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A Systems Approach

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FRESH-CUT PRODUCE QUALITY: IMPLICATIONS FOR A SYSTEMS APPROACH

Silvana NICOLA[1] and Emanuela FONTANA[2]

[1] Department of Agricultural, Forest and Food Sciences – AgriForFood. DISAFA, Università di Torino, Via Leonardo da Vinci 44, 10095, Grugliasco (Torino), Italy

[2] Emanuelafontana.com Consulting, Via Cottolengo 98/5, 10048 Vinovo (Torino), Italy

RUNNING TITLE

Quality of Fresh-Cut Produce

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SUMMARY

Fresh-cut fruit and vegetables represent an important food segment of interest to growers, processors, retailers and consumers. Fresh-cut products are more perishable than whole produce because they are physically altered from their original state during processing operations. Although they remain in a fresh state, fresh-cut products are living tissues characterized by an accelerated metabolism. Quality in the fresh-cut products preparation and distribution is crucial in terms of food safety, quality and the environmental impact. Cultivation is still a fundamental part of the supply chain, but the complex market dynamics require detailed knowledge of all stages in the supply chain. In the last twenty years, the fruit and vegetable market has developed a rich array of new products. At the same time, consumers have become more concerned about health and a proper diet (see also Chapters 3 and 5) and have increased the demand for healthy fruit and vegetables and guaranteed products. Globalization has shown that production systems need a new approach that should focus on safety and quality rather than quantity and has shown that a fully integrated and complex supply chain must be able to fulfill the consumers' needs. This chapter has considered the critical points concerning the safety and quality of produce that should be controlled by growers, who represent the first stage in the fresh-cut supply chain, and the technologies used by processors to maintain quality and guarantee safety. An optimal cultivation management on the farm, an efficient and rapid harvesting, proper postharvest handling and storage are key factors that favor the quality of the raw material. Quality raw material enhances processing and final product quality leading to increased competitiveness in the market for the fresh-cut producer. This, in turn, leads to increased bargaining power of, in particular, processors and retailers.

I. INTRODUCTION

Fresh-cut produce implies fruit or vegetables that have been prepared and subsequently packaged to provide convenient and safe ready-to-eat products for consumers, while maintaining their live, fresh state. Fresh and raw vegetables and fruits are subjected to minimal process operations such as cutting, trimming, shredding, peeling, washing, decontamination, dipping, rinsing, and packaging. Fresh-cut products, thus, are highly perishable, but also agronomically and technologically more susceptible to quality deterioration than whole vegetables or fruit. The processing operations eliminate any inedible parts, but reduce the edible product shelf life by several weeks or months, depending on the raw material. The nutritional and sensory quality should be comparable to the unprocessed product. Leafy vegetables, particularly baby leaves, are the consumers' favorite, but they are very delicate and susceptible to process manipulations. Control and innovation technology implementation needs to be pursued to optimize all the fresh-cut production and processing procedures.

A fresh-cut product is physically altered from its original state during trimming, peeling, washing and cutting operations. However, it remains in a fresh state and is thus characterized by living tissues that undergo or are susceptible to enzymatic activity, texture decay, undesirable volatile compound production and microbial contamination, which reduce the shelf life. In the fresh-cut industry, shelf life is the time required by a fresh-cut product to lose quality attributes, such as freshness, firmness, texture, color, aroma, and nutritional value, below a level acceptable to the consumer. The relative importance of each quality factor varies according to the product and market. The final potential postharvest quality and shelf life of fresh produce are determined before harvesting. Processing practices, e.g., packaging and storage temperature, do not improve quality; they can only slow the rate at which deterioration occurs. Practices such as washing, sorting, and sizing are services performed with the consumer in mind, and generally do not improve the inherent quality (Brecht et al., 2003). The first and most important aspect that affects the subsequent postharvest processing and shelf life phases is the raw material quality at harvest.

Fresh produce in general, and fresh-cut produce in particular, is perishable. Once harvested, quality deterioration occurs leading to raw material losses even before the produce reaches the consumer. Fresh fruit and vegetable postharvest losses have been estimated between 2% and 20% in developed countries and between 24% and 40% in developing countries, respectively (Sirivatanapa, 2006). High levels of waste result in higher prices for the final product. Improper handling during the harvest on farms causes quality deterioration. Quality in the supply chain is crucial in terms of food safety, quality and environmental impact. Low input and efficient cultural practices, postharvest technologies and supply chain management contribute to "making the difference" in an industry that wishes to be efficient and competitive. The critical points that need to be improved in the fresh-cut sector include:

- early cold chain implementation;
- storing and shipping conditions prior to reaching the processing plant;
- logistics;
- processing inputs;
- handling in distribution.

For these reasons, innovative technologies have been developed to enhance raw material production, preserve quality, guarantee safety, prolong shelf life, and diversify the fresh-cut products available to consumers.

A. Consumer trends and fresh-cut market

Most fruit and vegetables are low-cost food that contain low levels of fat and high levels of a number of nutritionally important compounds, such as vitamins, minerals, fiber, bioactive compounds, etc., many of which cannot be synthesized by the human body. Changing eating habits such as snacking, year-round product availability and a growing trend towards vegetarianism and healthy eating have resulted in an increasing demand for convenient products that fit into the modern consumer lifestyle, while offering healthy food. Fresh-cut products, especially vegetables, have, thus, become very popular.

In recent years, the consumer demand for fruit and vegetables decreased in Europe (see also Chapter 7). However, instead of a decrease, the ready-to-eat product sector reported an increase in sales. In the past few years, fresh-cut produce has seen an increase in sales throughout the world. Out of the total produce sales, fresh-cut sales have an estimated share of 18% in Europe, of 9% in the United States, and of 5% in Australia, respectively (Premier, 2007; Premier et al., 2007). Fresh-cut produce sales in the United States are ca $12 billion, according to the International Fresh-cut Produce Association reported by fruitgrowersnews.com professional portal (Fruitgrowersnews, 2013), with an increase of more than 50% in the last decade. This is an indication that the fresh-cut industry remains the fastest growing segment in the produce sector. The fresh-cut segment supplies both the food service industry and retail outlets in the United States. Approximately 60% of fresh-cut produce ends up in the food service industry and 40% in the retail market. Of the retail market, 62% consists of salads, 31% of vegetables, and 7% of fruit, respectively (Premier, 2007). The fresh-cut industry keeps growing in many European countries with the UK, Italy and France leading in terms of market share. The Rabobank estimated the value of the European fresh-cut fruit and vegetables market at about €3.4 billion (Van Rijswick, 2010). The market volume growth in the European Union (EU) is estimated of 4% year-to-year. Currently, the EU market volumes are represented by 50% fresh-cut salads, 40% other fresh-cut (stir-fry, crudités, etc.), and 10% fresh-cut fruit. The UK is the market leader in Europe with €1.1 billion in fresh-cut fruit and vegetables sales and one-third of total EU fresh-cut fruit and vegetables consumption (ca 480,000 tons, elaborated data).

In Italy, the second most important country after the UK for market value in Europe, the fresh-cut production reached 90,000 tons in 2008, with a corresponding value of ca €700 million (Pirazzoli and Palmieri, 2011). These values remained constant until 2012 when an increase of 4.4% was registered compared to the previous year, reaching 98,000 tons and €767 million (Aldinucci, 2013). Spain is the European country with the highest and constantly increasing production and market value in the latest years. In 2008, the Spanish fresh-cut market value was €200 million with a production of almost 57,500 tons, of which 25% for food service and 75% for retail market (Andujar Sànchez et al., 2010). The sector continued to grow at the pace of 4-6% per year reaching 70,000 tons in 2010 and a market value of more than €300 million (Fabbri, 2011; Van Rijswick, 2010).

Consumer demand for fresh-cut fruit and vegetables increased significantly in 2011 according to a survey of the Hartman Group commissioned by the Produce Marketing Association (PMA) (FreshFruitportal, 2012). The survey results showed that 22% and 15% of consumers were buying, respectively, more fresh-cut vegetables and fruit compared to 2010. The fresh-cut fruit and vegetables consumption per capita varies from 3 kg in Europe to 30 kg in the USA (Andujar Sànchez et al., 2010). Among the leading European countries for fresh-cut industry, the consumption per capita is 12 kg in the UK, 6 kg in France, 3.7 kg in Italy and 1.5-2.0 kg in Spain, respectively.

The fresh-cut production is widespread throughout the world; in some countries it is devoted to exports aimed at western countries (e.g., Thailand to the UK, Mexico to the United States). Fresh-cut market is developing in the South-East Asia and Latin America. In Asia, fresh-cut product sales are driven by demand in countries like Japan, Singapore, and the Republic of Korea. Sales of fresh-cut produce in Japan have grown from approximately $1 billion in 1999 to $2.6 billion in 2005, of which 89% consisted of fresh-cut vegetables and 11% of fresh-cut fruits (Kim, 2007). In 2011 sales were $1.9 billion, of which ca 37% was sold in retail outlets, ca 49% in food service industry and ca 14% in others (Izumi, 2013, personal communication from Agriculture and Livestock Industries Corporation). In the Republic of Korea, sales have grown from $0.5 billion in 2003 to $1.1 billion in 2006. These sales implied the production of 110,000 tons of which 33% consists of vegetable salads, 42.1% of ready-to-cook vegetables, 8.7% of wild vegetables, 15.6% of fruit, and 0.3% of mushrooms. It has been reported that fresh-cut produce has been increasing in China since the late 1990s, with an annual growth rate estimated at 20%, although no exact figures are available (Zhang, 2007). Despite the opportunity that this sector can offer the overall produce industry, the lack of reliable published data makes it difficult to appreciate the importance of fresh-cut business around the world.

B. Food safety risks in the fresh-cut chain

The fresh-cut vegetable safety is related to inherent anti-nutritional substances, such as nitrate and oxalate, accumulated during growth (Reinink and Blom-Zanstra, 1989; Weerakkody, 2003), and external microbial (see Chapter 12) and chemical contamination during postharvest (Cantwell and Ermen, 2006). These critical factors can be controlled throughout the entire chain by implementing targeted cultural techniques and observing sanitation programs. Good agricultural practices (GAPs) and good manufacturing practices (GMPs) provide recommended guidelines that guarantee a minimum safety level; the hazard analysis critical control point (HACCP), which includes good hygiene practices (GHPs), is regulated in the EU by EU-Reg. N. 852-853-854/2004. Produce sanitation should start in the field and should encompass all growing, harvesting, handling and processing areas and a documentation of all the procedures applied should be recorded by the producer (logbook).

Food safety management in the fresh-cut chain is expected before processing, thus the food safety risks depend on cultivation site location, planting materials (e.g., seeds, seedlings, bulbs, shrubs, trees), process technology, crop production practices, pre- and postharvest technology, and food quality management (Kirezieva et al., 2013). From 1996 to 2006, 26% of all food-borne disease outbreaks caused by the consumption of fresh produce implicated fresh-cut produce (FDA, 2007). Most of the outbreaks linked to fresh produce from 2005 to 2011 were caused by *Salmonella*, *Escherichia coli* O157:H7, *Listeria monocytogenes*, and *Shigella sonnei* (Olaimat and Holley, 2012). In Europe over 400 cases of Salmonellosis occurred from baby spinach and alfalfa sprouts and 3911 cases of *E. coli* from vegetable sprouts in 2011; in the USA over 2000 cases of Salmonellosis occurred from tomatoes, spinach, cantaloupe, sweet pepper, and over 500 cases of *E. coli* from leafy vegetables.

A larger volume and greater variety of fresh-cut products have become available because of the fresh-cut sector growth. Fresh fruit and vegetables normally contain high amounts of microorganisms at harvesting before processing. Soil, water, air and insects all contribute to the microflora of vegetables, but their importance differs according to the edible part of the plant. For example, leaves are primarily exposed to water, whereas roots have more contact with the soil. The numbers and the species of microorganisms found on fresh produce, and specifically on fresh-cut products, are highly variable. Fresh produce is considered to be a possible source of food-borne outbreaks caused by a variety of pathogens. Several specific pathogen-food combinations have emerged in recurrent outbreaks, such as *Salmonella* infections from melons and tomatoes, *E. coli* O157:H7 infections from leafy green vegetables, *Cyclospora* infections from raspberries and hepatitis A infections from green onions (Lynch et al., 2009). The range of the contamination depends on the harvest time, weather conditions at harvesting, applied fertilizer, handling by workers during harvest, hygiene worker's conditions, sorting, and the subsequent processing, e.g., the contact with cutting knives, transport belts, boxes or water used for washing.

The difficulties involved in killing and removing microorganisms from raw material can originate from preharvest sources, such as feces, soil, sewage and sludge, irrigation water, water used to apply fungicides, insecticides and herbicides, improper manure, dust, wild and domestic animals and human handling (Beuchat, 2007). The control of these contamination sources can enhance the successful management of microbial safety risk in the fresh-cut industry. Four types of microbes are present on the surface of fresh-cut produce (see also Chapter 12):

1. useful microbes, such as some lactic acid bacteria, which should not be removed or killed;
2. spoilage microbes, such as pectinolytic Gram negative bacteria belonging to *Pseudomonadaceae* or *Enterobacteriaceae* and yeasts with fermentative metabolism like *Saccharomyces* spp., found on fruit, which should be minimized during processing because they reduce shelf life;
3. pathogens (e.g., *Clostridium botulinum*, *Escherichia coli*, *Listeria monocytogenes*, *Salmonella* spp., *Staphylococcus aureus*) responsible for food-borne disease outbreaks;
4. commensal organisms, with no positive or harmful effect on either humans or plant and plant pathogens with no harmful effect on humans.

