PACKAGING & DISTRIBUTION of FRESH FRUITS & VEGETABLES

Vanee Chonhenchob, Ph.D.
Associate Professor, Kasetsart University

Paul Singh, Ph.D.
Professor Emeritus, Michigan State University

Jay Singh, Ph.D.
Professor, Cal Poly State University

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As children we would like to dedicate this book to our parents, Dr. K. Kirpal Singh and Mrs. Kuldeep Kaur, Dr. Athorn and Mrs. Pornratana Chonhenchob, and Mr. Surinder Singh and Mrs. Parkash Kaur, whose pursuit for our higher education was of utmost importance.

We also would like to dedicate the time and knowledge that our teachers and mentors shared with us, especially Dr. Chester Mackson, Dr. Gary Burgess, Dr. Jerry Cash, Dr. Bruce Harte, Dr. Janice Harte, and Dr. Julian Lee.

To all our families and friends.

Knowledge belongs to humanity!—Louis Pasteur

Foreword

I am pleased to offer a few words to potential readers of this book, Packaging and Distribution of Fresh Fruits & Vegetables, by Dr. Vanee Chonhenchob, Dr. Paul Singh and Dr. Jay Singh. My remarks will, I trust, help readers better understand the book's contents and professional background. I have known all three authors a long time and have had the pleasure to watch them develop and become established experts in their respective fields. Dr. Paul Singh and I were colleagues at the Michigan State University (MSU) School of Packaging, and I was on the faculty when Dr. Chonhenchob and Dr. Jay Singh were students at the same university.

Dr. Vanee Chonhenchob received her Ph.D. from Michigan State and since then has worked at Kasetsart University in Bangkok, Thailand. Initially, she was hired by the Department of Packaging Technology. Currently she holds multiple positions at Kasetsart, including Associate Dean for Communications; Associate Professor, Department of Packaging and Materials Technology; Associate Professor, Postharvest Technology Innovation Center; member Commission on Higher Education, Thailand; and Director of the Packaging and Distribution of Fresh Produce (PKD) Research Group. Much of her research and, in fact, much of her career has been spent working directly with fresh produce.

At Michigan State, Dr. Paul Singh rapidly developed expertise in the distribution of packaged goods and methodologies by which to test the effectiveness of package design in meeting the challenges of the distribution environment. Currently Paul is professor emeritus, Michigan State University and president of Packaging Forensics Associates, Inc.

Dr. Singh has worked closely with the fresh produce industry his entire career, from large growers and packers, to retailers and transportation companies. Much of his research has been devoted to the packaging, handling and transportation of fresh produce. During his career he has advised many packaging companies on ways to improve their packaging systems and handling techniques. Paul has created and delivered dozens of workshops and seminars on fresh produce subjects, often in association with industry organizations.

Dr. Jay Singh, a graduate of the MSU School of Packaging, is a professor at Cal Poly State University, and over the past 15 years has built an expertise on testing and evaluation of packaging and has contributed in those areas in this text. He has also led the development of a fresh produce consortium for packaging research at Cal Poly.

In sum, Dr. Chonhenchob and Drs. Singh share a uniqueness of background, career experience and international perspective that particularly qualifies them to author this book, which among other things will help working specialists address climatic and physical challenges in the distribution environment of a wide variety of fruits and vegetables.

The book is divided into eight distinctive chapters covering a broad and diverse set of topics directly associated with fresh produce. Each chapter is presented in substantial depth and detail, sufficient to help readers understand its overall importance in the broader perspective of the book. Each chapter has its own stand-alone value but when brought together as one, the book's chapters form a very cohesive and all-encompassing treatment of how fruits and vegetable are packaged for different purposes. The book is written both to inform and, in practical terms, to aid decision making. Chapter 1 introduces the subject by providing a clear set of definitions, principles and design criteria useful in the packaging of fresh produce. Chapter 2 describes the role of packaging in branding fresh produce, including the identification of the product and communication of its value to the consumer. The importance of packaging is also highlighted in the marketing and sale of goods. One of the most detailed chapters is Chapter 3. The most critical function of packaging is its protection and containment function, realized through the safe delivery of a quality product. Packaging materials and systems described include wood, paper and corrugated fiberboard, plastics, glass, metal, and cushioning materials. In Chapter 4, packaging technologies such as edible films and coatings, controlled atmosphere storage and modified atmosphere packaging (MAP) are described as important technologies for fresh produce. Newer technologies such as active and intelligent packaging and their application to fresh produce packaging are also discussed. Chapter 5 provides a discussion of fresh produce postharvest treatments, including harvesting techniques, packaging, precooling and cold chain management. Chapter 6 investigates food safety and the challenges to packaging to keep food products and particularly fresh produce safe. The growth of microorganisms is covered as affected by packaging materials and systems, atmospheric control, and temperature. Techniques such as in-package irradiation, high-pressure processing, impregnation of packaging materials with antimicrobials, and use of devices such as time-temperature indicators and sensors are included. Chapter 7 briefs the reader on methods to measure quality using both external and internal quality attributes. Methods to test packaging systems are covered in Chapter 8. These include gas barrier measurement and package performance testing for transportation and handling.

