of the food industry, several challenges still remain to be addressed. With globalization and the presence of several sources for most food products, the food industry faces margin shrinkage as it copes with the demand for high-quality products that are competitively priced. While tapping supplies from across the world helps reduce cost to address margin shrinkage and allows for the global availability of food products regardless of their local availability or seasonality, it comes with several risks that are primarily associated with compliance, and product safety, among others. The global regulatory environment is complex, with different sets of standards across different markets, and the race to comply with international regulations becomes an important factor.

To remain competitive, the food industry continually strives to develop innovative means to reduce its costs while it deals with uncertainties such as oil prices and their effect on transportation costs as well as on packaging and agrochemicals. The rapid changes in consumer demand, such as that toward healthier and sustainable food products dictates faster time to market and product offers that address consumer needs for the food industry to be successful and profitable.

The US Food Safety Modernization Act (FSMA) also places a strong emphasis on upstream visibility. While this may be easy to accomplish at a local level, it is very difficult on a global scale where food products are bought and sold across complex supply networks. To add to the stress of globalization, the food industry also has to face issues related to adulterated food and counterfeits. Traceability addresses issues related to counterfeits, regulations and compliance as well as the reduction of operational risks. Traceability also facilitates quick response to adverse events such as food contamination through targeted recall.

Changing consumer preferences, rising cost of energy and raw materials, safety and legislative factors, and sustainability concern require food producers and others in the food industry to always be vigilant and quickly adapt to demand variations while keeping cost, performance, and productivity in check. Given the thin margins and the need for quick payback through sales or reduced operational costs, the food industry has been slow at adopting technologies that may not allow for clear determination of their return on investment (ROI). Examples of such technologies include improved customer store experience (e.g., faster checkout, product information next to the product display). A similar argument can be made for adoption of RFID tags in the food industry because several of the benefits (e.g., reduced shrinkage, reduced waste, better inventory management, quick checkout) they provide do not yet exist in a retailing environment that relies solely on information retrieved through scanned bar codes. We discuss some of these in Chapter 6.

1.2.1 Political, economic, and social influences

The food industry plays a significant role in the lives of the world's population. It is also highly constrained on several fronts including those that originate from nature (e.g., perishability, rainfall, sunshine, flooding, drought), and man-made ones (e.g., demand for food products outside of their normal seasonality). A picture of the food industry is incomplete without consideration of its political and economic aspects and its complex relationships with the cultural and natural environment as well as the effects due to the globalization of food.

The food industry faces several challenges that include a decline in biodiversity, climate change, the wide and rapid spread of infectious diseases, and safety and sustainability concerns associated with global food sources. In addition to the overall population increase, the food industry is witnessing more pressure from worldwide migration trends, which are showing a strong tendency toward rural-to-urban movement. With demand for fuel crops, the use of arable land for human food production faces stiff competition. Overfishing and unethical fishing as well as the toxic pollutants that are dumped in the water supplies, degrade the oceans and their capacity to provide consumable seafood.

Within the globalization context, governments and citizens have witnessed a trend to redefine food security in terms of its production rather than market access. The end effect of this trend is the reinvigoration of regional food production for local consumption and reduced globalization in the food industry. The primary impetus for these movements includes issues related to water and energy supplies. Local food supply essentially translates into the inability to fulfil out-of-season demand for certain food items that are not local, thereby increasing the volatility in prices of agricultural products. The efforts to account for environmental costs associated with agriculture and food production introduces additional challenges to food products that are sourced from more distant locations. Nevertheless, consumer demand for cheap and convenient food products has remained on the rise.

The demand for sustainably produced food has never been higher. The new generation of consumers demand the food industry to demonstrate how it minimizes impact on the earth while sustainably producing and delivering safe food products. Sustainability signifies different issues to different consumers. In general, however, sustainability includes the use of child labor, poor working conditions on the farm as well as the entire food supply chain, the use of pesticides and other chemicals to grow or process food products, environmental damage, animal welfare, food packaging, food wastage, GHG emissions, among others. The greening of food supply chains addresses some of these environmental sustainability issues, and we discuss this general topic in detail in Chapter 7. We discuss some of the policy issues related to the food industry in Chapter 11.

