Chapter 3
Post-Harvest Treatments and Related Food Quality

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3.1 Introduction

Fruit and vegetables are still living plant organs after harvest with an active metabolism and ongoing respiration, ripening, and senescence processes which have to be controlled to maintain the quality of the products (Brasil and Siddiqui 2018). Post-harvest losses of, e.g., apples due to ripening and respiration may add up to 4–10% but can be reduced to 2–6% by appropriate post-harvest treatments (Roser et al. 2013). Quality of fruit and vegetables cannot be improved after harvest, it can only be preserved (Fallik and Ilic 2018). Therefore, the preservation of valuable compounds like vitamins and secondary metabolites is a main goal in post-harvest treatments. Furthermore, sensory parameters like appearance, texture, and flavour are important for acceptability by consumers and must be taken into account for post-harvest treatments (Aked 2002).

As fruit and vegetables are preferentially consumed at full ripeness, their sensory quality is mainly tested at this stage. However, certain fruits are typically harvested in an unripe stage for consumption (e.g., banana, kiwifruit, mango, and avocado) in order to enable shipment over long distances, often between continents. Such fruits have to be after-ripened in the country of destination (for example by an increase in temperature and an ethylene treatment) before marketing. While this is unavoidable from the economic point of view, the desired quality may be difficult to achieve by after-ripening of prematurely harvested fruit (Karapanos et al. 2015). On the one hand, kiwi fruit stored under controlled atmosphere and ripened after storage possessed a similar sensory quality as vine ripened fruit (Latocha et al. 2014). On the other hand, mango harvested in an immature status were found to be more sensitive to chilling injuries and may fail to ripen properly (Sivakumar et al. 2011). Further,

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the aroma profile changes significantly during ripening (Obenland et al. 2012) and this process may also be influenced by the time of harvest. Again, it has to be emphasized that quality of fruit and vegetables is determined during cultivation and can only be preserved, but not improved after harvest.

The most important factor to maintain fruit and vegetable quality is the appropriate temperature during storage and transport. For example, preservation of anthocyanins, an important group of secondary metabolites in fruit and vegetables, is very much influenced by temperature (Raffo et al. 2008; Odriozola-Serrano et al. 2009). Besides temperature, the composition of storage atmosphere is another important factor influencing respiration and in conjunction ripening and senescence of fruit and vegetables (Harman and McDonald 1989; Simões et al. 2011; Bekele et al. 2016).

Appropriate post-harvest storage and transport conditions are not always available especially in developing countries. Therefore, further post-harvest treatments in developing countries like Africa and Asia, e.g. hot water treatment, modified atmosphere packaging, and fermentation are necessary to maintain food security and world nutrition (Habwe et al. 2008; Wafula et al. 2016; Ndlela et al. 2017). The different post-harvest treatments described in the following sections are useable globally and not only in developing countries.

3.2 Post-Harvest Treatments and Food Quality

3.2.1 Methods for Quality Determination

The first quality determination has to be done before harvest. To determine the appropriate harvest time at an optimal product specific ripeness, the following parameters are evaluated: firmness, total soluble solid (°Brix), and starch content. These parameters together resulting in the so called Streif-Index for ripeness, especially for apples (Winter and Link 2002). After harvest, a larger set of basic chemical or enzymatic assays is traditionally performed in order to describe fruit quality status more comprehensively. In addition to the aforementioned parameters, in part depending on the kind of fruit or vegetable of interest, also vitamin C content, total polyphenols, reducing sugars, total acidity etc. are determined (Table 3.1). Furthermore, sensory testing by a trained panel can be an additional method for quality evaluation especially to determine consumer acceptance after post-harvest treatments. All the aforementioned analytical methods target specific compounds, compound classes or chemical sum parameters and provide thus valuable information about basic quality characteristics. However, recent technological advances have enabled the development of extremely powerful analytical instruments which are able to detect and quantify hundreds to thousands of known and unknown compounds in one analysis. This facilitated the wide-spread application of the untargeted metabolomics approach also in the post-harvest field which enables an in-depth evaluation of fruit composition and thus fruit quality (Nicolaï et al. 2010;

