

Review

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Microbial Safety of Foods in the Supply Chain and Food Security

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ABSTRACT

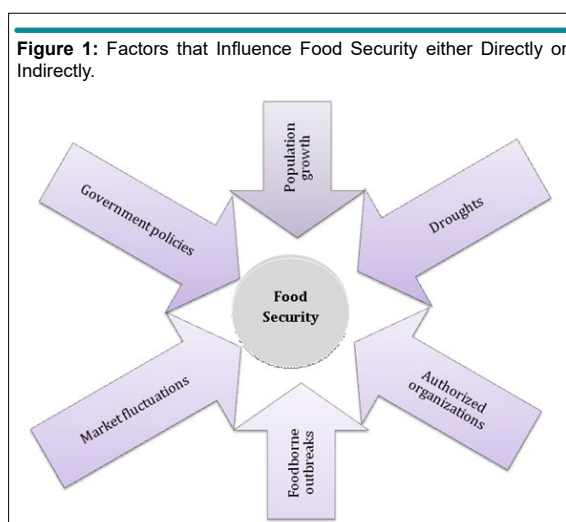
Most foodborne outbreaks in recent years have been linked to microbial contamination of food products. These food outbreaks can cause considerable food losses, and hence can play a role in global food insecurity. We discuss the importance of microbial food safety in the supply chain to reduce the potential for contamination. Microbial contamination may take place at pre-farming, farming or post-farming stages of the food supply chain. *Campylobacter*, *Salmonella*, *Listeria monocytogenes*, *Escherichia coli* O157:H7 and non-O157:H7 STEC *E. coli* are the most common pathogenic bacteria associated with food safety issues in the food supply chain. Efficient process controls and effective food safety management systems are vital elements to reduce microbial contamination and improve food security.

KEY WORDS: Food security; Food safety; Food supply chain; Microbial contamination.

ABBREVIATIONS: FSC: Food Supply Chain; FAO: Food and Agriculture Organization; STEC: Shiga toxin-producing *E. coli*; CDC: Centers for Disease Control and Prevention; CARMA: *Campylobacter* Risk Management and Assessment; COI: Cost-of-Illness.

INTRODUCTION

The difference between the terms “food safety” and “food security” is commonly misunderstood. These are separate issues but are, nevertheless, closely interrelated. The definition of food safety is the inverse of food risk and is the probability of a specific food not causing health problems after consumption.¹ Food security is defined as ensuring that all people at all times have both physical and economic access to the basic food they need.² Food security, a complex issue, is affected by multiple factors including microbial contamination of food, government policies, drought, global and national market fluctuations, and population growth (Figure 1). The importance of microbiological food safety is paramount because of the potential for harm-



ful microorganisms to grow and multiply in food commodities.³ Entry of possible contaminants such as microbiological agents into food is a threat to the safety of food products. This can result in food poisoning, increase in foodborne outbreaks and a decrease in food availability because of discarding the contaminated food products.⁴ Drought also can significantly affect the availability of irrigation water used in agricultural production and cause crop failures.^{5,6} The aforementioned factors affect food availability and food access and can result in an increase in global commodity prices and food market fluctuations.⁷

Globalization of the food trade is one of the factors responsible for the increased number of foodborne outbreaks caused by microbes.^{8,9} Bacterial pathogens are the most prevalent contaminants in food products followed by viruses, pesticide residues and mycotoxins.¹⁰ The presence of harmful bacteria on food surfaces can increase the risk of cross-contamination, causing food poisoning and/or food losses. Food safety in the manufacturing and production of foods is important to protect the consumer from potential health risks and to reduce food losses. Food safety and quality in the supply chains are crucial to achieving food security and allows food to flow from areas of surplus to areas of deficit in local, national and global markets.^{11,12} Emphasis as a priority is on microbiological quality throughout the food production chain, to minimize the risk of foodborne illnesses and, consequently to improve food security.

