Decontamination of Fresh and Minimally Processed Produce

Attempts to provide safer and higher quality fresh and minimally processed produce have given rise to a wide variety of decontamination methods, each of which have been extensively researched in recent years. Decontamination of Fresh and Minimally Processed Produce is the first book to provide a systematic view of the different types of decontaminants for fresh and minimally processed produce. By describing the different effects – microbiological, sensory, nutritional and toxicological – of decontamination treatments, a team of internationally respected authors reveals not only the impact of decontaminants on food safety, but also on microbial spoilage, vegetable physiology, sensory quality, nutritional and phytochemical content and shelf-life. Regulatory and toxicological issues are also addressed.

The book first examines how produce becomes contaminated, the surface characteristics of produce related to bacterial attachment, biofilm formation and resistance, and sub-lethal damage and its implications for decontamination. After reviewing how produce is washed and minimally processed, the various decontamination methods are then explored in depth, in terms of definition, generation devices, microbial inactivation mechanisms, and effects on food safety. Decontaminants covered include: chlorine, electrolyzed oxidizing water, chlorine dioxide, ozone, hydrogen peroxide, peroxyacetic acid, essential oils and edible films and coatings. Other decontamination methods addressed are biological strategies (bacteriophages, protective cultures, bacteriocins and quorum sensing) and physical methods (mild heat, continuous UV light, ionizing radiation) and various combinations of these methods through hurdle technology. The book concludes with descriptions of post-decontamination methods related to storage, such as modified atmosphere packaging, the cold chain, and modeling tools for predicting microbial growth and inactivation.

The many methods and effects of decontamination are detailed, enabling industry professionals to understand the available state-of-the-art methods and select the most suitable approach for their purposes. The book serves as a compendium of information for food researchers and students of pre- and postharvest technology, food microbiology and food technology in general. The structure of the book allows easy comparisons among methods, and searching information by microorganism, produce, and quality traits.

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Decontamination of Fresh and Minimally Processed Produce
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This text has the goal of being the first book providing a systematic view of the different types of decontaminants for fresh and minimally processed produce, and describing the different effects of decontamination treatments well beyond food safety.

There are a growing number of valuable books on emerging technologies. There are also high-quality texts on minimal processing; however, there is a lack of books that cover extensively and in detail the different aspects of the use of decontaminants, and especially detailing their effects on spoilage microflora, sensory quality, nutrient and phytochemical content, and toxicological and legal concerns.

This book is organized into six sections. In Section I, the preharvest and harvest contamination of produce is described in detail. This is followed by three chapters about factors impairing decontamination efficacy such as attachment and surface topography, biofilms, resistance, and sublethal damage.

Sections II, III, and IV cover different decontamination strategies based on six transversal axes:

1. Inactivation of human pathogens present in produce in order to reduce the risk of foodborne infections and intoxications.
2. Inactivation of indigenous microflora and microbial contaminants acquired during processing, together with controlling survival and growth during storage, in order to decrease microbial spoilage.
3. Preservation of sensory quality, immediately after processing and during storage.
5. Potential presence of toxic residues or formation of unacceptable levels of toxic by-products.
6. Regulatory status.

More specifically, Section II starts with a chapter describing produce washers, followed by others explaining the special characteristics of minimally processed fruits and vegetables. The chapter then describes, based on the six transversal axes, different decontaminants: chlorine, electrolyzed oxidizing water, chlorine dioxide, ozone, hydrogen peroxide, peroxyacetic acid, essential oils, edible films and coatings, and miscellaneous.

Section III is devoted to biological decontamination strategies such as viruses, protective cultures, bacteriocins, and quorum sensing. Section IV addresses physical methods such as mild heat, continuous UV light, ionizing radiation, and miscellaneous, and finishes with a discussion of a combination of decontamination methods in the frame of the hurdle technology concept.

Section V refers to preservation strategies after decontamination, where the principles of modified atmosphere packaging and cold chain are revised and discussed. Section VI covers modeling tools, which are not widely used in decontamination experiments, and should serve as a way to promote their use. These chapters focus on two perspectives: from
the point of view of microbial inactivation and from the point of view of microbial growth during shelf life.