The aim of the fresh-cut industry is to prevent the presence of pathogens and assure that they are not introduced during the processing system. Because of their growth, internalization and infiltration behavior, sanitizer treatments are not effective and cannot assure safety, thus GAPs, GMPs and HACCP are essential to prevent human pathogen contamination.

II. CULTIVATION MANAGEMENT FOR THE FRESH-CUT INDUSTRY

A. Raw material quality for the fresh-cut industry

Any preharvest condition that stresses a plant will affect the quality and shelf life of the final product. The understanding of these conditions is crucial to assess the postharvest potential of fresh produce, especially those that will be further stressed by fresh cutting. The raw material going to the fresh-cut industry must be in a perfect state with regard to safety, physiology, extrinsic and internal quality before processing. The most important prerequisites concern:

- the absence of insects, soil, metals and weeds, which increase the length and the cost of the washing phase and jeopardize the quality;
- a low level of microbial contamination that accelerates metabolic processes which reduce the shelf life;
- the absence of pathogens that cannot be either controlled or eliminated during processing;
- a high quality standard in terms of appearance, texture, flavor, and nutritional value.

Cultivation conditions, such as the culture system, irrigation, climate and fertilization, influence the quality of the raw material and can modify its physiological behavior and suitability for fresh-cut processing. The preharvest and harvest conditions that affect vegetable quality and shelf life are related to:

- genetically controlled factors (cultivar, strain);
- climatic conditions (light, temperature, relative humidity (RH), etc.);
- soil conditions (type of soil, pH, moisture, microflora, soil-borne diseases, etc.);
- culture systems (open field cultivation, protected cultivation, soil-less system, etc.);
- agricultural practices (use and kind of fertilizers, pesticides, growth regulators, irrigation, etc.);
- harvesting (harvest timing and temperature, mechanical harvest, manual harvest, etc.).

The influence of genome, growing conditions, maturity at harvest, and storage regime are critical factors that determine the ultimate quality level in fresh produce before fresh-cut processing (Kader, 2008). Climatic conditions (temperature, light, rain, wind) and cultural practices (planting density, tree pruning, fruit thinning, plant nutrition, cultural system, control of weeds, diseases and pests) allow to reach high yield, but can be detrimental to produce inherent quality. It is necessary to identify the optimal cultural practices that maximize both quality and yield avoiding nutrient and water excess, and to encourage the growers to adopt cultural practices that will enhance produce quality even with a reduction in yield, for providing premium quality raw material for fresh-cut processing. Raw material variability remains a challenge: cultivars, growing conditions, climatic conditions, preprocessing handling and storage all affect the visual quality, shelf life, flavor and the compositional and textural quality (Cantwell and Ermen, 2006).

B. Cultivars

Choosing the proper cultivar is not an easy task because various parties in the fresh-cut production and distribution have often conflicting needs. Breeding selects cultivars that can solve problems of growers and processors (see also Chapter 20), reduce production costs and optimize postharvest technology efficiency. In recent years, breeding programs have been focused on developing new varieties and selections especially for yield, fruit size, disease resistance, long shelf life, minimum harvest maturity, lowest storage and shipping temperatures. All these parameters are crucial for growers, processors, buyers and retailers, but can have negative consequences on flavor quality of the product (Kader, 2008).

Growers want cultivars that are resistant to biotic and abiotic factors, while assuring a high yield, suitability for mechanical harvesting, plant size uniformity, low waste and uniform maturity. The absence of biotic and abiotic damage reduces both the metabolic processes after harvest and microbial contamination at any stage. Resistance to biotic and abiotic factors allows not only reduction of pesticide use, but also production of unblemished raw material. Breeders have selected *Cichorium intybus* L. (chicory) cultivars with high bolting tolerance and frost resistance without any variation in color. Cultivars with high bolting tolerance satisfy commercial and organoleptic maturity requirements and lead to a reduction in the discarded material, thus lowering postharvest losses. Baby leaf cultivars of lettuce (*Lactuca sativa* L.) have been selected because of their resistance to different *Bremia lactucae* strains, while spinach (*Spinacia oleracea* L.) cultivars have been selected because of their resistance to *Peronospora farinosa*.

Processors want cultivars with low respiration and enzymatic rates and with tolerance to stress due to mechanical operations, such as washing, sorting, cutting, and drying. Selecting varieties with low respiration rates and lowering the respiration rate after harvest are very useful tools to extend the shelf-life of the fresh produce. Seefeldt et al. (2012) studied the effect of variety and harvest time on respiration rate of broccoli florets (*Brassica oleracea*, Italica group) and found that the respiration rate among the tested broccoli varieties can be related to the structure of the heads and the inflorescences size. Varieties with low respiration rate for oxygen (RRO_2) had small inflorescence gathered in a compact head, while those with high RRO_2 had a large inflorescence in loose heads. In addition, the varieties with high dry matter contents had also high RRO_2 within the same species. Also preferred are cultivars tolerant of low temperatures used in the supply chain. For instance, head vegetables (e.g., lettuce, chicory) are preferred to baby leaves (e.g., rocket, *Eruca sativa* Mill; corn salad, *Valerianella olitoria* L.) because they are more resistant to mechanical stress and extended storability prior to processing. The latter feature improves logistic management of the produce flow. However, the recent consumer demand for softer leaves with variation in taste, color, and shape has encouraged the development of new lettuce typologies. Martínez-Sánchez et al. (2012) compared the whole-head lettuce, as the most common raw material for the fresh-cut industry, with baby-leaf and multi-leaf as the newest baby-sized lettuce leaves (Green Leaf, Red Leaf and Lollo Rosso cultivars). The new baby-sized leaves both at immature and mature stages have been developed as high quality lettuce varieties for the fresh-cut sector.

Baby-sized lettuce compared to the whole-head lettuce presents some advantages:

- greater efficiency due to the higher percentage of usable product;
- easier and faster processing because the entire leaf is harvested and processed;
- more attractive presentation in the packaging because of 3-D structure;
- minimal oxidation due to the smaller stem diameter.

Martínez-Sánchez et al. (2012) recommended the development of baby-sized lettuce varieties because of excellent sensory characteristics and nutritional quality; they meet fresh-cut specific requirements in terms of visual quality, microbial load and high content of phytochemicals.

Leaf shape often depends on cultivar and can facilitate cleaning and washing operations during processing. This is typical the case of spinach. Spinach cultivars are often classified according to leaf shape, i.e., smooth, savoy or semi-savoy. The smooth leaf and semi-savoy types are mainly used for processing, while the savoy type is used for the fresh market. The savoy types are preferred for shipping because they are less likely to wilt or turn yellow before reaching the market. The smooth type spinach cultivars are suitable for canned, frozen or fresh-cut produce, because the leaves are easy to clean before processing.

Enzymatic rates can depend on cultivar. Cantwell and Ermen (2006) described lettuce cultivars that differed according to their enzymatic browning rate and the phenylalanine ammonia lyase (PAL) activity of the cut pieces. All types of “radicchio”, a chicory cultivar famous for its color and slightly bitter flavor, have a long shelf life associated with a reduced oxidation of the cutting point.

Cultivar selection is of great importance in fresh-cut fruit processing, because cultivars can widely differ for flesh texture, skin color, flavor, nutritional value, susceptibility to mechanical damage, and browning potential. The commercial success of fresh-cut peach and nectarine slices (*Prunus persica* [L.] Batsch) has been limited, due to their short shelf life because of cut surface browning and pit cavity breakdown (Gorny et al., 1999). Their shelf life can vary between 2 to 12 days at 0°C, depending on the cultivar. The selection of appropriate cultivars, along with an appropriate maturity at harvest and proper storage conditions, can be considered the most important factors that determine the shelf life of fresh-cut fruits. The shelf life of fresh-cut slices of pear cultivars (*Pyrus communis* L.) varies greatly due to their different degrees of flesh softening and surface discoloration. The shelf life of pear slices is reduced with an increased incidence of cut surface browning. Gorny et al. (2000), when comparing Bartlett, Bosc, Anjou and Red Anjou varieties, stated that Bartlett pears were the most suitable cultivars for fresh-cut processing, because they exhibited the longest post-cutting shelf life of all cultivars tested.

Ethylene receptor can be bound by 1-MCP which then can prevent the physiological action of ethylene for extended periods. The effectiveness of 1-MCP is cultivar-specific and influenced by the maturity of the fruit. Calderon-Lopez et al. (2005) found that slices prepared from apple cultivars (*Malus* x *domestica* Borkh.) treated with to 1-MCP had lower ethylene effect and were firmer than those of untreated fruits. Fruit firmness generally decreases with increasing core temperature, but postharvest quality decay due to storage temperature is not only species-specific but, also, cultivar-specific. This is, for instance, the case of apples. Toivonen and Hampson (2009) investigated the response of four apple cultivars (Gala, Granny Smith, Ambrosia, Aurora Golden Gala™) to fresh-cut processing at core temperature of 1, 5, 13, and 20 °C. It was concluded that Gala apples were best processed at low core temperatures, Ambrosia could be processed at all temperatures tested, and Aurora Golden Gala produced better quality slices when fruit was stored at room temperature (20 °C) before slicing. These results mark the necessity of developing new apple lines directed to their quality as fresh-cut products in addition to the potential storage quality of the intact fruit.

Nowadays, it is crucial to satisfy the consumer expectations in terms of quality. One of the main parameters considered by consumers when choosing a product is the color of the product. Consumers associate color with freshness, better taste, flavor, and ripeness, which depend on genotype, growing conditions, harvesting stage, processing, storage and distribution conditions. In fruit, such as apples, cherries (*Prunus avium* L., *Prunus cerasus*

L.), and strawberries (*Fragaria* x *ananassa* Duch.), there has been much interest in breeding fruit varieties with different color, hues, patterns, or with a total anthocyanin content. Red skinned apples are preferred to the other colored apples.

Differences between cultivars may give rise to specific different postharvest quality aspects valuable for the fresh-cut industry. Gonzalez-Aguilar et al. (2008) assessed the physiological and biochemical changes of different fresh-cut mango (*Mangifera indica* L.) cultivars (Keitt, Kent, Ataulfo) stored at 5°C. Ataulfo had a much greater shelf life than the other two cultivars, almost double or triple; there was also a correlation between the content of carotene and vitamin C of Ataulfo mango and its longer shelf life compared to the other cultivars. The importance of a high vitamin C content has extensively been indicated as a factor delaying tissue senescence (Lee and Kader, 2000; Bergquist et al., 2007). Wall et al. (2010) evaluated the physicochemical, nutritional and microbial quality of fresh-cut papaya (*Papaya carica* L.) prepared from 5 cultivars with varying resistance to internal yellowing (IY) (Sunrise, SunUp, Rainbow, resistant; Kapoho, Laie Gold, susceptible), a disease caused by *Enterobacter cloacae*, an opportunistic pathogen. A zero-tolerance for food-borne coliforms makes resistance to IY an important criterion in breeding papaya cultivars suitable for fresh-cut food, but because the infection is restricted to the flesh surrounding the seed cavity, infected fruit cannot be sorted from good quality fruit based on external appearance.

Microbial quality is fundamental to observe the food safety guidelines and the use of IY-resistant cultivars could eliminate or reduce coliform bacteria load. While Kapoho and Laie Gold cultivars are not good candidates because of susceptibility to IY, although Laie Gold is high in vitamin and sugar contents, Rainbow is one of the IY-resistant cultivars. The latter, in addition, is better than the former for its higher content in vitamin A and sugars, and it does not develop the flesh translucency problem. The authors concluded that the processors of fresh-cut papaya products should choose the best cultivars for processing by considering not only appearance, but also texture, flavor and nutritional content.

Raw material for the fresh-cut industry originates a certain amount of waste after sorting and processing that could be valuable as a source of bioactive compounds. The waste amount is species and cultivar dependent. Tarazona-Díaz et al. (2011) tested five fresh-cut watermelon (*Citrullus lanatus* Thumb.) cultivars to determine: 1) the percentage of waste product produced during fresh-cut processing, 2) the difference among the cultivars in terms of their bioactive compounds, and 3) the composition of watermelon rind and flesh, with the possibility of reusing the rind as an additive in functional foods. The authors compared the following cultivars: 1) Fashion, seedless, dark rind, 2) Azabache, seeded, dark rind, 3) Motril, seedless, striped rind, 4) Kudam, micro-seed (open-pollinated cultivar), striped rind, 5) Boston, seedless, striped rind. Results indicated that the amount of by-product generated by processing varied from 31.27% to 40.61% of initial fresh weight depending on the cultivar. All cultivars were poor in total antioxidant content. However, the sensory panel indicated that the five cultivars would have a good acceptance in the market. 'Fashion' watermelon had the highest citrulline content (an amino acid that may help regulate blood pressure) and could be used as a source for human consumption as fresh-cut watermelon or for citrulline extraction from discarded rind.

