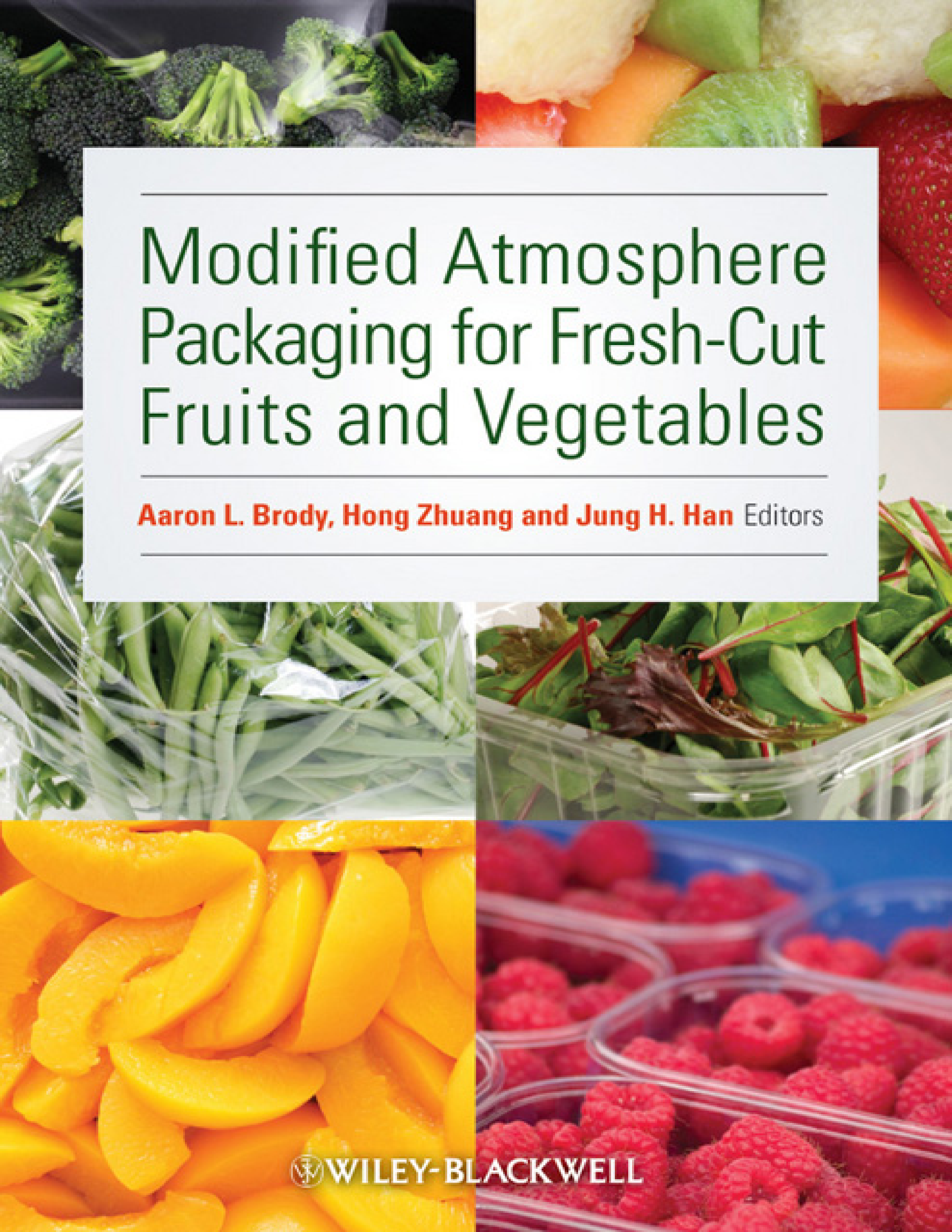

Modified Atmosphere Packaging for Fresh-Cut Fruits and Vegetables

Aaron L. Brody, Hong Zhuang and Jung H. Han Editors

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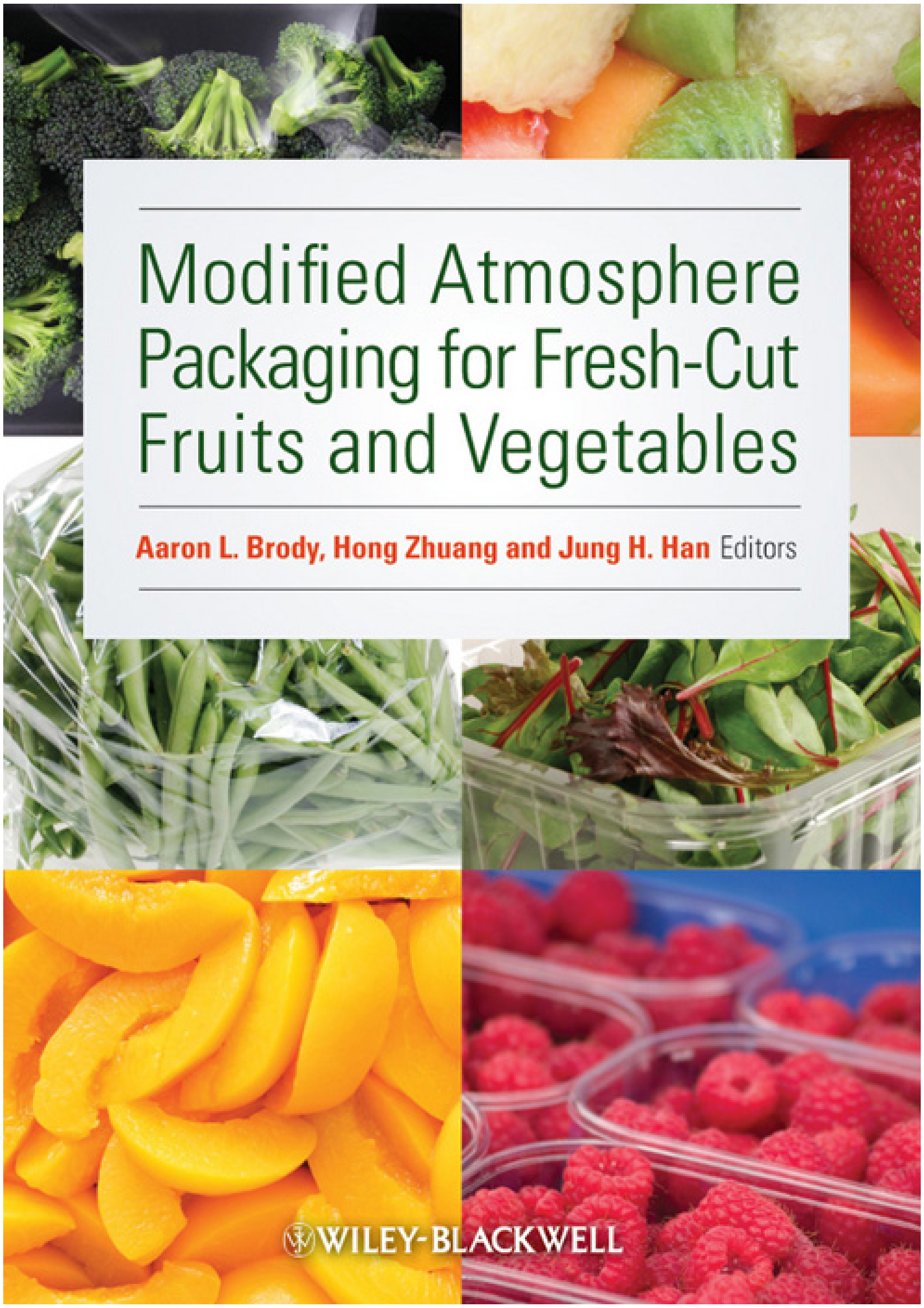
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Contributors

M. Margaret Barth (Chapters 3 and 5)
Responsible Source
Lake Forest, Illinois, USA

Aaron L. Brody, Editor
Packaging/Brody, Inc.
Duluth, Georgia, USA
and
Department of Food Science and Technology
University of Georgia
Athens, Georgia, USA

Alan Campbell (Chapter 7)
Packaging & Manufacturing
Department of Food Manufacturing Technologies
Campden BRI
Chipping Campden, Gloucestershire, U.K.

