Edited by Olusola Lamikanra

FRESH-CUT FRUITS AND VEGETABLES

Science, Technology, and Market

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CRC PRESS

Boca Raton London New York Washington, D.C.

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Version Date: 20131030

International Standard Book Number-13: 978-1-4200-3187-4 (eBook - PDF)

Visit the Taylor & Francis Web site at
http://www.taylorandfrancis.com

and the CRC Press Web site at
http://www.crcpress.com

Preface

Fresh-cut fruits and vegetables are a relatively new and rapidly developing segment of the fresh produce industry. Fresh-cut products have been freshly cut, washed, packaged, and maintained with refrigeration. They are in a raw state and even though minimally processed, they remain in a fresh state, ready to eat or cook. The International Fresh-cut Produce Association (IFPA) defines fresh-cut products as fruits or vegetables that have been trimmed and/or peeled and/or cut into 100% usable product that is bagged or prepackaged to offer consumers high nutrition, convenience, and flavor while still maintaining its freshness. Industry estimates in the U.S. indicate that fresh-cut sales of approximately $11 billion in 2000 account for over 10% of the total fresh fruit and vegetable market, with food service sales making up 60% of the total. Sales are projected to increase by 10–15% annually for the next five years.

High levels of quality accompanied by superior safety are essential for sustained industry growth and fresh-cut produce consumption. Fresh-cut fruit and vegetable products differ from traditional, intact fruit and vegetables in terms of their physiology, handling and storage requirements. The disruption of tissue and cell integrity that result from fresh-cut processing decreases produce product shelf life. Consequently, fresh-cut products require very special attention because of the magnitude of enzymatic and respiratory factors as well as microbiological concerns that impact on safety.

Knowledge of the nature of fresh-cut fruits and vegetables as they relate to pre- and post-harvest handling, processing, packaging and storage are essential for ensuring their wholesomeness and nutritional value, and for developing the most effective procedures and innovative technologies for maintaining their quality to meet increasing consumer demand. Attention to the market and economic factors will also ensure the ability of the industry to consistently deliver value to consumers, develop and implement new technologies and reward all participants in the supply chain.

This book is a comprehensive interdisciplinary reference source for the emerging fresh-cut fruits and vegetable industry. It focuses on the unique biochemical, physiological, microbiological, and quality changes in fresh-cut processing and storage and on the distinct equipment and packaging requirements, production economics and marketing considerations for fresh-cut products. Based on the extensive research in this area during the past 10 years, this reference is the first to cover the complete spectrum of science, technology and marketing issues related to this field, including production, processing, physiology, biochemistry, microbiology, safety, engineering, sensory, biotechnology, and economics. It will be particularly useful for senior undergraduate and graduate students, food scientists, plant physiologists, microbiologists, chemists, biochemists, chemical engineers, nutritionists, agricultural economists, and molecular biologists.

I am grateful to each of the authors for their participation, promptness and cooperation as well as many others for their contributions, advice and encouragement in the development of this book.

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Edith H. Garrett

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INTRODUCTION

Fresh-cut produce has been one of the hottest commodities in grocery stores over the past 10 years. The industry soared to over $10 billion in U.S. retail and food-service sales in 1999, and there are no signs of the trend slowing down (IFPA, 2000). In fact, sales for cut and packaged fruit are just getting off the ground, and new commodities such as cut tomatoes are emerging to answer the consumer's desire for more convenience in their daily lives.

What is driving this fresh-cut growth? Where did the industry come from, and what are the market influences affecting the continued growth of the industry? Where does the processor get ideas for new products, and what track did the processors

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take to build success? This chapter will cover the history, current trends and issues affecting the fresh-cut produce industry.

SIZE OF THE INDUSTRY

According to the Produce Marketing Association (PMA), the size of the fresh produce industry was $76 billion in sales for 1999, including foodservice and retail sales (PMA, 2000; Kaufman et al., 2000). Fresh produce has always been popular with consumers because of the wonderful flavors, the natural nutritious quality and freshness. In fact, the United States Department of Agriculture (USDA) reports that produce consumption in the U.S. rose from 284 pounds per capita in 1990 to 319 pounds per capita in 1998 (Kaufman et al., 2000).

FRESH-CUT PRODUCE

All these same attributes, along with added convenience, continue to drive sales for unique fresh-cut commodities. The International Fresh-cut Produce Association (IFPA) defines fresh-cut produce as "any fruit or vegetable or combination thereof that has been physically altered from its original form, but remains in a fresh state" (IFPA and PMA, 1999, p. 5).

IFPA estimates the U.S. fresh-cut produce market at approximately $10–12 billion in sales in 2000, with foodservice sales making up about 60% of the total (IFPA, 2000). Packaged salads have been rising stars in the grocery store for the past decade, and, with cut fruits and vegetables included, this category is estimated by IFPA to continue to grow in sales in the U.S. retail market at 10–15% a year for the next five years. The category in U.S. foodservice sales is difficult to measure but is estimated by IFPA to grow 3–5% a year for the next five years.

ORGANIC PRODUCE

Organically grown fruits and vegetables are another segment of the fresh produce industry that have experienced strong growth in the 1990s. This category includes both whole commodities and fresh-cut products. Making up an estimated $4 billion in sales in 2000 (PMA, 2000), the organic produce industry is projected to have an increase of 7% annually in sales in the next three years. Again, the consumer is looking for healthy, flavorful alternatives for their diets, and organic fresh-cut produce meets these criteria. As the availability of organic produce increases, production costs are reduced, making this an affordable product to serve in restaurants and sell in conventional grocery stores. Fresh-cut organic salads are now readily available in the marketplace.

IMPORTED PRODUCE

Consumption of imported commodities has grown in the past decade, and consumers now enjoy year-round availability of many produce items in the U.S. and Europe. Importation is necessitated by the fact that fruits and vegetables are not grown in any one locale every month. The market for imported produce continues to grow in many parts of the world. The latest USDA reports show that U.S. imports of fresh fruits and vegetables accounted for $4.1 billion in sales in 1997, a 105% increase over 1987's total of $2 billion (Kaufman et al., 2000).

IMPROVEMENTS IN OPERATIONS

Since the 1940s, produce companies have devised unique ways to cut and package produce for sale. Initially, some used bathtubs to wash produce, while others used the spin dry cycle on washing machines for the drying step. Ice was used in water baths to chill produce, and rudimentary packaging provided little more than protection from contamination during distribution. The industry built much of their own equipment as production increased in the 1970s from the growth in foodservice sales, but real innovation coincided with an increase in the number of restaurants in the 1980s.

IMPROVED ORGANIZATION OF INDUSTRY

Many technological advances occurred in the 1980s and 1990s as the industry became organized via their own trade association, the IFPA. Suppliers joined the trade association and participated in a growing annual equipment trade show to sell equipment and network with processors. This new forum for technology exchange helped propel the industry forward and enhance the quality and safety of fresh-cut produce.

Industry research revealed many new steps for shelf life improvement and convinced the industry to focus on refrigeration as the most critical step in the production process. The mantra became "the earlier the chilling step, the better the finished product." In other developments, major equipment innovations that improved fresh-cut production standards included the closed flume water bath, advanced cutters for a variety of cut sizes, advanced drying machines, the automatic packaging machine, automatic sanitation equipment and electronic monitoring equipment.

Each technological advancement increased production speed but caused new bottlenecks. Thus, there has been increased movement toward greater automation and electronic control by the industry. Today, the design of fresh-cut operations centers on food safety and sanitation, excellent refrigeration, higher production speeds through automation, quality enhancement and product traceability.

FOODSERVICE DEMANDS

In the mid 1970s, restaurants saw a great opportunity to save on labor costs by switching to convenient fresh-cut produce. Meeting the growing demands of McDonald's and other fast-food chains, growers and processors built the shredded lettuce and chopped onion business into a formidable niche within the fresh produce industry (Lawn and Krummert, 1995).

In the mid 1980s, there was tremendous growth in restaurants in North America. Salad bars became the latest craze with consumers. Soon, fresh fruits and vegetables took the place of canned produce on salad bars across America. Consistently an industry innovator, McDonald's Corporation decided it wanted to eliminate salad bars in its stores to reduce food safety risks to consumers. The company asked its suppliers for a fresh salad to be made and packed in 5-lb. bags that would be repackaged in single-serve trays for sale within its stores.

Mixing commodities together under hermetically sealed packaging was not a common practice at the time, but the success of the McDonald's salad motivated other restaurant chains to provide similar products. This was also a time when women began working outside the home in large numbers, and two-income families feeling a time crunch began looking for more convenience in their lives. Cut and packaged produce fit those needs perfectly, but the fresh-cut industry at that time could not provide consistent quality and sufficient shelf life for the retail marketplace. However, these obstacles were soon to be overcome.

Improvement of Quality Characteristics

Even though fresh-cut produce had been sold at retail since the 1940s, it was not completely successful, because the quality was unpredictable and the shelf life limited. Initially, processors used cast-offs, blemished product or second-quality commodities for the cut produce. In addition, refrigeration was poor throughout distribution, and appropriate packaging had not been developed. As the demand for better products with longer shelf life grew from foodservice customers, the industry's efforts were concentrated on quality improvements.

One thing the processors knew — their leading challenge was to stop the produce from turning brown after it was cut. Product appearance was the primary focus for quality measurement at the time, and processors found that refrigeration alone was not going to control discoloration and other visible defects. Instead, they had to start with healthier raw products, gentler handling procedures during processing and better packaging. Today, processors are concentrating on the importance of enhanced flavor development to provide even better ready-to-eat products.

Growers began supplying first quality commodities for processors, and new equipment processes were introduced such as air drying and gentle water baths. Some processors experimented with chemical washes or edible films to prevent browning, but low rates of improvement did not justify the additional costs. Improved packaging became the next step in the quest to address these quality challenges.