Table 3.1 Methods and assays used to determine basic fruit quality characteristics

Measured parameter	Analytical principle/ methodology	Detected property or chemical species. Possible limitations	Literature
Fruit colour	(a) Visual comparison with colour charts (rather subjective) (b) Instruments measuring the composition of light after reflection or transmission	Sum of all natural dyes, e.g., anthocyanins, carotenoids, betalains, chlorophyll, riboflavin and others	Mitcham et al. (1996/2003)
Gloss	Glossmeters measuring specular gloss or other types of gloss	The ability of fruit surface to reflect light without scattering	Mizrach et al. (2009)
Defects and disorders	Visual evaluation. Defects are counted and classified according to their severity.	Cuts, bruises, scald, bitter pit, internal browning, chilling injuries, etc.	Mitcham et al. (1996/2003)
Firmness	Handheld or benchtop penetrometers measuring, for example, the pressure needed to push a plunger of defined size through the peel into the pulp up to a certain depth	Firmness or degree of softness/crispness	Mitcham et al. (1996/2003) and OECD (2009)
Juice content	Gravimetric determination of the juice yield (in %) using an extractor or a juice press		OECD (2009)
Water content and dry matter (total solids)	Drying in a ventilated or vacuum oven, in case of fruit and vegetables usually at 60–70 °C	Water content and the residual dry matter	Mauer and Bradley (2017)
Total soluble solids	Determination of the refractive index (°Brix) using a refractometer	Mainly sugars derived from starch during ripening. Other compounds like organic acids, amino acids and polyphenols may also contribute significantly	Mitcham et al. (1996/2003) and OECD (2009)
pH	Potentiometric analysis using a pH meter (in juices or extracts)	Concentration (or activity) of H_3O^+ ions	Tyl and Sadler (2017)
Titratable acidity	Titration (of liquid foods or extracts) with a strong base (e.g., sodium hydroxide) until a target pH of 8.1 is reached or a colour change of a pH-sensitive dye occurs. Result is expressed as % or g/L of a reference acid	Total acid concentration including all organic (free and bound) and inorganic acids	Tyl and Sadler (2017)

(continued)

Table 3.1 (continued)

Measured parameter	Analytical principle/ methodology	Detected property or chemical species. Possible limitations	Literature
Total phenolics	(a) Photometric determination after reaction of phenolics with the Folin-Ciocalteu reagent.	Simple phenols and polyphenols. Gallic acid is used as reference for quantification. Limited selectivity, high amounts of, e.g., thiols, reducing sugars, amino acids or ascorbic acid may lead to biased results	Waterhouse (2002), Sánchez-Rangel et al. (2013), and Bunzel and Schendel (2017)
	(b) Direct photometric analysis		
Antioxidant capacity	Determination of the ability of antioxidants to react with radicals derived from a radical initiator in a given test system. Typically, the formation or the degradation of a photometrically or fluorimetrically active compound is measured. Quantification is performed in relation to a reference compound like Trolox	All compounds which are able to scavenge radicals derived from the radical initiator used, e.g., AAPH (ORAC assay), ABTS (TEAC assay) or DPPH (DPPH assay). Each test system has its specific limitations and comparison of results may be difficult	Karadag et al. (2009) and Bunzel and Schendel (2017)
Mono- und disaccharides	(a) Various enzymatic assays	Sucrose, D-glucose and D-fructose as well as other sugars	BeMiller (2017)
	(b) Determination using HLPC with RI or electrochemical detection		
Vitamin C	(a) Enzymatic determination	L-ascorbic acid (and dehydroascorbic acid, if reduced to ascorbic acid)	Matissek et al. (2018)
	(b) HLPC with UV detection		
Starch	(a) In-situ determination of starch content in fruit at harvest using iodine/potassium iodide solution	(a) Starch, colorized by intercalation of iodine in starch chain	OECD (2009)
	(b) Quantitative determination of starch content by an enzymatic assay, e.g. r-biopharm	(b) Starch after degradation to D-glucose	