The book is easy to read and readily comprehensible to individuals at different levels of technical expertise. It will function as a general reference, which all involved in fresh produce can use because of its diverse and in-depth presentation. At the same time, it should also be considered as a text for colleges and universities, particularly those where packaging is taught as part of a food science, bioengineering or horticulture curriculum.

BRUCE HARTE, Ph.D.
Emeritus Professor and Director, School of Packaging
Michigan State University

Preface

THIS book is intended to provide packaging professionals and university students with comprehensive knowledge regarding the packaging and transportation of fresh fruits and vegetables. Through education and experience, the technologies of packaging, understood broadly and in many forms, have been recognized as important throughout the entire supply chain, from harvesting to retailing. This is the first book that covers and explains the range of these technologies. In this volume we present the science and technology for packaging produce, both in general and to meet various regulatory and safety requirements and specifications. This book is intended to provide sufficient information to help professionals of all levels design and create packaging to meet current and future challenges in the fresh fruit and vegetable industries, thereby providing benefit to consumers. This book can also be used as part of a university curriculum for students in packaging, food science, and business.

Acknowledgments

WE would like to thank the faculty, staff, and students at our universities, Michigan State University, Kasetsart University, and California Polytechnic State University, for sharing their knowledge with us.

Special thanks are due to Dr. Koushik Saha and Dr. Javier de la Fuente of Cal Poly State University for their contributions and design of the cover page and to Ashlyn Chen Thompson and Rudy Rios of Packaging Research Associates for their assistance with images in Chapters 1 and 2. We also gratefully acknowledge Ron McCormick of Walmart and Michael McCartney of QLM Consulting and the Produce Marketing Association for the wealth of advice and knowledge shared with us through various projects and seminars over the past thirty years.

Dr. Chonhenchob would like to especially thank Professor S. Paul Singh for his wisdom, valuable guidance, and endless support for over twenty years and for the development of this book; Professor Jay Singh, whose intellectual inputs, expertise, and support made a significant contribution to the completion of this book and other collaborative projects; and Dr. Tanaboon Sajjaanantakul, Dean of the Faculty of Agro-Industry, Kasetsart University, for the encouragement, invaluable advice, and opportunities he always provided. She would also like to acknowledge President Jeffrey Armstrong and Dean Scott Dawson of Cal Poly State University for providing her an incredible chance to gain critical perspectives during her sabbatical at Cal Poly State University, where she started this text. Lastly, special thanks are given to her sisters, Shushira, Dhavanee and Dr. Areeporn Chonhenchob, and her nephew, Christian

Arthur Davis, for their loving and endless support during the writing of this book and in other times of both happiness and difficulty.

We are grateful to our friends and families who helped us during this time. A special thanks goes to Mary Anne Merrill for all her support and for allowing us to work on this book during her difficult times.

CHAPTER 1

Introduction

THIS book is intended to provide packaging professionals and college students a comprehensive knowledge on the packaging and transportation of fresh fruits and perishables. During our education at Michigan State University, School of Packaging, we saw a void in the knowledge and expertise that was available to packaging professionals to design and create packaging to meet the challenges and unique requirements that face fresh fruits and vegetables. As consumers, we relate to fruits and vegetables on a daily basis, yet fail to realize the importance of packaging in the entire supply chain that starts with harvesting, post-harvest treatments, grading and processing, packaging, transportation, and retail presence. We take these for granted, but do not realize the science and technology that exists to provide the "succulent and wow" experiences that we remember and wish to repeat and share with others. This chapter provides an insight into terminology and discusses some key approaches to designing and developing new packages. Later chapters then cover the marketing and technical basis for selection of materials, methods, safety, and testing.

Fresh fruits and vegetables undergo an enormous amount of physical and climatic challenges before they reach our refrigerator or palette. These challenges include protection against physical, climatic, and biochemical changes that accompany a freshly harvested produce through its complex and varying storage, transportation, and handling conditions prior to being displayed and sold to a consumer. Ultimately, the sales value and repeated sales in fresh produce are highly dependent on consumer perception and acceptance, and repeat sales are highly dependent on maintaining a consistent supply of fresh produce that is at its prime quality for appearance, smell, color, taste, and ultimate acceptance or a “wow!” feeling from consuming it. Therefore, the final certification of quality lies on consumer acceptance, and this is watched with great interest by retailers. This allows growers and retailers to differentiate themselves to ensure brand loyalty.

Based on over 30 years of teaching and research experience, we learned that the knowledge gained from a steady partnership with growers, distributors, packaging companies, cold chain storage and transportation companies, and retailers was important to summarize in this unique textbook. This text bridges packaging, post-harvest, and food sciences to deliver packaging solutions for fresh produce.