In conclusion, during the latest decade processing technologies and distribution chain have driven the demand of cultivar selection and breeding mostly based on yield and post-processing performance in terms of shelf life, leaving at a lower priority the consumer demand for high organoleptic quality, flavor and nutritional values. Nevertheless, there is an increasing interest to select and breed cultivars satisfying production and processing needs of growers and processors as well as satisfying nutritional and organoleptic characteristics requested by the consumer. Furthermore, research has been focused basically on few species that are the core of the fresh-cut industry, such as lettuce, spinach, melon, watermelon, apple and lately on some tropical fruit. There is a need to expand investigations on genetic material for several species that represent a niche in the fresh-cut industry but could gain popularity thanks to ameliorated performance. The constant expansion of the fresh-cut business all over the world can drive the demand for improved and new varieties or even species to be included in the supply chain.

C. Growing conditions and raw material production

Climatic conditions, including light and temperature, and soil type have an important influence on the chemical composition of horticultural crops (see also Chapter 5). The amount and intensity of light during the growing season have a definite influence on the amount of ascorbic acid that is formed, thus affecting the postharvest shelf life (Lee and Kader, 2000). A study on baby leaves (spinach, red chard - *Beta vulgaris* L., pea shoots - *Pisum sativum* L., rocket and corn salad) obtained from a grocery store throughout the season showed that total vitamin C content, that is, ascorbic acid (AA) and dehydro-ascorbic acid (DHA), vary significantly between species, between cultivars, and over the season (Mogren et al., 2014). The variations in the chemical composition in spinach due to the season was also found by Conte et al. (2008), who showed that the product harvested in February had a lower AA content than that of March, probably due to the lower solar radiation occurring in

February. The total vitamin C levels were very high (1494 mg kg^{-1} f.w. and 1559 mg kg^{-1} f.w., respectively), most probably because the favorable environmental growing conditions (Southern Italy).

High light intensity reduces the amounts of oxalate and nitrate in leaves (Proietti et al., 2004; Conte et al., 2008). Lowest levels of nitrate are accumulated in plants when higher radiation is available during plant growth, because of the high light-dependant activity of the nitrate reductase enzyme in reducing nitrate once taken up by the plants. Light and temperature affect anthocyanin synthesis in several species which, in many instances, is favored by UV wavelengths and low temperatures (Kleinhenz et al., 2003, and citations therein). Sunlight is the most important external factor that regulates anthocyanin synthesis in apple skin (Takos et al., 2006).

Environmental conditions and seasonal variation influence vegetable and fruit resistance to biotic and abiotic factors. Adverse conditions that negatively stress a plant make vegetables and fruits unsuitable for processing. Conte et al. (2008) studied the effect of the seasonality on the microbiological quality at harvest of baby leaf spinach grown in open field in a sandy clay soil in three different periods from October to January. The authors found that the growing period did not affect the total mesophilic bacterial contamination, which was equal to 10^5 cfu g^{-1} for all the investigated samples. Nicola et al. (2014b) studied the effect of the seasonality on the microbial contamination at harvest (total plate count, TPC; yeast and mould count, YMC) of green lettuce ('Green Lollo') grown in greenhouse with a continuous flotation system (FL) in three different periods (summer, fall and winter). Even in this case the seasonality did not affect the microbial quality at harvest in terms of total plate count (TPC) and of yeast and mould count (YMC), leading to an average contamination of 1.7 10^3 cfu g^{-1} and 4.7 10^1 cfu g^{-1}, respectively. At the end of 9 days of shelf life of the fresh-cut species results confirmed no effect due to seasonality (data not published). Rastogi et al. (2012) evaluated the effect of growing season (summer vs. winter), field location (northern region – California, summer season, vs. southern region – Arizona and South California, winter season), and environmental conditions on the variability of the bacterial community composition in open-field grown lettuce. The total bacterial population averaged between 10^5 and 10^6 per gram of tissue, whereas counts of culturable bacteria were, on average, one (summer season) or two (winter season) orders of magnitude lower. The bacterial core phyllosphere microbiota on lettuce was represented by *Pseudomonas*, *Bacillus*, *Massilia*, *Arthrobacter* and *Pantoea* genus. Summer-grown lettuce showed an over-representation of *Enterobacteraceae* sequences and culturable coliforms compared to the winter-grown lettuce.

In winter samples coliforms were much lower than in summer samples, following the seasonality of *E. coli* O157:H7. The specific mechanisms that allowed a clear separation between summer and winter in terms of the bacterial community composition that characterized the lettuce that was grown in the two regions was however not clear. Seasonal differences such as RH, temperature or irrigation practices can have a different degree or a different mechanism of action on the observed variation in bacterial community composition. Northern or southern production regions could have had, for instance, an influence *per se* rather than the summer or winter season on the observed variation.

After harvesting, quality deterioration can be accelerated in produce damaged by pests, fungi, bacteria and viruses, which alter the plant metabolism and increase the risk of a second microbial contamination. Cultivation for fresh-cut processing should take place in areas far from chemical, atmospheric or animal husbandry pollutant sources, which jeopardize the safety of the raw material.

Water influences the raw material microbial quality throughout the entire processing cycle. Water used for production and harvest operations can contaminate vegetables if the edible portions have been in direct contact with water containing pathogens harmful to humans or through water-to-soil and soil-to-product contact (Solomon et al., 2003). It is important to assure an appropriate chemical and microbial quality of the irrigation water and the water used in harvest operations. The chemical quality of water can influence plant growth. An example is salinity, which increases the susceptibility of plants to many diseases such as *Fusarium* spp. and *Verticillium* spp. wilts (Besri, 1997). The water should be periodically controlled through microbial and chemical analyses, including tests on the levels of fecal coliforms (i.e. *E. coli*) and heavy metals, whose absence is a safety indicator. However, growers may encounter difficulties in controlling water quality because it originates from source that could become polluted. Irrigation water comes from surface and underground sources that can be contaminated by drift, run off or leaching of water from polluted areas (Lunati, 2001; Steele and Odumeru, 2004).

Irrigation methods (e.g., drip irrigation, overhead sprinkler, furrow, sub-irrigation systems) can be chosen according to their potential to introduce or promote the growth of pathogens on produce. Water quality, irrigation and postharvest disinfecting treatments appear to be of paramount importance in reducing the risk of *E. coli* contamination in lettuce (University of Arizona-Cooperative Extension, 2004a). Fonseca (2006) evaluated the postharvest quality and microbial population of iceberg lettuce affected by moisture at harvest. Iceberg lettuce irrigated 4 days before harvest had microbial counts over 0.4 log cfu

g^{-1} higher than on lettuce irrigated 16 days before harvest. In addition, the microbial population of lettuce irrigated 4 days before harvest with overhead sprinklers was much higher than lettuce irrigated using the furrow system. Fonseca et al. (2011) assessed the contamination risk of *E. coli* in commercial lettuce grown under three different irrigation systems (overhead sprinkler, subsurface drip, surface furrow), investigated the survival of the pathogen once the bacterium reaches the soil and determined its potential relationship with irrigation management. Fonseca and co-authors confirmed that the risk of *E. coli* contamination on leafy vegetables increases when sprinkle irrigation is used and water is contaminated. Furthermore, *E. coli* survival in furrow-irrigated soil marks the importance of an early irrigation stopping for both sprinkler and furrow methods. After a 3-year survey, the researchers concluded that the highest risk of finding the pathogen in irrigation water is in warmer periods, but its survival in soil is lower in the same period.

Water influences not only the microbial quality, but also the shelf life of vegetables. Some studies suggest that in some cases ‘controlled’ water stress during plant growth can produce beneficial effects during postharvest storage (University of Arizona-Cooperative Extension, 2004b). Moisture stress imposed on broccoli (*Brassica oleracea* L. var. *italica*) during maturity increased their shelf life from 2-3 days to as many as 13 days at 15°C. Similarly, water stress can improve the postharvest quality of carrots (*Daucus carota* L.), melons (*Cucumis melo* L.) and celery (*Apium graveolens* L.), but the positive effect of stress depends on when the plants are subjected to it.

Because water influences cell expansion and leaf water status, it might be expected that irrigation affects postharvest quality of leafy vegetables. Luna et al. (2013a) studied the influence of both deficit and excess irrigation on respiration rate, tissue browning and microbial quality of fresh-cut romaine lettuce, the second most important type of lettuce after iceberg. The authors tested six different irrigation regimes set according to a standard irrigation regime (SIR): -35% SIR (<221 mm), -15% SIR (221-265 mm), SIR (266-320 mm), +15% SIR (321-370 mm), +35% SIR (>430 mm), +75% SIR (>430 mm). Irrigation regime influenced significantly not only the raw material at harvest, but also the post-cutting quality and the shelf-life of fresh-cut romaine lettuce. The excess of irrigation increased polyphenol oxidase (PPO) activity, accelerated the cut edge browning and the microbiological growth, while the deficit of irrigation reduced the cut edge browning despite the accumulation of phenolic compounds. Luna and co-authors (2013a) concluded that phenolic compounds in romaine lettuce is not a browning limiting factor, as it was reported in iceberg lettuce in another paper (Luna et al., 2012). The highest respiration rate was observed when lettuce was cultivated under the most severe deficit (−35% SIR) or excess of irrigation (+35% SIR). As expected, the highest deficit of irrigation decreased yield in terms of fresh weight, but also with the most extreme excess of water, as it was indicated by Fonseca (2006). A similar study conducted by the same authors growing iceberg lettuce gave similar results (Luna et al., 2012). Iceberg lettuce had greater head weight with medium irrigation regime than those cultivated under deficit or excess regime. Browning at the cut edge was increased with storage time particularly when the irrigation regime was increased during plant growth. Increasing the irrigation regime had negative effect on lettuce quality as high enzymatic activities were positively correlated with browning, while irrigation deficit preserved quality and shelf life of fresh-cut iceberg lettuce.

The soil type and management affects not only the nutritional quality, but also the safety of the raw material. Frequent soil chemical analyses are essential for an efficient management of the soil-water-plant system to avoid crop production losses and decrease the environmental impact. The soil texture influences the mobility and efficiency of nitrogen and mineral uptake, which in turn has an impact on the quality of the final product. Cantaloupe grown in clay soil produced better-tasting fruit, in terms of sweetness and flavor, with superior fresh-cut quality, in terms of less sour taste and off-flavor, than melons grown in sandy soil (Bett-Garber et al., 2005). Mylavarapu and Zinati (2009) found that the incorporation of compost improved the physical and chemical properties of sandy soils where parsley (*Petroselinum crispum* Mill.) was cultivated as well as increased parsley yields. The compost application resulted beneficial for water and nutrient properties of sandy textured soils.

The soil type and management is fundamental also for the prevention of preharvest contamination of fresh produce from pathogens, heavy metals, and pollutants. In order to develop strategies that minimize the risk of pathogen survival and spread within agricultural system and food chain, it is important to understand the fate of pathogens, such as *E. coli*, in environmental substrates like manure-amended soils and how manure-amended soils affect their survival. Franz et al. (2008) studied the effects of manure-amended soil characteristics on the survival of *E. coli* O157:H7 in 36 Dutch soils. Comparing sandy soils to loamy soils the authors observed that the initial rate of decline of *E.coli* O157:H7 is faster in sandy soils, but that decline rate slows down more with progressing time than in loamy soils. The pathogen survival increased in soils with a history of low-quality manure application (artificial fertilizers and slurry) compared to those with high-quality manure application (farmyard manure and compost). The authors concluded that *E. coli* O157:H7 population declines faster in soil with high carbon:nitrogen ratio and consequently a relatively low rate of nutrient release.

The pathogen contamination risk is high when growing vegetables, especially for leafy vegetables like spinach, lettuce, rocket, which are in direct contact with the soil and are consumed raw. In general, the presence of pathogens in soil amendments can be solved using stabilizing organic residues instead of fresh organic wastes, ensuring proper composting. The use of animal slurry is rare in intensive vegetable production in Mediterranean regions, mainly due to food safety issues (Nicola et al., 2013). In fact, several food-borne disease outbreaks in the recent decade have discouraged many vegetable growers from manure and slurry use, most probably as a preventive action because the safety of the available slurry and manure can be limited. The survival of food-borne pathogens is a potential threat to humans, far more important than any other quality aspect. Jensen et al. (2013) reported the transfer of *E. coli* from animal slurry fertilizer to lettuce. This occurred in a pilot study for which animal slurry was applied as fertilizer in three Danish agricultural fields, prior to the planting of lettuce seedlings and with *E. coli* serving as an indicator of fecal contamination and as an indicator for potential bacterial enteric pathogens. The study revealed a frequent contamination (44.9%) and levels above 2 log cfu g^{-1} in 42.4% of the contaminated samples of lettuce grown under natural conditions in slurry-amended soils. This fecal contamination indicates a potential presence of pathogens such as *Salmonella* and *Campylobacter*, which could represent a real hazard to human health. In addition, streptomycin- and ampicillin-resistant *E. coli* were found in 15.0 and 1.4% of the lettuce pools, respectively, which indicates a risk of transferring antimicrobial-resistant genes. Because a relatively high number of *E. coli* in lettuce was found at harvest as compared with the numbers found in the soil, it was suggested that the animal slurry fertilization was not the sole source of fecal contamination, but that the surrounding environment and wildlife played a role in the contamination with *E. coli*.

Evidently, all the environmental conditions surrounding plant growth have to be taken into account to set the most appropriate conditions to obtain optimal raw material at harvest. As fresh-cut produce is prepared from a raw material that is in contact with soil, microbial contamination can occur. GAPs and GHPs suggest that land used for grazing livestock is not suitable for growing vegetables and it is recommended that manure and compost are avoided as fertilizers because they can be sources of microbial and heavy metal contamination.

