Food Microbiology and Food Safety
Practical Approaches

Fernando Pérez-Rodríguez
Panagiotis Skandamis
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Quantitative Methods for Food Safety and Quality in the Vegetable Industry

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Dedicated to
Little Mary,
Clara,
and Ioanna

Contents

Quantitative Methods for Food Safety and Quality in the Vegetable Industry

Fernando Pérez-Rodríguez, Panagiotis Skandamis, and Vasilis Valdramidis

1 Introduction

The vegetable sector is key in EU agriculture, representing 13.6% of EU agricultural output. According to Eurostat, the price index of fresh vegetables increased by 6.8% compared to 2014 and by 2.1% if compared to the average of the previous 5 years. The sector employed 418,000 persons across the EU-27 in 2008 and generating about one sixth of the total value added within food, beverages, and tobacco wholesaling. These figures evidence the relevance of the vegetable sector in the European economy, being a leading sector in the food industry.

The vegetable transformation sector has undergone an important growth in the last decades due to higher consumption demand of fresh, natural, and easy and convenient food products. The changes in the developed country lifestyle have fostered the development of an ample and varied range of minimally processed and ready-to-eat products such as freshly cut fruits, snack vegetables, seedless fruit, easy peelers, etc. According to International Fresh-Cut Produce Association (IFPA)

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"these products are defined as any fresh fruit or vegetable or combination thereof physically altered from its original form, but remaining in a fresh state." These produces can be trimmed, peeled, washed and cut, and then bagged or prepackaged to offer consumers healthy products, convenience, and value while maintaining freshness.

A higher processing and handling level is usually associated with a higher probability of contamination. This together with the fact that vegetables are not submitted to any lethal treatment makes these products of special concern for industry and governments. A recent study conducted in Europe on consumption trends of fresh-cut vegetables demonstrated that shelf life and food safety are relevant factors in orienting consumer choices (Baselice et al. 2017). Indeed, the positive figures shown by the fresh-cut sector could be also related to the advances in product innovation and food quality and safety, which are generally appreciated by consumers.

In this food safety context, of prime concern to the vegetable sector, the quantitative methods are proposed as key for developing more efficient risk management strategies, facilitating a safer food production. Quantitative methods can enhance transparence, consistency, and interpretability of the food safety outcomes, providing a better basis for supporting decisions. The development of specific tools enabling quantitative and systems approaches to address food safety and quality issues may assist the industry to deal with an increasingly competitive market, where food safety attributes are well valued by consumers. Predictive microbiology and quantitative risk assessment are paradigmatic examples of how quantitative approaches can be incorporated in the food safety assurance systems at industrial and governmental levels to protect and improve public health. In addition, the use of quantitative data and methods in food analyses, shelf life determination, process optimization, or environmental impact assessment can provide with reliable tools to enhance food safety and quality enabling a rapid response to food quality problems while making best use of the available resources in the industry (time, workers, budget, etc.). The present book provides with a detailed review of those innovative and quantitative methods that are of relevant application for food safety and quality in the vegetable sector, describing methodologies and potential uses and presenting practical examples.

2 Aspects on Food Safety and Quality of Vegetable Products

Chapter "Quantitative Methods for Food Safety and Quality in the Vegetable Industry" by Cuggino et al. provides a brief introduction to the quality and safety assurance systems in the vegetable sector, defining the main concepts and presenting the international framework for food safety and quality. The chapter also describes the main components of the quality management systems such as good agricultural practices (GAP), good manufacturing practices (GMP), the integrated pest management (IPM), sanitation standard operating programs (SSOP), and the hazard analysis and critical control points (HACCP). The importance, for vegetable product safety and quality, of the development of an adequate regulatory framework and the application of quality certificates, food audits, and traceability systems is also highlighted in this work. Finally, Cuggino et al. present a general overview on the integrated quality management systems, in which GAP and GMP are essential elements, together with microbiological and chemical controls throughout the whole production chain. The most relevant microbial and chemical risks in the vegetable sector and associated control measures and regulations are also commented. Some of these hazards and risks will be in addition to the subject of different chapters in this book.

Minimally processed vegetables are perishable foods that may be contaminated pre- or postharvest from various sources and via multiple routes, including soil, irrigation water, insects, air, dust, human handling, transport vehicles, and processing equipment, e.g., for cutting and/or washing, etc. They are prone to microbial spoilage and contamination due to the following major characteristics: (1) the presence of cut surfaces and increased moisture content, which enhance microbial swarming and swimming (as taxis to nutrients), resulting in active or passive internalization (and sheltering) below the skin surface and, thus, enhanced microbial proliferation or extended survival, (2) the lack of sterility or microbial stability due to minimal processing, (3) the active metabolism of plant tissue, and (4) the confinement of the product in a modified atmosphere package. As a result, minimally processed vegetables have been repeatedly involved in foodborne outbreaks, with enteric bacteria and viruses (mainly Norovirus) being the major causative agents. Chapter "Relevant Pathogenic and Spoilage Microorganisms in Vegetable Products" by Pradhan et al. discusses the sources and routes of microbial contamination sources of vegetables and presents the biological safety and spoilage concerns of these products in two separate parts: in the first one, the chapter lists the recent foodborne outbreaks and details the occurrence of major biological hazards, namely, bacteria, viruses, and parasites in vegetables. Next, the pre- and postharvest risk factors contributing to hazardous contamination of vegetables are presented. The first part concludes with physical (irradiation and washing), biological (phages), and chemical (disinfection) mitigation strategies to control the aforementioned hazards. In the second part, the chapter reviews the spoilage organisms that occur in vegetables, and as in the first part, it ends with reviewing the physical (irradiation and heat, modified atmosphere), chemical (disinfectants), and natural (natural antimicrobials) technologies to prevent or delay spoilage and, thus, maximize the shelf life of packaged products.