In the introduction section we have started with a basic introduction to terminology critical to the technical content in this book. We would like the reader to look at the impact that packaging can play in today’s consumer-driven and retailer-supplied value chains where healthy choices and an aging population all contribute to a continued increase in consumption of fresh fruits and vegetables. The authors recognize that while food preservation methods are the key factors that make food safe and maintain quality [1], good packaging through its essential functions of containment, protection, utility, and communication delivers produce safely over a longer period of time (shelf life) and provides dispensing and consumption along with information critical for its sale. Therefore, in this text the authors will share information contributed by individuals who work as field pickers to graders; use forklift trucks to load trailers; and place fruits and vegetables on retail shelves to allow consumers to make the ultimate purchase decision and experience and enjoy food. Shown next are some pictures ranging from a cart selling fresh fruits and vegetables to a store in China (Figures 1.1–1.5) to major retailers in the United States (Figures 1.6–1.10).

Today, due to effective packaging, fresh flowers, fruits, and vegetables can be found any time of the year, day or night, at retailers close to home. Consumers today can therefore enjoy a bowl of fresh strawberries at any time of the day or share a vase of pretty flowers ranging from roses to lilies with their significant other on every day, just like Valentine’s Day. Prior to engaging in this book, the authors have published on packaging changes that affect the shipment of various fresh fruits such as tangerines [2], mangos [3], papaya [4], pineapple [5], mangosteen [6], sweet tamarind [7], etc.

FIGURE 1.1. *Cart selling fresh fruits.*

FIGURE 1.2. *Display of fruits at a specialty shop in China.*

FIGURE 1.3. Display of fruits at a specialty shop in China.

FIGURE 1.4. Display of fruits at a specialty shop in China.

FIGURE 1.5. *Display of flowers at a specialty shop in China.*

FIGURE 1.6. *Display of vegetables and fruits at a retailer in the United States.*

FIGURE 1.7. *Display of fresh salads in bags at a U.S. retailer.*

FIGURE 1.8. *Fresh fruits displayed at a U.S. retailer.*

FIGURE 1.9. *Fresh fruits displayed at a U.S. retailer.*

FIGURE 1.10. *Pears in various packaging forms, including inserts or bulk packs.*

1.1. WHAT IS PRODUCE?

Produce is a generalized term used for a group of farm-produced crops and goods, including fruits and vegetables. Generally, the term “produce” implies that the products involved are fresh and maintain the same quality as when they were harvested.

1.2. WHAT IS PACKAGING?

Packaging is the science and technology used to preserve the quality of fresh produce so that it can be sold to markets far away from where it is grown and harvested. Packaging also helps extend the marketing period by offering a layer of additional protection to keep the items safe for consumption and providing a barrier against pathogens and infestation, thus helping distributors and retailers reduce food waste. Packaging prevents food from spoiling under normal conditions and therefore allows it to be consumed safely over a longer period of time. Therefore, through the use of technologies that include postharvest preservation and packaging, the quality parameters of produce that include the human sensory responses to taste, smell, texture, and appearance (color) all play a key role in maintaining or extending the physiological degradation of fresh fruits or vegetables over days, weeks, and months. Figure 1.11 shows a display-ready corrugated (DRC) tray being used to transport fresh tomatoes. The tray liner also has preprinted graphics.

FIGURE 1.11. A display-ready corrugated (DRC) tray with fresh tomatoes.

1.3. SHELF LIFE

Shelf life is the length of time that a commodity may be stored without becoming unsafe for use, consumption, or sale. In some regions, a "best before" or "use by" expiration date or freshness date is required on packaged, perishable foods that are in a slowed state of degradation due to their packaging.

1.4. COLD CHAIN

In order to extend the shelf life of fresh produce, temperatures below ambient conditions are maintained to slow the respiration or heat generated by the produce. Therefore, for over almost two centuries, humans have learned that in order to keep produce from rotting or decaying fast, lower temperatures in storage or transportation need to be maintained. These conditions start with precooling of the produce right after it undergoes harvest. Low temperatures are then maintained during storage in warehouses through transportation ranging from refrigerated vessels such as ships, rail, trucks, and intermodal containers until they arrive at distribution centers. These low temperature levels prevail as they go into distribution ranging from truck shipments to retail stores and eventually across aisles and shelves where fresh produce is sold. This continuous transition of moving fresh produce through various stages of the supply chain at cold temperatures until it is found in a home refrigerator prior to consumption or cooking is referred to as cold chain. The United States of America, Holland, and Canada have been leaders in cold chain technologies where fresh food losses are extremely small compared to other nations. In addition, the distances that fresh flowers, fruits, and vegetables move to reach the North American palate are extensive, ranging thousands of miles as compared to other nations.