Inherent fruit quality parameters, such as sugar and acid content, ripening and storability, and external fruit quality parameters, such as color, shape, stage of growth and firmness, are closely correlated to the main nutrients: nitrogen, phosphorus, potassium, calcium, and magnesium. The nutrients can be supplied to the plant through distribution on the soil surface or by fertigation. Fertigation increases the efficient use of fertilizers and nutrient availability at root level, and fertigation in particular increases the mobility of potassium and phosphorus.

In fruits, nitrogen (N) is negatively correlated with the firmness, dry matter percentage, refractometric index, soluble sugar content and acidity. An excess of N availability causes poor fruit skin color development and increases plant susceptibility to pests and physiological disorders. In vegetables, particularly leafy vegetables, N supplied as nitrate is negatively correlated to the dry matter percentage and directly correlated to the nitrate content in the edible portion (Fontana et al., 2004; Nicola et al., 2005b). In leafy vegetables, N fertilization can be scheduled to reduce the nitrate accumulation in plant parts in order to reach acceptable threshold levels, which are generally below 2500 mg kg^{-1} f.w. In the EU, specific limitations are set for the nitrate content in the final product for lettuce (*Lactuca sativa* L.), spinach (*Spinaca oleracea* L.) and rocket (*Eruca sativa, Diplotaxis* sp., *Brassica tenuifolia, Sisymbrium tenuifolium*) (EU Reg. 1258/2011, amending EU Reg. 1881/2006 that amended EU-Reg. N. 563/2002).

Nitrate accumulation in plant parts depends on species, cultivar, season and cropping system and affect product marketability and postharvest shelf-life (Fontana et al., 2004; Nicola et al., 2005b). Koh et al. (2012) compared the levels of nitrate, oxalate, ascorbic acid, vitamin C and flavonoids in 27 varieties of spinach grown in certified organic and conventional cropping systems. The nitrate content varied in organic (316.3-1170.4 mg kg^{-1} f.w.) and conventionally grown spinach (961.3-2453.5 mg kg^{-1} f.w.) depending on the cultivar. The content of nitrate was significantly higher in the conventionally grown spinach compared to the organically grown spinach and was correlated positively with oxalate and negatively with ascorbic acid, vitamin C, and flavonoids. The cropping systems did not influence the oxalate content in spinach leaves, while it did the ascorbic acid, vitamin C and total flavonoids. For all these parameters spinach grown organically had higher contents than those grown conventionally. Of the 17 flavonoids determined, the levels of 10 were higher in the organic spinach compared to conventional spinach.

Among the plant mineral nutrients, potassium (K) is the cation having the strongest effect on fruit quality attributes that determine fruit marketability, consumer preference and the concentration of phytonutrients (Lester et al., 2010, and citations therein). K effects on fruit marketability attributes include maturity, yield, firmness, soluble solids and sugars; on consumer preference they include sugar content, sweetness and texture; on phytochemical concentrations they include ascorbic acid and carotenoid concentrations. All these aspects depend on K application modes (wet, through foliar or hydroponic application, or dry, in soil), doses (applications number) and timing (plant stage, cultural season). Supplementing sufficient soil K with additional foliar K applications during cantaloupe development and maturation improves the fruit marketable quality by increasing firmness and the sugar content, and fruit nutritional quality by increasing ascorbic acid, beta-carotene, and the K levels (Lester et al., 2007).

The preharvest nutritional status of fruit, especially with respect to calcium (Ca), is an important factor that affects the potential storage life (Gąstoł and Domagała-Świątkiewicz, 2006). Fruits with a high level of Ca have lower respiration rate and longer potential storage life than fruits containing low levels of Ca. Ca plays a key role in the retention of firmness, delaying fruit ripening and reducing physiological disorders. Many physiological disorders in fruits are associated with a Ca deficiency. The easiest way to maximize the Ca level in fruit is to use a foliar spray, although in many instances the uptake and penetration of Ca into the fruit and its movement within the fruit tissues is difficult to achieve (Mengel, 2002). Preharvest Ca sprays on apples increase fruit Ca, and frequently improve flesh firmness at harvest, especially during stressful seasons in which fruit Ca content is suspected to be relatively low, reduce the incidence of bitter pit and lenticel blotch after cold storage (Casero et al., 2009). The total fruit Ca increases in all seasons with Ca treatments, but this increase is not proportional with the number of applications.

Leafy vegetables used for the fresh-cut industry are, in general, from open field production. Conversely, in Italy, most of them are from protected cultivations, leading to increased yields and crop cycles, allowing out-of-season production, control the abiotic factors and facilitate pest management. In 2011, it was estimated that 6,500 ha were cultivated under leafy vegetables and greens, most of them in greenhouse (Casati and Baldi, 2011). The produce originates from different geographic areas, according to the season. Each geographic area is characterized by different environmental conditions, cultivar availability and cultural practices. These factors can influence not only the quality of the raw material at harvest, but, also, the efficiency of postharvest technologies, such as the choice of operational temperatures and packaging systems. Fruit and vegetables are produced both in open field (Figure 1) and in protected cultivations, either in macro-tunnel or in greenhouse (Figure 2a,b); some baby-leaf species (e.g., rocket, corn salad, baby lettuce, spinach) or aromatic plants are produced in soil-less culture such as floating systems (FS) (Figure 3). Compared to the open field system, the protected culture system offers many advantages, for example, protection from damaging winds and other adverse weather conditions such as rain and hail, a reduction in evapotranspiration rate, an increase in photosynthesis rate, and an advance in the harvest date. The covering material of the greenhouses enhances the internal air temperature, and leads to reduced air and soil temperature excursions. All these aspects affect plant health, and improve raw material quality, yield and safety.

Voća et al. (2006) compared strawberry crops grown in open field cultivation, soil protected cultivation and soil-less protected cultivation systems, and found that the cultivation system had a great influence on the color and firmness of the strawberry fruit cv. Elsanta. Overall better fruit coloring was obtained in the protected cultivation systems, although the soil-less system gave the lowest fruit firmness. The overall chemical composition of the fruit indicated that the highest quality was reached with the soil protected cultivation.

Vegetables usually contain relatively high numbers of microorganisms at harvest because they are in contact with soil during growth (Tournas, 2005). Not all microorganisms are capable to proliferate on vegetables. Several microbial species can break the protective cover of plants and, then, grow and cause spoilage; others can enter the plant tissue through wounds and can grow and damage the vegetable. Some fungal spores can survive for some time in the soil and contaminate plants one season after another; these organisms may cause plant disease in the field, as well as spoilage during storage. In these circumstances, field treatments with fungicides and the use of resistant cultivars are necessary to avoid disease development and spoilage. The avoidance of disease development and spoilage are main factors that favor the development of the soil-less culture system.

Protected cultivation is increasingly shifting from traditional culture systems (TCS) in soil to soil-less culture systems (SCS) (Nicola and Fontana, 2007), as SCS, based on the growing media, have some advantages over TCS. Most of the studies comparing TCS to SCS have indicated that SCS increase earliness, yield or both (Incrocci et al., 2001; Santamaria and Valenzano, 2001; Ferrante et al., 2003; Fontana et al., 2004; Nicola et al., 2005a,b; Fontana and Nicola, 2009).The protected SCS allows for higher qualitative and quantitative standards standardization of cultural techniques, and the reduction of both production costs and environmental impact. The system is a valid alternative to the soil cultivation system as it helps to avoid soil-borne diseases, and controls mineral plant nutrition to standardize the qualitative characteristics of the final product. The use of mineral and sterile media with a low environmental impact may be an alternative to the practice of soil disinfection. When investigating a soil-less system, to obtain uniform produce of high quality, it is crucial to adjust the nutrient solution, moisture and water content of the growing medium because they are the most important aspects, apart from growing environmental conditions.

The soil-less protected cultivation system is highly productive and has proved to enhance the postharvest shelf life of many fresh-cut vegetables (Fontana et al., 2003, 2004, 2006; Fontana and Nicola, 2008; Fontana and Nicola, 2009; Hoeberechts et al., 2004; Nicola et al., 2003, 2004, 2005a, 2005b; Sportelli, 2003). By comparing soil and soil-less culture systems for lettuce production in open field, Selma et al. (2012) showed that fresh-cut lettuce from SCS had significantly higher antioxidant content and better microbial quality than fresh-cut lettuce from soil. The same research group (Luna et al., 2013b) studied the influence of different nutrient solution ion concentrations (low: 1.40 dS m^{-1}; medium: 1.90 dS m^{-1}; high: 2.40 dS m^{-1}) on the quality characteristics of three lettuce genotypes, including one green (butterhead cv. Daguan) and two red-leafed lettuces (lollo rosso cv. Evasion and red oak leaf cv. Jamai), cultivated in a soil-less system in open field in summer and winter. Postharvest shelf-life of the fresh-cut product was also evaluated. The study indicated that quality differences at harvest and post-cutting changes depend more on the seasonal variation and genotypes than on the nutrient solution ion concentration. In summer, maturity index was higher and dry matter lower than in winter. Red-leafed lettuces showed the highest antioxidant content, helping the maintenance of sensory characteristics throughout storage; they are preferred to butterhead because they are more resistant to mechanical stress and have more extended shelf-life, thus red-leafed genotypes could be more adequate for growing under medium nutrient solution ion concentration.

Among the different soil-less cultivation systems, the floating system (FS) is a recent growing system that has led scientists and extension specialists to consider it as a way of producing leafy vegetables with characteristics that satisfy the requirements of the entire production chain. The system is suitable for raising vegetables with both short production cycle and high plant density; it can be considered an efficient system to produce leafy vegetables with high added value, processed as fresh-cut produce.

The FS is a sub-irrigation system that consists of trays that float on a water bed or nutrient solution (Nicola, 1993; Pimpini and Enzo, 1997; Thomas, 1993) (Figure 3a,b). FS can be implemented either with a continuous flotation (FL) or with an ebb-and-flow flotation (EF) scheduling. EF is scheduled with drying (ebb) periods. A sub-irrigation system increases the precision of fertilizer application to plants by reducing water leaching during irrigation. The FS allows the produce quality at harvest to be improved, reduces microbial contamination and eliminates soil and chemical residue spoilage. Normally, produce obtained from TCS can reach a total bacterial count of 10^6 to 10^9 cfu g^{-1}, which can be reduced by 2-3 log cfu g^{-1} after washing and sanitation practices. On purslane (*Portulaca oleracea* L.) grown in FL, the initial mesophilic load and *Enterobacteria* counts load was 2.7-3.0 log cfu g^{-1} and 2.1-2.2 log cfu g^{-1}, respectively, on processing day (Rodriguez-Hidalgo et al., 2010).

FL used to grow green lettuce, red lettuce and spinach, and EF used to grow rocket resulted at harvest in an average TPC of 10^3 cfu g^{-1} and YMC of 10^2; only spinach had a higher contamination of TPC (10^6 cfu g^{-1}) (Nicola et al., 2014b). In general, fresh-cut green lettuce at the end of 9 days of shelf-life at 4°C remained with the same magnitude of contamination, while fresh-cut mix of green lettuce and either red lettuce, rocket or spinach increased of two logs. The raw material obtained using FS in confined greenhouse is free of soil residue and dirt, and considering the overall very low microbial contamination, it was hypothesized, that washing is considered a critical point in the production process of the ready-to-eat vegetables. The use of floating systems allows to use softer washing procedures, such as eliminating chlorine from the water sanitation process, with less stress for the leaf tissue.

Selma et al. (2012) assessed the microbiological quality of fresh-cut lettuce obtained by soil- and soil-less grown lettuce. Cultivation was in open field and the SCS used was the NGS™ (New Growing System, NGS™ Almería, Spain, patent no. 2.221.636/7). The soil-less culture system was more effective in controlling microbial contamination because soil-less grown lettuce had a lower initial microbial load and slower microbial growth during storage. At the end of intended shelf life period, the differences in microbial counts were 3 and 1.5 log units higher for lactic acid bacteria and total coliforms then in samples from soil grown lettuce. A higher sanitary quality can be provided by the soil-less culture system as an alternative to traditional soil cultivation, because it avoids soil contaminants and achieves lower coliform counts.

D. Raw material harvest and handling

Good preharvest and harvest practices are necessary to reduce commodity damage. It has been extensively reported that the quality of a raw material and the storage conditions before processing are very important to keep the quality of a vegetable (Wiley, 1994). The harvest, handling, shipping and storage (HHSS) before processing are stages where low temperature conditions are vital to preserve the quality of the raw material. The cold chain should, in fact, begin as early as possible and be maintained from the field to the processing plant. Low temperatures, in a range from 0 to 10°C, depending on the species and cultivar, keep the turgor in vegetables unaltered and slow microbial contamination. However, production operations are not yet broadly organized or optimized to handle the harvest phase with a minimization lag time before implementing the cold chain.

Currently, fresh-cut vegetable shelf life is ca 6-7 days in Italy and in many EU countries. The shelf life of fresh-cut produce in the United States exceeds two weeks, depending on the species. The long shelf life is achieved, apart from the limited range of species and typologies produced, due to prompt cooling and the maintenance of the cold chain (see also Chapter 17), with temperatures generally below 4°C, after harvest during processing, shipping and distribution, while these temperatures are rarely maintained in many European countries.