The gap between the current global population and food production, as well as the difference between food supply and demand in many countries is widening.^{13,14} Understanding the relationships between microbial contamination, food safety and food security, and how these affect the global food supply, will help highlight areas in the food supply chain (FSC) that require more attention to improve food security. Governmental organisations have therefore introduced more rigorous policies to reduce the risk of food contamination and, thereby, ensure the supply of safe food.¹⁵

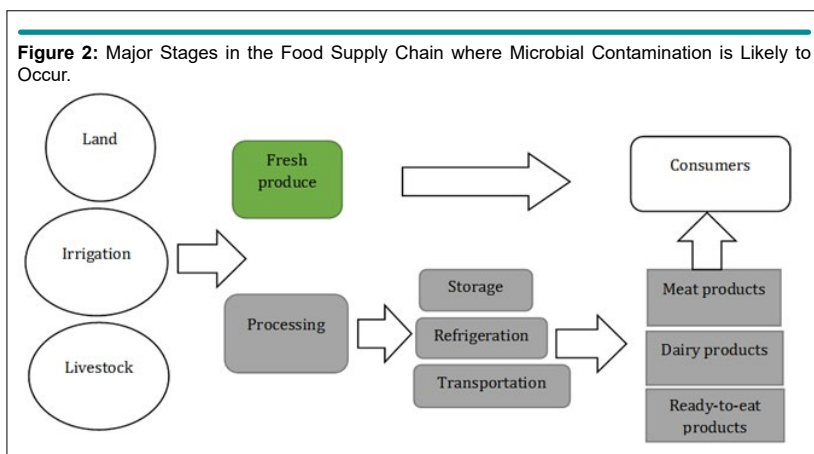
This paper discusses how microbiological food safety in the FSC could be useful in improving global food security. For the purpose of explanation in this report, the term “food safety”

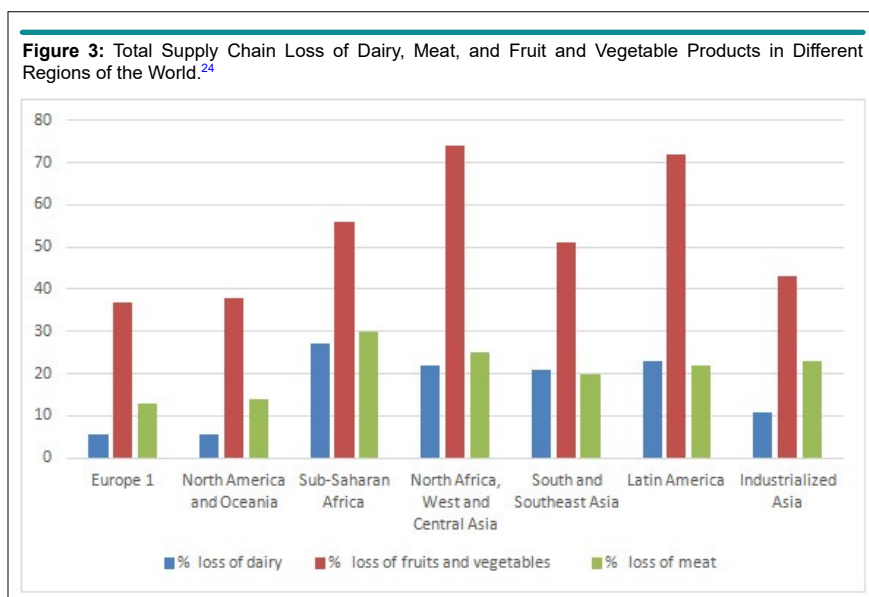
will refer to foodborne microbial infections and outbreaks and “food insecurity” as food losses and microbial spoilage of food during and post-food production.

FOOD LOSSES AND WASTE IN THE FOOD SUPPLY CHAIN

According to the Food and Agriculture Organisation (FAO), the world produces enough food to feed everyone living on earth. However, each year, almost one out of every four calories produced to feed people is not consumed and about one-third of total food production (1.3 billion tonnes) was either lost or discarded during production in the FSC. The FSC has been defined as “the total supply process from agricultural production, harvest or slaughter, through primary production and/or manufacturing to storage and distribution to retail sale or use in catering and by consumers”.³ It is designed to positively influence quality, safety, sustainability, logistics and efficiency of food production and processing from the farm to the fork.¹⁶ Food losses and waste can take place at any stage of the FSC, e.g., agricultural production, post-harvest, processing, distribution and consumption (Figure 2). The term food loss most commonly refers to food products that are intended for human consumption but have instead been lost in production, storage, transport and processing, mostly due to microbial contamination and/or spoilage.¹⁷⁻¹⁹ Food waste occurs at the end of the FSC within the retail and final consumption stages and it refers to edible food products that have been discarded, degraded and not consumed by humans.²⁰