Kenny Chuang (Chapter 4)
Mead Johnson Nutrition Co.
Glenview, Illinois, USA

Raymond Clarke (Chapter 9)
Apio Inc.
Guadalupe, California, USA

Xuetong Fan (Chapters 3 and 5)
Eastern Regional Research Center, ARS, USDA
Wyndmoor, Pennsylvania, USA

Roger Gates (Chapter 10)
R. W. Gates Packaging, Inc.
Cary, Illinois, USA

Jung H. Han, Editor (Chapter 14)
PepsiCo Advanced Research
Plano, Texas, USA

Loong-Tak Lim (Chapter 13)
Department of Food Science
University of Guelph
Guelph, Ontario, Canada
Qiang Liu (Chapter 2)
Guelph Food Research Centre
Agriculture and Agri-Food Canada
Guelph, Ontario, Canada
G. F. Mehyar (Chapter 14)
Department of Nutrition and Food Technology
University of Jordan
Amman, Jordan
Curtis Rempel (Chapter 2)
Richardson Centre for Functional Foods
and Nutraceuticals
University of Manitoba
Winnipeg, Manitoba, Canada
Claire Koelsch Sand (Chapter 15)
Stillwater, Minnesota, USA
and
Adjunct faculty member: Michigan State University, Rochester
Institute of Technology, and University of Florida
Chris van Wandelen (Chapters 11 and 12)
CVP Systems, Inc.
Downers Grove, Illinois, USA
Jun Yang (Chapter 6)
PepsiCo Fruit & Vegetable Research Center
Plano, Texas, USA
Yachuan Zhang (Chapter 2)
Guelph Food Research Centre
Agriculture and Agri-Food Canada
Guelph, Ontario, Canada
Hong Zhuang, Editor (Chapters 1, 3, 5, and 8)
South Atlantic Area, ARS, USDA

Athens, Georgia, USA

Preface

Fresh-cut fruits and vegetables are "any fresh fruit or vegetable or any combination thereof that has been physically altered from its original form, but remains in a fresh state" (IFPA, International Fresh-Cut Produce Association). Fresh-cut fruits and vegetables provide consumers convenience with healthy components of fresh produce and fresh-like taste. They have been the most rapidly growing convenient food products in history. Modified atmosphere packaging, commonly called MAP, is a technique used for prolonging the shelf-life period of fresh or processed foods by modifying the air (20.9% oxygen, 71% nitrogen, and 0.03% carbon dioxide) surrounding the food in the package to a different composition. MAP plays a key role in the success of fresh-cut produce products that are prepared at central facilities and sold in retail stores or used by foodservice businesses.

Since fresh-cut fruits and vegetables have become so popular, the research and development in this area has been extensively reviewed in the past decade, and MAP has been included in almost every published monograph on fresh-cut fruits and vegetables. However, the discussions on MAP have been mostly limited to MAP theories and physiological and quality effects. More than three years ago, when Dr. Aaron Brody, Dr. Jung Han, and Dr. Hong Zhuang worked together to review the ideas behind this book and the books that have been published, we felt that *Modified Atmosphere Packaging for Fresh-Cut Fruits and Vegetables* would be very valuable to fresh-cut industry and research; however, we had to make this book distinct from the other published monographs. Dr. Brody specifically suggested making this book aim at the end users in the fresh-cut industry. To achieve this goal, we should try to invite as chapter contributors those who worked or had experience with the fresh-cut industry practice.

Having this basic target in mind, we designed this book to benefit those who are currently working in the fresh-cut industry and are dealing with packaging in their day-to-day operations, including the R&D personnel, on-line managers, and operation machine engineers. Therefore, we wanted this book to not only have the basics of MAP but also to be the sharing of working experiences.

The book consists of three parts: (1) “Modified Atmosphere Packaging,” which covers the fundamental theories and physiological and quality effects of MAP on fresh-cut fruits and vegetables; (2) “Modified Atmosphere Packaging Materials and Machinery,” which covers the films and machines that are most commonly used in the fresh-cut industry; (3) “Novel Packaging Technologies,” which discusses the latest packaging innovations and their potential impact on fresh-cut fruit and vegetable products.