The United States not only demonstrates one of the best uses of this technology for its own consumption, but also uses it extensively in fruit and vegetable exports. A cold chain is a temperature-controlled supply chain, mostly at a temperature lower than ambient. In an unbroken cold chain, storage and distribution of fresh produce is done at an industry-acceptable low temperature range. This range is known to provide an extended shelf life. Unlike other goods or merchandise, cold chain goods are perishable.

1.5. FUNDAMENTALS OF PACKAGING DESIGN

In this section we would like to discuss some key fundamentals that we have learned and practiced over our careers related to the development of packages for food products, as well as all other products. These include the basic functions required of every package and principles for new packaging design. A package has four key functions that have been well described in literature for over six decades. These are:

- Containment
- Protection
- Utility (Filling and Dispensing)
- Communication

In addition to the above four functions, the past decade has required an added responsibility on behalf of both manufacturers and consumers to be environmentally responsible in terms of reduced material use in forming the package and discarding it after consumption. The terms "discard" and "disposal" are avoided as they presume solid waste dumps, and ultimately resistance to landfills. Nowadays most packaging materials and containers for fresh produce are made of paper or plastics. Hence the paper is recycled and most plastic containers are reused and eventually recycled.

The vast majority of food and consumer packages purchased in retail stores all have the basic functions of a "package." A package must contain, protect, fill and dispense, and communicate with the consumer. A key objective that is covered in a packaging development process is "a package must sell the product." The various forms of packaging used to display and merchandise fresh produce, from preprinted bags to thermoformed clamshells, use plastics or paperboard that provides both physical and shelf-life protection to the produce, from salads to fresh berries. In addition, shipping containers ranging from corrugated trays to reusable plastic containers are used to both ship fresh produce from the farm to retail stores and also provide precooling and temperature control in the entire cold chain. The reclosable and resealable features on fresh produce packages provide additional utility and protection functions for the consumer. The communication functions are conveyed through multicolor graphics and brand identity. The plastics used are representative of environmentally friendly packaging materials, while meeting primary functions. Similarly, corrugated fiberboard trays and boxes continue to dominate the shipping containers used for the vast majority of produce globally.

1.6. DESIGN CRITERIA FOR NEW PACKAGES

It is also important to understand some important design principles for new package development. The success of any new consumer package is strictly dependent on two critical aspects: consumer acceptance and cost. The most important premise for consumer acceptance is simplicity in a new design. Simplicity in a product or package design is dependent on the number of components used in creating a finished product or package. Multiple components in a package will enhance design complexity in all aspects from manufacturing to specifications to testing to end use. Package design incorporates two significant components in its conception. The first is technical, providing for strength, shelf-life protection, and manufacturing ability. The second is marketing, emphasizing shape, contour, color, graphics, and all the various factors associated with brand recognition and consumer appeal. It is often a challenge to meet both the technical and marketing aspects of a new design without some compromise. However, it is clear that no matter what principles of a new package design are followed and what technical and marketing objectives are met, it is not until after a new package is launched that its success can be truly measured as it is solely dependent on consumer acceptance across the range of price points at various retail stores. Such a success across all retail segments of a new package design is often referred to in the industry as an "innovation." An invention is the creation of a new design, a package, or process; however, innovation is marked with the immense success of an invention. Therefore, for a new package to achieve the recognition of being called an innovation, it has to demonstrate success by an increase in market share as well as increased presence on the shelf. It has to get consumers on board and not be a mere technical success, which is often covered by an invention and its patent.

An example of this is the transition from shipping fresh heads of lettuce for salads to the use of bagged salads beginning in the 1980s. These bagged salads use plastics with high gas transmission rates for CO_2 and O_2 to allow for respiration of the cut salads. This was very different than most conventional plastic films in packaging, which were generally high barrier to O_2 to prevent oxidation of most food products. Figure 1.12 shows an example of a fresh lettuce head, a bagged salad,

FIGURE 1.12. *Packaging forms for fresh salad include a tie band, bags, and thermoformed clamshells.*

and the more recent transformation to thermoformed clamshells. But since the invention of the bagged salad in the 1980s, consumers and retailers have turned this into an innovation. The success is evident by shelf space and presence in the retail store. Examples shown in Figure 1.12 are from Ready Pac® and Dole®. The invention was created by Fresh Express®, a company based in California, but as it became an innovation and market success, it was imitated by most companies in the salad business. The bagged salad segment is now a billion-dollar business in the United States today.

Every year new product and packaging companies launch new products based on new and creative ideas including those that are patented. These inventions may or may not achieve success in the marketplace, indicated by consumer acceptance and increased sales. Such inventions in their early launch may also be followed by "*imitations*," where competitors rush similar products (packages) into the marketplace with similar features in hope of not losing sales and presence on the shelf with their competitive product.