The stage of maturity of fruit and vegetables destined for fresh-cut processing is a critical factor that helps to determine the potential quality and shelf life of the product. The eating quality and shelf life of fresh-cut fruit products are influenced by the stage of ripeness at cutting (Gorny et al., 2000). Leafy vegetables are best tasting when harvested immature, while fruit vegetables and fruits are best tasting when harvested fully ripe (Kader, 2008). Maturity and ripeness stage at harvest are critical issues for fruits. Harvesting fruits before they reach optimal maturity is a common commercial practice because of the higher prices obtained when the supply is low at the beginning of the harvest season. Early harvesting of climateric fruits assures fruits are more resistant to mechanical stresses and store longer. Conversely, harvesting at optimal maturity based on flavor would be more appropriate to allow increase the synthesis of non-volatile and volatile compounds influencing fruit flavor or good eating quality cannot be achieved (Kader, 2008). Currently, customer dissatisfaction with produce flavor contributes to the low consumption of fruits and vegetables (Mitcham, 2010). It is necessary to encourage the growers to harvest fruits at partially ripe to fully ripe stage by developing handling techniques to protect fruit from physical damage (Kader, 2008).

Currently, the shelf life of fresh-cut fruits is ca 5 days because it is quite difficult for fresh-cut industry to maintain a proper ripening stage on a commercial scale. Fruit is generally harvested at ‘partially ripe’ stage, which is an imprecise definition (Bai et al., 2009) and varies within the same species according to the species and cultivar. The maturity stage of fruit for fresh-cut industry is much debated: harvesting ‘partially ripe’ fruit means an easier management of fresh-cut processing and quality control during distribution compared to harvesting ‘riper’ fruit, which is more flavorful and softer, but more difficult to handle for growers, processors, and retailers. For these reasons, fresh-cut apple offer has rapidly increased in recent years because apples are easier to manage compared to other fruit, such as peach, pear, or tropical fruit. Bai et al. (2009) suggested to harvest pear fruit one month later than the commercial practice for improving the quality of flat flavor, firm and rough texture, and to limit the high potential for browning. Results from experiments showed that by delaying harvesting, the fruit had larger size, lower flesh firmness, lower titratable acidity, lower phenolic content and higher volatiles. These parameters enhance the consumer acceptance and, in fact, a panel preferred the delayed-harvest cut fruit compared to those from commercial harvest, especially in terms of visual quality, flavor, texture and overall quality.

In the case of leafy vegetables, there is a wide range of possibilities for harvesting raw material depending on the final destination of the produce, the requested quality attributes and their resistance to the postharvest handling and processing. The maturity indicators of intact leafy vegetables are size, head length, head width, firmness and compactness; while for non-heading lettuces, the number of leaves can be used as a harvest index (Gil et al., 2012, and citations therein). Size is the maturity indicator for Belgian endive, cabbage, endive, iceberg lettuce, radicchio, spinach and Swiss chard. Furthermore, the head compactness is an important maturity indicator for cabbage and iceberg lettuce. In general, different maturity indicators can be used for harvesting lettuce for the fresh-cut industry. Head weight is the main parameter for quality evaluation of head vegetables, while for baby and mature leaves, leaf and petiole length are good maturity parameters to assure the quality of the fresh-cut product. For culinary herbs the harvest maturity can have relevance on the aromatic profile. Early harvesting, fresh-cut processing and shelf life conditions can differently influence each compound improving or worsening the essential oil (EO) quality according to the final use by the industry (Fontana et al., 2010). The aromatic profile of dill (*Anethum graveolens* L.) changed when dill leaves were harvested as young leaves (38 days after sowing), at pre-blossoming and blossoming stage (50-70 days after sowing) or at full fruit maturity (130 days after sowing) (Tibaldi et al., 2010a).

The growth stage at harvest can influence the shelf life of the baby leaves harvested at an early growth stage due to market demand. The rate of deterioration has often been related to the metabolic processes and respiration rate, which are usually higher in younger leaves. The high respiration rate explains why it is hard to reach a commercial shelf life longer than seven days. Young and tender baby leaf vegetables of new varieties and species are continuously been developed for fresh-cut industry, but younger plants tend to accumulate more nitrate (Fontana and Nicola, 2008). It is then crucial to establish the harvest maturity indicators to describe the right time for harvesting raw material with high nutritional value and optimal postharvest performance.

Harvesting directly affects the appearance and shelf life of the final product. The safety and the quality of fresh-cut produce depend not only on the cultural practices and postharvest conditioning, but also on the harvesting and handling procedures. Factors that can affect the microbial condition in the raw material include the climatic conditions which the plants are produced in, and the temperature and the air conditions at which the produce is stored after harvest. Harvesting in the heat of the day causes wilting, shriveling, softness and a high respiration rate and shortens shelf life considerably (Perkins-Veazie, 1999). Zhan et al. (2009) found that leaving garden cress (*Lepidium sativum* L.) harvested leaves at 28°C for 1 h, simulating summer air temperatures, negatively influenced the pigments content, which decreased over time, and caused ca 13% loss in ascorbic acid before packaging. Polyphenol oxidase (PPO) and peroxidase (POD) activities were higher in garden cress leaves kept for 1 hr at 28°C than leaves promptly processed. The high air temperature affects the leaf turgidity and increases the susceptibility of leafy vegetables to the physical damage during harvest handling practices. An efficient and rapid harvest handling and storage implementation after the cultivation phase are fundamental factors that favor the quality of the raw material, thus improving the processing and reducing the quality deterioration during shelf-life.

Rough handling creates areas that darken, soften and make the product vulnerable to pathogen attacks. Microbes can also readily attach to cut leafy vegetable surfaces (Takeuchi and Frank, 2001) reducing the safety and nutritional quality (see also Chapter 12). At harvest, appropriate measures should be taken to reduce or eliminate the potential risk of pathogen contamination through soil contact at the cut surface. The reduction or elimination of pathogens can be achieved by cleaning the cutters and containers, by increasing the cutting quality, e.g., cutter sharpening, and by guaranteeing the hygiene of the field workers.

The harvesting method, whether by hand or mechanical, and the handling can determine the variation in maturity and physical injury and, consequently, can influence the nutritional composition of vegetables. The use of good preharvest, harvest and handling practices is necessary to reduce commodity damage. Harvesting early in the morning, before plants become warm and respiration rate increases, lowers the needed cooling and often lengthens the preprocessing storage. Placing the harvested produce quickly under shade, in opaque or dark boxes, or using white tarpaulins to reflect heat from the filled bins can cut the load temperature by 30% (Perkins-Veazie, 1999). The often disregarded stages of the supply chain, the harvesting and handling, should be optimized and the cool chain implemented as early as possible to maintain product quality (Thompson et al., 2001) in order to guarantee food safety and to reduce the amount of cooling needed afterwards (Figure 4, see also Chapter 17).

Fresh fruit and vegetables are living tissues, and subject to continual changes after harvest. Fresh produce consumes photosynthates that were stored in the product before the harvest. The consumption rate depends on the respiratory activity of a particular commodity and its temperature. Delays between harvesting and cooling or processing can result in direct losses due to water loss and microbial contamination and indirect losses, such as flavor and nutritional quality loss (Thompson et al., 2001; Zhan et al., 2009) (See also Chapter 5). The rate of product deterioration is proportional to the rate of respiration, which increases exponentially with the temperature (Cantwell, 2007). Shriveling and the loss of fresh and glossy appearance are two of the most noticeable effects of cooling delays, particularly for commodities that lose water quickly and show visible symptoms at low levels of water loss, like most leafy vegetables. A correlation has been found between the respiration rate and shelf life (Ninfali and Bacchiocca, 2004). Vegetables characterized by low respiratory rates, such as carrots, have a long shelf life. Preprocessing storage conditions are fundamental to preserve raw material quality; the optimal vegetable storage temperature should be observed to avoid chilling injuries, such as browning or pitting, and vegetable thermal shock due to the high temperature gap between the field and the storage room.

III. PROCESSING MANAGEMENT FOR THE FRESH-CUT CHAIN

Fresh-cut processing accelerates the color, texture, firmness, flavor and nutritional value deterioration of a product and compromises its shelf life. Moreover, wounded surfaces provide favorable conditions for microbial growth. Therefore, adequate control strategies during the storage of fresh-cut produce should minimize nutritional and sensorial loss and microbial growth. Proper handling, the use of effective sanitizers, adequate temperature storage, and packaging are the main ways of reducing rapid degradation of the fresh-cut produce.

A. The postharvest quality of fresh-cut produce

It was previously stated that cultivars, environmental conditions, irrigation practices, fertilizers, and pest control programs affect produce quality. Practices such as washing, sorting (see also Chapter 13), sizing, cutting, blending, and packaging do not change the inherent quality, but add value for the consumer, who is looking for convenience, yet healthy and tasty food (Figure 5a,b). Like any perishable product, fresh-cut fruit and vegetables are characterized by an irreversible deterioration of quality. Therefore, the sensory quality of these types of products cannot improve during further storage; it can only be retained or deterioration can be retarded by applying optimal processing and packaging techniques, a proper storage temperature, and eventually application of enzymatic browning inhibitors (Watada and Qi, 1999) and ethylene or oxygen absorbers (Markarian, 2004). Because consumer preferences differ between consumer segments, part of the postharvest activity is also related to direct the appropriate product to the responsive consumer segment.

Fresh products are susceptible to deterioration between harvest and consumption and this may reach very high values after harvest, depending on the species, harvesting and handling methods, processing, length and temperature of storage and distribution, market conditions, etc. A longer shelf life, therefore, depends on a combination of correct cooling storage throughout the entire chain, modified atmosphere packaging conditions and good manufacturing and handling practices (Kader, 2002a). The main objectives of postharvest technology concern quality and safety assurance, and loss reduction in the postharvest chain.

B. Cutting

Producing fresh-cut fruit and vegetables involves substantial mechanical injury due to peeling, slicing, dicing, shredding or chopping (Portela and Cantwell, 2001) (Figure 6,a,b,c,d). Thus, the physiology of minimally processed fruit and vegetables is essentially the physiology of wounded tissues, which are subjected to an increase in respiration rate and ethylene production, membrane degradation leading to cellular disruption and de-compartmentalization of enzymes and substrates, and accumulation of secondary metabolites. All these biochemical reactions are responsible for changes in quality characteristics, such as texture, color, flavor, and nutritional value (Portela and Cantwell, 2001, and citations therein). Many factors affect the intensity of the wound's response in fresh-cut tissues. These factors include species and cultivar, stage of physiological maturity, temperature, O_2 and CO_2 concentrations, water vapor pressure, various inhibitors, and severity of wounding (Cantwell, 1992; Brecht, 1995).

The severity of wounding depends on the type of cutting, cutting area size and cutting shape. The response of the tissue to processing wounds usually increases as the severity of the injury increases. Peeling and cutting increase the respiration rate from one-fold to seven-fold, compared with the same fresh whole produce (Rivera-Lopez et al., 2005). Del Aguila et al. (2006) measured the differences of respiration rate, ethylene production, and soluble solids between whole and shredded radish (*Raphanus sativus* L. cv. Crimson Gigante) and between shredded and sliced radish. During cold storage, the respiration rate of whole radish remained stable, while oscillations in fresh-cut radish were observed, with a generally higher respiration in shredded radish. Nine hours after processing, ethylene production was higher in the shredded and sliced radish than in the whole radish, and the shredded radish lost more soluble solids than the sliced or whole radish. The decrease in soluble solids was partially attributed to the consumption of carbohydrates during respiration related to the repair of injury, and the higher injured area of shredded radish may have caused an amplification of the response to injury.

Tibaldi et al. (2010b) comparing two cutting shapes (slice vs. dice) on fresh-cut processing operations of pumpkin (*Cucurbita moschata* Duchesne), packaging the fresh-cut products in 3 films with different permeance to O_2 and storing the packaged bags either at 4° or 8°C, found that fresh-cut pumpkin can be stored for 9 days at 4°C if it is sliced and packaged with a film permeance above 1300 $cm^3\ m^{-2}\ d^{-1}\ bar^{-1}$ because of its lower respiration rate compared to dice-shaped pumpkin. Nicola et al. (2014a) repeated the same experiment on *Cucurbita maxima* Duchesne and confirmed the previous results. The larger cutting area of pumpkin dices than that of pumpkin slices accelerated the quality decay promoting anaerobic process at the end of the shelf-life. Deza-Durand et al. (2011) investigated the effect of cutting direction on aroma compounds and respiration rates in fresh-cut iceberg lettuce. During fresh-cut processing operations, lettuce was cut either longitudinally or transversally to the mid-rib and then stored either at 6°C or 10°C for 4 days after having placed the fresh-cut lettuce in jars sealed with punctured films. The results showed that cutting the lettuce transversally to the mid-rib caused more severe damage to the tissue than cutting longitudinally, based on the increase in the levels of volatiles produced through the lipoxygenase (LOX) pathway responsible of off-odors development. Deza-Durand et al. (2011) hypothesized that, because LOX is a stress-related enzyme, the higher damage in lettuce cut in the transverse direction might indicate a greater disruption of membranes. Higher respiration rate of lettuce was observed for transverse cutting at the beginning of the storage period in comparison with longitudinal cutting, but decreased sharply after 1 day of storage. The respiration rate was not as good an indicator of stress as cutting direction because it was mainly affected by storage temperature.