Apart from discussing the strategies for controlling microbial hazards on the fresh produce industry, it is also important to consider the quality of the used wash water. It has been reported that the improper wash water management in the fresh produce industry could be one of the most important contributing factors to large disease outbreaks (CDC 2011). Chapter "Water and wastewater use in the fresh produce industry: food safety and environmental implications" by Gil and Allende covers a general overview on process wash water and wastewater of the fresh produce industry. Additionally, the impact of this water on food safety and environmental implications is showcased. The reader is introduced to different water qualities that can be found in a fresh produce industry as well as the recommended intervention strategies based on water treatments as well as to the main differences among process wash water, recycled water, and wastewater. Hereafter, disinfection technologies for process wash water and their major by-products and their environmental impact are summarized.

3 Application of Quantitative Methods for Food Safety and Quality of Vegetable Products

It is evident that water quality and its proper management are important issues to be considered in the industry. Chapter "Advanced Oxidation Processes (AOPs) and quantitative analysis for disinfection and treatment of water in the vegetable industry" by Pablos et al. after introducing the policy framework for water analysis presents a series of chemical and microbial parameters that need to be measured to assess the water quality. The importance of detecting priority pollutants, as pharmaceutical compounds, or "emerging pathogens" with antibiotic resistant genes by the use of new generation of analytical methods is highlighted. Hereafter, the authors introduce the readers with novel effective and lower-energy demand technology as advanced oxidation processes (AOPs), capable of generating a high amount of hydroxyl radicals upon irradiation. An overview of conservation equations of momentum, energy, and mass that are required for the predictive design of large-scale AOPs is presented. Finally, quantitative approaches to assess the impact of AOPs on the microbial safety of vegetable are presented within the framework of risk assessment and predictive microbiology.

Apart from the use of analytical methods to assess the water quality and the fresh produce, recent advances focused on the development of process analytical technologies (PAT). Huang et al., in Chap. "Quality of vegetable products: Assessment of physical-chemical and microbiological changes in vegetables products by non-destructive methods", focus on the assessment of the physical-chemical and microbiological changes in vegetables products by nondestructive methods, also known as PAT. The focus is on sensing technologies, imaging processing, and chemometrics methods. Therefore, on the one hand, they refer to data collection through computer vision, multispectral imaging, near-infrared spectroscopy, and hyperspectral imaging and, on the other hand, to the analytical methods and chemometrics. These methods have applications in assessing external qualities such as shape, size, color, texture, and defects, and internal qualities such as soluble solids content (SSC), acid and internal defects, and microbiological changes such as microbial and fecal contamination are discussed in detail which the authors present based on literature examples.

As mentioned at the beginning of this introductory chapter, quantitative methods or tools, such as predictive microbiology and quantitative microbial risk assessment (QMRA), can be used to understand and predict the microbial behavior, to evaluate different control strategies and manage food safety risks to produce safer vegetable products and reduce the number of vegetable-related foodborne illnesses. Concepts and examples of the application of predictive modeling tools for assessing the safety and spoilage of vegetables can be found in Chap. "Ensuring fresh produce safety and quality by utilizing predictive growth models and predictive microbiology software tools" of this book by Koseki et al. Chap. "Quantifying human health risks associated with microbiological contamination of fresh vegetables" by Franz et al. presents an overview of existing QMRA approaches and discusses the advantages and mostly the complexity of QMRA which results in a number of limitations in the available QMRA. In particular, the use of QMRA to manage fresh produce safety risk is complicated by a vast number of produce items, production/processing conditions, as well as the lack of supporting data leading to uncertainties or variability in the outcomes. The complexity and variation of the fresh produce production chain may explain the fact that all QMRAs available differ with respect to their focus: manure versus water as primary source of contamination, phases and processes included/excluded, pathogens and produce items. In addition, there is a large variability between risk assessments with respect to the origin of data (different studies, testing strains, experimental conditions, data from surveys or experiments, etc.) and the choice of sub-models for growth/survival and dose-response. The chapter identifies the major data and knowledge gaps in performing QMRAs in fresh produce, including baseline prevalence data, survival/growth data, consumer practices, etc., and comparatively evaluates alternative approaches, e.g., meta-analysis and discrete population scales to deal with these data gaps.

Food industry is commonly considered as a more traditional industrial sector, where innovation and development are more slowly implemented. This is especially relevant in small and medium enterprises where resources are quite limited. Nowadays, process optimization has become a more relevant aspect in the food industry due to a more and more competitive market and a major pressure from the public administration. Reducing product and economical losses and increasing productivity are key to survive and grow in a global market. Quantifying food processes allows for assessing the process effect on production, in a more precise and objective fashion, identifying those process parameters and conditions resulting in better food production performance. Generating and increasing quantitative data through food chain can allow us to outline a clearer picture of risk through the food chain. Concepts such as appropriate level of protection (ALOP), food safety objective (FSO), performance criterion (PC) or performance objective (PO), and QMRA are proposed by international organizations as quantitative tools that can be applied to develop food safety recommendations, control measures, and microbiological criteria as well as determining risk factors. Chapter "Quantitative approaches for Microbial Risk Management in the vegetable industry: Case-studies of application of Food Safety Objectives and other risk metrics in the vegetable Industry" by Augustin and Guillier defines those concepts and describes how the acceptable level of risk for produces can be translated into FSO which is then translated into PO or product criterion, using different quantitative approaches (e.g., point estimate and probabilistic approach) and modeling strategies such as the approaches termed "top-down" and "bottom-up." The equation proposed by ICMSF (International Commission of Microbiological Specifications for Foods) is presented, and how this mathematical and conceptual tool can be used to derive and articulate different risk-based metrics (e.g., FSO and PO) is discussed. Finally, some examples are provided illustrating how POs can be derived for irrigation water for different foodborne pathogens as well as PCs can be determined for sanitizing washing and raw ingredients of a ready-to-eat salad for *Listeria monocytogenes* and *Bacillus cereus*, respectively.