For most countries, food losses and waste of fruit and vegetables are higher than for other products, such as dairy and meat.^{21,22} Liu et al²³ reported that fruit and vegetables suffered losses of up to 20-30% compared to meat and aquatic products (>15% loss) in the FSC in China. According to FAO,²⁴ the losses related to fruits and vegetables in the FSC in Latin America were over 70% while the dairy and meat product losses were only 22% and 25%, respectively (Figure 3). Insufficient refrigeration facilities in the FSC, particularly during transportation are noted as a major factor in these losses. In developed countries better FSC management has led to a reduction of food losses compared to less developed nations. It is widely accepted that an improvement in food safety reduces potential microbial risks and opera-





tional costs, both of which are vital in reducing food losses and foodborne outbreaks and thereby enhance food security.

Food may become contaminated with a range of microorganisms during harvesting, processing and handling operations as a result of the behaviour of farmers, retailers and consumers.^{17,19,25} It is not well-documented how much food loss or wastage is caused by microbial contamination each year. However, the cost of foodborne illnesses caused by microbial pathogens can be used as an indicator to evaluate the extent of the contamination problem. For example, organisations such as the Centers for Disease Control and Prevention (CDC) in the USA provide details of the 48 million Americans annually who suffer from foodborne illnesses associated with identified microbial contaminants.²⁶ Buzby and Roberts²⁷ estimated that 70% of diarrhoeal diseases are foodborne. Thus it is clear that microbial pathogens are associated with a large number of foodborne outbreaks, which results in food losses. Hence, it is important to understand the common microbiological hazards in foods.

COMMON MICROBIOLOGICAL HAZARDS IN FOODS

Food security, as we have seen above, not only means paying attention to the reasons behind shortages in food supply, but also addressing issues like food contamination and foodborne outbreaks that indirectly contribute to food losses. A foodborne outbreak is generally defined as an incident when two or more people become sick as a result of consuming a common food or meal.²⁸ The symptoms and severity of food poisoning vary, depending on the nature of the hazard (i.e., biological, chemical or physical agents) and its ability to cause adverse health effects. Pathogenic bacteria are the most common cause of foodborne outbreaks and food scares around the world. More than 50% of foodborne outbreaks in the USA have been linked to bacterial infections.^{29,30} In addition, microbial food contamination in the FSC that causes food losses and foodborne illnesses can result in heavy economic losses. Many studies have used cost-of-illness

(COI) to estimate the economic burden of an illness on a society.^{26,27,31} Such studies were also useful for making sound policy decisions about food safety interventions.^{32,33}

Lake et al³¹ used COI to estimate the burden of disease for certain potentially foodborne diseases (e.g., campylobacteriosis, salmonellosis, listeriosis) and their sequelae in New Zealand. The cost of foodborne infections in New Zealand is considerable and has been estimated at \$86 million per year, with approximately 90% due to campylobacteriosis. In Sweden, the estimated cost of foodborne illnesses is about \$171 million per year.³⁴ The Economic Research Service of the United States Department of Agriculture (USDA) reported that, in the USA, five foodborne pathogens (*Campylobacter*, *Salmonella*, *L. monocytogenes*, *E. coli* O157:H7 and *E. coli* non-O157:H7 STEC) cost \$6.9 billion each year.³⁵ Examples of a number of bacterial foodborne outbreaks are given in Table 1. International organisations such as the FAO and the World Health Organization (WHO) have accepted the challenge to work together in order to initiate risk assessment studies of a number of pathogens in food commodities to improve consumer health and indirectly the economy.³⁶ Some of the most prevalent foodborne pathogens are discussed below.