Benkeblia 2014). Consequently, an increasing number of metabolomics studies has been performed especially in the last decade, for example to investigate pre- and post-harvest ripening or fruit development processes (Jom et al. 2011; Nardozza et al. 2013; Mack et al. 2017), to describe changes of the metabolite profile during storage (Hatoum et al. 2014; Brizzolara et al. 2017) and to elucidate the effects of technological treatments (Rudell et al. 2008; Picó et al. 2010; Leisso et al. 2013; Lopez-Sanchez et al. 2015) or the mechanisms of fruit resistance against pathogens (Wojciechowska et al. 2014). It can be expected that a broader application of metabolomics in the post-harvest field will further improve our understanding of the molecular basis of a high fruit quality.

3.2.2 *Optimized Storage Conditions*

3.2.2.1 Cold Storage

Fruit and vegetables have still an active metabolism and a respiration activity after harvest. These activities are strongly influenced by temperature during transport and storage. A reduction of temperature of 10 °C is slowing the metabolic activity (activity of ripening and degradation enzymes) of fruit and vegetables by a factor of two to three (Winter and Link 2002). Therefore, on the one hand, temperature during transport and storage should be at a product specific minimum to preserve harvest quality of fruit and vegetables. On the other hand, diverse fruit and vegetables have different susceptibility for chilling injuries, which means that a fruit- and in part cultivar-specific optimal temperature needs to be figured out (Table 3.2).

Table 3.2 Storability of different fruits and vegetables under cold storage conditions at normal atmosphere

Type of fruit or vegetable	Species/cultivar		Cold storage conditions		
			Temperature (°C)	Relative humidity (%)	Storage time
Pome	Apple	Berlepsch	1	93–95	4 months
		Boskoop	3–4	90–92	5–6 months
		Braeburn	1	90–95	5–6 months
		Elstar	2–3	93–95	3–4 months
		Fuji	1	93–95	5–6 months
		Gala	1	93–95	3–4 months
		Golden Delicious	1	93–95	4 months
		Ingrid Marie	1–2	90–92	3–4 months
		Jonagold	1–2	90–93	3–4 months
		Pinova	1	90–93	3–4 months
		Rubinette	−0.5 to 2	90–93	3–5 months
		Topaz	1	90–93	3–5 months
	Pear		−1 to 0	90–93	4 months
Stone fruit	Apricot		−1 to 0	95–97	3 weeks
	Cherry (sour)		−0.5 to 2	90–95	2 weeks
	Cherry (sweet)		−1	90–95	1–3 weeks
	Peach/nectarine		−1 to 0	90–95	2–5 weeks
	Plum		1	90–95	2–5 weeks
	Yellow plum		0.5–1	90	3 weeks
Berries	Currants		0–1	90	4 weeks
	Gooseberries		1	90–95	3 weeks
	Raspberries		−1 to 0	90–95	3 days
	Strawberries		0–2	90–95	5 days
	Table grapes		−0.5 to 1	95	6 weeks

(continued)

Table 3.2 (continued)