Modified atmosphere packaging is the most common commercial packaging type for minimally processed vegetables and especially fresh-cut salads. MAP should aim to balance between the postharvest (in-package) respiration rate of the packaged tissue and the indigenous enzymatic activity of the tissue, which both may contribute to quality decay, *via* discoloration and texture breakdown, the microbial activity and the exchange of gases (with O_2 and CO_2 being the most critical ones) between the interior of the package and the environment *via* the packaging film. Chapter "Optimal packaging design and innovative packaging technologies for minimally processed fresh produce" by Vermeulen et al. first explains the principles that control the quality and safety of minimally processed fruits and vegetables relying on: (1) physiological and (2) microbial processes. Then, the chapter reviews the state-of-the-art methods for preserving minimally processed vegetables through packaging. In principle, it discusses how the aforementioned physiological and/or microbial processes can be retarded by using the optimal packaging design, defined as EMAP (equilibrium modified atmosphere packaging). Reference to the pros and cons of super atmospheric oxygen packaging is also made. The performance of EMAP is highly influenced by the accuracy of the respiration rate assessment and by the initial microbial load on the fresh produce. Once the respiration rate has been assessed, the optimal packaging concept can be designed based on the necessary permeability. The chapter deals with methods for determining the respiration rate, so that the product-specific properties that determine quality decay are determined and then discusses the standards of packaging material, e.g., structure, permeability, film composition, and mechanical properties that can be adjusted so that the film permeability matches the respiration rate of the product.

Predictive microbiology is an area of food microbiology intended to study the behavior of microorganisms in food environments as a function of extrinsic and intrinsic variables. The information collected from these studies is used as base to build up mathematical functions able to simulate and predict microbial response in foods. The predictive models are key elements in the development of quantitative risk assessment and can be applied in the different steps within a hazard analysis and critical control point (HACCP) system. They can also be deployed to determine product shelf life based on the level of growth and inactivation of pathogens and spoilage microorganisms predicted by the model. The models can be classified in different types according to the model structure. The primary models are those reflecting the microbial load change with respect to time. Secondary models relate the kinetic parameters from primary models to environmental factors. Finally, tertiary models are not models itself, but rather they refer to implementations of primary and secondary models in software tools (e.g., spreadsheet software) in order to provide estimates of microbial behavior under specific conditions defined by users. Tertiary models enable non-expert users to easily apply models in different food context and applications. Chapter "Ensuring fresh produce safety and quality by utilizing predictive growth models and predictive microbiology software tools" by Koseki presents a brief review of predictive microbiology models for vegetable products and introduces readers to the use of tertiary models, with special emphasis in the web tool, microbial responses viewer (MRV), for which some examples for vegetables included in the software are described. Hereafter, Posas et al. in Chap. "Quantitative tools and procedures for shelf life determination in minimally processed fruits and vegetables" shows how the previously discussed predictive microbial principles have been used in literature to assess microbial growth responses in different fresh produce. Additionally, the authors provide an overview on processes influencing quality changes, i.e., biochemical, physiological, and microbiological, of minimally processed fruits and vegetables as well as the available procedures and quantitative tools that are applied in shelf life determination. The reader is introduced to the currently used methods for shelf life determination in minimally processed fruits and vegetables. Finally, the chapters present a case study on ready-to-eat lettuce shelf life estimation by using the powerful computational tool of MicroHibro.

The One Health concept is a worldwide approach for enhancing interdisciplinary collaborations and communications concerning health care for humans, animals, and the environment. Food safety is not considered as an isolated and independent concept anymore. On the contrary, food safety should closely be connected to environmental health and waste reduction. In keeping with this, the waste derived from the processing of raw vegetable and fruit materials is a relevant concern to the food industry that should be approached from a multidimensional perspective.

The life cycle assessment (LCA) is a multidimensional quantitative tool that allows for the evaluation of environmental impacts and food safety of a product or production system. The LCA applied to the food industry can comprise all the stages through the food chain: raw materials, packing/packaging, distribution, use of products, reuse or recycling process, and management of produced waste. As consequence from this multidimensional approach, LCA can be considered in line with the One Health concept, where the health of people is connected to the health of animals and the environment. The goal of One Health is to encourage the collaborative efforts of multiple disciplines—working locally, nationally, and globally—to achieve the best health for people, animals, and our environment.

Chapter "Quantitative methods for Life Cycle Assessment (LCA) applied to the vegetable industry" by Moreno et al. introduces readers to the main types and steps (goal and scope, inventory analysis, impact assessment, and interpretation) in the development of LCA studies, providing a detailed analysis on its application in the vegetable industry. For that, different studies taken from literature are used as example for different vegetable products (e.g., tomatoes, RTE lettuce, broccoli, etc.). Furthermore, the work presents a thorough analysis of the main environmental impacts identified in the different types of vegetable industry. Finally, the work developed a case study of application of LCA for packaged lettuce salad produced in Spain.

4 Concluding Remarks

Presence and persistence of pathogens in vegetable products pose a potential risk of causing foodborne diseases as most of the vegetable products (e.g., leafy greens) are consumed raw without any additional lethal step. Different preharvest and postharvest mitigation strategies especially during washing and sanitization steps are aimed at reducing risk of pathogens and spoilage microorganisms. Advanced oxidation processes (AOPs) have emerged as a set of sustainable and innovative sanitation technologies intended to improve microbiological and chemical quality of processing water, even though their impact on microbial risk in RTE vegetables still needs further study. Also, packaging is considered as an effective technology able to retard microbial growth and biochemical deterioration in foods. In the vegetable sector, packaging design should consider tissue respiration rates and film permeability to determine the most suitable packaging parameters enabling longer product shelf lives.

Spectral data processing and analysis is another tool with promising application in the vegetable industry, allowing nondestructive, rapid, and reliable analyses of safety and quality attributes in foods. Nevertheless, these techniques will require further developments for assessing the internal quality and safety assessments (multispectral imaging) and improving detection limits and sensitivity (near-infrared spectroscopy) before being applied widely in the sector.