New Packaging Technology

In the 1940s, during the early days of fresh-cut produce, packaging consisted of cellophane wrappers over cardboard trays for products like coleslaw or salads (Holderfield, 1946). Cellophane, styrene and other plastics were used to wrap cauliflower heads in the mid 1950s in California produce fields to reduce shipping weights and prolong shelf life. In the early 1960s, lettuce growers began wrapping head lettuce. Both products are still popular in today's retail markets (Anderson, 2000).

The next step for lettuce growers was to trim and core the iceberg heads before packing them in plastic bags for shipment to the East Coast. This practice is still carried out today, and growers are even packing cleaned and cored lettuce in large bins for shipment to processors around the country.

In the mid 1980s, the fresh-cut industry was small and fragmented in the U.S., and packaging suppliers did not focus research efforts on developing films specifically for use with cut produce. European companies, however, were consolidating and developing equipment and packaging systems to move their industry forward.

New packaging was not as easy to find in the U.S. in the 1980s, because polyethylene film was the only breathable film on the market that could preserve produce and hold up to the rough handling conditions. Initially, processors used bags that were designed for other foods such as turkey and other meats. The advent of automatic packaging machines in the late 1980s spurned the development of new and innovative packaging that solved quality problems and helped launch fresh-cuts into mainstream marketing and distribution channels.

With the advent of automated packaging machines for fresh-cut produce in the late 1980s, the plastics industry jumped into action to design materials for fresh-cut produce. Film companies looked for new polymers and manufacturing processes to create breathable films that could run on the automatic machinery. Companies like Mobile, Exxon and Amoco provided new polymers from petroleum products and entered the market to better understand the needs of the industry. Automatic machines and these new films combined to allow processors to launch smaller, branded bags for the new fresh-cut products in the early 1990s.

In 1995, the Flexible Packaging Association (FPA) reported in their annual survey of packaging converters that for the first time, produce had overtaken medical packaging as the number one product for their production facilities (FPA, 1995). Estimated at $90 million in U.S. sales (Packaging Strategies, 1999), packaging for produce would be the number one product for the next five years, respondents reported in the 2000 survey (FPA, 2000).

Shelf Life Improvement

Beyond the revolutionary impact on the plastics industry, the processors have also influenced fruit and vegetable growers to focus on the burgeoning fresh-cut market. Instead of second quality, misshapen commodities or blemished fruits and vegetables, processors ask for first quality and negotiate contracts for the best quality raw products they can procure. Today's trends include growers competing for processor contracts by committing whole fields to processors, seed companies developing new varieties to suit the needs of processors and equipment suppliers engineering innovative tools to reduce harvesting damage to the produce.

Other engineering feats positively impacting the fresh-cut industry today include advanced air-drying techniques to reduce damage to the cut produce, vastly improved refrigeration in the processing plants, retail outlets' increased attention to refrigeration and sanitation and application of HACCP and other food safety systems. Clearly, the industry's commitment to develop researchers and supplier partners who collaborate to solve quality and shelf life challenges has resulted in better quality, longer shelf life and steady sales growth today.

Today, salads and most vegetables have a 12–14 day shelf life, while fruits are more perishable and have a shorter shelf life of 8–10 days if held at temperatures between 33°F (1°C) and 41°F (5°C) (IFPA and PMA, 1999). Consumers now enjoy fresh-cut salads, fruits and vegetables on a year-round basis, and the industry is committed to developing better products to continue delivering reliable quality for their customers.

MARKET PRESSURES

In North America, the fresh-cut business is comprised of two general categories of processors. National companies are represented by large grower/shipper/processor operations, frequently including multiple processing plants in several regional locations, with a main office located in California's agricultural areas. These grower-based companies are able to focus on a specific commodity such as baby carrots, packaged salads, broccoli or onions. Their facilities are designed for efficiency in the production of large quantities of a few commodities, and they specialize in selling to retail and/or foodservice chains.

A second category is made of medium- to small-sized regional processors that grew out of produce distribution companies in metropolitan areas. These companies are frequently family-owned single-facility operations that have evolved in a regional market and are usually designed for flexibility to serve the needs of retail or foodservice distributors. Their customer base may order small amounts of a variety of commodities to sell to many grocery or restaurant outlets within a defined region, or they may be large distributors for chains that are buying from several regional fresh-cut operators in different parts of the country. These processors often operate short production runs of numerous products during the course of a day.

CONSOLIDATION

The fresh-cut industry has not escaped the influence of recent corporate consolidation trends. Foodservice and retail buyers are combining at a rapid rate around the world, forcing processors to consolidate (Kaufman et al., 2000). Bigger companies want to buy from bigger suppliers, and this trend pushes down to the basic level of growers and other suppliers. This domino effect is resulting in the creation of larger processors who sell specific commodity lines to large customers, thus forming partnerships that make for tough competition. National operators who are looking for distribution rights, regional locations and volume consolidation are buying regional operations. In some cases, regional companies are combining to form larger companies to supply the growing foodservice chains.

Nelson (1999) identified 10 innovative options that processors are taking to remain competitive in the consolidating marketplace:

1. Joining the trend and selling out to a larger corporation
2. Concentrating on one commodity such as carrots or onions and becoming specialized in all aspects of that commodity, from growing through brand marketing (for example, Grimmway Farms' baby carrots)
3. Forming a strategic alliance with a larger company to process a branded product (for example, Verdelli Farms processing Mann broccoli)
4. Creating a cooperative buying or marketing group to reap the savings realized by other larger corporations

5. Specializing in processing under a private label for store-branded foods
6. Co-branding with a non-produce company that wants to have its brand associated with the successful fresh-cut product line (for example, Weight Watcher's salads)
7. Choosing a marketing niche for product line focus (for example, organic produce)
8. Developing or utilizing proprietary technology to set their products apart from others
9. Creating new market segments (for example, sliced tomatoes)
10. Specializing in the difficult or unusual (for example, hand-carved vegetables for luxury hotels and restaurants)

Labor

Another pressure felt universally by the fresh-cut industry is a general labor shortage. Company owners continue to plan strategies to find new sources of reliable hourly labor, but they are rapidly investing their resources toward automation to reduce their reliance on hourly employees. In developed economies, immigrants make up the vast majority of the manual labor needed in fresh-cut operations. If immigration is impeded for any reason, the shortage increases. In addition, a variety of languages and cultures in one operation can result in barriers to effective training. These limitations continue to especially plague smaller operators in the metropolitan areas.

Customer Demands

Aside from the enormous upheaval in the wake of customer consolidation, the fresh-cut industry continues to be influenced by the distribution characteristics, product development demands and purchasing specifications set by retail and foodservice corporations. These customers demand that their suppliers drive costs out of the system by requiring the use of internet technology for electronic data transfer and communication, productivity improvements, food safety audits, approved supplier programs and other system-wide streamlining.

The safety of produce continues to capture the attention of purchasing agents in the foodservice and retail sectors. The latest trend in North America is toward requirements from retailers for third-party food safety audits of growers (Hilton, 1999; Wright, 1999). Fresh-cut processors have complied with these types of audits for many years from foodservice customers, but this is new for fruit and vegetable growers.

As consolidation blurs the boundaries of foodservice and retail companies, exemplified by the recent purchase of PYA/Monarch, a large U.S. foodservice distributor, by Ahold, the sixth largest global retailer (Reuters, 2000), food safety and other standards may also blur between the two industries. A retail industry bellwether to watch in the consolidation game is the discount retailer, Wal-Mart, as they continue to set new standards. Global food chains and their suppliers struggle to keep up with formidable competitors like Ahold and Wal-Mart.

Other

Internet technology growth and increasing government regulation round out the list of major pressures for fresh-cut manufacturers around the world. Food safety regulation has been impacting the food industry around the world for the past five years and promises to continue to remain in the spotlight. Perhaps one consolation in today's global market is that many countries are working together to create food safety standards that will affect this industry on an even and fair basis. With food importation and exportation on the rise, it makes sense that new regulations should be harmonized around the world to level the playing field within the global marketplace.

FOOD SAFETY REGULATORY STATUS

The risk of developing foodborne illness from fresh produce is not precisely known at this time, because the outbreaks associated with fruits and vegetables have been sporadic and incompletely reported. There is even some debate of whether the incidence of foodborne illness associated with produce is on the rise or only tracked and reported more efficiently (Harris et al., 2000). Also, there are no definitive intervention strategies that assure the elimination of pathogens from fresh produce. Therefore, the industry must focus on the prevention of contamination of fresh produce with human pathogens to assure that these products are safe and wholesome for human consumption (Gorny and Zagory, 2002).

In the past five years, media stories featuring produce have not been very positive, and the result of this negative attention has been increased regulatory oversight of the produce industry. In the U.S. and Canada, guidance or regulations have been developed for the safe and hygienic production, harvesting, packing, processing and transporting of produce.

Likewise, in Europe, Australia and other countries, new standards or regulations are addressing contamination issues linked to produce. The international standards-forming body, Codex Alimentarius, hopes to have a document for hygienic procedures in the harvesting and packing of fresh fruits and vegetables ready in the next several years. There are currently two annexes to this draft standard, one covering sprouts and one covering fresh-cut produce (Codex, 2000). This particular initiative will apply to all countries in the World Health Organization and the Food & Agriculture Organization to further harmonize the global marketplace.

The food industry has received broad coverage in the news in the last five years due to many issues such as biotechnology, foodborne illness outbreaks and product recalls. But, according to the International Food Information Council Foundation (IFCF), the tide may be changing to a more positive image for food, and produce in particular, in the media.

IFCF reports that the number of food news stories increased from 810 to 1260 in May–July 1999, a 38% rise as compared to the same time frame in 1998. Twenty-nine percent of all the coverage measured focused on general wellness and health-boosting aspects of food, and these benefits outweighed negatives 57% vs. 43%. The previous year, the negatives outweighed the benefits, 54% vs. 45%. They also noted that scientific researchers and experts were the most frequently quoted sources in food news reporting, which adds credibility to the stories (IFIC, 2000).