Salmonella spp., one of the leading causes of foodborne outbreaks and foodborne illnesses, are a serious threat to public health worldwide. In the USA, the annual estimated economic loss was \$2.4 billion in 2014 due to foodborne *Salmonella* infections.³⁷ *Salmonella* spp. are commonly associated with foods of animal origin (e.g., red meat, chicken and pork). The most common symptoms of salmonellosis are abdominal cramps, diarrhoea and fever.³⁸ Contamination by *Salmonella* can occur during production or due to inappropriate food handling during manufacturing. Data from foodborne outbreaks in the USA indicate that *Salmonella* infections were responsible for 18% of foodborne diseases in 2006,³⁹ but increased to 35% in 2011⁴⁰ and 38% in 2013.⁴¹ In New Zealand, *Salmonella* spp. were respon-

Table 1: Selected Examples of Foodborne Outbreaks and Recalls Caused by Pathogenic Bacteria

| Foodborne outbreak | Pathogenic bacteria | Region/Country | Initial announcement | Casualties | Estimated economic losses | Reference |
|--------------------|-------------------------|---------------------------|----------------------|--|--|-------------------------------------|
| Bean sprouts | <i>Salmonella</i> | USA | November 2014 | 115 people infected, 25 % of ill persons were hospitalized | Contaminated bean sprouts and any remaining products were destroyed | CDC ^a 2014 ⁵¹ |
| Nut mix | <i>Salmonella</i> | New Zealand | December 2014 | No illnesses were reported | Contaminated nut mixes batches were recalled | MPI ^b 2014 ⁹⁵ |
| Fresh cream | <i>E. coli</i> | New Zealand | January 2014 | No illnesses were reported | 8,700 bottles of fresh cream distributed to retail and foodservice outlets were recalled | MPI 2014 ⁹⁵ |
| Cheese | <i>L. monocytogenes</i> | Australia and New Zealand | March 2014 | No illnesses were reported | Cheese was recalled from Australian and New Zealand supermarkets | MPI 2014 ⁹⁵ |
| Chicken | <i>Salmonella</i> | Puerto Rico and USA | March 2013 | No illnesses were reported | More than 23,000 units (approximately 102,000 pounds) of contaminated chicken were recalled | CDC 2014 ⁵¹ |
| Cheeses | <i>L. monocytogenes</i> | USA | September 2013 | Six ill persons hospitalized. One death in Minnesota | All cheese products made on a specified date or earlier were recalled and destroyed | CDC 2014 ⁵¹ |
| Sprouts | <i>E. coli</i> O104:H4 | Europe and North America | May 2011 | More than 4,000 persons were infected | Ban by the EU on the importation of fenugreek seeds and various other seeds, beans, and sprouts from Egypt that were the source of the sprouts responsible for the outbreaks in Germany and France | WHO ^c 2011 ⁹⁶ |
| Spinach | <i>E. coli</i> O157:H7 | USA | 2006 | Not specified | Spinach was recalled and banned to sell | CDC 2007 ⁹⁷ |

^a Centers for Disease Control and Prevention; ^b Ministry for Primary Industries; ^c World Health Organization

sible for 6.6% of foodborne outbreaks in 2011 (Institute of Environmental Science and Research (ESR))⁴² and increased to 10 % in 2012.⁴³ Despite the improvements to food safety standards in the FSC, *Salmonella* infections have continued to increase and cause considerable losses to global food safety through productivity/production losses and recalls.

Campylobacter spp. cause serious bacterial food poisoning. In the USA, *Campylobacter* is responsible for more than 600,000 illnesses that cost over \$1.3 billion each year.⁴⁴ Approximately, 50% of these illnesses were attributed to poultry products such as chicken burgers and nuggets.⁴⁵ In the Netherlands, the *Campylobacter* Risk Management and Assessment (CARMA) estimated the cost of campylobacteriosis at 21 million euros annually, with 20-40% of cases attributed to contaminated poultry.⁴⁶ These bacteria infect about 1% of the population of Western Europe, and most of the infections are caused by inappropriate handling of contaminated food.^{17,47} In New Zealand, campylobacteriosis has been a notifiable disease since 1980.⁴⁸ ESR reported that *Campylobacter* spp. were the most commonly identified agents in poultry and dairy outbreaks in 2013 and caused 13.3 % of the total reported foodborne disease outbreaks.⁴⁹ The economic loss due to a *Campylobacter* outbreak in August 2012 was estimated at \$1.184 million.⁵⁰