From this book, it can be concluded that all these technologies, applied in the vegetable sector, both traditional and innovative, as well as the food safety and quality assurance systems can largely benefit from the use of a quantitative framework that can be built upon risk-based metrics in combination with predictive microbiology models and data analysis and processing. A more holistic view should be also taken into consideration, in the vegetable sector, looking at public health and environmental health, as both aspects are closely related, to attain major level of protection for consumers and the environment. For that purpose, there are science-based frameworks based on a systems approach and proposed at an international level, such as QMRA and LCA methods, where the quantitative approach is paramount to obtain reliable and useful outcomes. In the next decades, these aspects will become increasingly relevant to the food industry, including the vegetable sector, compelling them to adopt a more data and science-based approach to cope with food safety and quality issues.

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Quality and Safety Management Systems in the Production of Vegetables

Sofia G. Cuggino, Alejandra Pérez Agostini, Sandra Kopp, and Ricardo Novo

1 Food Security in the Production of Vegetables

According to the definition of the Food and Agriculture Organization of the United Nations (FAO), "Food security exists when all people, at all times, have physical and economic access to sufficient safe and nutritious food that meets their dietary needs" (1996). Food security not only implies the offer but also the availability of safe foods, taking innocuousness as the intrinsic attribute of a product to be considered suitable for human consumption. Safe food must be free of physical hazards (bones, stones, metal fragments, or any foreign matter), chemical hazards (veterinary drugs, pesticides, toxins from microorganisms, cleaning and disinfection agents), and biological hazards (microorganism pathogens) for the consumer.

In all the stages of the production chain of vegetables, the possibility of having high-risk contaminants that affect consumer's health is present, thus reducing the safety of the product or driving to its seizure. The concept food safety refers to the conditions and practices applied in the food environment to prevent food contamination and foodborne illness.

To attain the maximum protection of consumers, it is essential that the concepts of food security are introduced in the whole agricultural production chain, from the production to the consumption. An integrated and systemic planning is crucial "from the farm to the table" in which the producer, manufacturer, carrier, seller, and consumer have an essential role in ensuring food quality and safety (FAO and WHO 2003; FAO, IFAD and WFP 2014).

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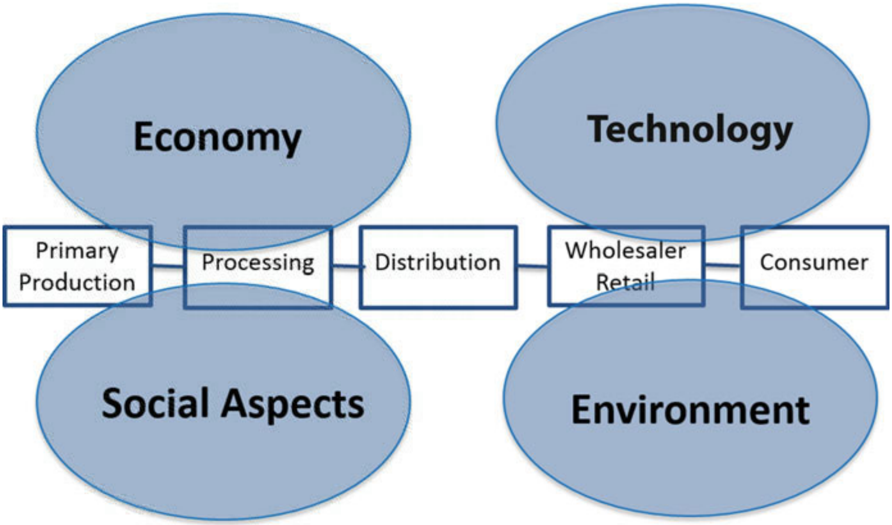

Fig. 1 Different approaches to the production of vegetables

When the production chain of vegetables is analyzed as a whole, from the primary production to the final consumer (Fig. 1), the different focuses that integrate it shall be considered to improve understanding:

- Economic focus: It lets a company to make profit and meet the changing needs of the consumers.
- Environmental focus: It allows for the adequate use of the necessary resources for the production and transformation of food within a sustainable frame.
- Technological focus: It refers to the method of production and transformation of food linked to other steps in the process through technological advances, transport, information, and communication to obtain high-quality and safe vegetables as a result.
- Social and legal focuses: Evidenced through the imbalanced growth of some steps in the production chain of agricultural food and to the business barriers that alter the benefit-cost relationship and, last, but not least, the sustainable socio-economic development.

All the interested parties in the food system, including producers, food transformation, and handling, from the production to the storage and final consumption steps, share the responsibility of ensuring safe and nutritious foods throughout the whole food production chain. Therefore, it is the responsibility of stakeholders throughout the whole food production chain to adopt a quality management system with an integral focus on food safety. This responsibility also involves an interaction with scientific institutions, regulatory and standardization bodies, as well as social and economic agents, both, at national or international level. Nevertheless, the challenge is to develop integral food systems that ensure long-term involvement and commitment of all the interested parties in order to achieve the desired objective: a safe and nutritious food supply for consumers.

2 Quality Management System in the Production of Vegetables

A quality management system (QMS) is a set of planned actions aiming at attaining consumers' confidence to obtain a high-quality product or service. The term "quality management" refers to four main stages: planning, control, assurance, and improvement. All of them are necessary to reach success.

Among the QMSs used to ensure food safety, more widespread in the production of vegetables, the good agricultural practices (GAP), good manufacturing practices (GMP), the integrated pest management (IPM), sanitation standard operating programs (SSOP), and the hazard analysis and critical control points (HACCP) are applied. Some of them are framed under governmental regulation, both national and international, upon voluntary or obligatory compliance (Fig. 2).