Cutting and shredding should be performed with the sharpest possible knives or blades made from stainless steel (Allende et al., 2006). Saltveit (1997) considered that very sharp cutting tools could limit the number of injured cells. Barry-Ryan and O'Beirne (1998) observed that carrot slices prepared using a sharp blade had a reduced microbial load and off-odor development, and were characterized by a higher microscopic cellular integrity and a longer shelf life than slices prepared using a blunt blade. Portela and Cantwell (2001) evaluated the consequences of blade sharpness and thereby, the degree of wounding on the appearance and physiology of fresh-cut cantaloupe. Pieces prepared using a sharp borer maintained marketable visual quality for at least six days, while those prepared using a blunt borer were unacceptable at six days, due to surface translucency and color changes. Borer sharpness did not affect the changes in decay, firmness, sugar content, or aroma, while blunt-cut pieces had increased ethanol concentrations, off-odor, and electrolyte leakage compared to sharp-cut pieces.

Cutting technique quality can influence microbial growth and the bacterial cross-contamination. Gleeson and O'Beirne (2005) evaluated the effects of different slicing methods on the subsequent growth and survival of *E. coli*, *L. innocua*, and background microflora during storage at 8°C on modified atmosphere packaged vegetables (sliced carrot, and sliced iceberg and butterhead lettuce). In general, the slicing method had no significant effect on the initial inoculation levels. *L. innocua* grew better and *E. coli* survived better on vegetables sliced with blades that caused the most damage to cut surfaces. Slicing manually with a blunt knife or with machine blades gave consistently higher *E. coli* and *L. innocua* counts during storage than slicing manually with a razor blade. The effects of hand tearing were similar to slicing with a razor blade. The slicing method also affected the growth of the total background microflora; razor sliced vegetables tended to have lower counts than other treatments. Product respiration was also affected by the slicing method; the use of a razor blade resulted in lower respiration rates.

Different new solutions have been tested to prevent the acceleration of decay due to peeling, cutting or slicing, e.g. the "immersion therapy", which consists of cutting a fruit while it is submerged in water. The cutting of a submerged fruit controls turgor pressure, due to the formation of a water barrier that prevents movement of fruit fluids, while the product is being cut (Allende et al., 2006). Additionally, the watery environment helps to flush potentially damaging enzymes away from plant tissues. Another technique is the cutting operation performed under ultraviolet-C (UV-C) radiation. Lamikanra et al. (2005) observed that post-cut application of UV improved shelf life of cut cantaloupe, while cutting fruit under UV-C radiation further improved product quality. More specifically, the study found that UV-C radiation during processing reduced rancidity and improved firmness retention in the stored fruit. The UV-C radiation also reduced spoilage microorganisms such as mesophilic and lactic acid bacteria.

Finally, the "water-jet cutting" method which is successfully used for, e.g., meat, poultry, and vegetables (McGlynn et al., 2003), can also be used in the fresh-cut industry. This is a "non-contact" cutting method (Allende et al., 2006) which slices fresh fruit and vegetables utilizing a high pressure fluid jet that minimizes bruising in the cut pieces and tissue damage in the vicinity of the cut surface (http://www.freepatentsonline.com/4751094.html). This method reduces the excessive tissue damage caused by compression and tearing the piece along the cut surfaces. It has been found that in fruit and vegetables sliced with a high pressure fluid jet, the cell tissue damage is minimized, so that when the fruit or vegetable is subsequently eaten, it provides essentially the same sensory qualities, odor, texture, and taste as the freshly harvested fruit or vegetable. This type of slicing, together with proper storage conditions, allows produce shelf life to be prolonged in comparison to other conventional cutting methods, such as regular kitchen paring knives, commercial rotary blade cutters, razor sharp, or thin blade knives. The vegetables particularly adapted to being cut by this method are fresh root vegetables, leafy vegetables and fruit and vegetables with firm tissue. The efficiency of this cutting method depends on the orifice size, water pressure, and standoff distance, which must be tuned according to the inherent characteristics of the species and cultivar (Bansal and Walker, 1999). McGlynn et al. (2003) assessed the effect of water-jet cutting on the shelf life of cut watermelon (*Citrullus lanatus* cv. Sangria). A comparison of pieces cut with a water jet with those cut with a knife showed that the former were firmer than the latter after seven and ten days of storage, and this difference was presumed to be due to weight loss. The experiment showed that water-jet-cut watermelon pieces tended to lose less moisture during storage than knife-cut pieces. The decrease in weight loss due to the loss of liquid during storage could have a significant impact on the consumer perception of freshness and texture and could influence microbial control strategies.

C. Washing, sanitation systems and processing aids

During processing, pre- and post-cutting washing operations of produce are crucial to make the product ready-to-eat. The produce has to be clean, free of soil residue, insects, metals and weeds, and safe. The raw material should be carefully cleaned before processing because fresh-cut produce is prepared from material grown mostly in contact with soil and without any strong antimicrobial treatments, such as pasteurization or sterilization. Even healthy looking products from the field can harbor large populations of pathogens, particularly during warm weather.

Washing raw material before cutting (fruit and vegetables) and during fresh-cut processing (leafy vegetables) is the most effective way of minimizing the risk of the presence of pathogens and of any residue left on the produce from harvest and handling conditions (Figure 7a,b,c). When fruit and vegetables are exposed to water containing pathogens, they often become infected and subsequently decay during shipping and handling. Pathogens present on freshly-harvested products accumulate in recirculated water handling systems and greatly reduce sanitation efficiency. Fresh-cut produce is highly susceptible to microbial contamination, because microbial cross-contamination can occur through shredders and slicers and the inner tissues can be exposed to microbial attachment and growth after cutting. Many postharvest decay problems result from the ineffective sanitizing of dump tanks, flumes and hydro-coolers. Moreover, the operations should be conducted at a low temperature to reduce microbial growth. A delay between pre-washing and subsequent operations without product refrigeration can allow microbial growth and a subsequent shortening of the shelf life, as reported by Sinigaglia et al. (1999) concerning cut lettuce salad and shredded carrots.

The effectiveness of washing to remove soil impurities and microbial contaminations is related to numerous factors, such as raw material spoilage, the duration of the washing treatment, the washing water temperature, the method of washing (dipping, rinsing, or dipping/blowing), the type and concentration of the sanitizer, the type of the sanitation method (chemical or physical treatment) and the type of fresh-cut fruit or vegetable. At the moment, the disinfection agents used and tested for water and produce sanitation are chlorine, ozone, organic acids, hydrogen peroxide, alcohols, phosphoric acids, while the physical methods used and tested are ultraviolet (UV) light radiation, ultrasound, high pressure (HP), high-intensity electric field pulses (HEP), radio frequency (RF), ionizing radiation, and hot water treatments, including the combinations of some of them for synergistic effects (Weyer et al., 1993; Zhuang and Beuchat, 1996; Beuchat et al., 1998; Sapers and Simmons, 1998; Day, 2001; Seymour et al., 2002; Allende et al., 2006, and citations therein; Artés et al., 2007; Kim et al., 2007; Gil et al., 2009; Gopal et al., 2010; Nou and Luo, 2010; Beirão-Da-Costa et al., 2012; Birmpa et al., 2013; Kim et al., 2013; Ramos-Villarroel et al., 2014; Wulfkuehler et al., 2013).

In the last decade, essential oils (EOs) have also been studied as natural disinfectants or antimicrobial agents (Roller and Seedhar, 2002, and citations therein; Scollard et al., 2013). In a review written by Ayala-Zavala et al. (2009) on using the antimicrobial and aromatic attributes of essential oils to enhance safety and aroma appealing of fresh-cut fruits and vegetables, the antimicrobial effect of thymol, eugenol, menthol and others compounds against pathogens and suggested possible combinations of fresh-cut fruit and vegetables with essential oils are extensively reported. However, the high risk of transference of off-odors from the essential oils to the commodities raises the needs for further sensorial investigations; the positive or negative sensorial impact of essential oil on fresh-cut produce should be additionally considered. Scollard et al. (2013) examined the anti-listerial effectiveness of selected EOs and shredded herbs (thyme, oregano, and rosemary) on a range of modified atmosphere packaged fresh-cut vegetables (lettuce, carrot discs, cabbage and dry coleslaw mix). The authors found that the anti-listerial effects were in the order: thyme EO > oregano EO > rosemary herb. The antimicrobial effects of EOs varied depending on which EO was used and the type of fresh-cut vegetable involved. Both anti-listerial and general anti-bacterial effects were observed for thyme and oregano EOs. Thyme EO was found to be the most effective treatment against *Listeria*. Oregano EO was also found to have strong anti-listerial effects, but not as strong as those of thyme EO. Rosemary EO showed no anti-listerial effects except in the presence of shredded cabbage, and these effects were considerably smaller than those of the other EOs. By contrast, strong anti-listerial effects were evident from rosemary herb, but only after stomaching, indicating that the herb is only effective when it is completely macerated with the vegetable sample in the stomacher. Furthermore, the efficacy of the treatments varied according to the vegetable tested.

Alternative methods to extract the active compounds became recently available. They have the advantages of being less time and energy consuming than hydro-distillation, the traditional procedure used for the industrial extraction of EOs. do not require re-distillation to obtain the pure product and avoid the problems of compound thermal degradation (Orio et al., 2012). These techniques include supercritical fluid extraction, ultrasound-assisted extraction and microwave assisted extraction. Comparison between the extraction methods have indicated a comparable profile of volatile secondary metabolites in the EOs obtained from mint species (Orio et al., 2012) and other *Lamiaceae* species (Binello et al., 2013). Several tests are undergoing testing the efficacy of the EO extracts with these different methods for studying the anti-microbial effects directly on microbial culture obtained from organically grown lettuce (Nicola et al., data not published).

Ozone reduces the amount of wastewater, lowers the refrigeration costs of chilled water because of the less frequent flume water changing, and it can be combined with chlorine, whose use can be reduced by 25% leaving less residual odor on the product (Strickland et al., 2010). The main systems for ozone application include the gaseous phase storage or ozonated dips. Several studies demonstrated that gaseous ozone is generally more effective than in aqueous solutions (Ramos et al., 2013). The use of ozonated water has been suggested as an interesting alternative to chlorine due to its efficacy at low concentrations (0.2-5 ppm) and short contact times (from 15 sec to few minutes). However, the efficacy of ozonated water depends on ozone solubility, which increases as the water temperature decreases and is influenced by organic content and pH of the water (Artés et al., 2009; Ölmez and Kretzschmar, 2009).

Organic acid (e.g., lactic, citric, acetic or tartaric acid) dippings have a much more residual antimicrobial effect than ozone and chlorine treatments on the microflora of lettuce during storage (Akbas and Ölmez, 2007). The antimicrobial action of organic acids depends on several factors, such as a reduction in pH, the ratio of the un-dissociated fraction of the acid, chain length, cell physiology and metabolism. Organic acid with only one carboxylic group, such as lactic acid, has been found to be less active than citric acid which has more carboxylic groups. A calcium lactate treatment has been reported to have potent antibacterial properties (Saftner et al., 2003). Martín-Diana et al. (2005) compared calcium lactate with chlorine as a washing treatment for fresh-cut lettuce and carrots. Calcium lactate was not significantly different from chlorine treatment in terms of maintaining color and texture during the entire storage period. Furthermore, carotenoid levels were higher in calcium lactate-treated carrots than chlorine-treated samples after ten days of storage at 4°C. Ultimately, the mesophilic, psychrotropic and lactic acid bacteria counts were not significantly different for the calcium lactate and chlorine treatments for either vegetable. Thus, calcium lactate appears to be a suitable washing treatment, which has no post-treatment bleaching effect on fresh-cut lettuce and does not cause the appearance of whiteness on the surface of sliced carrots.

At present, chlorination is used primarily in processing plants, although there have been many attempts to find alternative washing treatments to chlorine because of the formation of carcinogenic chlorinated compounds (chloroamines and trihalomethanes) in water. Furthermore, chlorine compounds can burn the skin and release dangerous chlorine gas into the work environment (Martín-Diana et al., 2005; Page et al., 1976; Parish et al., 2003; Suslow, 2006; Wei et al., 1995). However, a sure and conclusive disinfection system that is able to remove dirt, weeds, pesticide residues and microorganisms, while, at the same time, not negatively affecting the intrinsic and extrinsic quality of the product has yet to be found.

When planning the concentration of chlorine to be used one should consider its reaction to organic matter. When the chlorinated solution comes in contact with a cut produce, the sanitizer will react with the organic matter (such as vegetable tissue, cellular juices, soil particles, microbes) and the available (free) chlorine will be depleted. The difference between total chlorine and available chlorine depends on the amount of organic matter and inorganic compounds that react with the free chlorine (resulting in combined chlorine) during washing (Pirovani et al., 2004). The smaller the amount of organic cellular compounds released by cutting the produce, the smaller the difference between the total and available chlorine. Consequently, the proper concentration of chlorine to be used during sanitation should also be considered according to the type of produce, cut size and type (e.g., slice, shred, whole leaf).