This book would not have been possible without the contributions of the chapter authors. They kept their commitments and took valuable time from their busy work and family activities to write these chapters. We really appreciate their willingness to share their invaluable experiences and expert knowledge, as well as working within a tight schedule. Also, we specially thank commissioning editors of Blackwell Publishing, Mark Barrett and Susan Engelken, for their encouragement, valuable suggestions, and patience during the book preparation process and Blackwell Publishing staff to have this book finally completed.

Aaron L. Brody
Hong Zhuang
Jung H. Han

Modified Atmosphere Packaging for Fresh-Cut Fruits and Vegetables

1 Introduction

Hong Zhuang

Fresh-cut fruits and vegetables are minimally or lightly processed produce that offer consumers ready-to-eat or ready-to-use fruit and vegetable products. They are convenient, healthful, and in a fresh-like state. Processing of fresh-cut produce involves sorting, cleaning, washing, trimming/peeling/deseeding/coring, and cutting (such as chopping, slicing, shredding, chunking, and dicing). Fresh-cut fruits and vegetables are prewashed and packed in bags or containers without any thermal treatments. They used to be called *minimally* or *lightly processed* produce and are the most rapidly growing convenient food category in history (Shewfelt 1987; Huxsoll et al. 1989; Brecht et al. 2004; Christie 2008). Sales of fresh-cut fruits and vegetables are approximately $12 billion per year in the North American foodservice and retail markets, and they now account for 17% of all produce sales (Christie 2008). The largest portion of US fresh-cut vegetable sales at retail is fresh-cut salads, with sales of nearly $5 billion (Christie 2009). Retail fresh-cut fruit products are the fastest growing fresh-cut produce. In 2004, 3.5 million units of fresh-cut fruit were sold, bringing in $719 million in sales. Between January and February 2005, those numbers were up 17% over 2004 (Warren 2005).

The success of fresh-cut fruit and vegetable products in the marketplace has been made possible by modified atmosphere packaging (MAP) innovations, as well as improvements in the chill chain and processing technology (Gorny 1997). MAP is a packaging technology that modifies or alters the gas composition around the products in food packages from normal air (20.95% O_2, 78.09% N_2, 0.93%

argon, and 0.038% CO_2) to provide an atmosphere for increasing the shelf life and maintaining the quality of the food. In some of the literature or communications, *controlled atmosphere* (CA) and *modified atmosphere* (MA) are often used interchangeably, but they do have different meanings. Although in CA storage the beneficial atmosphere around the product is also different from air as in MA, the gas composition is continuously monitored and adjusted and the product is usually stored in storage rooms or transportation containers. In contrast, in MA packaging, the gas composition is not closely monitored (it might be controlled by using a gas-scavenging sachet; in this case, the MAP could be classed as CA packaging) and the product is more limited in a package, such as a plastic bag or rigid container. Modification of the atmosphere in MAP may be achieved either actively or passively. One of the active MAP examples is gas flushing, or displacing the air with a controlled, desired mixture of gases in packages before sealing. Passive modification occurs as a consequence of the food's respiration and/or the metabolism of microorganisms associated with the food and the permeation of gases through the packaging materials. However, for the fresh-cut fruit and vegetable products, which require O_2 for their freshness and continue using O_2 and release CO_2 after processing, no matter which MA method (active MAP, passive MAP, or CAP) is employed, the equilibrated internal atmosphere is partly or wholly dependent upon the factors that control the passively modified atmosphere. In other words, it depends on the equilibrium between the respiration rate of cut produce and the permeability of the packaging materials.

Using a modified or controlled atmosphere to maintain or extend the quality of food is not really a new technology. Based on ancient writings, it can be traced back at least 2,000 years to underground grain storage. In this case, the underground storage room was dangerous to enter, a likely result of atmosphere modification with O_2 depletion and CO_2 accumulation due to the respiratory activity of the grain. The modified atmosphere was unintentional, although probably beneficial, and presumably protected the grain from rodent and insect pests, thereby preserving the quality and storage life of the grain (Beaudry 2007).