2.1 Good Agricultural Practices

The GAP are a set of rules, principles, and technical recommendations applied to the different stages of the agricultural production. They include the IPM and the integrated crop management (ICM) which aim at providing a safe and high-quality product with minimal environmental impact, for the well-being and safety of consumers and workers. Furthermore, they enable a framework of sustainable agriculture that can be registered and assessed (FAO 2014). A simple definition

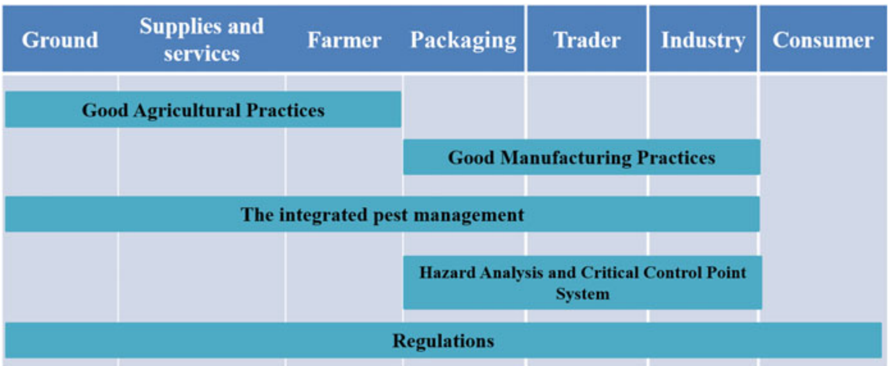

Fig. 2 Areas of application of regulations, guidelines, and standards

of the GAP is “to do things right” and “to be able to give assurance of this.” In this sense, its implementation includes, in each stage, knowledge, planning, recording, and management toward the achievement of social, environmental, and specific productive goals.

The application of a GAP system is successful when it includes the previous knowledge of the actions and guidelines that rule it, such as environment, food safety, their traceability using records, and the safety for workers and consumers.

The application of the GAP is based on the guidelines or manuals that describe the most recommended practices to be applied during the primary production. Particularly, for the production of fresh vegetable for consumption, there are many national manuals that detail the best recommended practices for small- as well as large-scale producers, in specific environmental conditions.

In European countries, the EUREPGAP standard (1997) applies. Its origins come from the private sector, and it was developed from an initiative of retailers, along with representatives from all the stages of the agro-food production chain and organizations of producers from other parts of the world. In 2007, the name was changed to GLOBALGAP, more illustrative due to the protocol’s repercussion at international level, together with the third revision of the standard (GLOBALGAP 2016).

Global compliance with GAP is optional. However, if production is to be marketed in Europe, many customers require compliance with GLOBALGAP standards and its certification. Compliance in these cases becomes a compulsory requirement to operate in that market. Instead, if the buyer is the United States, their application is only recommended.

In Argentina, specifically, the National Food Commission (*Comisión Nacional de Alimentos*, CONAL), in charge of updating the Argentine Food Code (*Código Alimentario Argentino*, CAA), approved in 2008 (RECORD No. 78/2008, ANNEX I) the proposed standard to include the GAP into the CAA for the vegetables, fruits, and aromatic sectors and to declare them compulsory as of 2010.

2.2 Good Manufacturing Practices

The GMP are a means to getting products safe for human consumption, focusing on the hygiene and handling in the food transformation stage.

The scope of the application of the GMP reaches any facility where any of the following activities is carried out: food manufacturing, industrialization, fractioning, storage, and transport.

The GMP are applied in:

1. Raw materials
2. Facilities: related to structure and hygiene (SSOP)
3. Personnel
4. Hygiene during manufacturing

5. Storage and transport of raw materials and finished product
6. Production processes control
7. Documentation

In order to take part in many countries of the global market and in the national market, all facilities that wash, pack, and label vegetables shall comply with the GMP.

Follow-up of the hygiene conditions can be done through the sanitation standard operating programs (SSOP) which are well-established and prescribed methods to routinely keep track of food safety and hygiene operation performance.

2.3 Integrated Pest Management Programs

The integrated pest management (IPM) programs use all the available resources through standardized operative procedures to minimize the hazards pose by pests. Pest makes reference to any animal that competes with man in the search for water and food, invading spaces where human activities are carried out. Their presence alters the quality of food, and they represent one of the most important vectors for the spread of disease, specially foodborne diseases (FBD).

Unlike the traditional pest control (curative), the IPM is a preventive system in response to a plan intended for high-quality food. In this way, IPM is a system that allows for fruitful interrelations with other management systems, and it constitutes an essential prerequisite for the implementation of HACCP.

IPM can be voluntarily adopted in the primary and industrial production of vegetables. Its application is translated into a planned reduction of the risks of FBD.

2.4 Hazard Analysis and Critical Control Point (HACCP) System

HACCP is a model with a systemic approach to the identification, assessment, and control of practices, processes, and spaces in the food production that are critical for product's safety (FAO and WHO 2015). Currently, the HACCP principles are the basis for most of the quality assurance systems, and they involve the following actions:

1. Biological, chemical, or physical hazards analysis
2. Identification of critical control points (CCP)
3. Setting of preventive measurements with critical limits for each control point
4. Adoption of monitoring procedures over critical control points
5. Application of corrective actions due to the lack of compliance of any critical limit

6. Implementation of system verification procedures
7. Implementation of an effective recording method to keep track of the HACCP system

HACCP has gained international relevance as an essential tool to ensuring food safety for human consumption (FAO 2002). Its implementation is compulsory in order to engage in any business transaction in the European Community, while it is only recommended for the US market. In Argentine, there is a standard of voluntary observance (Argentine Normalization and Certification Institute [IRAM] 14,104:2001).

3 Regulations

Demand for perishable foods is no longer restricted to local or regional production; thus, product trade has considerably expanded its horizons. These changes have affected production, marketing, and distribution of vegetables intended for human consumption. By this, quality emerges as a crucial requirement for marketing. This implies compliance with specifications and certifications imposed by target markets. When analyzing the production, manufacturing, and sales sectors of ready-to-eat (RTE) vegetables, rules and regulations of voluntary and nonvoluntary application ensure the seamless production in accordance with the environment and that makes an efficient use of resources.