As explained earlier, innovation is demonstrated by success and widespread consumer acceptance among all retail outlet levels, and is shown by increased sales and shelf presence. On the contrary, companies that imitate let others take the risk and then jump on the bandwagon after the package has been accepted by the market and consumers. Since 1985, and during both our teaching and new package development consulting experience, an important part of our learning was that "a package sells the product." Two Michigan State University professors and colleagues, Dr. Theron W. Downes and Mr. Donald Abbott, presented the importance of the functions of a package that are essential in every new package development. A key feature was to understand the needs of a consumer and not merely a cost or productivity requirement. Therefore, features such as easy open, resealable, graphics, dispensing, and ergonomic handling are all essential to a market success. Over 30 years of our experience, we were able to show how important it is to understand this basic premise: Consumers are attracted to the same products, through various forms, shapes, sizes, and colors of packages that are introduced to enhance sales. This was demonstrated by our work and consulting relationship with Lindt and Sprungli, a Swiss chocolatier that started a chocolate manufacturing facility in Stratham, NH. While the basic product is the same, namely the Lindor truffle, the success of this company in the U.S. market was based on more than one hundred package forms that were offered to attract consumers at various retailers such as WalMart, Target, Costco, Walgreens, and so on, in various package forms from bags, to cans, to plastic jars.

It is important to note that the packaging design issues that are critically important in the United States may not be given the same weight in Europe or in Asia. While consumer acceptance and retailers may be primary drivers of packaging design and packaging success in the United States, manufacturing concerns play a bigger role overseas. A package that is successful in the United States may not be acceptable in Europe. The converse is also true: A package that is implemented and successful in Europe may not be able to be automatically used in the United States due to availability of materials and manufacturing equipment. Key challenges for adaptation include consumer acceptance, including retailer shelf presence, billboarding, and shelf space. When Fresh and Easy® launched a range of prepackaged sandwiches and rotisserie chicken in their deli labeled "fresh," consumers in the United States did not approve of this. U.S. consumers want a fresh sandwich made in front of them and to be able to select the chicken while still rotating on a rotisserie, whereas the European consumer will accept a prepackaged sandwich and chicken as "fresh" if packaged the same day. Therefore, consumer acceptance is vital in the package development process, while maintaining all technical requirements that ensure food safety and shelf life. The initial sales of a leading European based retailer were slow due to a lack of understanding of the US consumer.

While the name “Fresh” and “Easy” was part of the retailer, consumers failed to be attracted to their packaging, display, and presentation of deli items.

In order to discuss some of the successes of package designs that we have been involved with, I would like to discuss three different food packages, one of which we helped design to cover these various aspects.

In mid-1980s while working as a faculty member at Michigan State University School of Packaging, Dr. Paul Singh was engaged in a contract-testing project to evaluate the performance of plastic bottles for ketchup. This successful invention replacing the conventional glass bottle clearly became an innovation based on consumer acceptance. Consumers readily accepted the squeezable bottle with a multilayer plastic to extend shelf life, dispense, and prevent breakage. In the two decades that followed, the two key competitors in this product category, Heinz and Hunts, both shed the conventional glass package in favor of the squeezable plastic bottle (Figure 1.13) for ketchup and other sauce products. Similar projects were carried out for Kraft Foods® with mayonnaise, resulting in a transition from glass to plastic jars.

FIGURE 1.13. The squeezable plastic bottle for ketchup.

FIGURE 1.14. *Driscoll's thermoformed clamshell plastic container.*

In 1989, Dr. Paul Singh was contracted as a consultant by the leading fresh berries producer, Driscoll's, in Watsonville, CA. Strawberries and raspberries were traditionally packaged in paperboard and wire mesh baskets, and often covered with clear plastic film held in place with a rubber band. Working over one and a half years with Packaging Corporation of America, a leading packaging supplier, we were able to develop the first hinged clamshell plastic thermoformed container that had venting to allow precooling of berries after harvesting. When launched in late 1990s, this package clearly became the package of choice by consumers, and this innovation has become the preferred means of packaging berries among all growers and retailers. Developed and introduced by Driscoll's, the thermoformed clamshell plastic container (Figure 1.14) became an outright success for which they received the Ameristar Award.

Similar to the above successes we want to discuss the evolution of today's orange juice containers (Figure 1.15). Since the 1980s the two largest suppliers of orange juice and direct competitors, Tropicana and Minute Maid, have offered orange juice in paperboard gable-top cartons. The original orange juice cartons were similar to the milk cartons with no pour spout. However, to enhance the concept of a "reclosable" carton for packaging of juice, which generally has a longer shelf life than milk, a tamper-evident spout with a threaded screw-top closure was introduced and was widely accepted by consumers. It was not until the early 2000s when a new product and package launch by Simply Orange, a clear PET plastic bottle with a wide mouth screw-top cap, created the biggest success with an innovation in this competitive category. Not only was this package introduction clearly successful, but Simply Orange quickly became a leader in this category, and consumer demand forced the two former giants in this category (Minute Maid

FIGURE 1.15. *Orange juice containers.*

and Tropicana) to adapt to the PET bottle with a wide screw-top cap as a packaging choice. The innovation created by Simply Orange was imitated by Minute Maid and Tropicana.