I am very grateful to each of the contributors for their commitment to this book. Since the start of this project, I was sure that this book’s success would rely on the strong team of authors that assured from the beginning its top quality. I also want to thank the editorial staff of Wiley-Blackwell, especially Mark Barrett, Susan Engelken, Carys Williams, David McDade, and Samantha Thompson for their guidance in all the aspects that made possible the publication of this book.

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Section I

Produce Contamination
1 Microbial ecology

Marilyn C. Erickson

Abstract: Outbreaks associated with fresh produce have been traced to farms in several cases. Potential sources of contamination in preharvest environments have been identified, and minimizing their input is needed. In addition, understanding the fate of enteric pathogens introduced to soil and plant systems is essential to providing safe guidelines on when crops may be planted and harvested. Moisture availability and temperature are key abiotic factors affecting pathogen survival. Indigenous soil and epiphytic bacteria, however, also appear to play an important role in a pathogen’s fate and thus future survival studies should routinely monitor the types and levels present. Internalization of enteric pathogens through lateral root junctions or through leaf stomata has been documented but generally requires high exposure concentrations. Plant defenses, whether basal or activated by the invading enteric pathogen, appear to inactivate internalized populations as persistence has not been observed, but this subject deserves further investigation.

Keywords: *Escherichia coli* O157:H7, *Salmonella*, internalization, rhizosphere, phyllosphere, competitive bacteria, plant defenses, moisture, preharvest, produce

1.1 Introduction

Fresh and fresh-cut produce is a recognized rich source of many nutrients and leads to numerous health benefits. Based on these acknowledged merits, consumers have been advised to increase their consumption. Assisting consumers in meeting that goal is the year-round availability of many produce items through a global production and distribution system. One drawback that has accompanied this increased demand and consumption, however, has been that the proportion of outbreaks attributed to this commodity group has increased (Lynch *et al.*, 2009). For example, in the 1970s, produce-associated outbreaks accounted for 0.7% of total outbreaks in the United States, but by the 1990s this had increased to 6% (Sivapalasingam *et al.*, 2004). Furthermore, between 1990 and 2005, produce outbreaks in the United States accounted for 13% of foodborne illness outbreaks (DeWaal and Bhuiya, 2007). In Australia, by contrast, only 4% of all foodborne outbreaks...
reported from 2001 to 2005 were attributed to fresh produce (Kirk et al., 2008). In Canada between 1976 and 2005, 3.7% of 5745 outbreaks with a known vehicle of transmission were attributed to produce (Ravel et al., 2009).

Produce items most commonly associated with outbreaks in the United States between 2000 and 2007 were leafy greens or greens-based salads, tomatoes, cantaloupes, carrots, strawberries, and watermelon (Table 1.1). For many of these produce types, norovirus was the dominant etiological agent. The most common bacterial etiological agent, on the other hand, was Salmonella spp., followed by Escherichia coli O157:H7. Less commonly identified pathogens were Campylobacter jejuni, Shigella spp., hepatitis A, and the protozoan parasites Cryptosporidium parvum, Giardia spp., and Cyclospora cayetanesis.

Over the past 10 years, an extensive number of outbreaks associated with fresh produce have been described in reports, and these are compiled in Table 1.2. A point worth noting is that many of these outbreaks are multi-national in scope, which infers that food safety within many countries is also dependent on the production and processing practices of those countries from which food is imported. Disparities in food safety exist between industrialized countries and developing countries as evidenced by the higher prevalence of Salmonella spp. in produce collected and sampled in many developing countries compared to industrialized countries (Table 1.3). In addition, raw and minimally processed produce within many of these developing countries is characterized by the presence of helminth and protozoan parasites (Table 1.4), pathogens that are rarely present in domestic products from industrialized countries. These disparities in pathogen prevalence have been attributed to a number of factors and include the use in developing countries of fecal-contaminated irrigation water for fruit and vegetable production, the use of human excrement as a soil amendment, a lack of basic infrastructures to treat wastewater, and longstanding cultural attitudes of using sustainable agricultural practices that are insanitary (Erickson and Doyle, 2008). In Section 1.2, these and other sources of pathogen ingress to produce fields will be discussed in further detail. In subsequent sections, the fate of those introduced pathogens in both soil and plant systems will be explored. In particular, the impact of chemical, physical, and indigenous micro- and macrobiological organisms on the pathogen’s persistence in the system will be discussed. The ability of both plant and pathogen to exhibit molecular and biochemical responses to each other’s presence will then be briefly discussed relative to the pathogen’s survival. The chapter will conclude with an examination of harvesting practices that lead to cross-contamination of produce.