Type of fruit or vegetable	Species/cultivar	Cold storage conditions Temperature (°C)	Relative humidity (%)	Storage time
Tropical fruit	Banana (green)	13	90	10 days
	Banana (ripe)	13	90	3–5 days
	Grapefruit	10–12	85–90	3 months
	Kiwi	−0.5 to 0.5	90–95	6 months
	Kumquat	10	90	4 weeks
	Lemon	12	85–90	4 months
	Lime	8–10	90	6–8 weeks
	Lychee	0–2	90–95	4–6 weeks
	Mandarin	5–6	90	6 weeks
	Mango	10–14	90	6 weeks
	Orange	8–10	85–90	4 months
	Pineapple (green)	11–12	85–90	4–5 weeks
	Pineapple (½ ripe)	7–8	85–90	3–4 weeks
Vegetables	Artichoke	−1 to 1	90–95	4 weeks
	Beans	7–8	90–95	10 days
	Broccoli	0	96–98	2 weeks
	Cabbage	0–0,5	95	6–7 months
	Carrots	0.5	98	5–6 months
	Cauliflower	0	92–95	2–3 weeks
	Chicory	0–1	90–95	4 weeks
	Chinese cabbage	0.5–1	95–98	2–3 months
	Courgette	7–10	90–95	3 weeks
	Cucumber	7–10	90–95	10–14 days
	Egg plant	10	90–95	1–2 weeks
	Horseradish	−5	95	12 months
	Pepper (red/green)	8–9	90–95	3 weeks
	Pumpkin	10	60–70	2–6 months
	Tomato (½ ripe)	12–15	85–90	3 weeks
	Tomato (¾ ripe)	8–10	80–85	1–2 weeks

Sources: Max Rubner- Institut, Department of Safety and Quality of Fruit and Vegetables; Nicolaisen-Scupin/Hansen, Leitfaden für Lagerung und Transport von Gemüse und eßbaren Früchten, 1985; Osterloh et al., Handbuch der Lebensmitteltechnologie, Lagerung von Obst und Südfrüchten, Ulmer Verlag 1996

A few commodities tolerate mild freezing, for example parsnip, onions, and garlic (Aked 2002; James et al. 2009). Apples and pears for example can be stored at temperatures of 1–2 °C without physiological damages depending on the cultivar. For more sensitive apple cultivars a storage temperature of 3 °C is recommended. Even slight minus degrees are tolerated by certain apple species like ‘Rubinette’ (Schirmer 2001). In contrast, tropical and subtropical fruits are more susceptible to chilling injuries. These fruits must be stored at higher temperatures, mainly above 10 °C to avoid physiological damage of the fruit flesh and the skin. The storage temperature is depending on the fruit species. For example, banana and mango should be stored at 13 °C, where they keep their quality and do not ripe too fast. Citrus fruit like oranges, limes, and lemons can be transported and stored at 10–12 °C. The optimal transport and storage temperature is also depending on the maturity of the fruit. Immature, mature, unripe, and ripe fruit show a different sensitivity to temperature (Aked 2002). Ripe tropical and subtropical fruits can be stored at lower temperatures than unripe fruits. Climacteric tropical fruit like banana, mango, and avocado can be ripened after harvest by exposure to ethylene and temperatures around 20 °C. Because of this property, these products are harvested at a less mature status for better transport and ripened at the target destination.

3.2.2.2 Controlled Atmosphere Storage

Generally, storage under controlled atmosphere helps to preserve quality of fruit and vegetables over a long time, but optimal conditions for different cultivars must be determined regarding the specific requirements of the fruit and vegetables. Table 3.3 shows optimized controlled atmosphere conditions for selected fruit and vegetables. In addition to low storage temperatures, storage under controlled atmosphere (at lower oxygen concentrations, e.g., 1–3% for apples) reduces respiration, ethylene production, and physiological activity (Bekele et al. 2016) and helps to preserve harvest quality of fruit and vegetables. In general, chilling-sensitive products can be stored at slightly higher temperatures under controlled atmosphere without losing quality. However, not all fruit and vegetables tolerate elevated carbon dioxide (CO_2) concentrations in combination with very low oxygen (O_2) concentrations. For example, the apple cultivar 'Braeburn' is prone to internal browning (Felicetti et al. 2011) at higher CO_2 concentrations and very low O_2 concentrations. Therefore, for 'Braeburn' apples a storage atmosphere of <1% CO_2 and >1.5% O_2 is recommended. CO_2 resistant cultivars can be stored at 3% CO_2 and 1% O_2. Insensitive apple cultivars can so be stored under these conditions for 6–8 months at 1 °C. In contrast, redcurrants are very resistant to high CO_2 concentrations and can be stored at 25% CO_2 with 2% O_2 for a few months to preserve their quality, e.g. outer appearance, texture, and taste. In contrast, kiwifruit can be stored at CO_2 levels between 3% and 8% without any negative influence whereas carbon dioxide levels over 14% lead to less titratable acid content and abnormal texture (Harman and McDonald 1989).