Food safety issues are very important, and the industry needs to institute updated sanitation practices, but the produce industry has a very positive message for the consumer, because most fruits and vegetables are low in fat and high in fiber and nutrients. A balanced, science-based approach is appropriate for media coverage of produce.

SUMMARY

The value of fresh-cut produce lies in the primary characteristics of freshness and convenience. Food safety, nutrition and sensory quality are required while providing extended shelf life and freshness. Fresh-cut produce is a safe, wholesome food when produced under Good Agricultural Practices (GAPs), Good Manufacturing Practices (GMPs) and sanitation procedures. Today's food marketplace is alive with new products and changing trends, and fresh-cut produce remains at the top of the list of products meeting the needs of today's busy consumers. This publication is providing the industry an up-to-date summary of the current science and marketing trends to assure that we continue to earn the trust and confidence of consumers everywhere.

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2 Quality Parameters of Fresh-cut Fruit and Vegetable Products

Adel A. Kader

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Quality of fresh-cut fruit and vegetable products is a combination of attributes, properties, or characteristics that determine their value to the consumer. Quality parameters include appearance, texture, flavor, and nutritive value. The relative importance of each quality parameter depends upon the commodity or the product and whether it is eaten fresh (with or without flavor modifiers, such as dressings and dips) or cooked. Consumers judge quality of fresh-cut fruits and vegetables on the basis of appearance and

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freshness ("best if used by" date) at the time of purchase. However, subsequent purchases depend upon the consumer's satisfaction in terms of textural and flavor (eating) quality of the product. Consumers are also interested in the nutritional quality and safety of fresh-cut products.

Quality of the intact fruit or vegetable depends upon the cultivar, preharvest cultural practices and climatic conditions, maturity at harvest, and harvesting method. Handling procedures, conditions, and time between harvest and preparation as a fresh-cut product also have major impacts on quality of intact fruits and vegetables and, consequently, quality of the fresh-cut products. Additional factors that influence quality of fresh-cut fruits and vegetables include method of preparation (sharpness of the cutting tools, size and surface area of the cut pieces, washing, and removal of surface moisture) and subsequent handling conditions (packaging, speed of cooling, maintaining optimum ranges of temperature and relative humidity, expedited marketing, and proper sanitation procedures). An effective quality assurance program must take into consideration all the factors that affect quality of the intact fruits or vegetables and their fresh-cut products.

QUALITY PARAMETERS

Appearance (Visual) Quality Factors

These may include size, shape, color, gloss, and freedom from defects and decay. Defects can originate before harvest as a result of damage by insects, diseases, birds, and hail; chemical injuries; and various blemishes (such as scars, scabs, russeting, rind staining). Postharvest defects may be morphological, physical, physiological, or pathological. Morphological defects include sprouting of potatoes, onions, and garlic; rooting of onions; elongation and curvature of asparagus; seed germination inside fruits such as lemons, tomatoes, and peppers; presence of seed stems in cabbage and lettuce; doubles in cherries; and floret opening in broccoli. Physical defects include shriveling and wilting of all commodities; internal drying of some fruits; mechanical damage such as punctures, cuts and deep scratches, splits and crushing, skin abrasions and scuffing, deformation (compression), and bruising; and growth cracks (radial, concentric). Temperature-related disorders (freezing, chilling, sunburn, sunscald), puffiness of tomatoes, blossom-end rot tomatoes, tipburn of lettuce, internal breakdown of stone fruits, water core of apples, and black heart of potatoes are examples of physiological defects.

Examples of defects that do not influence postharvest life potential of fresh produce include healed frost damage, scars, and scabs; well-healed insect stings; irregular shape; and suboptimal color uniformity and intensity. Most other defects (listed above) reduce postharvest life potential of fresh fruits and vegetables.

Tissue browning, which can be a major defect of fresh-cut fruits and vegetables, depends upon the concentration of phenolic compounds, the activity of polyphenol oxidase (PPO), and the concentration of antioxidants in the tissue. Wound-induced loss of cellular compartmentation between the phenolic compounds (mainly in the vacuole) and PPO (in the cytoplasm) results in tissue browning at a rate that increases with temperature and water stress.

TEXTURAL (FEEL) QUALITY FACTORS

These include firmness, crispness, juiciness, mealiness, and toughness depending on the commodity. Textural quality of fruits and vegetables is not only important for their eating and cooking quality but also for their shipping ability. Soft fruits cannot be shipped long distances without extensive losses due to physical injuries. This has necessitated harvesting fruits at less than ideal maturity from the flavor quality standpoint in many cases, such as the melons sold during the winter months in the U.S. markets.

Tissue softening and associated loss of integrity and leakage of juice from some fresh-cut products can be the primary cause of poor quality and unmarketability. Increasing calcium concentration in the tissue can slow down its softening rate. Also, initial firmness, temperature, and vibration influence the rate of softening and juice leakage from fresh-cut fruits.

FLAVOR (EATING) QUALITY FACTORS

These include sweetness, sourness (acidity), astringency, bitterness, aroma, and off-flavors. Flavor quality involves perception of the tastes and aromas of many compounds. Objective analytical determination of critical components must be coupled with subjective evaluations by a taste panel to yield useful and meaningful information about flavor quality of fresh fruits and vegetables. This approach can be used to define a minimum level of acceptability. To find out consumer preferences of flavor of a given commodity, large-scale testing by a representative sample of the consumers is required.

Flavor quality of most fruits is influenced by their contents of sugars (sweetness), organic acids (acidity), phenolic compounds (astringency), and odor-active volatiles (aroma). More information is needed about the optimum concentration ranges of these constituents to assure good overall flavor (based on sensory evaluation) of each kind of fruit (to satisfy the majority of consumers). Also, future research and development efforts on objective quality evaluation methods must include nondestructive segregation of fruits on the basis of their contents of sugars, acids, phenolics, and or odor-active volatiles. In many cases, consumers are willing to pay a higher price for fruits with good flavor, and there is a growing trend of high-quality-based stores that serve this clientele.

NUTRITIONAL QUALITY FACTORS

Fresh fruits and vegetables play a significant role in human nutrition, especially as sources of vitamins (vitamin C, vitamin A, vitamin B_6, thiamine, niacin), minerals, and dietary fiber. Other constituents that may lower the risk of cancer, heart disease, and other diseases include flavonoids, carotenoids, polyphenols, and other phytonutrients. Postharvest losses in nutritional quality, particularly vitamin C content, can be substantial and are enhanced by physical damage, extended storage duration, high temperatures, low relative humidity, and chilling injury of chilling-sensitive commodities.

Nutritional value varies greatly among commodities and cultivars of each commodity. By using plant breeding and biotechnology approaches, it is possible to develop genotypes with enhanced nutritional quality and improved flavor quality to encourage consumers to eat more fruits and vegetables (at least five servings per day).

This can have a major positive impact on human health and should be given high priority in research and extension programs worldwide.

PREHARVEST FACTORS INFLUENCING QUALITY

GENOTYPES AND ROOTSTOCKS

Within each commodity, there is a range of genotypic variation in composition, quality, and postharvest life potential. Plant breeders have been successful in selecting carrot and tomato cultivars with much higher carotenoids and vitamin A content, sweet corn cultivars that maintain their sweetness longer after harvest, cantaloupe cultivars with higher sugar content and firmer flesh, and pineapple cultivars with higher contents of ascorbic acid, carotenoids, and sugars. These are just a few examples of what has been accomplished in improving quality of fruits and vegetables by genetic manipulations. However, in some cases, commercial cultivars, selected for their ability to withstand the rigors of marketing and distribution, tend to lack sufficient quality, particularly flavor.

Rootstocks used in fruit production vary in their water and nutrient uptake abilities and in resistance to pests and diseases. Thus, rootstocks can influence fruit composition and some quality attributes as well as yield, in many cases.

There are many opportunities in using biotechnology to maintain postharvest quality and safety of fresh-cut products. However, the priority goals should be to reduce browning potential and softening rate, to attain and maintain good flavor and nutritional quality to meet consumer demands, and to introduce resistance to physiological disorders and/or decay-causing pathogens to reduce the use of chemicals.

A cost/benefit analysis (including consumer acceptance issues) should be used to determine priorities for genetic improvement programs. For example, increasing the consumption of certain commodities and/or cultivars that are already high in nutritive value may be more effective and less expensive than breeding for higher contents of nutrients.

CLIMATIC FACTORS

Climatic factors, especially temperature and light intensity, have a strong influence on composition and nutritional quality of fruits and vegetables. Consequently, the location and season in which plants are grown can determine their ascorbic acid, carotene, riboflavin, thiamine, and flavonoids content. In general, the lower the light intensity, the lower the ascorbic acid content of plant tissues. Temperature influences uptake and metabolism of mineral nutrients by plants because transpiration increases with higher temperatures. Rainfall affects the water supply to the plant, which may influence composition of the harvested plant part and its susceptibility to mechanical damage during subsequent harvesting and handling operations.

CULTURAL PRACTICES

Soil type, the rootstock used for fruit trees, mulching, irrigation, and fertilization influence the water and nutrient supply to the plant, which can affect the nutritional quality of the harvested plant part. The effect of fertilizers on the vitamin content of plants is less important than the effects of genotype and climatic conditions, but their influence on mineral content is more significant. For example, sulfur and selenium uptake influence the concentrations of organosulfur compounds in *Allium* and *Brassica* species. High calcium content in fruits has been related to longer postharvest life as a result of reduced rates of respiration and ethylene production, delayed ripening, increased firmness, and reduced incidence of physiological disorders and decay. In contrast, high nitrogen content is often associated with shorter postharvest life due to increased susceptibility to mechanical damage, physiological disorders, and decay. Increasing the nitrogen and/or phosphorus supply to citrus trees results in somewhat lower acidity and ascorbic acid content in citrus fruits, while increased potassium fertilization increases their acidity and ascorbic acid content.

