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Effects of equipments and processing conditions on quality of fresh-cut produce

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Abstract

A wide range of fresh conveniently packaged, minimally processed products are available on both local and global market in response to consumer demand for ready to eat food. Majority of these products are leafy vegetables, which are highly susceptible to quality changes during minimal processing operations (trimming, cutting, washing, drying, and packaging). Despite the available precautionary measures for maintaining quality attributes of raw and processed material, quality degradation due to minimally processing is unavoidable, also considering that a peeling, trimming and/or cutting operation is always present except than for baby leaves and small fruits. In addition, other operations as washing and drying are known to cause mechanical stresses and loss of sugars and nutrients. However, the extent to which quality is compromised depends on the produce and on the processing conditions, including equipment and their operational settings. This review aims to describe the main processing operations and equipment used, resuming the available information on their impact on final quality of fresh-cut products over storage, in order to identify areas for future research aiming to the enhancement of product quality.

Introduction

A variety of conveniently packaged, lightly processed fresh products also known as *minimally-processed* or *fresh-cut* products are available on the market in response to a worldwide consumer demand for ready to eat food. Majority of these products, highly susceptible to quality changes during minimal processing activities (trimming, cutting, washing, centrifugation or drying of surface water), are represented by leafy vegetables, although an increasing share of the market is also represented by fruit-based convenience product. Processing and handling of fresh produce at appropriate low temperature, relative humidity, optimum atmosphere storage and suitable packaging protect their color, texture, flavor and nutritional attributes (Paull, 1999; Kader, 2002). Despite the available precautionary measures for maintaining quality attributes as mentioned, alteration of physiological processes of the produce during minimal processing is unavoidable. However, the extent to which quality is compromised depends on the produce and on the processing conditions. Produce characteristics include the type of crop (tissue, organ and its composition), respiration rate, time of harvest, maturity stage and any pre-processing treatment it may have been subjected to prior to processing. The processing conditions include the temperature in the facility, water quality, used sanitizer, equipments used during processing, and packaging solutions. Therefore, understanding the changes that occur during minimal processing and how each processing activity and equipment used contribute to product stress and quality loss will aid to improve minimal processing and product quality.

This review aims to describe the main processing operations and equipments used, resuming the available information on their impact on final quality of fresh-cut products over storage, in order to identify areas for future research aiming to the enhancement of product quality. Main research paper and some specific review are included in Table 1.

Influence of minimal processing operations/ equipment on quality changes

The equipments required for minimal processing of fresh produce perform different functions during the various processing steps (*i.e.* de-coring, peeling, cutting, shredding, washing, drying, *etc*.), influencing the final quality of the product. At each step operations may alter the integrity of the raw material, especially in the cut products, making them more prone to deterioration (Sanz *et al*., 2002). Also, different unit operations may provide opportunities for cross-contamination, as a small lot of contaminated product may affect a large lot during the processing steps (Gil *et al*., 2015). In addition due to leaching of nutrients and exudates, it is important to process different leafy vegetables in different processing lines or to carefully clean the lines before changing product. A classic example is with cabbage which releases a high concentration of organic nutrients into washing water during processing (Cantwell and Suslow, 1999).

The main risk factors for product quality and safety are related to the temperature during processing, water quality and sanitation, hygienic design and hygienic status of equipments, as well as employee hygiene and training (Castro-Ibáñez *et al*., 2016). The main minimal processing steps and the effects of the various equipments used for fresh-cut processing are discussed in detail in the subsequent section. Particularly only the steps directly involved in manipulation of the product will be discussed, omitting phases as product grading and classification for which an extensive review is already published (Giovenzana *et al*., 2015). Figure 1 depicts the mostly practiced minimal processing steps and product handling operations for fresh-cut processing.