Codex Alimentarius recommendations let governments design and adjust policies and programs within a national control system for food. Thus, the commission has raised international standards for RTE vegetables establishing specific requirements referred to pesticide residues, microbiological contamination in food, hygiene, and labeling.

Many countries have created specialized agencies or programs intended for ensuring food safety for consumers. In line with this, the European Union has created the European Food Safety Authority (EFSA). The United States has coordinated programs of food safety in charge of federal agencies, such as the Food and Drug Administration (FDA), the Food Safety and Inspection Service (FSIS), and the United States Department of Agriculture (USDA).

Latin American countries have created agencies specialized in food safety in order to increase competitiveness of their products in international markets. Clear examples of this are Chile with the Agriculture and Livestock Service (*Servicio Agrícola y Ganadero*, SAG), Argentina with the National Animal Health and Agri-food Quality Service (*Servicio Nacional de Sanidad Animal y Calidad Agroalimentaria*, SENASA), Brazil with the National Agency for Sanitary Vigilance (*Agencia Nacional de Vigilancia Sanitaria*, ANVISA), and Bolivia with the National Service of Agriculture Sanity and Food Safety (*Servicio Nacional de Sanidad Agroalimentaria*, SENASAG).

Among some compulsory regulations for vegetables, available for the European Union, the following can be mentioned:

– General Food Law—Principle (EC) 178/2002: It establishes the general principles of food legislation and it creates the "European Food Safety Authority." It also determines that compliance with the law is responsibility of the economic operators. It informs the obligatory nature of a traceability system. It forces withdrawal from market of food lots that pose health risk to consumers and the reporting to sanitary authorities. Moreover, it sets an alert network for the community.
– Principle 852/2004 relative to the hygiene of food products (H1): its application environment includes the whole chain, from primary production (agriculture and farming) to the industrial stage. In this principle, it is mentioned the compulsory nature of the procedures based on the HACCP and of determining microbiological criteria and requirements relative to temperature according to scientific assessments. The main function is to ensure that imported foods meet the same level of hygiene and sanity than local foods.

Moreover, there are standards of voluntary application in the different countries. The following are the most important ones in the production of vegetables:

- ISO 22000: Project ISO 22000 "Food Safety Management Systems—Requirements" is an international standard that includes the specific requirements based on the *Codex Alimentarius* principles of the HACCP system.
- Global Food Safety Initiative (GFSI): Brought by CIES-The Food Business Forum, it includes the world's most important supermarkets, and it aims at implementing a scheme of world standards related to food safety and applicable to the whole food production chain.
- British Retail Consortium (BRC): Developed by the English supermarkets, it sets requirements for the safety and innocuousness management systems. It requires the adoption of the HACCP system, maintenance of a documented quality management system, and the implementation of GMP and a control system of the product, process, and personnel.
- AIB: The American Institute of Baking (AIB) of the United States is a nonprofit organization created as a technological center for bakers and food processors in general. It developed its own standards in food manufacturing, production, storage, and safety.

4 Quality Certifications

In the agro-food industry, it is important to define the most valued quality attributes of all consumer groups, its relative importance, and its assessment method. Once defined, the main concern of the company is to achieve continuous production and supply of safe products with quality levels constantly improving. Quality management systems are developed to keep the set of quality standards over time so that the consumer can establish a durable association between the brand or the product and certain level of quality. The compliance of products, processes, services, and management systems with the defined requirements in papers so-called technical standards or specifications is assessed by the certification bodies that determine if a company meets the set of requirements or not, which lets them gain more prestige among consumers.

Moreover, producers and manufacturers try to set apart from the rest and to stand out by the added value of their products. To this aim, they employ designations of origin and quality labels issued by organizations that accede to a set of specifications, whose compliance is verified by certifying bodies, credited by public entities.

European legislation allows for three types of certifications: the protected designation of origin (PDO) designates the name of a product of which production, transformation, and manufacturing must be done in a specific geographical area, with well-known and proven specific knowledge; the protected geographical indication (PGI) in which the link to the geographic means is still present in, at least, one of the production, transformation, and manufacturing stages; and the traditional specialties guaranteed (TSG) that do not refer to the place of origin, but that seeks to highlight a traditional composition of the product or a traditional method of production.

5 Audits

The audit is a well-organized process of data collection needed to check efficiency of the quality system applied (GAP, GMP, HACCP, ISO, etc.). It is systematic and includes observation and an on-site review of records to determine if the planned actions are adequate to the ultimate aim of food safety and quality. It is a planned and organized activity based on preset rules and directives due to its formal nature.

Information obtained from the audit is registered in checklists: files that include key points for the execution of the activities. They are presented as forms, surveys, or spreadsheets, and they represent memory aids that help the auditor follow an organized sequence of observations during the audit. Checklists must be adequate according to the specificity of each audit. They must be simple, objective, easy to use, to read, and to understand, and they must identify data and facts.

Audits can be classified as follows:

– *Related to the type*:

  Adequacy audit: It is an objective report to check adequacy of a quality system implemented in the facility.

  Compliance audit: It is done to check if requirements set in the quality system plan are met in the facility on a daily basis.

– *Related to the company*:

Internal audit: It is done at the initiative and responsibility of the company.

External audit: It is done at the initiative of buyers and the competent sanitary authority of other inspection authorities, among others, not at the initiative of the company itself.

The main purposes that lead to an audit's planning and application are the following:

- To determine compliance or noncompliance of the quality system elements with the specified requirements
- To provide quantitative results of compliance with the quality management system assessed in the facility
- To assess the need of improvements or corrective actions based on the non-conformities found
- To assess efficiency and efficacy of corrective actions
- To abide by regulatory requirements

6 Traceability of Vegetable Products

Traceability can be defined as the documented system that ensures the origin of food and that identifies all the processes and movements of a product from farm to table. The main objective of the adoption of a traceability system is food safety to protect and reinforce consumers' confidence.