The first recorded scientific investigation into the effect of MA on fruit ripening was conducted by Berard, a professor at the school of pharmacy at Montpellier in France, who published his findings in 1821, which showed that harvested fruits utilize O_2 and give off CO_2. Fruits placed in an atmosphere deprived of O_2 did not ripen as rapidly as in air (Robertson 2006).

Franklin Kidd initiated the first intensive and systematic research on CA storage of fruits in England in 1918. He used various storage temperatures and atmospheres with different fruits. The atmospheres were generated by fruit respiration and were dependent on the O_2 consumed and the CO_2 evolved by the fruit within a gastight building (Robertson 2006).

In 1930, Killefer in England demonstrated that lamb, pork, and fish remained fresh twice as long in 100% CO_2 compared with storage in air at chill temperatures (Robertson 2006). On the basis of research discoveries of MAP and meat quality, practical application of controlled or modified atmosphere was made in the shipment of chilled beef carcasses from Australia to England in the early 1930s with an atmosphere of 10% CO_2 and a temperature of –1°C providing a storage life of 40–50 days without spoilage (Inns 1987).

In the 1940s, mathematic modeling was introduced to MAP. Platenius (1946), using permeability data, determined that the diffusion rate of O_2 through transparent films available at the time was inadequate to meet respiratory demands of the packaged produce. Allen and Allen (1950) noted that MAP suppressed ripening in tomatoes and suggested that polymers needed to be perforated if sealed or that polymers with higher permeability to O_2 were needed.

The first significant trials of retail size MAP took place in the late 1950s, with vacuum-packed meat, fish, and coffee (Inns 1987). Commercial application of MAP has steadily increased since then.

In the 1970s, reports and patents were published on using MAP to extend the shelf life of fresh-cut vegetables and pre-prepared and bagged cut salads and lettuce. Priepke et al. (1976) investigated refrigerated storage of prepackaged salad vegetables and sealed mixed vegetable salads with either air or an atmosphere containing 10.5% CO_2 + 2.25% O_2. After 2 weeks of storage at 4.4°C in packages, they found that the modified initial headspace was beneficial for the shelf life of fresh-cut salads. Rahman et al. (1976) published a method for extending the storage life of cut lettuce and claimed that shelf life was significantly extended by washing and packing cut lettuce in bags of vinylidine chloride–vinyl acetate copolymer film with low O_2, CO_2, and water vapor transmission rates. Dave (1977) patented a method (including package) for storing cut leafy vegetables and reported that the shelf life of the chlorine-washed and shredded lettuce and chopped green cabbage packaged in a polyester film was between 3 and 4 weeks, significantly longer than the shelf life of about 8–10 days in a conventional polyethylene bag. In 1980, Woodruff filed a patent (Woodruff 1980) and demonstrated that to extend shelf life, cut vegetables (including shredded and chopped lettuce, shredded red cabbage, cut broccoli, cauliflower, and celery) needed to be placed in enclosures, such as low density polyethylene bags, permeable to CO_2, CO, and O_2. He concluded that the permeability of packaging materials for cut vegetables should be sufficient to prevent the CO_2 concentration from rising much above 20% by volume, and to prevent the oxygen concentration from falling much below about 2% by volume.

In the 1980s, several reviews were published on the research and development of the MAP for fresh-cut produce. McLachlan and Brown (1983) summarized the emerging use of atmosphere control in the retail pack of ready-to-eat prepared produce and concluded that in the type of package tested the final atmosphere attained is a result of product respiration, gas permeation through the packaging film, type and amount of produce, film type and thickness, and holding temperature. Careful selection of all conditions is therefore necessary to prevent a potentially injurious or microbiologically hazardous atmosphere from developing. Barmore (1987), in his review on packing technology for fresh and minimally processed fruits and vegetables, pointed out that MAP represented a new technology that can be used to extend the shelf life of minimally processed produce. Myers (1989) discussed the packaging conditions for minimally processed fruits and vegetables in his review published in *Food Technology*. In the same year (1989), Fresh Express, the biggest fresh-cut produce maker in the United States, created the first ready-to-eat packaged garden salad available in grocery stores nationwide. Since then, total sales for MA packaged fresh-cut fruits and vegetables has increased from near zero (Beaudry 2007) to approximately $12 billion in North America by 2009 (Christie 2008). Fresh-cut produce varieties have expanded from lettuce-based salads to almost every major produce commodity with different cuts, blends, and package methods and sizes for both the foodservice and retail markets. With this rapid development, research on identifying optimal MAP conditions (including packaging methods, packaging sizes, films with different gas permeabilities, and storage conditions) for individual commodities (or individual fresh-cut produce products) and using mathematical models to predict the best MAP gas compositions in bags for different fresh-cut produce products has exploded. The package methods have been developed from passive MAP to active MAP. The packaging materials have been developed from regular polyethylene and polypropylene to intelligent membrane packaging and from nonperforated or macroperforated film to microperforated film.