There are numerous physiological disorders associated with mineral deficiencies. For example, bitter pit of apples; blossom-end rot of tomatoes, peppers, and watermelons; cork spot in apples and pears; and red blotch of lemons are associated with calcium deficiency in these fruits. Boron deficiency results in corking of apples, apricots, and pears; lumpy rind of citrus fruits; malformation of stone fruits; and cracking of apricots. Poor color of stone fruits may be related to iron and/or zinc deficiencies. Excess sodium and/or chloride (due to salinity) results in reduced fruit size and higher soluble solids content.

Severe water stress results in increased sunburn of fruits, irregular ripening of pears, and tough and leathery texture of peaches. Moderate water stress reduces fruit size and increases contents of soluble solids, acidity, and ascorbic acid. On the other hand, excess water supply to the plants results in cracking of fruits (such as cherries, prunes, and tomatoes), excessive turgidity leading to increased susceptibility to physical damage, reduced firmness, delayed maturity, and reduced soluble solids content.

Cultural practices such as pruning and thinning determine the crop load and fruit size, which can influence composition of fruit. The use of pesticides and growth regulators does not directly influence fruit composition but may indirectly affect it due to delayed or accelerated fruit maturity.

MATURITY AND RIPENING

Maturity

Maturation is the stage of development leading to the attainment of physiological or horticultural maturity. Physiological maturity is the stage of development when a plant or plant part will continue ontogeny even if detached. Horticultural maturity is the stage of development when a plant or plant part possesses the prerequisites for utilization by consumers for a particular purpose.

Maturity at harvest is the most important factor that determines storage life and final fruit quality. Immature fruits are more subject to shriveling and mechanical damage and are of inferior quality when ripe. Overripe fruits are likely to become soft and mealy with insipid flavor soon after harvest. Any fruit picked either too early or too late in its season is more susceptible to physiological disorders and has a shorter storage life than fruit picked at the proper maturity.

All fruits and mature-fruit vegetables, with a few exceptions (such as European pears, avocados, and bananas), reach their best eating quality when allowed to ripen on the tree or plant. However, some fruits are usually picked mature but unripe so that they can withstand the postharvest handling system when shipped long distance. Most currently used maturity indices are based on a compromise between those indices that would ensure the best eating quality to the consumer and those that provide the needed flexibility in marketing.

For most non-fruit- and immature-fruit-vegetables (e.g., cucumbers, summer squash, sweet corn, green beans, and sweet peas), the optimum eating quality is reached before full maturity. In these vegetables, the problem frequently is delayed harvest, which results in lower quality at harvest and faster deterioration after harvest.

Ripening

Ripening is the composite of the processes that occur from the latter stages of growth and development through the early stages of senescence and that results in characteristic aesthetic and/or food quality, as evidenced by changes in composition, color, texture, or other sensory attributes.

Fruits can be divided into two groups: fruits that are not capable of continuing their ripening process once removed from the plant and fruits that can be harvested mature and ripened off the plant. The following are examples from each group:

- Group one includes berries (such as blackberry, raspberry, strawberry), cherry, citrus (grapefruit, lemon, lime, orange, mandarin, and tangerine), grape, lychee, muskmelons, pineapple, pomegranate, tamarillo, and watermelon.
- Group two includes apple, pear, quince, persimmon, apricot, nectarine, peach, plum, kiwifruit, avocado, banana, mango, papaya, cherimoya, sapodilla, sapote, guava, passion fruit, and tomato.

Fruits of the first group, with the exception of some types of muskmelons, produce very small quantities of ethylene and do not respond to ethylene treatment except in terms of degreening (removal of chlorophyll); these should be picked when fully ripe to ensure good flavor quality. Fruits in group two produce much larger quantities of ethylene in association with their ripening, and exposure to ethylene treatment (100 ppm for 1 to 2 days at 20°C) will result in faster and more uniform ripening. Once fruits are ripened, they require more careful handling to minimize bruising. Fruits in group two must be ripened, at least partially, before cutting to assure better flavor quality in the fresh-cut products.

POSTHARVEST FACTORS INFLUENCING QUALITY

Physical Damage During Harvesting and Handling

Harvesting method can determine the extent of variability in maturity and physical injuries and, consequently, influence composition and quality of fruits and vegetables. Mechanical injuries (bruising, surface abrasions, cuts, etc.) can accelerate loss of water and vitamin C and increase susceptibility to decay-causing pathogens. The incidence and severity of such injuries are influenced by the method of harvest (hand vs. mechanical) and management of the harvesting and handling operations.

Physical damage before, during, and after cutting is a major contributor to tissue browning, juice leakage, and faster deterioration of the fresh-cut products.

Temperature and Relative Humidity Management

Keeping intact and fresh-cut fruits and vegetables within their optimal ranges of temperature and relative humidity is the most important factor in maintaining their quality and minimizing postharvest losses. Above the freezing point (for non-chilling-sensitive commodities) and above the minimum safe temperature (for chilling-sensitive commodities), every 10°C increase in temperature accelerates deterioration and the rate of loss in nutritional quality by two- to threefold. Delays between harvesting and cooling or processing can result in quantitative losses (due to water loss and decay) and qualitative losses (losses in flavor and nutritional quality). The extent of these losses depends upon the commodity's condition at harvest and its temperature, which can be several degrees higher than ambient temperatures, especially when exposed to direct sunlight.

The distribution chain rarely has the facilities to store each commodity under ideal conditions and requires handlers to make compromises as to the choices of temperature and relative humidity. These choices can lead to physiological stress and loss of shelf life and quality. The weakest two links in the postharvest handling cold chain of fresh fruits and vegetables are the retail and home handling systems.

Supplemental Treatments Applied to the Commodity

These include curing of "root" vegetables, cleaning, sorting to eliminate defects, sorting by maturity/ripeness stage, sizing, waxing, treating with fungicides for decay control, heat treating for decay and/or insect control, fumigating for insect control, irradiating for preventing sprouting or insect disinfestation, and exposing fruits to ethylene for faster and more uniform ripening. In most cases, these treatments are useful in maintaining quality and extending postharvest life of the produce. However, there is a need to determine the maximum storage period that can be used for each commodity between harvest and preparation as a fresh-cut product. Generally, the longer the storage duration of the intact commodity between harvest and cutting, the shorter the post-cutting life of the products.

Supplemental Treatments Involving Manipulation of the Environment

Responses to atmospheric modification vary greatly among plant species, organ type and developmental stage, and duration and temperature of exposure. Maintaining the optimal ranges of oxygen, carbon dioxide, and ethylene concentrations around the commodity extends its postharvest life by about 50–100% relative to air control. In general, low O_2 atmospheres reduce deterioration and losses of ascorbic acid in fresh produce. Elevated CO_2 atmospheres up to 10% also reduce ascorbic acid losses, but higher CO_2 concentrations can accelerate these losses. On the other hand, CO_2-enriched atmospheres can be beneficial in delaying browning and microbial growth on some fresh-cut fruits and vegetables.

Exposure to ethylene can be detrimental to the quality of most vegetables and should be avoided by separating ethylene-producing commodities from ethylene-sensitive commodities, by using ethylene scrubbers, and/or by introducing fresh, ethylene-free air into storage rooms. Treating the fruits and vegetables or their fresh-cut products with 0.5–1 ppm 1-methylcyclopropene for about six hours protects them against ethylene action.

Flavor vs. Appearance Life of Fresh-cut Fruit Products

Even under optimum preparation and handling conditions, postcutting life based on flavor is shorter than that based on appearance. More research is needed to identify the reasons for the flavor loss and possible treatments to slow it down and to restore the ability of the fruit tissue to produce the desirable esters and other aroma compounds.

Use of calcium chloride or calcium lactate in combination with ascorbic acid and cysteine as a processing aid (two-minute dip) has been shown to be effective in firmness retention and in delaying browning of fresh-cut fruits. Ethylene scrubbing and modified atmosphere packaging (to maintain 2–5% O_2 and 8–12% CO_2) can be useful supplements to good temperature management in maintaining quality of fresh-cut fruit products. Additional research is needed to optimize preparation and subsequent handling procedures for maintaining quality and safety of each fruit product.

QUALITY ASSURANCE PROGRAMS

An effective quality assurance system throughout the handling steps between harvest and retail display is required to provide a consistent good-quality supply of fresh-cut fruits and vegetables to the consumers and to protect the reputation of a given marketing label. Quality assurance starts in the field with the selection of the proper time to harvest for maximum quality. Careful harvesting is essential to minimize physical injuries and maintain quality. Each subsequent step after harvest has the potential to either maintain or reduce quality; few postharvest procedures can improve the quality of individual units of the commodity.

Exposure of a commodity to temperatures, relative humidities, and/or concentrations of oxygen, carbon dioxide, and ethylene outside its optimum ranges will accelerate loss of all quality attributes. The loss of flavor and nutritional quality of fresh intact or cut fruits and vegetables occurs at a faster rate than the loss of textural and appearance qualities. Thus, quality assurance programs should be based on all quality attributes, not only on appearance factors as is often the case.