1.2.2 Global warming

Although the debate on global warming and climate change continues, the environmental damage caused by pollution is indisputable. The contribution of the food industry to pollution is also indisputable and includes contamination of air, soil, and water through the application of pesticides, herbicides, fungicides, fertilizers, and other chemicals; energy that is primarily derived from fossil fuel and is used throughout the food industry; greenhouse gases from various sources that include livestock as well as food waste that ends up in landfills, and so forth. While models that estimate the amount of greenhouse gas emissions and their absorption into the environment are still under development and refinement, such as the recent revision of previously underestimated amount of absorbed CO_2 by plants (Sun *et al.* 2014) in extant models, there is no doubt on the existence of such emissions. Clearly, as pollution causes harm and not all of this pollution can be eliminated, there is an urgent need for its reduction. The food industry therefore faces the huge responsibility of ensuring that the world population does not suffer from hunger and malnutrition, while it simultaneously strives to develop means to revolutionize its production methods fundamentally in order to reduce its environmental footprint. We discuss some of these topics in detail in Chapters 3 and 4.

Climate change contributes to drought, floods, storms, and other adverse conditions. The effect of climate change on the food industry is undeniably harsh in terms of crop failures and supply disruptions, resulting in more hunger and poverty. Paul Polman, CEO of Unilever, estimates that the company loses 300 million euros a year due to extreme weather events such as flooding and extreme cold (Yeo 2014). Researchers estimate that, by 2050, climate change could result in an additional 25 million malnourished children under 5 years old (Nelson *et al.* 2009) and 50 millon more hungry people (IPCC 2007). This unfolding human dimension of climate change crisis affects the poorest and most vulnerable people hard first, with the rest of the world population not too far behind given that the earth is a closed system for all practical purposes.

While the fossil-fuel industry is commonly accused of being the primary source of greenhouse gas emissions, the food industry plays a major role as well. The recent report from the Intergovernmental Panel on Climate Change (IPCC) shows that agriculture and deforestation (Hansen *et al.* 2013) that is largely driven by a need for more agricultural land share about a quarter of the global greenhouse gas emissions (IPCC 2014). With the projected increase in world population and related increase in demand for food, there will a concomitant increase in agricultural emissions of 30% by 2050 (Tubiello *et al.* 2014). Within the food industry, the lion's share of emissions arise from raw material production, which includes nitrous oxide from fertilizer use, methane from livestock, and carbon emissions from expansion of agricultural land into forests. In its recent assessment, the IPCC concluded that climate change has already lowered wheat and maize yields in many regions and globally on average since the 1960s (IPCC 2014).

1.3 Traceability in the food industry

Based on the discussion so far, it is clear that there is a need for more visibility regarding what happens at the "farm" as well as in the rest of the food supply chain. A high level of detailed visibility would help (i) effectively and efficiently manage raw-material production, (ii) identify imminent potential for as well as actual deviations in processes and procedures, (iii) guarantee food product quality and safety through immediate identification of deficits or compromises in production equipment before or as soon as they happen, (iv) ensure that all appropriate quality and safety measures are taken throughout the food supply chain to prevent contaminants, (v) keep track of perishables and ensure that they reach the consumer in good condition with the most appropriate choice of outlets, (vi) discourage adulteration, (vii) extend the shelf life of food products through proper management of their ambient conditions (e.g., gas, temperature, humidity) throughout the food supply chain, (viii) facilitate highly targeted and effective recalls when mishaps do occur, (ix) facilitate effective inventory management and reduce overall shrinkage, (x) fine tune production and distribution of food products so that their overall environmental footprint is reduced, and (xi) reduce overall wastage of food products so that more people can be fed with fewer raw materials.

Long ago, when the locations where food products were grown in small quantities and the locations where such food products were consumed were physically within a few kilometers of each other, it was possible to manually trace every food product item from farm to fork. It was possible because the individual food products were highly visible at all times to the humans who handled those products.

With industrialized food production in place today, it is impossible to imagine the achievement of a high-level visibility through manual means alone. Visibility, and associated traceability, are achieved through unique identification of the entity (e.g., truck, container, pallet, case, item) of interest.

With traceability, the finer the granularity is across the entire food supply chain the better it is to ensure detailed visibility. While a coarse level of granularity is better than no traceability, the coarser levels do not allow for finer level control, which is essential if traceability is to be most effective. It becomes increasingly expensive as we move from the coarsest to the finest level of granularity in terms of traceability. The finer levels necessarily require the deployment of an increased number of identifiers that are attached to and travel with the entity (e.g., truck, container, pallet, case, item) that is traced. Traceability at truck level, while it provides some level of benefit, does not support the making of decisions that really make a difference. For example, consider a truck load of strawberries, a third, which are located farthest from the cooling unit are about to be spoiled – i.e., have a remaining shelf life of a few hours as opposed to a few days for the rest of the truckload. When truck-level traceability is in place, the probability is very high that the entire truckload will be rejected by the recipient. On the other hand, if traceability is at the pallet level, the pallets with strawberries that have almost no remaining shelf life can be locally sold at a discount for immediate use (say, at a cafeteria nearby) with the remainder of the truckload sold to its intended recipient at the originally intended price.