1.2 Sources of preharvest contamination

Based on the low prevalence of pathogen contamination in retail produce reported in many surveys, information regarding potential sources of preharvest contamination is based mainly on initial hypotheses that have been tested with experimental studies. These include (1) soil amendments (raw animal manure and other waste products of domesticated animals), (2) water (irrigation and run-off), (3) wildlife and insects (deposing waste products or serving as pathogen carriers), (4) plant stock (seeds and seedlings), (5) humans, (6) fomites (harvesting equipment and storage bins), and (7) bioaerosols (dispersed particles carrying pathogens from adjacent animal production or human waste sites). In consideration of these sources, it should be kept in mind that they have different frequencies at which they are contaminated and thus entail different inherent risks for the introduction of pathogens into agricultural fields. For example, the prevalence rates of E. coli O157 in cattle feces ranged
<table>
<thead>
<tr>
<th>Produce item</th>
<th>Bacterial agents</th>
<th>Viral agents</th>
<th>Other agents</th>
<th>Protozoan parasites*</th>
<th>Unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>Salmonella</em> spp.</td>
<td><em>Escherichia coli O157:H7</em></td>
<td><em>Shigella</em> spp.</td>
<td><em>Campylobacter jejuni</em></td>
<td><em>Other</em></td>
</tr>
<tr>
<td>Cabbage</td>
<td>1 (8)</td>
<td>1 (41)</td>
<td>1 (2)</td>
<td>3 (78)</td>
<td>1 (16)</td>
</tr>
<tr>
<td>Lettuce</td>
<td>6 (254)</td>
<td>10 (242)</td>
<td>1 (4)</td>
<td>2 (110)</td>
<td>33 (895)</td>
</tr>
<tr>
<td>Spinach</td>
<td>1 (210)</td>
<td>1 (25)</td>
<td>3 (9)</td>
<td>2 (9)</td>
<td>1 (2)</td>
</tr>
<tr>
<td>Sprouts</td>
<td>7 (120)</td>
<td>3 (25)</td>
<td>1 (2)</td>
<td>6 (30)</td>
<td>2 (25)</td>
</tr>
<tr>
<td>Herbs</td>
<td>3 (70)</td>
<td>1 (20)</td>
<td>1 (29)</td>
<td>6 (191)</td>
<td>1 (20)</td>
</tr>
<tr>
<td>Leafy green salads</td>
<td>20 (931)</td>
<td>13 (281)</td>
<td>7 (190)</td>
<td>7 (42)</td>
<td>9 (143)</td>
</tr>
<tr>
<td>Coleslaw</td>
<td>1 (26)</td>
<td>4 (22)</td>
<td>19 (592)</td>
<td>1 (8)</td>
<td>3 (20)</td>
</tr>
<tr>
<td>Broccoli</td>
<td>1 (9)</td>
<td>4 (77)</td>
<td>1 (1)</td>
<td>1 (11)</td>
<td></td>
</tr>
<tr>
<td>Celery</td>
<td>6 (191)</td>
<td>1 (20)</td>
<td>1 (20)</td>
<td>1 (20)</td>
<td>1 (20)</td>
</tr>
<tr>
<td>Cucumbers</td>
<td>1 (300)</td>
<td>1 (10)</td>
<td>4 (123)</td>
<td>1 (10)</td>
<td>1 (10)</td>
</tr>
<tr>
<td>Mushrooms</td>
<td>1 (93)</td>
<td>1 (28)</td>
<td>2 (6)</td>
<td>1 (2)</td>
<td>2 (6)</td>
</tr>
<tr>
<td>Peppers</td>
<td>1 (93)</td>
<td>1 (28)</td>
<td>2 (6)</td>
<td>1 (2)</td>
<td>2 (6)</td>
</tr>
<tr>
<td>Squash/zucchini</td>
<td>1 (93)</td>
<td>1 (28)</td>
<td>2 (6)</td>
<td>1 (2)</td>
<td>2 (6)</td>
</tr>
<tr>
<td>Tomatoes</td>
<td>23 (1837)</td>
<td>1 (886)</td>
<td>1 (13)</td>
<td>1 (2)</td>
<td>14 (395)</td>
</tr>
<tr>
<td>Carrots</td>
<td>1 (8)</td>
<td>1 (7)</td>
<td>2 (8)</td>
<td>11 (325)</td>
<td>5 (67)</td>
</tr>
<tr>
<td>Green onions</td>
<td>3 (184)</td>
<td>1 (28)</td>
<td>1 (4)</td>
<td>3 (90)</td>
<td>5 (967)</td>
</tr>
<tr>
<td>Onions</td>
<td>12 (457)</td>
<td>1 (56)</td>
<td>1 (55)</td>
<td>6 (233)</td>
<td>4 (53)</td>
</tr>
<tr>
<td>Raspberries/ blackberries</td>
<td>1 (13)</td>
<td>1 (5)</td>
<td>6 (274)</td>
<td>2 (11)</td>
<td>4 (153)</td>
</tr>
<tr>
<td>Strawberries</td>
<td>3 (72)</td>
<td>1 (736)</td>
<td>6 (208)</td>
<td>2 (19)</td>
<td></td>
</tr>
<tr>
<td>Watermelon</td>
<td>11 (1143)</td>
<td>11 (126)</td>
<td>327 (11 870)</td>
<td>9 (1017)</td>
<td>8 (746)</td>
</tr>
<tr>
<td>Total</td>
<td>84 (4092)</td>
<td>31 (1840)</td>
<td>239 (352)</td>
<td>327 (11 870)</td>
<td>8 (746)</td>
</tr>
</tbody>
</table>