Following is a list of handling steps and associated quality assurance functions:

1. Training workers on proper maturity and quality selection, careful handling, and produce protection from sun exposure during harvesting operations
2. Checking product maturity, quality, and temperature upon arrival at the processing plant

3. Implementing an effective sanitation program to reduce microbial load
4. Checking packaging materials and shipping containers to ensure they meet specifications
5. Training workers on proper processing and packaging operations
6. Inspecting a random sample of the packed product to ensure that it meets grade specification
7. Monitoring product temperature to assure completion of the cooling process before shipment
8. Inspecting all transport vehicles before loading for functionality and cleanliness
9. Training workers on proper loading and placement of temperature-recording devices in each load
10. Keeping records of all shipments as part of the “trace-back” system
11. Checking product quality upon receipt and moving it quickly to the appropriate storage area
12. Shipping product from distribution center to retail markets without delay and on a first-in/first-out basis unless its condition necessitates a different order

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3 Overview of the European Fresh-cut Produce Industry

Patrick Varoquaux and Jérôme Mazollier

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INTRODUCTION

History of Fresh-cut Fruits and Vegetables in Europe

When research into optimal processing of fresh-cut produce began in France about 20 years ago, the per capita consumption of fruits and vegetables had steadily declined since 1971 due to the development of catering and the integration of women in the task force (Scandella and Leteinturier, 1989). As a consequence, the time devoted to meal preparation was reduced accordingly. Moreover, fruits and vegetables are short-lived commodities hardly compatible with one shopping trip a week. As shown in Figure 3.1, the reduction in butterhead lettuce consumption exceeded 25% from 1971 to 1982. It is noteworthy that easy-to-use vegetables such as tomato and endive tips (witloof) did not follow this trend.

This trend alarmed nutritionists and supervisors of supermarket fresh fruit and vegetable departments. During a visit to the United States in the 1970s, Claude Chertier, fruits and vegetables buyer with Monoprix (French supermarket chain), noticed the salad bar in fast-food restaurants and supermarkets and decided to adapt

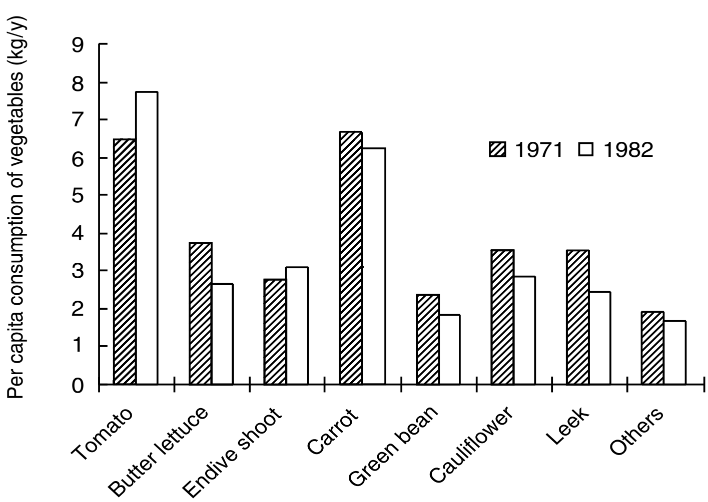

FIGURE 3.1 Per capita consumption of vegetables in France in 1971 and 1982 (Scandella and Leteinturier, 1989).

the concept of "ready-to-eat" salads to the French market. Claude Chertier got in touch with INRA (National Agronomic Research Institute) to develop his idea (1980).

Shredded celeriac and carrot, along with shredded iceberg lettuce, were already available in Northern Europe (1970), but these unpacked products (sometimes just overwrapped with stretchable PVC), mostly designed for catering, were not adapted to the French market, because their organoleptic and hygienic quality was poor, their shelf life was limited to two to three days, and iceberg lettuce was not popular in France. At this time, some French processors were already manufacturing precut fresh vegetable mixes for soups.

Claude Chertier wanted the new range of products to be recognized as fresh, safe, and user-friendly. The technical specifications were that the salads (200–300 grams) should be packed in order to facilitate supermarket distribution and to prevent microbial cross-contamination, the products should be distributed at room temperature (around 20°C), the shelf life should reach seven days plus an additional two days in the consumer's possession, the salad composition should be adjusted to the taste of French consumers, and processing should not include any additives.

The proposed ingredients were broad-leaved endive (*Cichorium intybus* L. cv *latifolia*), curly endive (*Cichorium intybus* L.), red Italian chicories such as variegated-leaved chicory (i.e., *chioggia* cv), sugar loaf, lamb's lettuce (*Valerianella locusta* L.), and some lettuces such as romaine and butterlettuce (*Lactuca sativa* L.) for the mixed salads. In order to offer consumers an acceptable range of salad, Claude Chertier also asked for packed shredded carrot (*Daucus carota* L.) and celeriac (*Apium graveolens* L.) plus shredded red and white cabbages (*Brassica oleracea* L.).

From 1981 to 1983, INRA therefore studied their first plant model, broad-leaved endive. The experiments on the effect of unit operations on physiological disorders, bacterial spoilage, and discoloration of the leaves resulted in a realistic process. Obviously, a shelf life of nine days was not attainable at 20°C but was possible at 4–6°C. In 1983, the procedure for each operation units of processing was established, and two processors invested in rudimentary processing equipment. At this time, the equipment was selected from other processing methods such as canning and freezing and was not well adapted to the fresh-cut industry. In 1984, a Swiss equipment manufacturer started to produce specific machines for the new fresh-cut industry. The production of "ready-to-use" fresh salads in France amounted to only 1400 metric tons in 1984, but their success was immediate since the production reached 8000 metric tons in 1985. These new products were rapidly known as "quatrième gamme" or "fourth range" in commercial terminology. Fruits and vegetables are fresh in the first range, canned in the second, frozen in the third, and fresh-cut or minimally processed in the fourth.

In 1985, CTIFL (Fruit and Vegetable Professional Technical Center) and other organizations such as ADRIA (Association for Agro-food Research and Development) Normandy, Pasteur Institute (Lyon), and different CRITT (Regional Center for Technology Transfer) were also involved in the development of the fresh-cut industry and provided processors with technical assistance. As a consequence, INRA focused its activity on a more theoretical approach to the field of the physiology and microbiology of "fresh-cut" plant tissues. Since the new produce was thought to be potentially hazardous, INRA undertook extensive research into the microbial hazards associated with prepacked plant tissues.

At the same time, the fresh-cut industry's approach spread throughout northern Europe, and a survey (Anonymous, 1986) concerning minimally processed vegetables counted eight processing units in Holland, four in Belgium, 11 in Germany, at least two large units in England, five in Switzerland (plus numerous small units around the cities), and 19 in France. The concept of ready-to-eat salad was not as successful in southern Europe. There, shelf life ranged from four to six days in the chill chain (from 2–4°C). At the same time, most European food-processing machinery developed specific processing lines fitted with American, Japanese, and European equipment. Bottled gas companies and film manufacturers proposed new gas mixtures and films designed to optimize actively and passively modified atmospheres.

Development and Statistics

After this development period, around 1990, there were up to 70 producers in France. Most manufacturers operated under poor hygienic conditions, and the chill chain was not respected either by transporters or by distributors. The visual quality of most fresh-cut produce at the end of their shelf life was poor. These factors inhibited industry growth (Figure 3.2). Fresh-cut processing was, nevertheless, responsible for a dramatic increase in the consumption of lamb's lettuce that had been steadily declining. This salad, which is grown on sandy soil, is difficult to wash. Presently, the production of fresh-cut lettuce is increasing (10–20% a year) in all European countries. In 1999, the annual tonnage production of fresh-cut leaf lettuce was, respectively, 45,000 in the UK, 39,000 in France, 21,000 in Italy, 20,000 in Germany, 10,000 in Spain and Netherlands, and 8,000 in Benelux.

In order to stop the decline and restore hygienic processing and distribution, CTIFL and DGCCRF (a French governmental organization similar to the American FDA) published a guideline for the fresh-cut produce industry. This guideline was turned into a regulation in 1988 (Anonymous, 1988) and was modified in 1993 (Anonymous, 1993), and was then modified again in 1996 (Anonymous, 1996). Its enforcement resulted in a rapid improvement in the quality and in a dramatic decline

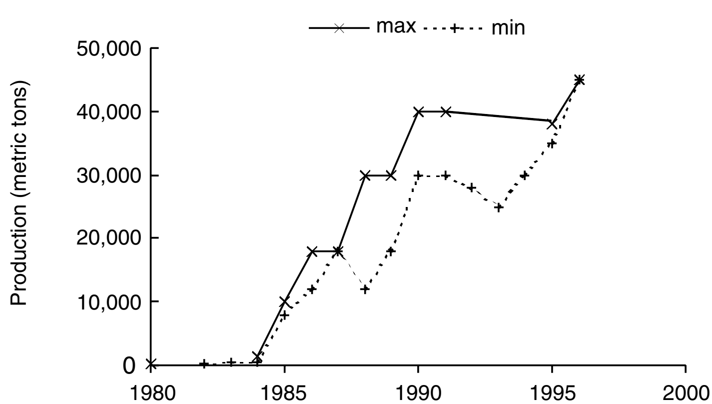

FIGURE 3.2 High and low estimates of fresh-cut produce production in France (Sabino, 1990).

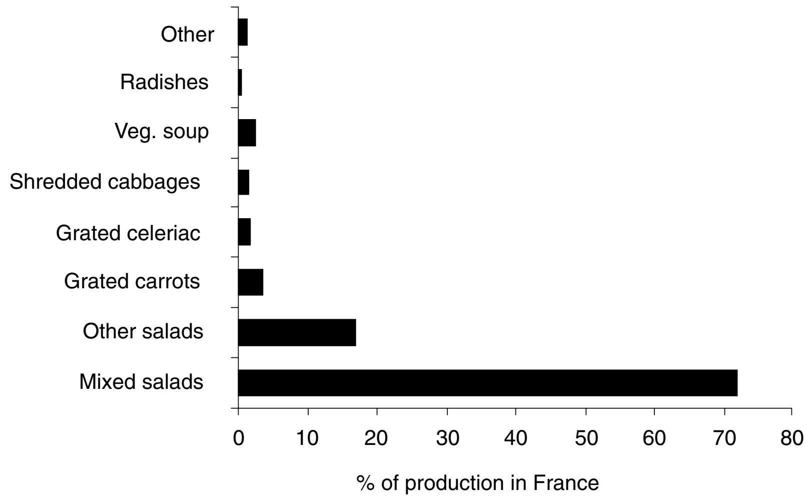

FIGURE 3.3 Percent of the different fresh-cut vegetables in 1986 (Scandella and Leteinturier, 1989).

in the number of processing companies. In 1998, four companies were responsible for 80% of the fresh-cut production. This trend was identical in all European countries.