The chlorine concentrations and washing times vary to a great extent from processor to processor, and these differences are mainly related to the different operational temperatures and the resulting bleaching effects that are tolerated by the consumers in any given market. Chlorine lethal effect increases with temperature and its effect on microbial removal occurs when the water is warmer than the produce (Hernandez-Brenes, 2002; Beuchat, 2007). According to Beuchat (2007), the lethal effect of chlorine occurs within the first few seconds of treatment, and the population of microorganisms decreases as the concentration of chlorine increases to about 300μg ml^{-1}, above which its effectiveness is not proportional to the increased concentration. Treatments with 50-200μg ml^{-1} chlorine and a washing time of 1-2 min can reduce the number of microorganisms by 1-2 log cfu g^{-1} in some instances, but can at the same time be completely ineffective in others (Hernandez-Brenes, 2002; Roller and Seedhar, 2002). Most fresh-cut processors in the Mediterranean use a concentration of chlorine of between 30 and 50μg ml^{-1} to avoid bleaching and fading effects on the products, with operational water temperatures close to 12°C. Several studies have demonstrated that chlorine rinses can decrease the bacterial load from <1 log cfu g^{-1} to 3.15 log cfu g^{-1}, and its efficacy depends on inoculation method, chlorine concentration, contact time, and microorganism type (Ramos et al., 2013).

Raw material is generally washed in cold water, because low temperatures slow down plant respiration, transpiration, warming and microbial activity. Water temperatures range between 4°C and 12°C, although washing hot raw material (e.g., summer in the Mediterranean) with colder water could cause the vegetable tissues to absorb any chemical contaminants present in water (Hernandez-Brenes, 2002, and citations therein). Maintaining the water temperature 5°C above the internal temperature of the produce can prevent this "suction" effect. One precaution could be an initial air-cooling step before washing to minimize the temperature gap between the produce and the water temperature.

After washing, with or without a chemical sanitizer, a sanitation physical method or a dipping treatment could occur on whole or cut or peeled produce. Several studies have investigated the effect of dipping treatments on quality and safety of fresh-cut fruit and vegetables. Dipping operations are processing aids used for chemical and physical treatments and post-cutting application of additives. Heat treatments are becoming very popular in the fresh-cut industry, especially in preventing the detrimental effects of enzymatic browning responsible of color, flavor and texture change as well as of nutritional value decrease and in inhibiting microorganisms growth. Heat treatments can be applied in the form of hot water treatment, vapor heat treatment, hot air treatment, or hot water rinse brushing (Sivakumar and Fallik, 2013). The former treatment is currently the most common in fresh-cut industry. Several studies have investigated the application of heat treatments by dipping for quality retention and safety control to replace the use of chemical treatments in fresh-cut carrot (Alegria et al., 2012), melon (Aguayo et al., 2008), broccoli florets (Moreira et al., 2011), potato (Tsouvaltzis et al., 2011), mango (Djioua et al., 2010), peach (Steiner et al., 2006; Koukounaras et al., 2008), and kiwifruit (Beirão-da-Costa et al., 2008). In general, temperatures used for hot water dips on different fresh-cut products can range from 40° to 60°C, while dipping duration ranges from few seconds to many minutes (up to 70 minutes). The hot water treatment conditions depend on the type of produce (leaf, fruit, root, etc.), maturity stage, fruit size, cultivar, growing conditions, and on timing of application as pre- or post-cutting treatment. The selection of appropriate treatment conditions (temperature x duration) is a crucial factor in determining the overall quality of the horticultural product at the end of treatment and during shelf life.

Dipping treatments could consist of using a solution containing anti-browning compounds, such as ascorbic acid or a calcium salt with an organic acid, antimicrobial agents or edible coatings to extend the post-cutting shelf-life of fruit and vegetables. Edible coating, a new strategy to prolong the shelf-life and improve food quality of fresh-cut fruits, have been applied to many fresh-cut products, such as papaya (Tapia et al., 2008), carrots (Vargas et al., 2009), pears (Oms-Oliu et al., 2008; Xiao et al., 2010; Xiao et al.,2011), banana (Bico et al., 2009) apple (Rojas-Graü et al., 2007; Freitas et al., 2013), melon (Poverenov *et al.*, 2013), and mango (Robles-Sánchez et al., 2013). The coating supplies a selective barrier to moisture transfer, gas exchange or oxidation processes, which slows ripening, reduces weight loss, and helps to preserve fresh aroma and flavor. One of the most important advantages of using the edible coating is that several active ingredients can be incorporated into the polymer matrix and consumed with the food (Rojas-Graü et al., 2009a). Edible coatings are also used as carriers of active ingredients, such as anti-browning (ascorbic acid), antimicrobial (organic acids, fatty acids esters, polypeptides, plant essential oils), and texture enhancer (calcium chloride, calcium lactate, calcium gluconate) compounds, as well as flavors and nutraceuticals (vitamins, minerals, fatty acids), to improve quality, safety, and nutritional value of fresh-cut fruits. Among the edible coatings, alginate, chitosan, gellan, and pectin are the most common coating materials used for fresh-cut fruit industry.

Chitosan (CH) is a natural, non-toxic, biodegradable polymer with antimicrobial activity and film-forming capacity, even though the functional properties of chitosan films can be enhanced by combining chitosan with other hydrocolloids, controlled atmosphere or chemical dip. Xiao et al. (2010) investigated the effects of pure oxygen pretreatment and chitosan coating containing 0.03% rosemary extracts on the quality of fresh-cut Huangguan pears. The authors found that the combination of pure oxygen pretreatment prior to slicing and chitosan coating plus rosemary extract may be a potential method to maintain the fresh-cut fruit quality and to reduce browning, softening and decay, which are the main problems in fresh-cut pears during storage. Xiao et al. (2011) evaluated the effects of sodium chlorite dip treatment and chitosan coatings on the quality of fresh-cut d'Anjou pears. The edible coatings were prepared from chitosan and its water-soluble derivative carboxymethyl chitosan. The authors found that the combination of sodium chlorite with carboxymethyl chitosan had beneficial effects in reducing the cut-surface discoloration and in inactivating *E. coli* O157:H7. At the moment, the dipping operation to provide anti-browning and antimicrobial agents, texture enhancer and edible coatings is used only for fruits. After dipping, the cut fruits are drained and dried by air, then packaged.

D. Drying systems

An important factor for the stability of fresh-cut product is moisture control. After washing, the excess water should be removed from the fresh-cut product before packaging to prevent rapid microbial development and enzymatic processes that lead to product quality deterioration. Various methods exist to remove washing water, including the centrifugation, the passing the produce over vibrating screens with air blasts or blotting. Water remaining on the product is a critical issue.

The duration and speed of centrifugation need to be adjusted for each product (Figure 8). Minimal centrifugation can leave residual water on the produce surface, thus, favoring microbial growth, while excessive centrifugation can result in cellular damage and cause cellular leakage. Fresh-cut products are often left with too much moisture, which causes their rapid deterioration. Pirovani et al. (2003) evaluated the effect of speed (from 0rpm to 1080rpm) and operation duration (from 1 min to 9 min) of spin drying on the excess water remaining on washed, fresh-cut spinach as well as the microbial growth and sensory deterioration during storage of fresh-cut packaged spinach. The combination of the centrifugation speed and operation duration affected the water removal. According to their results, it is necessary to reach higher centrifugal speeds than 600-700rpm and a duration longer than four min to obtain an optimal drying level of spinach (i.e., 0.1-0.3% of water excess).

Luo and Tao (2003) used imaging technology to determine the tissue damage of fresh-cut iceberg lettuce and baby spinach during a centrifuge drying process. Large differences in damage were found for fresh-cut iceberg lettuce between the two centrifuge-drying speeds of 150rpm and 750rpm. Furthermore, a significant difference was found at 750rpm depending on the location of the samples in the centrifuge drying basket; the tissues of samples located near the side of the drying basket were more damaged than those located at the top, in the center, or at the bottom. For baby spinach, the damage due to the centrifugal force was similar to the results for iceberg lettuce, the samples at the bottom of the basket in addition to those near the side of the basket suffered from severe tissue damage. The damage to the spinach tissues was possibly influenced by both the centrifuge speed and the weight of the product in the drying basket.

Drying tunnels with continuous air flows are also used, especially for more delicate vegetables (Donati, 2003). The critical points when using air drying tunnels are the optimal adjustment of the air temperature to avoid possible raw material fading, the thermal shock between air temperature flow and raw material temperature, and the residual water on the raw material, all of which are factors that could reduce shelf life quality. Some companies have recently introduced cool-drying tunnels, which are very efficient but require an additional cost.

E. Packaging

Packaging is not only the final operation of fresh-cut processing that allows the products to be distributed and safely reach the consumers, but also the tool which, together with the cold chain maintenance, allows the quality of fresh-cut product to be preserved and prolongs its shelf life (Figure 9). The most studied packaging method is modified atmosphere packaging (MAP). Low O_2 concentrations (1-5%) reduce the respiration rate, chlorophyll degradation and ethylene biosynthesis, while high CO_2 concentrations (5-10%) reduce the respiration rate and slow plant metabolism. The aim of packaging is to create an atmosphere that slows produce respiration, so that the minimal necessary O_2 concentration or maximum tolerated CO_2 concentration of the packaged produce is not exceeded, and both fermentation and other metabolic disorders are avoided (Jacxsens, 2002). However, Rojas-Graü et al. (2009b) reported that the use of elevated O_2 atmospheres ($\geq$ 70 kPa O_2) has been recently proposed as an alternative to low O_2 atmospheres to inhibit the growth of naturally occurring microorganisms, prevent undesired anoxic respiration processes and preserve the fresh-like quality of fresh-cut produce. According to several authors, high O_2 concentration can generate reactive oxygen species (ROS) that damage microbial cells and, thus, reduce microbial growth in packages. However, there is still limited information about the effects of high O_2 concentrations on the antioxidant content of fresh-cut produce.

A modified atmosphere (MA) is generated by respiration of fresh-cut produce (passive MAP) or attained by a gas flushing (active MAP) (Bolin and Huxsoll, 1991; King et al., 1991; Artés, 2000a; 2000b; Kader, 2002a). The passive MAP is applied to fresh-cut vegetables sealed within bags of semi-permeable films, harnessing the naturally occurring respiration of the living vegetable tissues, which will obviously modify the atmospheric conditions (Thomas and O'Beirne, 2000). One of the most important factors of this technique is the gas permeability of the selected film that must allow an adequate O_2 and CO_2 exchange between the product and the atmosphere in order to establish the desired gas composition inside the bag. Due to perishability of freshly processed produce, the MA is often actively established either by flushing with the desired atmosphere or by creating a slight vacuum and replacing the package atmosphere with the desired gas mixture (Artés, 2000a; Kader, 2002a).

The choice of packaging film depends on the permeability of the film to the O_2 and CO_2 that must be adapted to the O_2 consumption rate and CO_2 production rate of the produce. If the permeability for O_2 and CO_2 is perfectly matched to the respiration rate of the produce, an ideal equilibrium modified atmosphere (EMA) can be established inside the package. The EMA depends on many factors: the product respiration rate, respiring surface area, storage temperature, packaging film permeability and equipment, RH, filling weight, pack volume, film surface area, degree and kind of illumination of the display in the retail store, as well as the initial microbial load (Artés and Martínez, 1996; Jacxsens et al., 1999; Day, 2000; Kader, 2002a, 2002b; Nicola et al., 2010).

It was previously mentioned that the biological agents that limit the shelf life of vegetables differ because of a number of factors. Thus, it is expected that the range of recommended atmosphere composition varies according to the different kinds of products as well as the success of the atmosphere modification (Saltveit, 1997). The subsequent maintenance of the optimum atmosphere during storage is, therefore, effective in delaying quality deterioration, as well as the deterioration during shipping. It has also been observed that when shipping fresh-cut products by air, the volume of the packages increases with decreasing external air pressure; the packages can open and, thus, become unmarketable (Emond, 2007).

At the moment, traditional MAP atmospheres are not sufficient to ensure safety and high-quality products. Most of currently used MAP systems alone are not effective in preventing tissue browning, decay processes and slowing the microbial growth. The polymeric films used in MAP have some limitations because of their structure and permeation properties. They may cause the water loss, which results in softening, translucency or weight loss, or, on the contrary, can increase the formation of water condensates that promote microbial growth. For these reasons, in recent years, research has been focused on increasing the effectiveness of MAP by combining it with other sanitation technologies, such as ozonation and UV-light, or with dipping operations, such as the application of edible coating added of anti-browning and antimicrobial agents (Rojas-Graü et al., 2009b; Chauhan et al., 2011; Krasnova et al., 2013). In a review, Rojas- Graü and co-authors (2009a) extensively report the scientific works of the last years on the use of innovative atmospheres and edible coatings for maintaining freshness and safety of fresh-cut fruit and vegetables.

Packaged fruit and vegetables are usually exposed to different surrounding temperatures during shipping from the processing plant to the consumer, storage, and display at retail; MAP is not a substitute for a proper cold chain management, but it can help extend the shelf life. A change in the environmental temperature creates a specific problem in EMA establishment because the respiration rate is influenced more by temperature changes than film permeability to O_2 and CO_2 (Jacxsens et al., 2002).