*a* Data compiled from the CDC website on outbreak surveillance (http://www.cdc.gov/outbreaknet/surveillance_data.html).

*b* Outbreaks and illnesses attributed to each pathogen group include both confirmed and suspected.

*Includes other Shiga toxin-producing *Escherichia coli*.

*Includes where multiple bacterial pathogens have been found and cases involving the agents of *Bacillus cereus*, *Clostridium botulinum*, and *Staphylococcus aureus*.

*Includes *Cryptosporidium parvum*, *Cyclospora cayetanensis*, and *Giardia lamblia*.
Table 1.2  Major produce-associated outbreaks caused by foodborne pathogens (2000–2010)

<table>
<thead>
<tr>
<th>Year</th>
<th>Pathogen</th>
<th>Cases (#)</th>
<th>Country of origin</th>
<th>Affected regions</th>
<th>Implicated food</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>S. Senftenberg</td>
<td>51</td>
<td>Israel</td>
<td>United Kingdom, United States, Denmark, Netherlands</td>
<td>Basil</td>
<td>Elviss et al. (2009)</td>
</tr>
<tr>
<td>2007</td>
<td>S. Senftenberg</td>
<td>74</td>
<td>Israel</td>
<td>United Kingdom, Denmark, Netherlands, United States</td>
<td>Basil, fresh</td>
<td>Pezzoli et al. (2008)</td>
</tr>
<tr>
<td>2008</td>
<td>S. Litchfield</td>
<td>51</td>
<td>Honduras</td>
<td>United States, multi-state</td>
<td>Cantaloupe</td>
<td>CDC (2008a)</td>
</tr>
<tr>
<td>2001</td>
<td>S. Poona</td>
<td>50</td>
<td>Mexico</td>
<td>United States, multi-state</td>
<td>Cantaloupe</td>
<td>CDC (2002)</td>
</tr>
<tr>
<td>2002</td>
<td>S. Poona</td>
<td>58</td>
<td>Mexico</td>
<td>United States, Canada</td>
<td>Cantaloupe</td>
<td>CDC (2002)</td>
</tr>
<tr>
<td>2006</td>
<td>S. Saintpaul</td>
<td>36</td>
<td>Domestic</td>
<td>Australia, multi-jurisdiction</td>
<td>Cantaloupe</td>
<td>Munnoch et al. (2009)</td>
</tr>
<tr>
<td>2006</td>
<td>Clostridium botulinum</td>
<td>4</td>
<td>Domestic</td>
<td>United States, GA</td>
<td>Carrot juice</td>
<td>CDC (2006a)</td>
</tr>
<tr>
<td>2004</td>
<td>Shigella sonnei</td>
<td>163</td>