In spite of an attempt to diversify the range of commodities proposed to the consumer (more details in the conclusion), fresh-cut green salads still account for about 85% of the overall production, as they did in 1986 (Figure 3.3).

GENERAL PROCESSING CONDITIONS

Processors apply HACCP principles as described in *Codex Alimentarius* (annex to CAC/RCP 1–1969, Rev. 3–1997) and in the code of hygienic practices for refrigerated packaged foods with extended shelf life (Alinorm 99/13, pp. 41–57) for all existing product types and for new product designs.

The guidelines for fresh-cut processing adapted by the French Administration are aimed at reducing biological, physical, and chemical hazards associated with this new type of produce. It proposes conditions under which raw materials are grown, as well as processing and distribution guidelines. In this review, details concerning recommendations and legislation that are specific to fresh-cut processing are presented.

FORWARD-ONLY MOVEMENT

This requires that there should be no "crossing over" in the processing line between the raw material and clean products.

The examples in Figure 3.4 show that the forward-only principle does not impose a linear processing, but it tolerates no crossing over (product line or waste disposal).

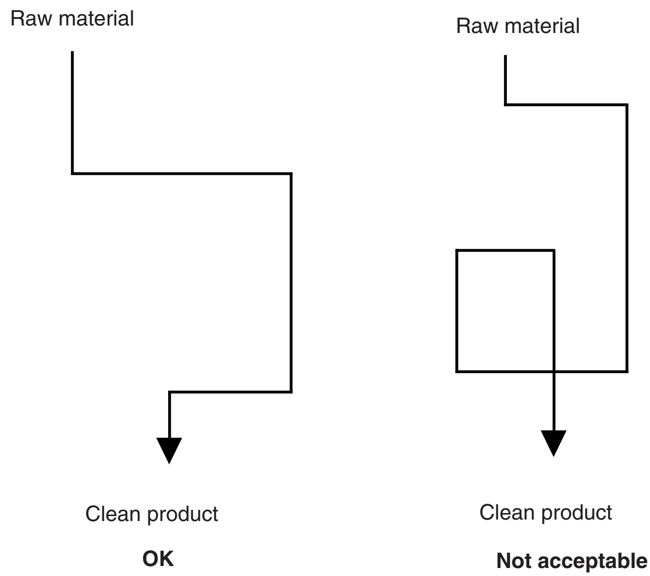

FIGURE 3.4 Principle of the forward-only movement.

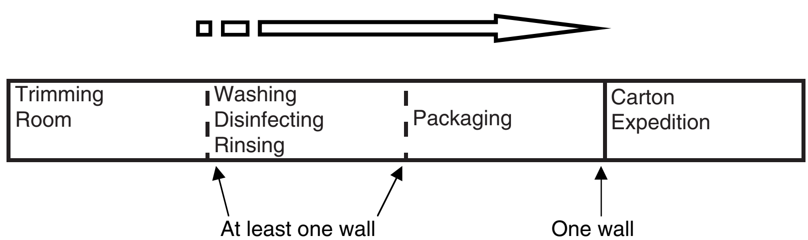

FIGURE 3.5 Segmentation of the processing line.

Separation of the Trimming Room, the Washing Room, and the Packing Room

In order to prevent cross-contamination, the different processing rooms must be delimited by walls in order to progressively increase cleanliness from the trimming room to the packaging section (Figure 3.5).

Temperature Control

Units are designed and equipped in such a way that the temperatures inside the different rooms are in accordance with the requirements summarized in Figure 3.6. According to French regulation, fresh-packed products must be immediately stored at 4°C and maintained at 0–4°C until delivered to consumers.

Airflow ←		Positive pressure		
Ambient T	12°C →		4°C	4°C
	Washing			
Raw materials	Trimming Prewashing	Disinfecting Rinsing Draining	Packing	Carton Expedition

FIGURE 3.6 Temperature gradient and airflow in the processing unit.

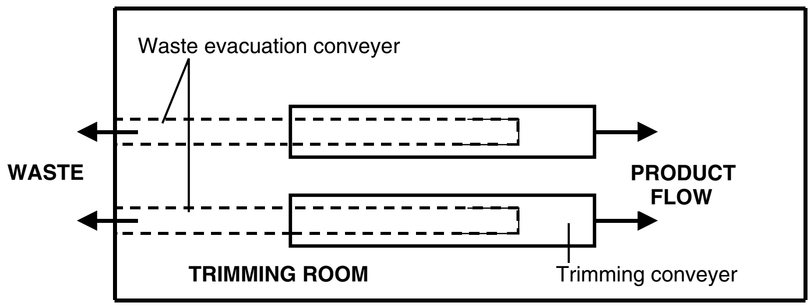

FIGURE 3.7 Waste disposal.

The following are therefore recommended:

- limit exposure to temperatures above 10°C
- refrigerate the product at 0–2°C before packing in order to be at the right temperature during the operation
- maintain this temperature during storage

The temperature gradient and flow of products run countercurrently. Temperature in the trimming and disinfecting rooms must not exceed 12°C and must not exceed 4°C in the packing room and warehouse.

Airflow

Ventilation systems are designed to maintain the required temperature and prevent both condensation and circulation of dust. The air current must flow from the packing to the trimming room (Figure 3.6).

Wastes

Waste materials are evacuated from the facility to avoid any cross-contamination (Figure 3.7).

Inside the premises, equipment and machinery used for nonedible material and waste must be clearly identified and never used for edible products. Moreover, they should be easy to wash and sanitize.

Outside the premises, any reusable receptacle for nonedible material and waste should be waterproof and easy to wash and sanitize.

Cleaning Equipment, Material, and Utensils

Washing should be performed by any method or combination of methods involving mechanical action (scrubbing, brushing, water jet spraying) or chemical cleaning (acidic or alkali detergent). The washing must include the removal of objectionable matter of any sort. A detergent or a disinfecting detergent should be applied so as to permit the elimination of dust and bacterial biofilms.

Efficient rinsing with potable water should eliminate the detached particles and detergent residues.

Sanitation

After washing the premises, the machines must be submitted to an efficient disinfecting, either by using steam or chemicals.

Hygienic Procedure for Operators

Personnel should know the hygienic procedure (International Code of Practice, General Principles of Food Hygiene) and wear protective clothing and footwear specific to the area.

Chlorinating

Use of chlorine, associated with hygienic processing, permits a significant improvement in the microbiological quality of the product. According to French Regulations, chlorine disinfection must be followed by rinsing with potable water (less than 0.5 ppm active chlorine).

There are different forms of chlorine in water solution. A part of dissolved chlorine combines immediately with organic matters (combined chlorine). The remaining part is the "free" chlorine. Concentration of free chlorine, which averages 80% of total chlorine, may be assessed using a specific electrode (which also permits automatic regulation of chlorine content) or a spectrophotometric method with DPD (N,N–diethyl phenylene–1,4 diamine) as a reagent. Considering the instability of the chlorine solution, frequent determinations are required.

In most disinfecting equipment, there is a very large dispersion in transit time of the vegetable chunks. The recommended mean duration of disinfection is 2 minutes. pH is an important factor for chlorine efficiency. The pH of the disinfecting solution should range between 6.5–8. Microbial load (aerobic mesophilic bacteria) changes during processing are shown in Figure 3.8.

Distribution Conditions: Chill Chain and Sell-by-Date

In order to maintain produce quality until the time of purchase, fresh-cut manufacturers must stamp the "best before date" on the bag. Determination of the shelf life is the processor's responsibility. The shelf life of the product must be established using scientific data, taking into account the chill chain temperature.

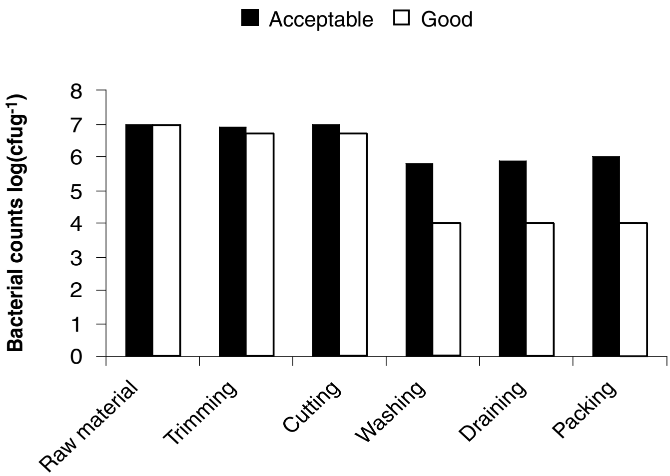

FIGURE 3.8 Microbial count (cfu·g^{-1}) during fresh-cut processing of green salads (Scandella and Leteinturier, 1989).

In order to simulate a realistic distribution of fresh-cut commodities, the temperature profile is two-thirds of the shelf life duration at prescribed temperature (4°C) and the remaining one-third at 8°C. The following are the microbial limits for fresh-cut commodities in France (Anonymous, 1993): *Listeria monocytogenes* and *Salmonella* should not be present in the final product (five samples of 25 g), but only 100 cfu·g^{-1} Listeria is tolerated at consumption.

Escherichia coli tests are done to ensure that contamination is within the following limits: for five samples of 25 g, no count should exceed 100 cfu·g^{-1}, and three out of five should be below 10 cfu·g^{-1}. These conditions are similar to those recommended by the International Commission on Microbiological Specifications for Foods (ICMSF, 1986, 1988). The Good Manufacturing Practice Guide also recommends that aerobic mesophilic flora be lower than $5 \cdot 10^6$ cfu·g^{-1} with three out of five counts below $5 \cdot 10^5$ cfu·g^{-1} in bags after processing. This recommendation is not enforceable and cannot be attained for some commodities such as aromatic herbs (parsley, tarragon, chives, sweet basil, and coriander leaves, which are processed in France) and sprouted seeds.