Cutting

Cutting or size reduction is an important step in the preparation of fresh-cut fruits and vegetables. Moreover peeling and trimming may be also additional operations which also induce the same kind of damage to the tissues. Rotating blades are used for leafy and some fruit vegetables, whereas more complex and species-specific cutting machines are used for fruits. The choice and type of cut depend on the intended use of the product in relation to the commercial standards; moreover, the level of machinery automation may vary from very low (*i.e*. manual operation) to very high, particularly for fresh-cut fruit processing. Peeling may be achieved via chemical, mechanical or high-pressure methods, but the mechanical method is the most used. Manual peeling machines for fruits consist of a cylinder blade which, after applying a manual pressure, cut the external ring of the fruits including the skin. Other simple and discontinuous peeling machines make the fruits rotate while a mobile arm equipped with a vertical blade removes the skin. This is also the principle adopted for automatic machines where the fruits are well oriented before peeling and subsequently cut; these machines may process from 5 to 30 fruits per minute. In discontinuous lines, or in flow-chart where peeling is not required, knives of different kinds, or dicers, slicers, choppers, and shredders are used for further size reductions, exerting different forms of stresses and injuries on cut products. Different slice height and piece dimensions may generally be achieved by regulating the blade distance or changing the cutting accessories. All these processes break the surface epidermal layer and may ruin cell integrity in deeper tissues of produce, causing an increase in respiration, a release of phytonutrients while exposing the product surface to microbial contamination. The limitations related to these processing steps include, desiccation, microbial spoilage, browning of tissues, discoloration, development of off-flavor and taste defects (Bansal *et al*., 2015).

Several studies have reported the effects of cutting on fresh-cut produce.

Wound-induced respiration rate for each type of cut increased with the number of cutting as for whole, half, sliced potato and potato sticks (Gorny 2003), or for shredded and sliced radicchio (Saavedra del Aguila *et al*., 2006), and particularly with increasing of the ratio as cut surface area by the tissue weight as shown on carrots (Surjadinata and Cisneros-Zevallos, 2003). Moreover some authors also observed different responses of cut pieces to the atmosphere composition, reporting that the reduction of respiration induced by controlled atmosphere storage was greater in slices or sticks than in shredded carrots (Izumi, *et al*., 1996).

Aguayo *et al.* (2004) also found that melons cut in cylinders exhibited more translucency after 10 days storage compared to slices and trapezoidal cuts. In addition cutting may cause the release of exudates that provide nutrients to promote the growth of enteric pathogens (Matthews, 2013). Notably, this step is a critical point that requires processing line hygiene.

Equipments used for cutting need to be cleaned, disinfected and sharpened at regular intervals every working day to avoid the build-up of organic residues and microbial contaminants, as well as to reduce damage caused to the product (CAC, 2003; FDA/CFSAN, 2008).

Barry-Ryan and O'Beirne (1998) showed the effect of blade sharpness on the severity of physical damage, physiological stress and microbial growth of a commodity as razor blade < sharp machine blade < blunt machine blade (razor blade cause the least damage). In confirmation, fresh-cut carrots prepared with sharp cutting blades showed reduced wound response, lignin accumulation, white blush, softening, and microbial growth (Barry-Ryan and O'Beirne, 1998); melon pieces cut with a sharp blade exhibited less ethanol concentrations, off-odor, and electrolyte leakage compared to pieces processed with a blunt blade (Portela and Cantwell, 2001). Though the level of sharpness was not quantified, Grout *et al.* (2002) reported that maintaining cutting knives at a high level of sharpness, delayed the onset of enzymatic browning on sliced green beans by up to one day in cold storage. The use of new knife blades, in fact, caused less damage compared to used and sharpened blades which induced red discoloration and whitening dehydration on cut romaine lettuce after 12 days in air at 2.5°C (O'Beirne, 1995).