3.2.2.3 Modified Atmosphere Packaging

An increasing consumer demand for convenience products – especially minimally processed and fresh-cut fruit and vegetables free of preservatives and artificial colours (Del-Valle et al. 2009) – makes it necessary to develop appropriate technologies to maintain the fresh quality of the products even outside of CA storage

Table 3.3 Storability of fruit and vegetables under controlled atmosphere (CA)

Type of fruit or vegetable	Species/cultivar		CA storage conditions: Temperature (°C)	Relative humidity (%)	CO_2 (%)	O_2 (%)	Storage time
Pome	Apple	Berlepsch	1	95	3	1–2	6 months
		Boskoop	4	93–95	2	2	5–7 months
		Braeburn	1	90–95	1	1–2	6–8 months
		Elstar	2–3	95	1	3	5 months
		Fuji	1	95	3	1	7 months
		Gala	1–2	93–95	3–5	2	5 months
		Golden Delicious	1–2	95	3–5	1–2	6–8 months
		Ingrid Marie	1–2	90–93	2–3	3	5 months
		Jonagold	1–2	90–95	3–5	1–2	6–7 months
		Pinova	1	90–95	3	1	6–8 months
		Rubinette	1–2	90–95	1	2–3	4–6 months
		Topaz	1	90–95	3	1	6–8 months
	Pear		−1 to 0	95	1–3	2–3	6 months
Stone fruit	Cherry (sour)		0–2	95	15–20	2–5	4 months
	Cherry (sweet)		0–2	95	15–20	1–5	7 months
	Peach/nectarine		0	95	5–10	2–5	4–6 months
	Plum		1	90–95	25	6	5–6 months
	Yellow plum		0.5–1	90	15	Air	6 months
Berries	Currants		0–2	90–95	20	1–2	6–8 months
	Gooseberries		1	90–95	15	Air	5 weeks
	Raspberries		0–2	90–95	20–25	Air	10 days
	Strawberries		0–2	90–95	15	6	10 days
	Table grapes		−0.5 to 1	90–95	15	6	2–3 months
Tropical fruit	Banana (green)		13	90	5–8	4–5	2 months
	Banana (ripe)		13	90	6	2	2 weeks
	Grapefruit		10–15	85–90	5–10	3–10	3–4 months
	Kiwi		−0.5 to 0.5	90–95	3–5	2–3	6–9 months
	Lychee		5–7	90–95	5	3–5	6 weeks
	Pineapple (½ ripe)		8–13	85–90	5–10	2–5	3–4 weeks
Vegetables	Artichoke		1	95	5–6	2	6 weeks
	Beans		7–8	95	3–5	2	2 weeks
	Broccoli		1	96–98	2–3	2–3	4 weeks
	Cabbage		0–1	95	4–5	2–3	8 months
	Cauliflower		1	95	5	3	6 weeks
	Chicory		1–2	95	4–5	3–4	8 weeks
	Chinese cabbage		0–1	98	0,5–2	2–3	4 months
	Cucumber		7–10	95	5	2	3 weeks
	Pepper (red/green)		1	95	2–3	2–3	6 weeks
	Tomato (¾ ripe)		14–15	85	3	4	3–4 weeks

Sources: Max Rubner- Institut, Department of Safety and Quality of Fruit and Vegetables; Nicolaisen-Scupin/Hansen, Leitfaden für Lagerung und Transport von Gemüse und eßbaren Früchten, 1985; Osterloh et al. Handbuch der Lebensmitteltechnologie, Lagerung von Obst und Südfrüchten, Ulmer Verlag 1996 facilities. Because of an intensive metabolic activity and spoilage caused by microorganisms, fresh cut fruits are very perishable.