The "one-up/one-down" traceability solutions in use today are clearly insufficient for effective recalls, and also for quality management and reduction of food wastage. The use of some form of e-pedigree right from the food source is ultimately the goal or gold standard for effective traceability. Given the costs associated with each unique identifier as well as associated systems, it is mostly the large food supply chain players that have adopted such traceability systems. While it is economically possible for the smallest of food product producers to be included in an effective track-and-trace system, the lack of necessary infrastructure has precluded their fullest participation. For traceability to be effective, it is necessary for all stakeholders in the food supply chain to join forces and pool their resources as well as to play their roles. For example, traceability only at the lowest downstream stages of the supply chain is useless because it misses out on opportunities to improve the food supply chain upstream. Moreover, when food products are improperly handled upstream due to lack of a track-and-trace system, the effects are magnified and felt downstream. Surprisingly, even in the pharmaceutical industry, which can afford such technology (at least relative to the food industry, where margins are rather low), implementation of the "mass serialization" e-pedigree initiative has been slow and rather basic; data are collected but visibility is not at the level that one would expect in those supply chains.

Based on currently available technologies for unique identification of entities where such an identification process is quick and automated, RFID is clearly superior to both in terms of functionality, form factor, and price. RFID tags are not new to the food industry, as these tags have been used to identify livestock for more than a decade now. Nevertheless, RFID tags are increasingly being used in food supply chains as a means to provide visibility in these supply chains. However, to our knowledge, these are very basic tags, which provide identification information as well as some information on the tagged entity's pedigree at best. The potential for RFID tags in the food industry is vast when sensors are used to measure ambient conditions as well as the presence of microbial organisms. The technology to do this exists already. It is therefore only a matter of time before mass adoption of RFID technology occurs in the food industry with an associated drastic reduction in adoption and maintenance costs.

Cost is certainly the main factor in RFID adoption decisions. However, as more and more firms such as those in the pharmaceutical and apparel industries adopt and incorporate RFID tags in their supply chains and show evidence of a sustainable return on investment (ROI), there will be fewer barriers to entry for even the smallest players in the food industry. Unlike the apparel industry where vertical integration and therefore adoption of very fine granular identifiers are easy (here, *item-level* RFID tags in use at American Apparel, Trasluz), it is challenging in the food industry because there are not many completely vertically integrated firms in this industry. This state of affairs necessarily calls for concerted action by all players in the food industry for such an initiative that promotes the adoption of RFID tags at lower levels of granularity to be successful. Research (Piramuthu *et al.* 2014) has shown that placing RFID tags on items that cost even less than these tags is sometimes necessary at retail stores. Moreover, consideration of only the cost component in RFID adoption decisions is misleading at best because the RFID tag is superior to the bar code in several important ways. The bar code is the RFID tag's main and, for all practical purposes, only competing technology in common use today for automatic identification and data capture (AIDC). The benefits attributable to RFID tags for their ability to provide real-time visibility easily override any cost-related issues. Regardless of the trend toward real-time visibility in several industries (e.g., apparel, pharmaceutical), and the richness of information generated in such real-time systems, the food industry has been a rather slow adopter of RFID technology for various reasons.

Upon implementation of real-time RFID tags in an environment that for a long time has supported only bar codes, each of which were scanned maybe a few handful of times at the most in their lifetimes, the sheer volume of data that are automatically generated by RFID tags necessitates a system that has the capability to use such data in real time as they are generated. Data thus generated that cannot be utilized for decision-making purposes or for the provision of necessary information that lead to actionable outcomes is considered useless. It is therefore important to have appropriate systems in place to handle such "big data" as they are generated. We discuss big data from the perspective of the food industry in detail in Chapter 10.

When appropriately deployed in the food industry, RFID tags can and will provide necessary real-time or near real-time information that can readily be used in automated systems to make decisions. We consider several opportunities for RFID tags both in terms of traceability as well as a part of sensor networks for other purposes (e.g., precision farming) in the food industry throughout this book.