1.7. INTERACTION OF PACKAGING AND DISTRIBUTION

A lot of newly invented packages for food and beverages fail in their first year of launch. While companies invest millions of dollars in the creation of a new package, its interaction with filling the container after cleaning, washing, and marking is important. Most fresh produce today is identified by a PLU sticker. For example, the PLU code for bananas is 4011, and the code helps consumers purchase bananas at automatic cash registers. In addition, packages and trays must be easy to palletize, stack, and load into trucks and containers for safe shipment through an entire cold chain that consists of precooling to actual display at a retail shelf.

Figure 1.16 shows packing of sorted and graded mangos in trays to be shipped to the United States from South America. The trays are then stacked in a 4 × 3 configuration, or 12 trays per layer, on wooden stringer-style pallets (Figure 1.17), 21 layers high, and unitized using 10–11 horizontal plastic straps with vertical (extruded plastic) corner angle boards (Figure 1.18). These are then subjected to either a forced-air cooling system, or just placed for longer times in cold air warehouses. Palletized loads are then loaded inside precooled ISO intermodal containers for shipment by truck to the port (Figure 1.19), and then by ship to the United States, where they are sent to regional distributors [8].

Based on trips to all four countries, the research team has concluded the following critical items with reference to mango shipments:

1. The trays used to ship mangos come in a range of different designs and shapes, varying sizes, and different quality of wood pallets, all aimed at maximizing and optimizing the shipment in a standard ISO intermodal container or truck trailer. Depending on the tray size, design, and corrugated board material, there is a variation in compression strength of these trays. This was seen in the three sets of sample trays that were procured from packing houses in Brazil and Peru.
2. A very small percentage of wood pallets currently being used for mangos are designed to meet U.S. GMA pallet standards.
3. Trays are either designed with interlocking or nesting tabs, but these features provide very little pallet stability during transit. A

FIGURE 1.16. *Packing of sorted and graded mangos in trays.*

FIGURE 1.17. *Wooden stringer pallet.*

strong tray (high compression strength) with bottom sections of the load having more horizontal straps is necessary for long intermodal shipments that include truck and sea voyage. Ideal designs need 10 to 11 horizontal straps and corner posts for long intermodal container shipments from South America (Figure 1.18), and five to seven straps and corner posts for shorter truck shipments from Mexico.

4. The design of the tray should utilize forced-air cooling to save energy and reduce the time required to precool fruit, and thereby extend shelf life. The new tray design (Figure 1.20) with a 12- or 15-down footprint will allow forced-air cooling at a reduced time. The 14-down footprint with the new tray design will not be as effective.
5. The horizontal opening in the sides of trays for cooling is more critical than vertical openings in bottom of the tray; that is, temperature should be lowered and controlled before loading the palletized fruit inside the trailer or ISO container.

FIGURE 1.18. *Palletizing of trays and use of plastic bands to secure loaded pallets.*

FIGURE 1.19. *Palletized loads inside a precooled ISO intermodal container.*

6. A 4 kg tray is impossible to accommodate all varying mango sizes for the five- to 18-count fruit (that includes all Keitt, Kent Atuffo, and Tommy Atkins varieties) (Figure 1.21) using a 40-by-48 GMA footprint. The reason for this is that the five-count fruit is large and will not meet the 4 kg requirement, and the 12- to 18-count will result in almost 5 kg of fruit per tray. While the tray may be standardized, the smaller fruit will significantly exceed the tray weight requirement, whereas larger fruit will not meet weight requirement.

New 12 down tray with 5 kg fruit **New 15 down tray**

5 kg
New 12-down tray

4 kg
Existing non-GMA trays

3.75 kg
New 15-down tray

FIGURE 1.20. *New tray design for mangos imported to the United States.*

FIGURE 1.21. *Varying size of mango variety.*

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CHAPTER 4

Packaging Technology

4.1. INTRODUCTION

THIS chapter will cover the challenges that fresh fruits are exposed to during postharvest due to physical and climatic changes they undergo. In this stage the time of exposure and levels of physical and climatic changes can affect the shelf life and post maturity of the perishables before reaching the consumer. While the use of postharvest treatments helps maintain quality of produce, packaging methods, processes, and technology can enhance shelf life and quality of the fruits or vegetables from farm to fork. Some of the prominent technologies are discussed in this chapter.