Furthermore, scanning electron and fluorescence microscopic imaging showed that sharp blade cutting (thickness, 0.04 mm) of eggplants caused less physical injury and cell death, compared to conventional knife (blade thickness about 0.25 mm); particularly a reduction of phenolic leaks and of polyphenol oxidase activity was observed wich resulted in lesser browning (Mishra *et al.*, 2012). Moreover the effect of cutting type and intensity may still be observed on quality and composition of cut produce after storage. It has been shown that increasing the number of cutting increased metabolic activity and decreased sensorial evaluation of sweet pumpkins (Lee *et al.*, 2008), and reduced flavor and phytochemical content of cut lemons (Artés-Hernández *et al.*, 2007). In a recent work the effect of the wounding intensity was studied on strawberries, which were cut into 4, 16, 64, 128 pieces and chopped (Solomon *et al*., submitted). Results showed that respiration rate increased with wounding intensity up to the level of 64 pieces compared to whole fruits and then decreased in the chopped samples, in which the damage compromised cell functionality. The extent of loss of ascorbic acid in iceberg lettuce has also been attributed to the cutting method and sharpness of the blade; machine and manually slicing caused a lower retention of ascorbic acid than manual tearing on cut iceberg lettuce (Barry-Ryan and O'Beirne, 1999).

Besides sharpness, the type of blade itself and equipment used may also influence cutting quality. Fresh-cut lettuce processed with sharp rotating blades was reported to have lower respiration rates and microbial counts during storage than those with sharp stationary blades (O'Beirne, 1995). Some authors also recommended food grade water-jet cutting to have superior cutting quality (in terms of product visual quality and discoloration) than blade cutting (Cantwell *et al.*, 2016), but literature is scarce and contradictorial. McGlynn *et al.,* (2003), found that water jet cut melon were darker but firmer than kinfe-cut pieces, whereas Wulfkuehler *et al.* (2014) did not find any difference in terms of microbial, physiological and sensorial quality of fresh-cut lettuce cut with water jet compared to blade cutting.

Despite the effects of the cutting equipment, the severity of the cutting may also be influenced by the direction and may vary from product to product. However, research work with regards to cutting direction is not very extensive. Abe *et al.,* (1998) reported that longitudinal cut direction produced banana slices that browned and softened rapidly and with higher respiration rate than those cut in the transverse direction. On the contrary, Deza-Derund and Petersen (2011) assessing the impact of cutting direction on respiration rate and volatiles formation reported that transverse cutting of lettuce through the mid-rib was a more severe method of preparation, which emitted volatiles of the lipoxygenase (LOX) pathway, while longitudinal cutting enhanced formation of volatiles from other metabolic routes.

Generally, selecting the right type of blade, using sharp blades and reducing the extent of tissue damage would minimize quality losses, provided temperatures are low enough to minimize respiration and metabolism.

Washing

Washing has the objective to remove foreign material, soil, dust and any agrochemical residues weakly bound to the surfaces of whole or cut products (Lopez-Fernandez *et al*., 2013). Moreover washing is considered as the primary step for reducing the total microbial count of the product (Allende *et al*., 2008) before it is packaged although, if not done properly, cross-contamination may occur (Olaimat and Holley, 2012). Usually washing systems in the fresh-cut industry are made up of three washing phases: the first two taking place in 2 adjacent tanks, while the third, namely a rinsing phase, is usually carried out through a showering system. However, depending on the product and operating conditions of a company, the washing phases in tanks could also be single or double with various wash and spray combinations (Luo, 2007). Figure 2 depicts a typical washing system in the minimal processing industry. This washing system is sometimes termed as *jacuzzi* due to the produced bubbling action. Water and product normally flow in opposite directions, with the purity of the water-decreasing passing from last to first washing tank.

The first wash removes all dirt, soil and debris combining in most of the case both the shower and water immersion.