1.4 Structure of this book

We consider the entire food supply chain that begins with the food source at the farm all the way until it reaches the consumer. The overall structure and framework of this book is given in Figure 1.1. Throughout the book, we "explode" or expand each of these modules or stages and consider their underlying dynamics in detail, with the specific goal of identifying potential or existing RFID applications.

We consider each of the stages in this structure in turn in the remainder of the chapters. Specifically, we highlight some of the topics that are covered in each of the chapters below.

Chapter 2: RFID, Sensor Networks

In this chapter, we provide an overview of RFID technology, EPC standards, sensor networks and their market potential. In general, RFID and sensor networks can be used throughout the food supply chain, from precision agriculture, food

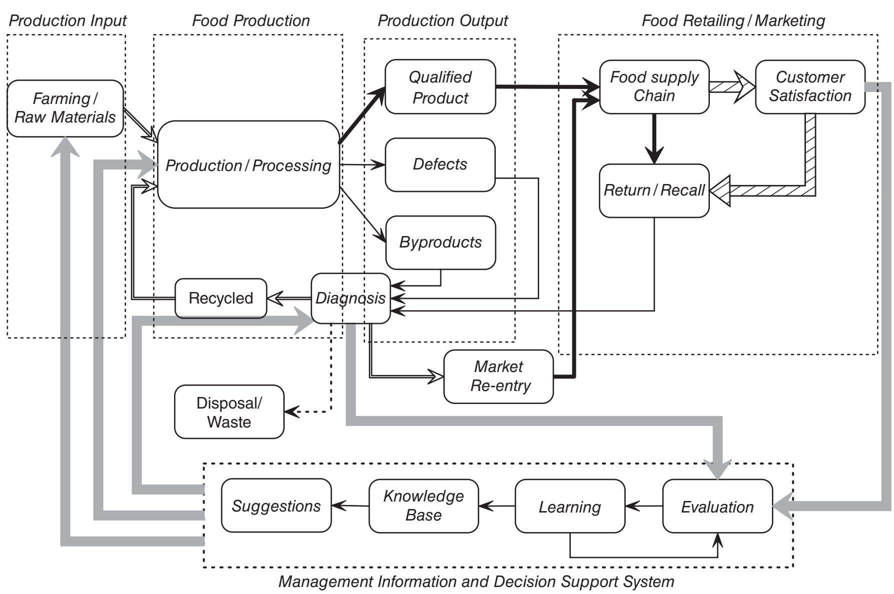

Figure 1.1 Food processing with RFID and sensor network

processing and packaging, transportation, storage to final consumption. We first review the history of RFID and relevant technologies. We then provide a technological overview of RFID, followed by its integration of sensor networks in food industry. We also discuss some of the main challenges that are generally associated with the adoption and use of RFID and sensor network systems in the food industry.

Chapter 3: RFID in Agriculture

In this chapter, we review agricultural practices and principles. We first introduce the agricultural production system, including crop cultivation, livestock, and mixed systems. We then discuss the role and practices of RFID-enabled sensor-network automation in agriculture such as environmental monitoring, precision agriculture, machinery management, facility automation and agricultural traceability. Finally, we discuss RFID implementation standards, challenges, and limitations in agriculture.

Chapter 4: RFID in Food Processing

In this chapter, we review the technologies and procedures used in food processing, including preparation and separation, conversion, structural formation, stabilization, and packaging. We discuss the role and importance of RFID and sensor networks in various food-processing procedures. We provide a general technological overview of the synergistic use of RFID, wireless sensor networks, and automated process control in food processing.

Chapter 5: RFID in Food Supply-Chain Management

In this chapter, we introduce the concept of food supply-chain management. We first define the concept of RFID-enabled supply-chain traceability. We then discuss the importance of global food supply-chain collaboration via electronic means. We also discuss a special case of RFID in cold-chain logistics management, and third-party certifications (TPC).

Chapter 6: RFID in Food Retailing

In this chapter, we investigate modern marketing concepts enabled by granularized product-retailing information and customized consumer information. These concepts and practices are mostly enabled by RFID and other recent advances in information and communication technologies. Specifically, we first review internationalized food marketing and retailing. We then discuss the concept of dynamic food retailing management with the incorporation of RFID technology. In what follows, we introduce the concept of multiple channel retailing in the food chain with the inclusion of both online and offline sales channels. We then discuss the role of RFID in perishable food retailing practice. We conclude by discussing loyalty programs and customer-relationship management with RFID from a food-retailing perspective.