Although MAP is a key element for fresh-cut products, the reviews of the development in MAP for fresh-cut fruits and vegetables have been published only as parts of a fresh-cut monograph. It is time to have a specific treatise dedicated to the MAP for fresh-cut produce. *Modified Atmosphere Packaging for Fresh-Cut Fruits and Vegetables* was designed as such a treatise and covers several aspects of MAP technologies for fresh-cut fruits and vegetables. The application of MAP in the fresh-cut industry is the special interest of this book and is covered intentionally.

The book (Part 1) begins with chapters on the basic principles of MAP, including the mathematical modeling of MAP for fresh-cut produce and the effects of MAP on the physiology and biochemistry, microbiology, quality, and healthy components (phytochemicals) of fresh produce. For an overall review of MAP fundamentals, MAP theory is introduced by mathematical modeling rather than by a generic summarization. For the physiological and biochemical bases of fresh-cut fruits and vegetables for MAP, only respiration and browning discoloration of fresh-cut produce are comprehensively discussed. For quality impacts of MAP, a review has been written based on produce commodities.

Subsequently, in Part 2 the book discusses packaging materials and machinery for MAP, with not only the basic information about thermoplastic MAP films and machinery, but also two examples of emerging films, microperforated films and Breatheway® membrane (a component of intelligent films), which have been showing potential application for fresh-cut fruit and vegetable products. Raymond Clarke with Apio Inc. was invited to detail Apio's intelligent film (Breatheway® membrane) technology and its application with produce. Roger Gates was invited to share his personal experiences with the application of microperforated films for fresh-cut products. Chris van Wandelen, Vice President of CVP Systems, Inc., a packaging equipment manufacturer, is a contributor for MAP machinery and hygienic design for fresh-cut business.

In Part 3, nanostructure packaging, active packaging (including antimicrobial packaging), and packaging sustainability, the three latest trends and developments in food packaging technologies, are introduced by experts in each selected area for researchers who are looking for new opportunities to improve MAP for fresh-cut fruit and vegetable products.

I hope that this book will be valuable to fresh-cut industry and research, and I hope it will provide all readers, including fresh-cut academic researchers, fresh-cut R&D personnel, and fresh-cut processing engineers, with unique, essential, and helpful information about MAP theory and application.

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Part I

Modified Atmosphere Packaging

2 Mathematical Modeling of Modified Atmosphere Packaging

Yachuan Zhang, Qiang Liu, and Curtis Rempel

Introduction

The storability of postharvest crops is dependent on some salient factors such as moisture content, respiration rate (*RR*), heat production, texture characteristics, and physiological phase of ontogeny (Haard 1984). Among these factors, *RR* has been recognized for decades to have an inverse relationship with storability. Crops that exhibit a relatively high *RR* tend to deteriorate rapidly, whereas crops that respire slowly can be stored for extended periods of time (Haard 1984). Figure 2.1 shows the relationship between *RR* and storability of selected fruits and vegetables.

Although the biochemical basis for the relationship between respiration and storability is not entirely clear, it is clear that reducing *RR* has positive outcomes for storage. Two methods have been commonly developed to reduce *RR* of crops. One is the reduction of the storage environmental temperature; the other is the modification of the storage atmosphere by reducing oxygen and increasing carbon dioxide partial pressure. The latter is usually termed *modified atmosphere packaging* (MAP).

Figure 2.1 Relationship between respiratory rate and storability of selected fruits and vegetables at 5°C. [Reprinted from Haard (1984).]