Some *E. coli* strains are pathogenic and flourish in the gut of many host species. *E. coli* O157:H7 was identified in 1982 and is now recognized as a dangerous foodborne pathogen. This, and the foodborne Shiga toxin-producing *E. coli* (STEC), have been implicated in many outbreaks around the world and the illnesses cost about \$280 million annually in the USA.³⁵ The an-

nual foodborne outbreaks reported by CDC⁵¹ attributed 29 confirmed outbreaks to STEC in the USA in 2013, mostly caused by fresh produce (raw fruits and vegetables). These strains were also responsible for an outbreak in the UK in 2007 that caused 157 hospitalized cases and one death.⁵² In Germany, in 2011, approximately 941 people were infected with *E. coli* O104:H4 from food.⁵³ In New Zealand, STEC caused two outbreaks, and 11 illnesses were reported by ESR.⁵⁴ In the case of *E. coli* O157:H7, most of the infections were from beef and minced meat.²⁹

L. monocytogenes is a pathogenic bacterium that has caused a number of food outbreaks over the last decade with dairy products being the main vehicle associated with foodborne illnesses, with the capacity to affect infants and the elderly. Unlike other bacteria, infection by this bacterium has a high fatality rate of 20-30%,⁵⁵ and the annual estimated economic loss is \$2.6 billion in the USA.³⁵ *L. monocytogenes* has been the most infamous foodborne pathogen in Australia because of its high numbers of fatal cases and substantial economic losses of \$1.2 billion per year.⁵⁶ One of the most serious listeriosis outbreaks was reported in Europe in 2009-2010. The reported data showed a total of 26 people were infected, with eight fatalities in three different regions.⁵⁷ In Australia, five outbreaks caused by *L. monocytogenes* infections between the years 2001 and 2010 led to 57 cases and 14 deaths.⁵⁸ The severity of listeriosis and the difficulty of avoiding *L. monocytogenes* in the environment have highlighted the importance of improving the food safety system against *Listeria*. However, listeriosis outbreaks have recently been connected to the ability of a food to harbour viable *L. monocytogenes* throughout the manufacturing process⁵⁹ and

have often been associated with inappropriate storage processes. As outlined above, the number of outbreaks caused by each pathogenic bacterium, number of reported illnesses and the associated food vehicles are well-documented in many Western countries, including New Zealand. This information has been used to estimate economic losses and highlight food safety issues in the FSC^{9,60} but losses are probably underestimated because many foodborne illnesses are not reported unless they are severe. It is suggested that the pathogenic bacteria associated with foodborne outbreaks are a major cause of foodborne illnesses and will have a considerable influence on future efforts to enhance food security.

FOOD SAFETY AND FOOD SECURITY

Compromised food safety can disrupt the supply of food at any time and create the condition of food insecurity. A supply chain strategy emphasizes the management of all food safety issues that can arise due to improper transferring, handling and distribution of the product.^{61,62} In fact, when managing food safety, it is essential to implement proactive strategies to minimize the probability of delivering an unsafe product. Ensuring this will reduce food scares and food losses.

Many studies have investigated different stages in the FSC where strategies for food safety have failed. A recent study investigated the occurrence of *L. monocytogenes* in 12 meat and dairy products from small-scale direct marketers in Europe.⁶³ The study categorized these food business operators into uncontaminated and contaminated sectors according to existing data on the occurrence of *L. monocytogenes* in each food business, which showed that *L. monocytogenes* was a common colonizer of processing environments in European food processing factories. The study revealed how environmental factors can cause cross-contamination during food production if poor hygiene practices are in place, effects that can lead to significant food losses. The influence of environmental factors on foodborne outbreaks and food security is therefore a widely debated and investigated issue.

Foodborne illnesses associated with the consumption of specific food products, such as fresh produce, cause serious issues for public health.⁶⁴ According to international organizations (FAO/WHO), agro-food products present the greatest concern in terms of microbiological hazards that influence public health.^{65,66} In rapidly developing China, agro-food products account for more than 70% of the total food consumption.⁶⁷ This has prompted the Chinese government to establish efficient food control systems to reduce foodborne illnesses and outbreaks caused by agro-food products. The establishment of food control systems in China was delayed; however, as the various difficulties and problems in the FSC were investigated.⁷⁴ The many studies on the subject agreed; however, that lack of agro-food legislation and food safety structures were major obstacles to food security, and that in the absence of an effective food safety system, numbers of foodborne illnesses and foodborne outbreaks increase, thereby leading to food insecurity.