Good agricultural production practices along with an appropriate use of temperature and modified atmosphere packaging are indispensable to preserve fruit quality by reducing spoilage and thus enabling a longer shelf life (Day 2002). Modified atmosphere in plastic bags is created by using foils with a different permeability of oxygen and carbon dioxide, e.g., to increase carbon dioxide concentration and reduce oxygen concentration. This change in atmosphere aiming to preserve product quality is depending on the respiration of the packed product with higher or lower carbon dioxide production. As an example, modified atmosphere packaging may help to preserve fresh-cut fruit and vegetables, which are especially prone to degenerative changes and a shorter shelf life (Putnik et al. 2017). Therefore, temperatures from 2 to 4 °C are recommended for storage of fresh-cut fruits to reduce spoilage, quality loss, and to improve food safety. However, storage of fresh-cut fruit and vegetables at such low temperatures is not always possible, especially during transport. To preserve food quality even at slightly higher temperatures, the use of modified atmosphere packaging can be very helpful. For example, fresh-cut pepper can be stored in modified atmosphere bags at 5 °C for 21 days without quality loss (González-Aguilar et al. 2004). Also in case of mandarin segments, another fruit with a high metabolic activity, modified atmosphere packaging may be advantageous: Mandarin segments stored under a micro-perforated film had an internal atmosphere of 19.8% O_2 and 1.2% CO_2 and their sensory quality was positively evaluated (Del-Valle et al. 2009).

3.2.3 Hot Water Treatment

Fruit and vegetables are susceptible to microbial decay and loss of valuable compounds after harvest. Increasing awareness of chemical residues on fruit and vegetables makes it necessary to find alternative methods to reduce microbial decay especially caused by fungi. Physical treatments became more and more important in recent years to control diseases in fruit and vegetables (Usall et al. 2016). Hot water treatment as a physical treatment has an antimicrobial effect, mainly due to the temperature influence on microorganisms. Therefore, an appropriate temperature for each disease causing microorganism has to be evaluated. Hot water treatment at 52 and 56 °C for 20 s up to 2 min can reduce post-harvest decay of apples and citrus fruit caused by *Gloeosporium* and *Penicillium digitatum* (Porat et al. 2000; Trierweiler et al. 2003; Maxin et al. 2014). Furthermore, hot water treatments of only parts of vegetables like stems of broccoli can reduce the senescence and preserve the product colour (Perini et al. 2017). According to two recent reports (Trierweiler et al. 2003; Auinger et al. 2005), the basic quality parameters of apples like titratable acidity, antioxidative capacity, total phenolics, and vitamin C are not negatively influenced by hot water treatment. The impact of hot water treatment on the metabolite profile and the overall quality of fruit has, however, not yet been studied in detail. Another important field of hot water treatment are fresh-cut fruit, especially tropical fruit which are more perishable than fresh-cut apples or pears. Hot water treatment of whole mangoes before processing shows a global beneficial effect on the nutrient quality of the fresh-cut product and a better acceptability over a shelf-life of 6 days (Djioua et al. 2009). Therefore, product specific hot water treatment is a good opportunity to reduce post-harvest diseases and preserve sensory and nutritious quality of fruit and vegetables without leaving chemical residues behind (Trierweiler et al. 2003). An appropriate treatment temperature and time is important to prevent for example apples of superficial scald.

3.2.4 UV-C Treatment

Another physical non-thermal processing technology for preservation of fruit and vegetable quality and safety is the UV-C treatment. The use of UV-C light reduces microbiological deterioration and quality loss by enzymatic browning in different fruit and vegetable juices (Zhang et al. 2011; Müller et al. 2014; Riganakos et al. 2017). Not only fruit and vegetable juices can be treated with UV-C to reduce microbial spoilage and changes in nutrients: Leafy vegetables exhibited higher contents of nutritious compounds after UV-C treatment possibly because of an induced stress situation followed by a plant associated defence mechanism (Gogo et al. 2018). UV-C treatment of leafy vegetables especially in developing countries can help to provide people in these countries with healthy and safe food. Additionally, UV-C treatment requires less energy than the normal thermal treatment of fruit and vegetables which are normally used for quality preservation (Riganakos et al. 2017). This could be an advantage in developing countries where energy is often limited and expensive to provide the consumer with safe and high quality food.