UNIT OPERATIONS

Raw Materials

It is obvious that the quality of the raw material is one of the most essential factors determining the quality of the final product. Green salads should be, as far as possible, cultivated in open fields. Broad-leafed and curly endives must be etiolated in the field in order to increase the processing output using either a rubber band or a plastic bell. This operation should be carried out carefully so as to avoid overstressing etiolated plant tissues. For hygienic reasons, no manure or fertilizer of animal origin should be used.

Numerous research projects in many countries, including the United States, Australia, and France are assessing the suitability of salad cultivars for minimally processing from the processor's point of view.

The main criteria in assessing this suitability of cultivars to fresh-cut processing are as follows:

1. Processing yield—for example, the output of butter lettuce ranges from 25–30% and reaches 50% for broad-leaved endive (Scandella and Leteinturier, 1989)
2. Low sensitivity to physiological disorders and microbial diseases
3. Mechanical resistance of the tissue
4. Resistance to elevated CO_2 concentration (Varoquaux et al., 1996) and/or low oxygen
5. High sugar contents because sugar depletion may be responsible for energy stress (Forney and Austin, 1988)
6. Low respiration rate (Varoquaux et al., 1996)
7. Special requirements—for example, all leaves of butter lettuces must be released when coring, because this salad is not cut thereafter in the process (Scandella and Leteinturier, 1989)

Harvesting

- Most of the raw material for fresh-cut processing is cultivated under contracts that specify the cultivars and cultivation techniques (including acreage, sowing time, pesticide and fertilizer applications, and harvest conditions).
- It is required that the salads be harvested in the morning because of the cooler temperature, but the sugar content of the leaves is higher late in the afternoon.
- It is well known that produce should be precooled to 1°C as soon as possible after harvesting in order to extend the potential shelf life. One of the conditions required for processors to achieve the quality distinction called "Label Rouge" is vacuum cooling of the salads at 1–2°C within four hours after harvest.
- Most salads, except lamb's lettuce, which is more resistant, should be processed within two days. Radicchio can be stored for up to two months.

Quality Assessment

The first operation on receipt of the raw materials is quality control, which is necessary to achieve a standard product quality. The main criteria are the appearance of the salads, including overall freshness, the absence of insects, physiological and microbial diseases, presence of necrotic tissue, and compliance with regulations on pesticide residues and nitrate content. With some salads stored, as variegated-leafed Italian chicory, for example, the absence of pathogenic bacteria such as *Listeria monocytogenes* is checked. All quality assessments are noted on an input grid to comply with "tracing" requirements.

Trimming

The required proportions of the ingredients in salad mixes are achieved during trimming. The trimming table is supplied with the final percentage of each salad, taking into account their respective processing output. All unwanted parts of the plant, including most of the outer green leaves and core area, are removed manually. This operation causes injury that could be minimized by using very sharp knives (Bolin and Huxsoll, 1991). This is much easier said than done. In fact, classical stainless steel used to manufacture blades is rather soft, and intensively used knives should be sharpened very often (every hour or so). Carbon steel used for scalpel blades is brittle, may be dangerous for operators, and releases iron ions that may be involved in brown discoloration. Ceramic blades are also breakable and are very expensive. Trimming may be partly mechanized, at least for broad-leaved and curly endives. A new automatic trimmer was developed by a French company (Soleco SA). This patented machine (U.S. patent 5,421,250; 1995) improves the yield of raw material from 5 to 10 points and reduces the manpower cost by a factor of two. The use of the trimmer is, however, limited to broad-leafed and curly chicory. Mechanization of the trimming of butterhead lettuce is more complex. Wounding of plant tissue results in leakage of enzymes and their substrates that are normally in different cell compartments. The destruction of cell microstructures leads to biochemical spoilage such as texture breakdown, off-flavor, and browning (Varoquaux and Wiley, 1996).

One of the most conclusive examples of the effect of wounding on firmness was observed on kiwifruit after slicing. The slices lose about 50% of their initial firmness within two days at 10°C. It appears as if this phenomenon was due to the release of enzymes with pectinolytic and proteolytic activities by injured cells (Varoquaux et al., 1990).

It is well known that bruising or cutting plant tissues with browning capability will result in a brown discoloration. Because most green salads contain polyphenoloxidases and phenolic substrates, mainly chlorogenic acid, caffeoyl tartaric ester, and caffeoyl shikimic ester (Goupy et al., 1990, 1994), browning of the cut surface is a major problem for minimal processing. As previously mentioned, browning can be reduced by using very sharp blades and chill storage, but another extremely important factor is the interval between slicing and washing. This was demonstrated with apple slices.

In Figure 3.9 the reflectance absorbance difference at 440 nm of apple slices for two cultivars is reported as a function of time after slicing. The slices cut in air were dipped into water 30 seconds after slicing. Browning of these slices appeared as a peak in absorbance in the 400–440 nm region of the spectrum. Surprisingly, the slices cut in water did not visually turn brown for a few hours when stored at 8°C under air. Browning did not affect internal tissue, because no discoloration was observed when the slices were cut again.

It is most likely that the prevention of browning in slices cut in water is due to the instant washing out of cell sap liberated by cutting. In slices cut in air and rapidly dipped into water, the exudate immediately diffused into inner tissue layers prior to washing. The longer the interval between cutting and washing, the browner the slices turned during storage. A similar phenomenon occurs with cut salad leaves.

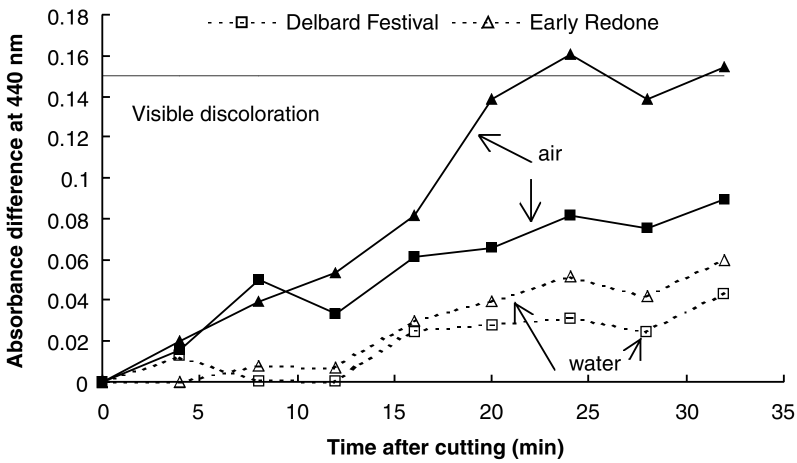

FIGURE 3.9 Absorbance of apple slices cut in air (open symbols) and cut under water (closed symbols) as a function of time for two cultivars (Kuczinski et al., 1993).

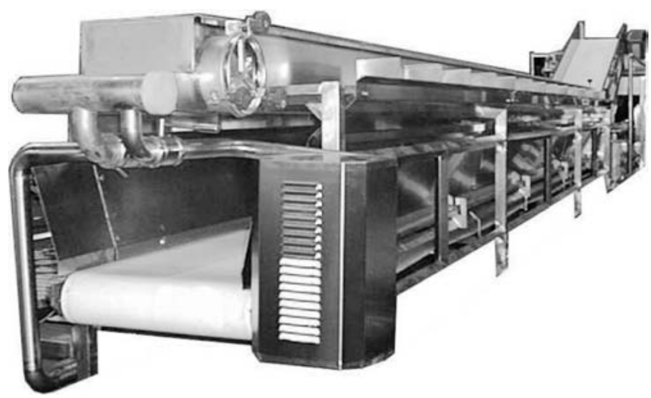

FIGURE 3.10 Trimming table fitted with water conveyor (upper part) to convey the trimmed product. (Photo courtesy of Turatti.)

It seems unrealistic to trim the salads manually under water. To reduce discoloration, new trimming tables were fitted with a hydraulic flow (upper part) to convey the trimmed parts and a belt conveyor (lower part) to evacuate the wastes, as shown in Figure 3.10.

Slicing and Shredding

Chicory leaves are cut into 2–3 cm pieces using rotating blades (perpendicular to the flow) or disk knives (parallel to the flow). This process also causes injury to plant tissue that could be minimized by using very sharp blades sharpened once or twice a day. When trimming, salad leaves must be washed immediately after cutting;

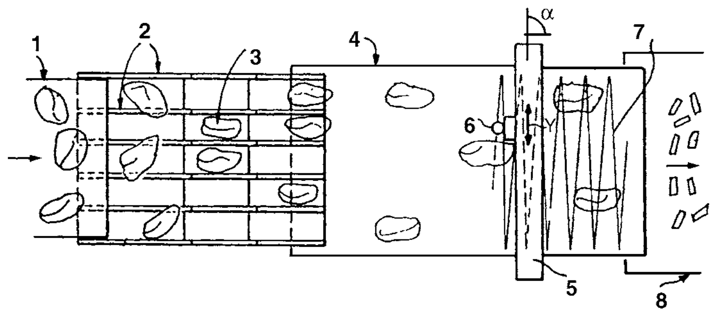

FIGURE 3.11 Sketch of a water jet cutter for fresh-cut commodities (Béguin et al., 1995).

any delay in prewashing will enhance browning. Washing the leaves after cutting is essential to prevent browning in the same way as trimming. In most processing lines, the product immediately drops into a washing tank after shredding. Since the cutting should take place under water, one of the approaches tested in France was water jet cutting (Béguin et al., 1995). Because the internal liquid of injured cells is removed by the water flow, browning is markedly reduced compared to any commercial cutting techniques. The principle of this machine is shown in Figure 3.11. The leaves (3) are conveyed (1) to a multi-U-shaped grooved belt (2) designed to position the main nervure of the leaves parallel to the direction of flow and to limit the thickness of the products to two or three layers on the stainless steel grill conveyor (4). The leaves (or other plant tissues) are cut by the transversal and alternative displacement of a water jet (6) on a fixed rail (5). The water jet pressure ranges between 50–100 MPa depending on the product to be sliced. The average width (cm) of the chunks is $P/2v$, where P is the period of the water jet cross-head (min^{-1}), and v is the conveyor velocity in $cm{\cdot}min^{-1}$ (7). The cut products are dropped into the washing (8).