The production and consumption of foods, especially fresh produce and agro-food products, involves growing, transferring and handling food under conditions that vary considerably.⁶⁸ At any stage in the FSC if food safety is compromised, it can lead to food spoilage and microbial food contamination.^{65,69} A research report from Canada investigated the relationship between the incidence of *Salmonella*, pathogenic *E. coli* and *Campylobacter* infections between 1992 and 2000 in two Canadian provinces, using weekly reports of confirmed cases of these three pathogens.⁷⁰ The results showed a strong association between ambient temperature and the occurrence of all three enteric pathogens. Pathogenic bacteria are present in the food processing environment because of their saprophytic lifestyles.⁷¹ An inadequate hygiene system, poor hygiene practices and unhygienic design of equipment may cause pathogenic contamination of the food manufacturing plants.⁷² This contamination can be the initial step in the transmission of pathogenic bacteria from their original source in the food crop to food processing elements⁶⁰ and, ultimately to the consumer, which can result in outbreaks of foodborne illnesses.

In order to protect consumers from microbiological and also chemical hazards, many countries have evaluated their current food control systems.^{73,74} For example, two national studies were conducted, in Kuwait and the Sultanate of Oman, on the effectiveness of their current food management systems and elements of these, including the food control systems used by food producers, implementation of food legislation, food inspection protocols and the use of accredited food testing laboratories.^{9,75} Both reports highlighted deficiencies in the development of standards relating to food safety and quality, and the weak food and food products inspection system at different stages during production and processing. Without addressing these problems, food losses and food insecurity are unavoidable. The impact of unclear information and knowledge among stakeholders and food handlers about the importance of food safety control can result in an ineffective food safety system.

Uncertainty in the food service sectors in the FSC and limited knowledge of food safety strategies can negatively affect food safety control during production and handling.^{24,76} An inadequate system for training food handlers in food safety practices contributes to increasing incidences of microbial contamination of food.⁷⁷ With the recent increase in global food production, some international food manufacturers are relying on third parties to produce and export thousands of tonnes of food ingredients. Inadequate food safety training for these third parties handling food in the early stages of food manufacturing can lead to an increase in the number of foodborne outbreaks. Consequently, this will cause a significant loss of food products, damage the reputation of the international food manufacturing companies as food producers and, ultimately, influence food insecurity. Thus, provision of information and education about food safety and quality issues for food handlers across the FSC is important and a significant first step towards reducing food safety problems and improving food security.

It is now clearly evident that a national food safety management system is important for any country and, if compromised, can significantly increase food losses and foodborne incidents with consequent food insecurity.

IMPROVED MICROBIAL FOOD SAFETY IN THE FSC IS VITAL TO ENHANCE FOOD SECURITY

A food safety management system, therefore, is vital for ensuring the safety and quality of foods prepared for consumers. An improvement in food safety control systems can significantly reduce microbial contamination of foods throughout the FSC.¹⁶ Therefore, it is necessary to understand how best to manage the FSC to improve microbiological food safety. Currently, different food industries apply different food safety controls in their food safety management systems, and the functioning of such systems is also variable. To ensure sustainable control of product quality it is important to have a well-managed operation at each step within the FSC. With the world facing a challenge to reduce the large amount of food produced globally that is currently lost (Figure 3), managing the different aspects of the FSC is essential.

Implicated as sources of infection that may cause microbial contamination, food outbreaks and economic losses are the primary materials for food manufacturing, such as milk, meat, fruits and vegetables (Table 1). Farmers are responsible for supplying consumers and manufacturers with the raw products for use in food manufacturing and processing. Fresh produce and raw products receive special attention because they are more likely to contain pathogenic bacteria, such as *Salmonella* spp. and *E. coli* O157:H7.⁷⁸⁻⁸⁰ This concern has demanded the use of Good Agricultural Practices (GAP) in both crop and animal production on farms, in order to reduce the risk of microbial

contamination.^{81,82} Practising GAP includes all activities before and during production and at harvest. GAP also requires product inspection reports from suppliers, and these are essential records to ensure that the products are not contaminated by pathogens or toxins. Thus, applying GAP and more hygienic procedures at the farming stage is important to ensure maximum safety of the products.