3.2.5 Fermentation

Fermentation is a common method for food preservation mainly where transport and storage at low temperatures are not always guaranteed. Furthermore, it is easy to carry out in households without a lot of technology. Fermented food products are highly appreciated not only because the shelf life of products is prolonged, but also because taste, aroma, texture, and digestibility are enhanced (Holzapfel 2002). Fermentation of foods like leafy vegetables can happen spontaneously, caused by the autochthonous microbiota occurring on the raw leaves. The success of this fermentation is depending on the composition of the autochthonous microflora, especially the presence of lactic acid bacteria which are able to use sugars and produce different acids and several antimicrobial substances. In contrast, fast lowering of the pH of a fermentation approach is very important to inhibit the growth of undesirable spoilage and potentially pathogenic microorganisms like *Salmonella Enteritidis* and

Listeria monocytogenes and to obtain a safe food. To achieve this goal, the use of well-characterized lactic acid starter cultures is a big advantage in comparison to a spontaneous fermentation because they produce a certain amount of acid and reduce the pH of the fermentation batch. A fermentation approach with nightshade leaves (African indigenous vegetable) using starter cultures led to a pH below 3.5 in 24 h in comparison to a pH of about 6.5 without starter cultures (Wafula 2017). The same author also found a good preservation of vitamin B_2 and E after fermentation of cowpea leaves (African indigenous vegetable) with lactic acid bacteria *Lactobacillus plantarum* BFE 5092 and *Lb. fermentum* BFE 6620 as starter cultures.

3.3 Perspective

Quality of fruit and vegetables cannot be improved after harvest. It is only possible to try to preserve the quality produced on the field. Therefore, appropriate technologies must be available during transport and storage and even at the consumer level. Generally, low temperatures should be preferred with the exception of tropical and subtropical fruit which are sensitive to chilling injuries. In addition, storage under controlled atmosphere helps to preserve fruit and vegetable quality by slowing down the metabolism of the products. In the future, the use of optimized product specific post-harvest treatments like modified atmosphere packaging, hot water treatment, and UV-C-treatment could support the preservation of high quality fruit and vegetables during transport, storage, and the supply chain and to provide health promoting foods to the consumers. It is also important for the future to develop product specific conditions of the above mentioned post-harvest treatments to take all the possible susceptibilities of different fruit and vegetables into account to achieve the best quality and safety of the products for the consumer.

3.4 Conclusion

Quality of fruit and vegetables cannot be improved after harvest. It is only possible to preserve the quality produced on the field. Therefore, appropriate technologies must be available during transport, storage, marketing, and even at the consumer level. Generally, low temperatures should be preferred with the exception of tropical and subtropical fruit which are sensitive to chilling injuries.

In the future the use of optimized product specific post-harvest treatments like modified atmosphere packaging, hot water treatment, UV-C-treatment could support the preservation of good quality of fruit and vegetables and deliver the consumer with possibly health promoting food.

Fermentation is a common post-harvest method for food preservation mainly where transport and storage at low temperatures are not always guaranteed. Fermentation of foods like leafy vegetables can happen spontaneously, caused by the autochthonous microbiota occurring on the raw leaves. Fast lowering of the pH of a fermentation approach is very important to inhibit the growth of undesirable spoilage and potentially pathogenic microorganisms like *Salmonella Enteritidis* and *Listeria monocytogenes*. To achieve this goal, the use of well-characterized lactic acid starter cultures in comparison to a spontaneous fermentation is recommended because they produce a certain amount of acid and reduce the pH of the fermentation batch in the desired time of 24 h.

In addition to the targeted determination of basic quality parameters of fruit and vegetables after different post-harvest treatments, the untargeted metabolomics approach enables an in-depth evaluation of fruit composition and thus fruit quality.

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