Water in this tank increases rapidly in microbiological load, requiring an implementation of a filtration and refreshing water system that respects the product-to-water ratio, and application of a disinfecting agent to keep the microbial load of the water to a low level (López-Gálvez *et al*., 2010; Holvoet *et al*., 2012). A second wash is then performed in the following tank. At this phase, any microbiological load on the product is further decreased; however, cross-contamination within a lot or among lots may occur (Luo *et al*., 2011). In this same tank, sanitation of the product takes place and the water is treated with a chemical agent to reduce microbial load and prevent cross-contamination during washing (Soliva-Fortuny and Martin-Belloso, 2003). The turbulence or force of flowing wash water on produce surface mainly promotes the mechanical removal of microorganisms; however, it may also cause slight structural damage to soft leafy vegetables. Besides, in cut products the surface may absorb wash water, making disinfection very critical to prevent contamination (Cantwell and Suslow, 1999). Despite the quantity of water used, the quality of water used in washing whole products impacts on the effectiveness of washing (Allende *et al*., 2008; López-Gálvez *et al*., 2009). Moreover, conveyors used to transport fresh-cut products to the washer and from washer to the dryer are known to be one of the hotspots for microbial contamination (Buchholz *et al*., 2012).

The third and last washing phase before packaging is the rinsing step, which requires very low or, most frequently, no dose of disinfecting agent to achieve good results. Other commercial operations also adapt open and closed-flume systems (Luo, 2007). Recently, a patented system which has adapted the closed pipe flume concept, have been introduced to wash fragile and delicate products, such that contact time with sanitizing water solution is precisely controlled for full immersion and appropriate treatment time (Turatti, 2015). This has been recommended, as it does not remove the bloom of blueberries and may be applicable for delicate baby leaf vegetables. Other washing systems including ozone washers which operate in two ways, either by a rotational movement to stir washing water or by mid-range ultrasonic waves to produce bubbles have been proposed (Kim *et al*., 1999).

Chlorine is the most used among sanitizer. It is relatively easy to use, low cost and is able to prevent pathogen cross-contamination of produce during washing (López-Gálvez *et al*., 2009; Luo *et al*., 2011). However, the potential generation of trihalomethanes (THMs), when chlorine or chlorine-based sanitizers are used, may present health hazards, although recent studies have reported that total THM levels in the vegetable tissue were below the detection limit (Gómez-López *et al*., 2013). Moreover, chlorine-based sanitizers, used under optimal conditions, should not represent a high risk of THM formation (Artés-Hernández *et al*., 2013). Chlorinated water used for disinfection, has also been found to be effective in removing pesticide residue on the surface of fruits and vegetables (Bajwa and Sandhu, 2014). Nonetheless, loss of pesticide residues on the surface of leafy vegetables is dependent on the solubility of the pesticide in water as described for diethofencarb on crown daisy leaves during washing with stagnant and then running water (Kim *et al*., 2016). The use of sanitizers alternative to chlorine, as peroxyacetic acid (among the most promising), have been studied as reported in several studies (Gonzalez *et al*., 2004; Gómez-López *et al*., 2007; Baert *et al*., 2009; Gil *et al*., 2009; Vandekinderen *et al*., 2009).

The washing and cooling of products directly after cutting reduces respiration and minimizes the injury responses by removing sugars, stress-related compounds like acetaldehyde, phenols and other nutrients on the cut surfaces that may also favor microbial growth and tissue browning or discoloration (Cantwell and Suslow, 1999; Toivonen and Stan, 2004). Also, the unknown signal elicited by wounding which initiates tissue degradation might be removed by washing (Cisneros *et al*., 2014).

To prevent internalization and infiltration of bacteria, wash water temperature should not be much lower than product temperature (Sapers, 2003), as it could cause a negative temperature differential and a partial vacuum, due to gas volume reduction, that will draw in water, through the natural fruit cavities(pores or even cut surfaces), causing possible chemical or microbial contamination (Sapers, 2003). This is particularly true for products characterized by fairly large dimensions (*i.e*. melons, pineapples). Wash water temperature should be about 5°C higher than the internal temperature of the product to prevent the water *suction* effect

(Hernandez-Brenes, 2002; Nicola *et al*., 2009). Temperature gap between the produce and the water temperature could be minimized by air-cooling prior to washing (Nicola *et al*., 2009).