4.2. TECHNOLOGIES

A range of technologies has been applied to maintain freshness and quality, extend shelf life, and assure and/or improve safety of fresh fruits and vegetables. The main quality characteristics that are important for consumer acceptance include appearance, color, flavor, taste, texture, and nutrition. Deterioration of fresh fruits and vegetables is caused by internal factors, including respiration, transpiration, and ethylene production, when exposed to external factors after harvesting, such as temperature, relative humidity, atmospheric composition, and so on. Related packaging technologies are applied to fresh produce to help maintain the best quality for expected shelf life by reducing or eliminating factors causing deterioration. Important technologies are discussed below.

4.3. EDIBLE FILMS AND COATINGS

Edible films and coatings are biopolymer-based materials that have long been used for maintaining quality and prolonging shelf life of fresh produce. Many fruits such as apples, pears, plums, citrus, cucumbers, avocadoes, and tomatoes are commonly coated before marketing. Research on the use of wax coatings on citrus fruits has been well discussed in the 1990s [1]. Edible films and coatings provide a number of functions for fruits and vegetables, such as preventing or reducing moisture loss and controlling gas exchange. This is attributed to the selective permeability of edible films and coatings to water vapor and gas (O_2, CO_2). Loss of moisture is one of the main problems during storage of fruits and vegetables, primarily resulting in weight loss, wilting, and shriveling. Moisture loss is associated with changes in quality such as texture, color, appearance, and nutritional values. Gas exchanges through edible films and coatings depend on the film permeability and the produce respiration rate or emission of these gases. Thickness of the edible films and coatings also affects the permeability properties. Table 4.1 presents the permeability coefficients to oxygen, carbon dioxide, and water vapor of selected edible films and coatings for fruits and vegetables. In addition, edible films and coatings enhance appearance by providing gloss and shine, and also help protect fruits and vegetables from additional mechanical damage by providing surface protection against minor impacts and abrasion. Furthermore, edible coatings can be used as carriers for active substances, such as antimicrobials, antioxidants, antibrowning agents, colorants, and flavors for improving quality and safety. Edible films and coatings have received increased attention in recent years for health and environmental consciousness as they are generally recognized as safe and biodegradable. Edible films and coatings are differentiated in that films are thin layers of materials added and applied to the food products separately, while coatings are applied directly to the surface of the food [2].

Various film-forming materials are used for edible coatings and can be classified into polysaccharides, proteins, lipids, and their composites. These materials have the ability to form and create networks and structures in gels. The selection of the base materials primarily depends on the required functional properties of the coatings as summarized in Table 4.2. Important characteristics of edible films and coatings for fruits and vegetables are film-forming ability, mechanical, sensory acceptance, and barrier and optical properties. The cohesion forces between the polymer molecules mainly involve film forming and mechanical properties of the edible films and coatings. These include flexibility, brittleness, permeability, porosity, and resistance. Cohesion forces are attraction forces that exist between molecules of the same substance. Incompatibility of materials in the film matrix reduces cohesion forces and film strength. Adhesion forces involve the adherence between the films and the substrates or coated surfaces that also depend on film casting and coating processes. The composition of coating solutions can be determined based on the wettability, adhesion, and cohesion coefficients.

Polysaccharide-based materials are hydrophilic, hence are sensitive to moisture while possessing good gas, aroma, and lipid barrier and film-forming properties. Protein-based coatings possess good film-forming ability and mechanical properties and are generally an effective gas barrier, sensitive to moisture, and adhere well to the surface of fruits and vegetables. Lipid-based coatings are an excellent barrier to moisture due to their hydrophobic nature, but they do not adhere to the hydrophilic surfaces of the fruits and vegetables. Lipid coatings can result in anaerobic respiration due to limited gas exchanges through the coatings due to low gas permeability properties. Lipid-based coatings such as waxes and shellac are commonly used to improve gloss but exhibit poor mechanical and film-forming properties, hence requiring some plasticizers to improve flexibility. Composites are a combination of two or more components in to the matrices that may result in films with improved properties. For example, lipids can be combined with hydrocolloids (such as polysaccharides and proteins) to improve film-forming properties and mechanical strength while maintaining good moisture barrier. A composite film can exhibit in a bilayer (hydrocolloid and lipid layers) or a conglomerate (lipid and hydrocolloid components are dispersed throughout the film) [3].