F. Temperatures and cold chain

Temperature for fresh and fresh-cut produce should be maintained below 7-8°C at least to delay quality loss and to reduce the proliferation of spoilage microorganisms, while often times we experience temperature abuse. Therefore, an important step in cold chain management is recording the temperature of fresh produce throughout the entire supply chain (see also Chapters 1 and 6), helping also a good HACCP implementation and corrective measures to be taken. One of the research limitations is that research is usually conducted in simulated situations, that is, in laboratories or controlled cell rooms. There are, however, some results from investigations conducted in realistic circumstances encountered in the food industry. Rediers et al. (2009) used time-temperature data loggers to follow endive temperature from the on-farm refrigerators to the on-processor storage to the distributor company and to restaurants up to the act of consumption. All these steps were at air temperature setting of 4°C. In the production facility the processing water was at 4°C and the facility was at 8°C. The researchers found that in the on-farm refrigerators, where heads were stored in Euro Pool System (EPS) crates piled up on pallets, the endive was cooled more rapidly at the top of the pallet than in the middle or in the bottom (2.5 h extra to reach 8°C for the heads in the middle of the pallet and 3.5 h extra for those in the bottom of the pallet). In addition, regardless of the refrigeration temperature, endive required 3 h of cooling on a warm day (temperature range 14-35°C), while only 2 h on a moderate day (temperature range 5-19°C). During transport the endive temperature was 16°C and, once stored in the processing facility, it took from 5:00 PM to 4:00 AM to reach the temperature of 4°C. At that point, endive was kept at 4°C during processing and during the transport to the distribution company, while during the final transport to the three restaurants temperature rose 2-4 °C and kept fluctuating in the restaurant refrigerators because proximity to ovens and of more often opening of the door than that of industry refrigerators. In conclusion, it seems that the real critical points when fresh-cut produce rises its temperature were during transport, from farm to the processor and from the distributor company to restaurant delivery, and during storage in restaurants. The levels of all indicator microorganisms and pathogens were confined within the limits prescribed by EU Reg. EC 2073/2005. Thus, the critical issue is not food safety, while major factors appear to be cooling costs, product quality and product waste due to temperature abuse.

Fresh-cut packaged products need to be stored at low temperatures with 95% RH to slow the respiration rate, enzymatic processes and microbial activity. Storage conditioning generally refers to the storage or holding temperature, the time/temperature and the RH the fresh-cut products may encounter. However, other factors can play a role during storage, such as the effectiveness of the packaging material to preserve food safety and quality, the technical characteristics of the storage in the processing plant, and the cold chain implementation from the processing plant to the consumer. The storage temperature required by fresh-cut products needs to be adjusted not only according to their metabolic and microbial activities, but also according to the species/cultivar and applied processing techniques.

Several authors have studied the effects of storage temperature and storage time on quality and microbial growth. Lamikanra and Watson (2003) evaluated the effects of storage time and temperature (4°C or 15°C) on esterase activity in fresh-cut cantaloupe. The enzymatic activity, after 24 h in storage, was reduced by 40% and 10% in fruit stored at 4°C and 15°C, respectively. Pectin methyl esterase activity in cut fruit also decreased by about 25% at both temperatures after 24 h, but greatly increased after 72 h in fruit stored at 15°C. Fontana and Nicola (2008) studied the effect of storage temperature (four, eight or 16°C) on the freshness of fresh-cut garden cress stored from seven to ten days. The fresh weight loss increased linearly with increasing temperature, reaching a maximum value of 1.9% at 16°C after eight days of storage. An optimal temperature was defined as 4°C to guarantee microbial and sensory quality. Ukuku and Sapers (2007) investigated the effects of a waiting period at room temperature (ca 22°C) before refrigerating fresh-cut watermelon, cantaloupe and honeydew pieces contaminated with *Salmonella*. The *Salmonella* populations in the fresh-cut watermelon and honeydew pieces declined by 1 log cfu g^{-1} when stored immediately at 5°C for 12 days, while the populations in the fresh-cut cantaloupe did not show any significant changes. The *Salmonella* populations in the fresh-cut melons stored immediately at 10°C for 12 days increased significantly from 10^2 to 10^3 cfu g^{-1} in the watermelon, $10^{1.9}$ to 10^3 cfu g^{-1} in the honeydew and 10^2 to $10^{3.6}$ cfu g^{-1} in the cantaloupe pieces. Keeping freshly prepared, contaminated fresh-cut melon pieces at 22°C for three hours or more prior to refrigerated storage could increase the chances of *Salmonella* growth, especially if the fresh-cut melons were subsequently stored at an improper temperature.

Storage temperature is found to be of paramount importance for the evolution of the microbial and visual quality of fresh-cut products. Knowledge on temperature oscillations of fresh-cut product in the cold chain is necessary to determine the influence of the temperature on the loss of quality and shelf life. Many European countries lack specific regulation concerning temperature control for fresh-cut products. Italy is the first EU country that introduced a National law specifically for the fresh-cut industry (D.L. 13 May 2011, n. 77) that will have the specific decree in which temperature limits in the distribution chain are set to be below 8°C, and temperature limit is planned to be written in any package label for domestic refrigeration storage as well. Fresh-cut products are classified as refrigerated products, whose storage temperature must be kept at a maximum of 7°C with a tolerance of up to 10°C in the warmest conditions (Jacxsens et al., 2002).

The time/temperature conditions at harvest and during postharvest handling are an essential critical control point and should be monitored. The air temperature during sorting and preparation must be lower than 12°C, while during washing, cutting and packaging, the air temperature should be maintained at between 4°C to 6°C. Temperature ranges (≥ 10°C) can be found in a fresh-cut product cold chain during shipping and unloading at the supermarket, storage and display at retail, and in domestic refrigerators. During transport in refrigerated vehicles, the main problem is to maintain the cold chain as the door may be opened and closed frequently and the doors may be left open for variable periods of time, while orders are prepared and delivered. A rapid increase in product temperature can occur on transfer from temperature-controlled vehicles to ambient conditions during unloading at the distributor. The control of temperature performance and display units in supermarkets is rather poor, and the temperature of the fresh-cut product depends on its location on the chilled display shelf. The temperature distribution in the display environment is critical. The temperature is usually not optimal (8-10°C), and may accelerate fermentation inside packages and reduce both the shelf life and the packaging effectiveness (Emond, 2007). Finally, improper cold chain management continues in home refrigerators. Temperature abuse, such as storage at ambient temperature and improper cooling, has been identified as the main cause of microbial and quality deterioration. Nunes et al. (2009) investigated the temperatures registered inside local distribution trucks or in retailer displays and the effects on improper temperature management on the produce quality. The study evaluated the segment of the distribution chain that includes the time the produce arrives from distribution center to the store, is displayed at the store, and then stored under home conditions. A wide variation of the temperature measured inside the retail displays was registered depending on the store and the displays, from -1.2 °C to 19.2°C in refrigerated displays and from 7.6°C to 27.7°C in non-refrigerated displays. The major cause of produce waste was the improper temperature management (55%), while the expired date and mechanical damage counted for 45%. Thus, fruits and vegetables are often kept under improper storage conditions, resulting in produce with poor quality and shorter shelf-life and in waste increase at retail and consumer levels.

In recent years research has paid attention to the light conditions during shelf-life to simulate the retail display conditions, especially in leafy vegetables and greens, such as garden cress, broccoli, cauliflower, Swiss chard leaves, lettuce, celery (Olarte et al., 2009; Zhan et al., 2009; 2012a; 2012b; 2013a; 2013b; 2013c; Kasim and Kasim, 2012). However, the information on the effects of the exposure to light at retail store on the physiological response of fresh-cut products is still poor, and the scientific results are contradictory. Although the display of vegetables in stores is mostly done in light conditions, several studies recommend low light intensity conditions or darkness to delay the leaf yellowing of vegetables in retail markets. Light conditions favor the chlorophyll degradation causing the leaf yellowing, which is one of the most important factors determining the fresh-like appearance of the product and, thus, the consumer purchase. Despite this, some studies have been reported in which continuous light-stored leaves of fresh-cut products retained more chlorophyll than dark-stored leaves (Noichinda et al., 2007; Zhan et al., 2012a; 2013a; 2013b). Zhan et al. (2013b) found that light-stored leaves of fresh-cut romaine lettuce preserved more Chl *a* during 7 days of storage at 4°C than-dark stored leaves. Light delayed the decline of soluble sugar and total soluble solid content and concurrently increased the dehydroascorbic acid (DHA) and dry matter content in comparison to storing leaves in dark environment. Studies conducted by Zhan and coworkers highlighted that light exposure accelerates fresh weight loss during storage; this occurred in broccoli (Zhan et al., 2012a), romaine lettuce (Zhan et al., 2012b; 2013b) and celery (Zhan et al., 2013a), confirming similar results in the literature (in Chinese kale, Noichinda et al., 2007; in romaine lettuce, Martínez-Sánchez et al., 2011). A general tendency was that light conditions preserve or increase the amount of ascorbic acid compared to dark conditions (Zhan et al., 2012a; 2012b; 2013a; 2013b), as well as an inhibition of PPO and POD and a decrease of browning (Zhan et al., 2012b; 2013c). Light conditions can affect not only the physiological response of fresh-cut produce, but also the packaging performance in preserving the sensorial attributes (Olarte et al., 2009).

Further and detailed studies need to be conducted on the effect of light on physiological responses of fresh-cut fruit and vegetables. Ultimately, the effect of light and the type of bulbs used for the experiments should be checked in interaction with the temperature of the display cabinets, given that most of these are open and, thus, subjected to ambient temperature (Figure 10a,b,c). The latter is not only often time much higher than refrigeration temperature, but it can increase also due to the type of bulbs used: incandescent and halogen bulbs increase ambient temperature, while fluorescent light does not. In-bag product temperature is expected to be higher than out-bag temperature due to the greenhouse effect, to the reduced evaporative cooling and trapped warm air if the light is used in open display cabinet. Lastly, the effect of continuous light should be checked against store opening hours, that is, the fluctuation of light/dark conditions have not yet been investigated.

IV. FUTURE CONSIDERATIONS

The preharvest and postharvest issues described in this chapter highlight the research efforts that are being made to test and implement innovations to increase fresh-cut sector competitiveness in terms of safety and quality. A continuous exchange between scientists and the fresh-cut industry is necessary to guarantee the success of the fresh-cut system. It is advisable that new experiments would be conducted in real world situations after having been tested in simulated conditions, that is, in laboratories or controlled cell rooms, to verify the studies under realistic situations. In addition, there is still little connection between preharvest and postharvest conditions in the mind of researchers: most of the postharvest research is conducted by not knowing any preharvest conditions of the raw material, while, in most cases, being obtained from a grocery store, making unreliable many hypotheses of any determining cause in the field on postharvest quality.

The fresh-cut sector has progressed tremendously around the world in the last decade, especially in the fruit sector and, particularly, in tropical and exotic fruit. This development is in line with the general trend occurring in fresh produce. Thus, the critical issues in the fresh-cut management are similar to those in the fresh produce management. The wide spread of fresh-cut fruit and vegetables is visible in many emerging economies even though statistics are unavailable. In the coming decade, it is expected that the importance of the sector will increase even more, with most likely increase in the importance of safety rather than quality. Nevertheless, assessing fresh-cut produce quality remains of great importance because consumers are expecting more flavor and taste, especially from such high price products as fresh-cut products. Despite the five years of economic slowdown around the world that has hit some countries more severely than others, the demand for fresh-cut products keeps rising. The offer of new species and varieties expands the offer of fresh-cut items. There are promising innovations both at the farm production level and at postharvest processing level: cultivation techniques are becoming standardized, environmentally friendly, conserve water, reduce waste and emphasize the inherent and organoleptic quality of the raw material. Therefore, research should focus on the implementation of innovative tools and processing aids in postharvest processing able to preserve the freshness and organoleptic quality obtained in the field.

Lastly, the sector is facing a striking challenge in the coming years: “waste footprint”. Food waste is top of the issues when it comes to the food sector’s current sustainability agenda and fresh-cut products are among the most targeted products for waste production (Burrows, 2013). In fact, latest figures in the UK indicate that 68% of salad grown for fresh-cut salad bags is wasted. If it is true that tackling the issue of waste reduction starts from breeding and ends in homes, it is also true that solutions should be found either by reducing the discharge of ‘not compliant’ raw material along the chain or by making better use of it, such as re-cycling or re-using waste for other purposes, e.g., composting or the extraction of the bioactive compounds it contains.

List of Figures

Glossary of acronyms

AA	-	Ascorbic acid
cfu	-	colony forming unit
DHA	-	dehydroascorbic acid
EMA	-	Equilibrium modified atmosphere
EF	-	Ebb-and-flow system
EO	-	Essential oil
EPS	-	Euro Pool System
EU	-	European Union
FL	-	Continuous flotation system
FS	-	Flotation systems
GAP	-	Good agricultural practices
GHP	-	Good hygiene practices
GMP	-	Good manufacturing practices
HACCP	-	Hazard analysis critical control point
HEP	-	High intensity electric field pulses
HHSS	-	Harvest, handling, shipping and storage

HP	-	High pressure
IY	-	Internal yellowing
LOX	-	Lipoxygenase
MA	-	Modified atmosphere
MAP	-	Modified atmosphere packaging
NFT	-	Nutrient film technique
PAL	-	Phenylalanine ammonia lyase
PPO	-	Polyphenol oxidase
POD	-	peroxidase
RF	-	Radio frequency
RH	-	Relative humidity
ROS	-	Reactive oxygen species
RRO_2	-	Respiration rate for oxygen
SCS	-	Soil-less culture system
TCS	-	Traditional culture system
TPC	-	Total plate count
UV	-	Ultraviolet
UV-C	-	ultraviolet-C
YMC	-	Yeast and mould count

INDEX WORD