Most of the research studies on the use of sanitizer during washing have focused on microbial quality and reduction, with very little information about the effect on phytonutrients (Beltran *et al*., 2005; Martínez-Sánchez *et al*., 2006). Vandekinderen *et al.* (2007) reported that the use of peroxyacetic acid (*Chriox 5*) led to a loss of total vitamin C content varying from 15 to 25%. However, rinsing fresh-cut vegetables with water is already known to cause a loss of total vitamin C of about 20%, due to its hydrophilic properties. On the other side, decontamination with potable water or sodium hypochlorite (20 and 200 mg L^{-1}) did not lead to a decrease in alpha- and beta-carotene (not water soluble) of fresh-cut carrots (Vandekinderen *et al*., 2007).

The oxidative action of disinfectant, coupled with bubble action of the washer may also cause browning or loss of green color on the whole un-cut surface of leaves during storage. Optimizing washing operations could also help to reduce these effects.

Drying

After washing, removal of gained moisture on the produce surfaces is done using several systems, which include draining devices, centrifugal spin dryers, vibrating racks, rotating conveyors, hydro sieves, forced air and spin less drying tunnels (Gorny *et al*., 2002). Centrifugation or spin-drying is widely used in the fresh-cut industry, although other methods such as vibration screen and forced air tunnel have also been adopted for water removal (Moretti *et al*, 2007). Vibratory conveyors are used for dewatering of leafy vegetables (*i.e.* removing excess of water from the surface of the produce) before they enter into more thorough drying systems, represented by centrifuges/spin dryers. Surface drying on the conveyor belt is achieved through passing forced chilled air circulating over a perforated belt that transports the products as in the use of air-bed conveyors which are widespread in use across Europe and the United States, although their efficiency to dry high volumes should be optimized (Artés and Artés-Hernández, 2003; Turatti, 2011). Excessive centrifugal force not only removes water, but it may also crack and deform produce tissues hastening senescence (Ahvenainen, 2000). Liquid loss due to the damaged cells from the spinning process may also affect sensorial attributes like visual quality, taste and texture. It is therefore important to optimize speed and time requirements suitable for specific products to reduce quality losses during the process. Liquids removed from cell leakages during the drying process can support microbial growth and enzyme activity; populations of Salmonella were recovered from centrifugation discharge indicating this step as potentially hazardous for cross-contamination (Artés-Hernández *et al*., 2013). Research suggests that effluent water discharged by centrifugation represents a potential risk of cross-contamination to product and equipment prior to packaging (Tomás-Callejas *et al*., 2012). For leafy vegetables like lettuce, removal of slightly more moisture (*i.e*., slight desiccation of the product) may favor longer post-processing life (Cantwell and Suslow, 1999). This may also be true for rocket leaves as controlling the development of off-odors in packaged washed leaves during storage was related to the critical need for the complete removal of free water during the drying step (Rux *et al*., 2017).

Several studies have been published on the effect of drying systems on the nutritional quality of dried vegetable products, however, there are very few studies on the effect of drying operations on the content of phytonutrients in fresh-cut products. Although it has been reported that the retention of nutritional properties of leafy greens is higher at a faster drying rate (Negi and Roy, 2001), the extent to which drying dynamics affect the product quality is unknown. In air-tunnel drying systems, heated dry air absorbs moisture from the product, which then passes through a cooling unit which blows cold air before it exits the dryer.