Chapter 7: Green Food Supply-Chain Management

In this chapter, we review RFID and sensor network industry practices in food supply chain sustainability and carbon footprint management. We investigate the role of RFID in reducing food waste and energy consumption throughout the supply chain. We first introduce the concept of CF (carbon footprint) and LCA (life-cycle sustainability assessment). We then discuss the challenges associated with CF for food items, local food and the food miles concept, and CO_{2e} labels. At the end of this chapter, we discuss some mechanisms to reduce emissions through supply chain efficiency.

Chapter 8: Perishable Food and Cold-Chain Management

In this chapter, we discuss visibility in cold chains with specific emphasis on traceability and related issues. We first introduce cold-chain management and discuss some of its dynamics, followed by traceability in cold chains. We then discuss specific issues associated with supply chain visibility and its role in ePedigree as well as in alleviating effects due to contamination incidents. This is followed by discussion on food traceability. We conclude this chapter with a discussion on applications of RFID for traceability in cold chains.

Chapter 9: Food Quality, Safety and Security

In this chapter, our focus is on biological pathogens and chemical contaminants from the perspective of food quality, safety, and security. We begin with an overview of this general area. We then follow this with discussion on the use of different types of biosensors for foodborne pathogen detection. Food spoilage is an important facet of food quality and safety. We first discuss several factors that affect food spoilage and related illness. We follow this with discussion on food spoilage prevention as well as extension of food shelf life. We end the chapter with discussion of several methods of microbial detection and their general characteristics. Along the way, we intersperse discussions with related RFID applications as appropriate.

Chapter 10: Big Data in the Food Industry

In this chapter, we discuss big data and its applications in the food industry. Specifically, we discuss big data analytics and associated considerations. We then discuss several scenarios in the food industry that involve the use of big data.

Chapter 11: Food Policy

In this chapter, we discuss international food policies and regulations. Specifically, we consider food-safety certification and good manufacturing practice regulation. We then discuss the impact of information technology, including RFID, wireless sensor networks, and automated food manufacturing on food-policy compliance.

References

FAO/WHO (2001) Report of the CODEX Committee. Circular letter CL 2001/31-CPC. Joint FAO/WHO Food Standards Programme, Rome.

Hansen, M. C., Potapov, P. V., Moore, R., *et al.* (2013) High-resolution global maps of 21st-century forest cover change. *Science* **342**(6160), 850–853.

IPCC (2007) Climate Change 2007: Working Group II: Impacts, Adaptation and Vulnerability, Chapter 5, https://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch5.html (accessed September 29, 2015).

IPCC (2014) Climate Change 2014: Impacts, Adaptation, and Vulnerability, http://ipcc-wg2.gov/AR5/ (accessed September 28, 2015).

Nelson, G. C., Rosegrant, M. W., Koo, J., *et al.* (2009) Climate Change: Impact on Agriculture and Costs of Adaptation. International Food Policy Research Institute, Washington DC, http://www.ifpri.org/sites/default/files/publications/pr21.pdf (accessed September 25, 2015).

Oxfam (2014) Building a New Agricultural Future: Supporting Agro-Ecology for People and Planet. Oxfam International, Oxford, http://www.oxfam.org/en/grow/policy/building-new-agricultural-future (accessed September 25, 2015).

Piramuthu, S., Wochner, S., Grunow, M. (2014) Should retail stores also RFID-tag "cheap" items? *European Journal of Operational Research* **233**, 281–291.

Scully, M. (2003) Dominion: The Power of Man, the Suffering of Animals, and the Call to Mercy. St. Martin's Griffin, New York, NY.

Sun, Y., Gu, L., Dickinson, R. E., *et al.* (2014) Impact of mesophyll diffusion on estimated global land CO_2 fertilization. *Proceedings of the National Academy of Sciences of the United States of America* **111**(44), 15774–15779.

Tubiello, F. N., Salvatore, M., Cóndor Golec, R. D., *et al.* (2014) *Agriculture, Forestry and Other Land Use Emissions by Sources and Removals by Sinks: 1990-2011 Analysis. Food and Agriculture Organization*, Available: http://www.fao.org/docrep/019/i3671e/i3671e.pdf (accessed September 25, 2015).

Yeo, S. (2014) *Climate Action is Only Way to Grow Economy – Unilever CEO*, http://www.rtcc.org/2014/04/08/climate-action-is-only-way-to-grow-economy-unilever-ceo/ (accessed September 25, 2015).