Traceability in the production chain of minimally processed and RTE vegetables must consider the following basic aspects:

1. Products, lots, and logic units' identification
2. Record of all successive stages in the supply chain
3. Record of relevant information to be traced throughout the chain
4. Provision of all the necessary information to the next participant in the process to lend continuity

Traceability systems are characterized by their breadth, depth, and accuracy. Breadth describes the quantity of information that the system records. Depth refers to the extension of records throughout the whole production chain, including the control period. Accuracy refers to the degree of confidence with which the system can detect movements or characteristics of the product, assuming certain level of error depending on the size of the defined lot. Thus, availability of information about each product, from farm to retail point, is broad, extensive, and accurate, and it contributes to an efficient quality management in the production chain.

In the food industry, in general, and in the vegetable industry, in particular, with very tight profit margins, the possibility of reducing costs in transport, storage, control, and possible food recalls contributes to the success or failure of the business activity.

Although traceability systems for themselves do not improve the quality of vegetables intended for direct consumption or minimally processed, they have the ability to identify errors in the process, to assign civil liabilities for the alteration, and to test the proper function of the safety systems.

As regards the implementation of a traceability system, the main restraints are the costs associated with the record keeping. These costs may be reduced by dividing the flow of products in discrete units (lots) taking into account the processes or the set of common attributes, simplifying the distribution system, and integrating the suppliers' and distributors' sectors. This allows for coordination between production, transport, processing, and marketing. Each participant in the production chain shall harmonize all the systems present in the control of food safety.

Although records of primary production are kept, at present, traceability applied to the agroproductive system of fruits and vegetables needs a technical recording management system consolidated with professional counseling, if necessary. In the next stages of distribution and sales, a traceability system needs to be incorporated. This should consider the set of possible packages, identification codes, and logistics, and distribution solutions, available in the form of new technologies.

7 Quality and Non-quality Cost

The adequate application of an integrated system of management practices for the production and transformation of RTE vegetables that encompasses from the primary production to the transport, packaging, and marketing intends to ensure food safety and to achieve certain level of product quality. By these means, suitability of food for human consumption is guaranteed, in addition to ability to enter into different markets with laws that include concerns of suitability. The producer and processor that apply the good practices meet the requirements to place their products in foreign markets (more demanding and competitive than ever before). They are also able to distinguish their products in local market.

The production of vegetables that meets quality standards carries evident benefits from the economic and business points of view. Applying an integrated QMS, although it increases some operative costs, it reduces the costs of low quality which ultimately results in a measurable benefit. Not applying QMS leads to a greater increase in costs, mainly those derived from noncompliance with certain attributes imposed by clients. This results in rejected and returned goods or food recalls, loss of materials and labor, penalties and recharges, among other consequences.

8 Risks and Control Measures in the Production of Vegetables Using an Integrated Quality Management System

In recent years, due to changes in consumption patterns, consumers have increased the demand for food products that are of high organoleptic quality, healthy, safe, and easy to consume or prepare. This has sped up acceptance of RTE vegetable products. However, these products can pose a potential risk for health due to the absence of thermal treatment in their preparation. It is essential to apply a quality management system based on GAP and GMP, together with microbiological and chemical controls throughout the whole production chain.

9 Risks Associated with the Production of Vegetables

The concept of "risk" associated with food differs as perceived by consumers and the actual risk (Fig. 3).

Risk analysis is a process made up of three interrelated and integrated elements: risk assessment (RA), risk management, and communication of the risk.

Microbial risk assessment is a science-based process intended to determine hazards in food, the probability of exposure to them, and their effect on public health. It is based on scientific grounds, on the identification and characterization of hazards, and on the estimate of exposure and characterization of the risk (FAO and WHO 2009).

Risk management consists of using the collected data and attending to other considerations (technical viability, economic costs, social costs, etc.) in the assessment stage in order to make decisions as regards the need or viability to implement

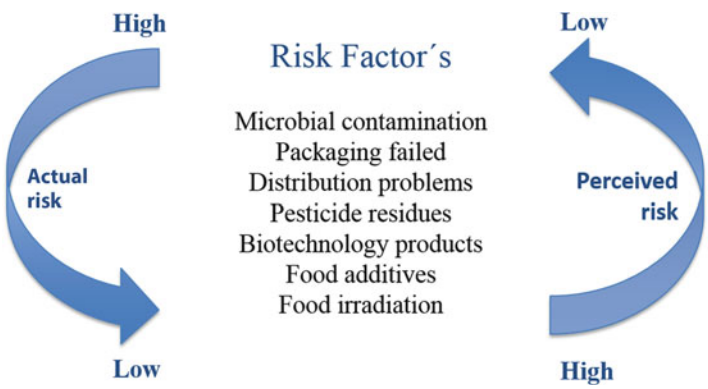

Fig. 3 Classification of risks for food safety as assessed by experts (actual risk) and according to consumer perceptions (perceived risk)

measures. The communication of the risk implies the interactive interchange (throughout the whole risk analysis process) of information and opinions in relation to hazard factors and risks, risk factors, and risk perceptions, established among those responsible for the risk assessment and management, consumers, food industries, the scientific community, and other interested parties.

Epidemiological information is critical to establish the cause that leads to certain food-related disease, apart from other factors involved. It is expected that epidemiological information allows for confirming the existence of a pathogenic-food-host link. This is the first stage of RA: Risk Identification.

The result of a RA can be used to support the decision of risk managers to set certain food safety objective (FSO). FSO is defined as “the maximum frequency and/or concentration of a hazard in a food at the time of consumption that provides or contributes to the adequate level of protection” (ICMSF 2002; CAC 2013). The objective of FSO is to translate an adequate and tolerable level of protection for the consumer in attributes measurable by the food industry, so appropriate control measures can be implemented.