Though the heated air is applied for a short period, high temperatures may induce several irreversible biological or chemical reactions, which may cause modifications in color, a decrease of sensory quality, and losses of nutrients, aroma and texture (Abid *et al*., 1990). Despite this, if drying is done under controlled conditions with cold air, then the fresh properties of the product can be maintained (Nagaya *et al*., 2006); the only limitation is that the air-dryers have low efficiency to dry high volumes of product (Artés-Hernández *et al*., 2013).

The use of predictive models like the multiphase transport model can be adapted to aid in improving drying efficiency as it is capable of predicting actual drying rates, operating conditions and it assures the absence of critical wet areas on product surfaces for microbial spoilage (Curcio *et al*., 2016). Other drying techniques that may be adapted include the use of low humidity air dryers, infrared air dryers (where infrared is used as the heat source) and radio frequency dryers (Naidu *et al*., 2016), which are also reported to minimize chemical degradation and nutrient loss (Van Loey *et al*., 2005).

Packaging

This is the final step of minimal processing. At this step, optimum packaging conditions depend on the characteristics of the fresh-cut fruit or vegetable and its packaging material requirements for manual or automated operations. The selection of an ideal packaging material for each product will depend among other factors on the kind of package (rigid tray, semi-rigid lidded tray or flexible bag); barrier properties (oxygen, carbon dioxide, and water vapour transmission rates); physical attributes of the film (clarity, durability, str*etc*h capability, thickness, machinability-resistance to tearing, puncture); sealing reliability-precision and integrity of heat sealing or closure, antifog properties; absence of toxicity and interaction with the product; resistance to chemical degradation; printable, economical and commercial suitability of the film (Mangaraj *et al*., 2009). Fresh-cut products are both weighed and packaged directly or temporarily stored (0-12 h) in a cold room prior to packaging.

Active MAP is aimed to rapidly substitute air with the desired gas composition by gas-flushing with addition of nitrogen and CO_2 to speed up the achievement of the equilibrium. Passive MAP on the other hand is developed by the only interaction of packaging film gas permeability and respiration rate of the product (Zagory, 1999; Artés *et al*., 2006; Gavara *et al*., 2009) and is used for a product for which the use of gas composition different from air is less critical to the final quality and shelf-life, for instance, in whole adult leaves for which browning is not a limiting factor.

Automatic fill-seal systems equipped with gas mixers are commonly used to apply either passive or active MAP. They are made up of vertical or horizontal flow pack systems. The packaging machines are usually made of round vertical tubes wrapped with tubular packaging material. The machine seals first the bottom part of the bag, fills it with the product transported it in the internal part of the tube by using weight-based portion control machines (Gil *et al*., 2015); after filling the upper part of the bag is sealed. These equipments may also have a gas mixer or filler such that exiting product is flushed with the appropriate gas compositions. The mixture of O_2, CO_2 and N_2 gases flushed into film packages during form-fill sealing may affect fresh-cut product quality depending on the sealing strength, respiration rate of the product and the packaging film. Generally, modified atmosphere with low O_2 and/or high CO_2 concentrations, compensated with N_2 gas is used. Usually, low O_2 and/or high CO_2 gas concentrations, decrease the respiration rate of the product, the growth of postharvest pathogens, preserve the visual appearance, maintain nutritional quality, slows down browning process and the rate of deterioration during storage (Kader *et al*., 1989; Gorny, 2003). Note that low O_2 and/or high CO_2 as used is in relation to that of normal air, which is about 21% O_2, <0.03% CO_2 and about 78% N_2.