Coatings can be applied to the product surfaces by dipping, spraying, or brushing. Edible films can be produced separately by wet or dry process. In a wet or solution casting process, film- forming materials are typically dispersed or dissolved in solvents, followed by an evaporation of the solvent. Most proteins and polysaccharides exhibit thermoplastic behaviors; therefore, they can be processed through extrusion or compression molding. Plasticizers, emulsifiers, surfactants, cross-linking agents, and other additives can be added to improve gel forming and other properties. Plasticizers are low-molecular-weight compounds typically added to increase flexibility, decrease brittleness, and enhance the processing ability of films by lowering the glass transition temperature (T_g). For example, addition of glycerol results in increased film flexibility by increasing the mobility of amylose and amylopectin chains [4]. Addition of plasticizers might affect other film properties such as barrier and optical properties. The most common plasticizers for edible coatings are glycerol, sorbitol, ethylene glycol, propylene glycol, sucrose, among others. Types and concentrations of plasticizers (or additives) and conditions (such as temperature, pH, drying rate) are important factors affecting film properties. Interactions between plasticizers and polymers are different in polymer matrices. In polysaccharide-based films the interaction generally occurs through hydrogen bonding with reactive hydroxyl groups, whereas with the presence of various groups in protein, the interactions can be through both covalent bonding (peptide and disulfide linkage) and noncovalent interactions (ionic, hydrogen, and van der Waals), and hydrophobic interactions between nonpolar groups of amino acid chains. A number of chemical and physical methods can be used to modify the characteristics of edible films and coatings.

Extensive studies in edible films and coatings for whole and fresh-cut fruits and vegetables are well-documented in literature. This section presents a few examples of edible coatings' potential benefits in some fruits and vegetables. Amylose-based coatings in strawberries were shown to reduce water loss and changes in color and firmness, and extend shelf life [5]. Cellulose-based coatings in fresh-cut carrots reduced surface whitening while retaining carotene and resulted in re-

TABLE 4.1. Permeability of Some Edible Films and Coatings (adapted from [12,13,14]).

	Permeability at 25 ± 2°C, 50% to 70% RH		
Edible Coating Material	O_2 ($m^3 \cdot m/m^2 \cdot s \cdot Pa$)	CO_2 ($m^3 \cdot m/m^2 \cdot s \cdot Pa$)	H_2O ($m^3 \cdot m/m^2 \cdot s \cdot Pa$)
Methylcellulose (MC)	3.85×10^{-6}	6.9×10^{-5}	9.35×10^{-11}
Hydroxypropyl cellulose (HPC)	3.1×10^{-6}	1.13×10^{-4}	5.55×10^{-7}
Sucrose polyester	2.10×10^{-18}	–	4.2×10^{-13}
Zein	7.84×10^{-19}	2.67×10^{-18}	1.17×10^{-10}
Chitosan	1.4×10^{-21}	–	4.9×10^{-10}
Wheat gluten	2.89×10^{-17}	2.13×10^{-18}	9.18×10^{-11}
Whey protein isolate (WPI)	1.13×10^{-18}	–	1.1×10^{-9}
Soy protein	3.14×10^{-19}	–	3.49×10^{-10}

TABLE 4.2. Edible Coatings Grouped by Base Materials and Their Primary Functions (Adapted from [15,16]).

Types of Materials	Examples	Primary Functions
Polysaccharides	Cellulose, methylcellulose (MC), carboxymethylcellulose (CMC), hydroxy propyl cellulose (HPC), hydroxypropyl methyl cellulose (HPMC), pectin, starch, alginates, chitosan, carrageenan, gums, amylose	Provide high gas (oxygen, carbon dioxide) barrier (regulate gas exchange), create modified atmosphere, provide poor moisture barrier (high permeable to water vapor), provide oil barrier
Proteins	Casein, gelatin, soy, zein, egg albumen, whey, collagen, wheat gluten, collagen, maize, ß-lactoglobulin, keratin, myofibrillar, peanut, cottonseed, rice bran	Provide high barrier to nonpolar (oxygen, volatile flavor compounds), provide poor moisture barrier (high permeable to water vapor)
Lipids	Paraffin wax or oil, petroleum wax, beeswax, carnauba wax, candelilla wax, rice bran wax, mineral oil, vegetable oil, acetylated monoglycerides, stearic acid, lauric acid, sucrose esters of fatty acids, shellac	Provide semipermeable to gas (regulate gas exchange), regulate gas exchange, create modified atmosphere, provide moisture barrier, improve surface shine
Composites	A mixture of polysaccharides or proteins and lipids	Improve water vapor barrier to polysaccharide- and protein-based films by the addition of lipids, improve mechanical strength of lipid-based films by the addition of polysaccharides or proteins

duced ethylene production and extended shelf life [6]. Polysaccharide-based films are typically highly permeable to water vapor. The addition of lipids to edible coatings increased their moisture barrier. In the past several decades, chitosan (poly b-(1,4)N-acetyl-D-glucosamine) has been studied as a coating for many fruits and vegetables because of its biodegradable properties, good film-forming ability, and antifungal activity. Chitosan coatings were shown to reduce fungal decay in strawberries [7,8], raspberries [8], peaches [9], and cherry tomato fruits [10]. A number of studies have reported the beneficial effects of edible films and coatings incorporated with active substances. For example, alginate-based coatings incorporated with essential oils (cinnamon, clove, lemongrass oils) and their active compounds (citral, cinnamaldehyde, eugenol, respectively) reduced respiration rate and *E. coli* O157:H7 population and extended shelf life of Fuji fresh-cut apples [11].

Index