However, food safety control systems are also important in other stages of the FSC to ensure the production of safe food. An ever-increasing number of food outbreaks around the world each year are linked to processed foods and cross-contamination.⁸³⁻⁸⁵ Microbial contamination during food processing can result from poor application of Hazard Analysis and Critical Control Point (HACCP) principles.^{86,87} In many countries, including Australia, processed and ready-to-eat meats are, potentially, a vehicle for foodborne illnesses associated with *Clostridium perfringens*, *Salmonella*, *E. coli* (EHEC) and *L. monocytogenes*.^{88,89} An increase during manufacturing in the incidence of foodborne outbreaks by these bacteria⁷⁴ has resulted in the identification of specific risk profiles for these bacteria in different foods to provide the industry with risk ratings for hazardous meat and meat product combinations.⁹⁰ Such development of risk management systems and the implementation of HACCP-based food safety strategies across the FSC for different food products are essential for all countries to reduce food poisoning outbreaks and improve global food security.

Applying HACCP or a similar system of hazard control in food manufacturing business is important to control hazards and, thereby, improve the safety of food.^{91,92} Table 2 lists common microbial contamination issues and the possible solutions using a food safety management system. Nevertheless, many recent studies have suggested that a combination of two or more

Table 2: Most Common Microbial Contamination Issues and the Possible Solutions Using a Food Safety Management System.

| Microbial contamination issue | Frequency/impact | How to improve | References |
|--|---|--|---|
| Contamination of raw materials | <ul style="list-style-type: none"> Fresh vegetable products implicated as sources of infection Inappropriate suppliers' processes or wrong storage may cause microbial contamination | <ul style="list-style-type: none"> Apply good agricultural systems and more hygienic performance in both crops and on farms Establish effective cleaning/sanitizing programmes Request a product inspection report from the suppliers that contains a self-evaluation document to ensure the materials were not contaminated by pathogens or toxins | Lehto et al ⁸² ; Gustavsson et al ²² ; Wu et al ⁹⁸ |
| Risk in food packaging | <ul style="list-style-type: none"> Air combined with packaging in the food supply chain is one of the major potential sources of pathogenic microorganisms | <ul style="list-style-type: none"> Use appropriate air filters combined with production processes at all times that can control high-risk microbial aerosol generation Use good hygienic practices in food processing and supply a product inspection report form to ensure the products are not contaminated by pathogens or toxins | Harris et al ⁹⁹ |
| Risk in food refrigeration | <ul style="list-style-type: none"> Inappropriate refrigeration systems can cause microbial contamination that can result in a big loss of food products | <ul style="list-style-type: none"> Refrigerate food products as that should produce a safe product by reducing the temperature of the meat and vegetables to a point where the rate of growth of spoilage microorganisms is slowed down and the growth of most pathogenic microorganisms is prevented Supply a refrigeration inspection report | James et al ¹⁰⁰ ; Sampers et al ¹⁰¹ ; Carpentier et al ¹⁰² |
| Risk in transportation and food service operations | <ul style="list-style-type: none"> Unsuitable and untimely transportation services can cause microbial contamination Product handling at the end destination and/or at wrong temperatures can cause microbial contamination and food loss | <ul style="list-style-type: none"> Employ time and temperature control in all stages of transportation Use good personal hygiene Establish effective cleaning/sanitizing programmes Supply product inspection report forms at the products destination for all products from the initial process to the ultimate end-products | Gitahi ¹⁰³ ; Hassouneh et al ¹⁰⁴ ; Linton and McSwane ¹⁰⁵ |

safety control programmes, such as the International Organization for Standardization (ISO) quality management system, good manufacturing practices (GMP) and HACCP, markedly improves microbial food safety management^{93,94} and, thereby reduce food contamination. Implementing one or more of these systems during food production is therefore widely recommended for food manufacturing businesses to achieve more effective food safety management to improve food security.

CONCLUSION

The threat of food insecurity is real. Many approaches have been suggested to tackle this challenge. One-third of total food produced globally never makes its way to consumers' tables due to several factors, microbial contamination being the important one. A wide variety of pathogens (e.g., *Salmonella*, pathogenic *E. coli*, *L. monocytogenes* and *Campylobacter*) are associated with foodborne illnesses and outbreaks and the consequent food and economic losses. Reducing microbial contamination and other food safety issues will significantly improve the food supply. Efficient food process controls and effective food safety systems (e.g., GAP, HACCP, ISO, GMP) are helpful in controlling microbial contaminations. Such improvements in microbial food safety practices will definitely bring additional food to the table and thereby improve food security.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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