CO_2 is a colorless gas and has a slightly pungent odor when it is used at very high concentrations, which is valued in the modified atmosphere packaging of foods, due to its bacteriostatic and fungistatic properties. It inhibits the growth of the many spoilage bacteria and the inhibition rate increases with increased CO_2 concentrations in the given atmospheres. However for elevated CO_2 to be effective against microorganisms, low temperature conditions are required because its solubility decreases with increasing temperature (Sivertsvik *et al*., 2002). High CO_2 modified atmosphere has also been reported to significantly inhibit phenolic accumulation in fresh-cut lettuce and carrots due to the ability to inhibit the phenylalanine ammonia lyase activity (Mateos, 1993; Amanatidou *et al*., 2000). An equilibrium atmosphere is attained when film permeation rates for O_2 and CO_2 match the respiration rates of the packaged fresh produce inside a package (Jacxsens *et al*., 2001; Almenar *et al*., 2007). This is critical for the success of MAP storage since exposure of fresh produce to too high CO_2 levels may cause physiological damages while exposure to too low O_2 levels may induce anaerobic respiration and the development of off-flavors (Zagory and Kader, 1988; Pesis, 2005; Manolopoulou and Varzakas, 2015). High levels of CO_2 may have a deleterious effect on cell membrane and can cause physiological damage, browning reactions, produce off-flavors and increase the aging rates of fruit and vegetable products (Pascall, 2011). As observed by la Zazzera *et al.* (2012) fresh-cut artichokes stored in air + 25% CO_2 showed a tendency to develop brown spots on the external bracts and higher ammonia accumulation compared to lower CO_2 concentrations at the end of 8 days storage at 5°C.

The optimal atmosphere concentration for most popular cut-products have been identified (Gorny, 2003), and there are many studies on the effect of gas composition and on packaging optimization for less popular species such as fresh-cut coconut (Amodio *et al*., 2004); basil leaves (Amodio *et al*., 2005); rocket salad (Cornacchia *et al*., 2006); fennels (Rinaldi *et al*., 2010); fresh-cut pumpkins (Amodio *et al*., 2010); artichokes (la Zazzera *et al*., 2015); broccoli raab (Cefola *et al*., 2016a); zucchini flowers (Cefola *et al*., 2016b); mushrooms (Capotorto *et al*., 2015), and peaches (Colantuono *et al*., 2015). Beside conventional atmospheres, non-conventional gases like argon, nitrous oxide, helium or superoxygen (O_2>20%, generally from 60 to 100%), have emerged they are still being tested (Baldassare *et al*., 2013; Ansah *et al*., 2015; Inestroza-Lizardo *et al*., 2016) and not introduced commercially.

Despite knowing the optimal gas levels for a given product, very often in real conditions, some shifts are observed from desired gas levels and the effective composition obtained at the equilibrium in the package headspace, mainly depending on packaging film and storage temperature (Sandhya, 2010).

The design and selection of the appropriate polymeric films, together with suitable trays, and an appropriate sealing is crucial (Artés *et al*., 2006). Low-density polyethylene and polypropylene are the main films used for packaging fruits and vegetables (Lee *et al*., 1996; Kader and Saltveit, 2003). They contribute to the prevention of desiccation and flaccidity due to vapor barrier properties and reduce the rate of senescence and re-contamination by microorganisms (Brecht *et al*., 2004). MAP packages are checked periodically for seal integrity in water-filled pressurized chamber. Despite the ample information available on packaging films in the horticultural industry (Lange, 2000), modified atmosphere packaging machines, modes of operation,and different method of gas packaging (Parry, 2012), there is scarce literature on the effects of packaging machines on sealing ability and subsequent quality of fresh-cut products. A typical limitation on produce quality will be the inability of vertical form-fill-seal packaging machines to seal films with narrow sealing ranges without accurate temperature controllers (NIIR Board, 2002). Temperature may, in fact, cause thermal degradation of films, which can lead to suboptimal sealing (Mihindukulasuriya and Lim, 2012). Secondly, the type of heat sealers and film material used in automated packaging may affect the shelf life quality of products. The feasibility of using vertical-form-fill with thermal sealers on biodegradable high-density polyethylene (BHDPE) and biodegradable polypropylene (BPP) was studied by Brown *et al.* (2009) on fresh-cut romaine lettuce. Seal integrity was not guaranteed for both films performing much worse than the control in conventional polyethylene/oriented polypropilene (PE/OPP). In a second experiment, a hand impulse sealer provided sufficient hermetic conditions for BHDPE bags such that packaged romaine lettuce had similar decay rate and level of pinking after 14 days storage as that of the PE/OPP conventional bags (Brown *et al*., 2009).