Prewashing

When the salad leaves are cut, they fall into the prewasher that washes away exudates and saps that would otherwise rapidly pollute the disinfecting tank.

Washing with Chlorinated Water

The maximum active chlorine allowable in the disinfecting tank was set at 120 ppm by law in France in 1988, and the 1992 guidelines, which are still valid, proposed reducing it to 80 ppm. In current processing, the minimum chlorine concentration should not drop below 50 ppm. Chlorine may be hypochlorite or chlorine gas. The latter is more complex to handle but is slightly more efficient due to a noticeable decrease in pH of the disinfecting solution. Conversely, addition of hypochlorite increases the pH, resulting in a bigger dissociation of hypochlorite and, thus, in a decrease in disinfecting efficiency. In some processing units, the chlorine concentration is monitored and adjusted continuously, while in others, it is measured and readjusted every hour or so. Agitation in the disinfecting tank is insured either by tangential air bubbling or water jets or mechanically by rotating arms (Figure 3.12). It should be

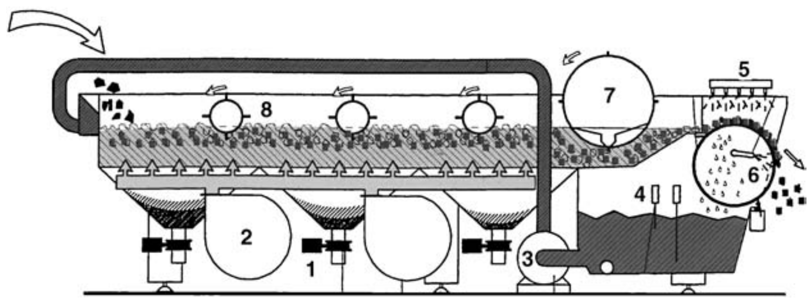

FIGURE 3.12 Conventional washer: (1) sediment discharge valves, (2) ventilator with blowing system, (3) pumps and hydraulic manifold, (4) level gauges, (5) cold water nozzles, (6) drum outlet filter, (7) insect removal drum, and (8) flow adjusting drum. (Courtesy of Turatti.)

noted that chlorine is not actually authorized but only tolerated by French regulations for disinfecting minimally processed products. Its use is, however, banned in some European countries such as Belgium, Germany, and Holland. The current trend is to eliminate chlorine from the disinfection process. In the washing equipment described below, a minimal chlorine concentration of 8 ppm was established as an efficient safeguard against possible contamination by pathogenic bacteria.

In previous work, American researchers stated that there was a significant relationship between the initial bacterial load and the spoilage of shredded iceberg lettuce (Bolin et al., 1977). Nguyen-The and Carlin (2000) reported a clear relationship between the number of aerobic mesophilic bacteria at the end of shelf life and spoilage on fresh-cut broad-leaved endive packed in sealed polypropylene film, but microbial pollution may be the consequence of the decay as stated by Carlin et al. (1989). Varoquaux and Wiley (1996) claimed that injury stress at processing and physiological disorders induced by detrimental packaging conditions along with temperature abuse were the main causes of the premature decay of fresh-cut produce.

The growth rate of aerobic mesophilic bacteria in highly disinfected salad is higher than that in control samples washed in tap water (less than 0.5 ppm free chlorine). After a 2 log reduction in bacterial count, due to an efficient sanitation, the bacteria population was identical to the untreated sample after only four days at 10°C (Carlin et al., 1996). The growth of *Listeria monocytogenes* under the same conditions is dramatically enhanced compared to that of the untreated control (Figure 3.13). Elimination of the saprophytic flora may favor the development of unwanted bacteria such as *Listeria monocytogenes*, which grows faster in highly disinfected samples.

It was postulated that a 2 log reduction in microbial count after disinfection was not necessary to ensure product quality. That is why alternative milder sanitation processes were developed (see Conclusion).

The last step of the washing operation is a rinsing with tap water containing less than 0.5 ppm active chlorine. This unit operation is necessary only when chlorine at a concentration higher than 1 ppm is used. The cold water (1–3°C) must be continuously renewed in order to avoid chlorine accumulation from the disinfecting section. This rinsing water can be recycled to the upstream washer after filtration and chlorinating.

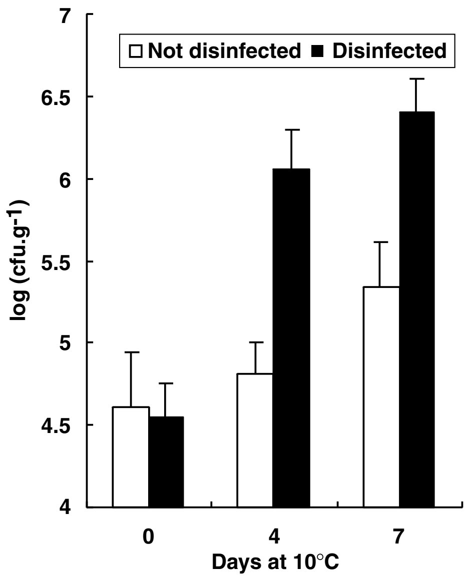

FIGURE 3.13 *Listeria monocytogenes* growth on inoculated broad-leaved leaves after drastic (empty bars) or light (closed bars) chlorine disinfecting (Carlin et al., 1996).

The new washer, illustrated in Figure 3.14, is based on the succession of torrential and laminar flows. The salad is elevated to the feeding hopper (3) filled with chlorinated water (5–8 ppm of active chlorine). The chlorine concentration is regulated with a specific electrode, and the recycled solution is filtered. The product is swept along in the overflowing water (11). The bottom of the first section (1) is equipped with bumps (10) which, combined with the optimal slope α of the disinfecting section, results in a succession of laminar and torrential flows. The surface of the commodity is washed in a permanently renewed turbulent chlorine solution. This process also eliminates aphids. At the end of the first section, the product is separated from the chlorine solution onto a perforated conveyor (5). The water is returned (7) to the water buffer tank (not shown) and partially recycled after adjustment of the chlorine concentration. The salad falls into a tank (9) filled with drinkable water (chlorine concentration lower than 0.5 ppm). The rinsing section (13) is also fitted with bumps (12) designed to turn over the leaves and to expose both sides to a UVc tube (24), which prevents any microbial cross-contamination in the rinsing section. The leaves are separated from water onto a second sieve (15). The water is recycled (14) and (17) either to the first section or to the upstream prewashing. The product is collected into crates (19) or sent directly to the drying system (spin dryer or tunnel).

Draining

Excessive free water in packs results in rapid bacterial spoilage mainly at the leaf-film interface (Herner and Krahn, 1973). Draining should result in about 1% residual moisture compared to the unprocessed salad. Two methods are presently used for this

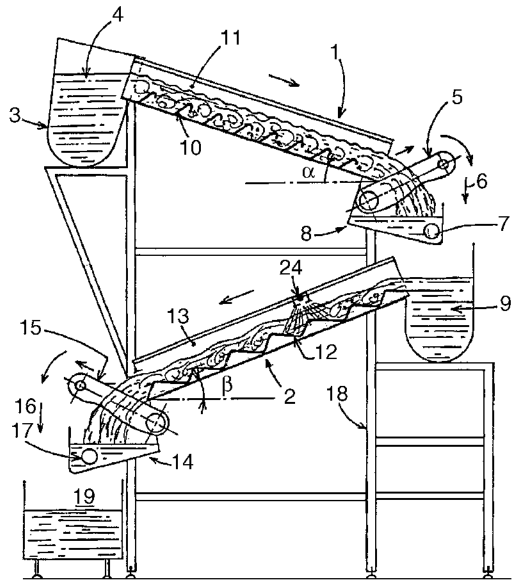

FIGURE 3.14 New washer based on a succession of laminar and torrential flows, including a regulation of chlorine concentration and a rinsing section (Béguin and Varoquaux, 1996).

operation: a spin dryer and an air tunnel. Drastic centrifugation results in bruising, so the process was improved using special centrifuges to achieve optimal draining. The centrifugation cycle begins with a soft loading of the fragile leaves followed by a smooth acceleration and a careful discharge of the drained products (Figure 3.15).

Air tunnel drying is a new technique developed in Italy that is currently used in several processing plants in Europe and in the United States (Figure 3.16).

The drying tunnel is composed of "cascade" vibrating tables to transport the product and a battery of air drying units. The product progression is countercurrent with both air temperature and dryness. The dryer is microprocessor piloted to optimize its efficiency. In order to limit cross-contamination by airborne microorganisms, the airflow is filtered and disinfected with a UV tube (250–280 nm).

Weighing and Packing

The packing room must be clean and refrigerated at 1–2°C and must be separated from the washing section. Packing is performed around a vertical tube at the top of which is the associative weighing machine, an example of which is shown in Figure 3.17.

Salad bits (or any other products) are poured into the infeed funnel (or a vibrating cone) designed to distribute the vegetable chunks evenly into feed buckets, which release them into weighing buckets. The successive bucket system permits a continuous operation of the machine provided the level sensor is not activated. The weight of plant tissues in all the buckets is transmitted to a computer that calculates the best combination to optimize the required weight. Both mean weight and acceptable standard deviation are entered into the computer.