<td>United States, HI, caterer</td>
<td>International</td>
<td>Carrots</td>
<td>Gaynor et al. (2009)</td>
</tr>
<tr>
<td>2003</td>
<td>Yersinia pseudotuberculosis</td>
<td>111</td>
<td>Domestic, traced to farm</td>
<td>Finland</td>
<td>Carrots</td>
<td>Jalava et al. (2006)</td>
</tr>
<tr>
<td>2006</td>
<td>Yersinia pseudotuberculosis</td>
<td>427</td>
<td>Domestic, traced to vegetable distributor</td>
<td>Finland</td>
<td>Carrots, grated</td>
<td>Rimhanen-Finne et al. (2009)</td>
</tr>
<tr>
<td>2002</td>
<td>E. coli O157</td>
<td>21</td>
<td>Belgium</td>
<td>United Kingdom, France</td>
<td>Cucumber</td>
<td>Duffell et al. (2003)</td>
</tr>
<tr>
<td>2003</td>
<td>Hepatitis A</td>
<td>601</td>
<td>Mexico</td>
<td>United States, PA</td>
<td>Green onions</td>
<td>Wheeler et al. (2005)</td>
</tr>
<tr>
<td>2004</td>
<td>S. Newport</td>
<td>807</td>
<td>Not known</td>
<td>England, Scotland, Isle of Man, and Ireland</td>
<td>Lettuce</td>
<td>Irvine et al. (2009)</td>
</tr>
<tr>
<td>2000</td>
<td>S. Typhimurium DT104 (ACSSuSpT)</td>
<td>361</td>
<td>Not known</td>
<td>United Kingdom</td>
<td>Lettuce</td>
<td>Horby et al. (2003)</td>
</tr>
<tr>
<td>2000</td>
<td>S. Typhimurium DT204b (ACGNeKSSuTmNxCp)</td>
<td>392</td>
<td>Imported</td>
<td>Iceland, Netherlands, United Kingdom, Germany</td>
<td>Lettuce</td>
<td>Crook et al. (2003)</td>
</tr>
<tr>
<td>2005</td>
<td>E. coli O157 VT2</td>
<td>120</td>
<td>Domestic</td>
<td>Sweden</td>
<td>Lettuce, iceberg</td>
<td>Soderstrom et al. (2005)</td>
</tr>
<tr>
<td>2005</td>
<td>S. Typhimurium DT104b (ACSSuT)</td>
<td>60</td>
<td>Spain</td>
<td>Finland</td>
<td>Lettuce, iceberg</td>
<td>Takkinen et al. (2005)</td>
</tr>
<tr>
<td>2010</td>
<td>Norovirus and E. coli ETEC</td>
<td>264</td>
<td>France</td>
<td>Denmark, Norway</td>
<td>Lettuce, Lollo</td>
<td>Ethelberg et al. (2010)</td>
</tr>
<tr>
<td>2001</td>
<td>Hepatitis A</td>
<td>54</td>
<td>Imported</td>
<td>Sweden</td>
<td>Lettuce, rocket</td>
<td>Nygard et al. (2001)</td>
</tr>
</tbody>
</table>