Although the FSO is the proposed tool for the design and control of operations in the food industry, it is intended to verify the acceptance of a lot. However, a FSO can be used as a basis for setting microbiological criteria.

A microbiological criterion must be set and applied when actual need exists and when its application is deemed useful. Such a need is shown: (1) by epidemiological evidence that the food poses a risk for public health and that certain approach is of utmost importance for the protection of the consumer or (2) as a result of a RA.

A microbiological criterion defines the acceptability of a food, a lot, or a process based on the absence, presence, or the number of microorganisms and/or its toxins/metabolites per unit of volume, surface, or lot.

Microbiological criteria related to food involve:

– A description of microorganisms and/or its toxins/metabolites and the reason of interest
– Analytical methods of detection
– A plan that defines the number of field samples to be taken
– The magnitude of the analytical unit
– Microbiological limits considered appropriate for food in specific point(s) of the food chain
– The number of analytical units that must adjust to these limits
– The food to which they apply
– The points in the food chain
– The measure to be taken when this criterion is not followed

The *Codex Alimentarius* regulates the application of the microbiological criteria through a set of food standards globally adopted, uniformly presented and taken as referential in the resolution of business problems by the World Trade Organization. The aims of these standards are to protect consumers’ health and to enable global trade of food. They intend to serve as a guide and to encourage production, manufacturing, and consumption of safe food.

10 Microbial contamination in vegetables

Vegetables have the potential to harbor pathogens, such as *Salmonella* spp., *Listeria monocytogenes*, *Shigella* spp., *Clostridium botulinum*, *Escherichia coli*, *Campylobacter*, *Yersinia*, *Vibrio* y *Staphylococcus aureus* (FAO and WHO 2008), *Cryptosporidium*, and Hepatitis A virus, and fecal contamination indicators, i.e., *Escherichia coli*, which can be ingested by food consumption. As regards canned vegetables, the most common contaminants are *Bacillus* spp. and *Clostridium* spp.

Contamination of vegetables may be superficial or it may go deeper into inner tissue. When these microorganisms are present in vegetables, they are able to survive in different surfaces, to overcome stress conditions, and to remain latent until the optimal conditions to grow and colonize are present.

FBD are caused by the ingestion of contaminated food and/or water in quantities enough to adversely affect the consumers' health. They can be divided into infections and intoxication depending on the nature of the contamination: by microorganisms or by the toxins they produce, respectively.

11 Reduction of Microbiological Risk in Vegetables

At present, different technologies and treatments are used to control microbiological risks, i.e., disinfection, thermal treatment, edible coating, a modified atmosphere, and refrigeration to extend shelf life of these vegetables.

The most widely used processes for vegetable sanitation can be classified as follows: physical methods, such as washing under high-pressure water at low temperature (4 °C); soft thermal treatment (water at 40–45 °C); ionizing radiation; UV light application, among others. Some examples of chemical methods include washing with sodium hypochlorite, acetic acid, hydrogen peroxide, peroxyacetic acid, chlorine dioxide, electrolyzed water, and ozone.

The washing stage is the most relevant part in the ready for consumption vegetable processing because its utmost aim is to reduce leftover dirty and microbial contamination (pathogenic and altering types) in food. At the same time, water used is the main vehicle for the spread of pathogenic microorganisms. All currently effective international regulations for the production of vegetables demand that the water used along the whole production chain meets sanitary and safety standards.

It is important to highlight that during packaging of RTE vegetables, the microbiological quality of the product must be assured. To this end, packages with modified atmosphere can be employed, while keeping vegetables' cold chain during storage and transport. Moreover, the application of combined treatments of antimicrobial coating has been under consideration.

In the particular case of canned vegetables, sterilization and fast cooling are the most effective methods for reducing microbial contamination.

12 Microbial Detection Methods in Vegetables

Both quantitative and qualitative microbial detection methods are applied in quality management systems in the production chain of any food to assess acceptability. None of the commonly used methods allow to determine the exact number of microorganisms present in a piece of food.

Application of appropriate analytical methods, such as investigation or count of colony forming units or the Most Probable Number (MPN), is proposed by official bodies and international regulations in consideration of their ability to determine or quantify the microorganisms concerned. Methods to be used must have statistically-proven reliability based on comparative studies. Tolerance limits for each type of microorganism, their characteristics and their implications are also defined.

To ensure reliability, data obtained shall be certified in an accredited laboratory, validating results of each microorganisms.

On the other hand, the industry may observe microbiological specifications to check compliance with regulatory requirements, to establish design requirements, and to assess products as a means for checking or validating efficacy of their good hygienic practices (GHP) and HACCP. These criteria can be stricter than those imposed by regulatory authorities, and they are not applied with regulatory purposes.

13 Chemical Risk

Pesticide residues in food represent a risk of chemical contamination of vegetables is a concern for a large fraction of consumers. The development of quantitative analytical techniques allows for detection of extremely small concentrations of pesticide in food which were used or previously used in crops.

Pesticides are chemical or biological substances designed to control biotic agents harmful for agricultural production, such as insect pests, dust mites, fungi, bacteria, nematodes, mollusks, rats, among others. Products like plant growth regulators, pest attractants, and repellents or ectoparasiticides are also considered pesticides. Pesticide residues are defined as “any substance present in a food product intended for human and animal consumption, as a consequence of a pesticide use” (FAO and WHO 2015). This definition not only includes the original product but also its metabolites with toxicological importance, components of the formulation (coadyuvants, inerts, etc.), and factory impurities.

Due to the biocide nature of pesticides, their presence in crops is the reason why many people are opposed to their use. Moreover, lack of information available generates confusion, thus affecting the precautions that consumers may take.

Studies have shown that these residues generate a minimal, though not null, risk for consumers. Levels of sensitivity to different residual chemical principles vary