Package sealing integrity and precision can also be compromised by an interference of water from the fresh-cut product itself at the film-film interface during the filling process. However, processing parameters of the form-fill-seal machines can help to improve sealing strength when carefully tailored to film characteristics irrespective of water or liquid interference. Mihindukulasuriya and Lim (2012) found that a combination of 165°C jaw temperature and 1s dwell time was required to form intact seals on water-contaminated linear low-density polyethylene (LLDPE) films, but interface temperature of 130-140°C provided the most optimum seal strength for both water contaminated and clean LLDPE films. Sealing strength is important to maintain intact modified atmosphere gas conditions for fresh-cut quality. Temperature near the fusion point, but below the melting point is recommended for achieving the highest peel seal strength (Aithani *et al*., 2006); particularly temperature should ensure that high-molecular-weight and less branched chains began to melt and diffuse across the interface (Mueller *et al*., 1998). In contrast to welded films, intact seals can be obtained for peelable films at a lower temperature and lower pressure but with longer dwelling times (Baker, 2009). However line speed may directly influence dwelling time, the faster the speed, the shorter the dwelling time (Yuan *et al*., 2007) and vice versa.

Finally, once a processor individuates the packaging material and dimensions for a given product, a variation in the respiration rate of the raw material may lead to unexpected and undesirable gas composition at the equilibrium (Sivertsvik *et al.*, 2002). This may be the case of products having variable respiration with the season, or if different varieties are alternated along the year. Tudela *et al.,* (2013) found that a faster accumulation of CO_2 in the headspace of cut-products from immature heads than in over-mature ones, and an extreme variability among different varieties and in different months during the winter-spring seasons. As another example, respiration rate of rocket leaves was found to vary with the season and the number of cutting (first, second, *etc.*) or maturity (Martínez-Sánchez *et al.*, 2008; Seefeldt *et al.*, 2012). The same variability has been reported for different variety and time of harvest of broccoli florets (Seefeldt *et al.*, 2012). All these factors suggest that respiration rate is a very critical factor to be monitored before packaging, particularly in the case of different sources of raw materials. Mastrandrea *et al.,* (2017a) showed that when respiration rate is underestimated, the improper gas atmosphere in the packaging can reduce shelf-life of rocket leaves, even if stored at proper temperature (5°C). In addition, any temperature abuse during transport, distribution and display, will induce an increase of product metabolism dramatically affecting the gas composition within the packaging. Even a short period of temperature abuse can, in fact, be detrimental to the final product quality and shelf-life, enhancing degradative reaction and the growth of microorganisms, with the consequent development of off-odors, as shown for several fresh-cut products (Kou *et al.*, 2014; Luca *et al.*, 2016;). Amodio *et al.,* (2015) showed on fresh rocket leaves that an abuse at 13°C for 24 hours reduced the product shelf life of about 10% (from 5.8 to 5.2 days). Moreover the authors also showed that a fluctuation of 5°C in the temperature (remaining between 5 and 10°C), could decrease the shelf-life of almost 1 day. In addition Mastrandrea *et al.* (2017b) found an increase of acetaldehyde and dimethyl sulfide following temperature abuse over storage in MAP of minimally processed rocket leaves, which persisted even when the cold chain was restored. The temperature recommended for storing fresh-cut products packaged in a modified atmosphere is between 0°C and 5°C, but these products are often kept at temperatures of 10 to 12°C, during display (Oliveira *et al*., 2010). Such temperature conditions also increase the risk of water condensation within packages due to poor gas exchange between the film, the product and the surrounding environment (Artés *et al*., 2006).

Conclusions

This review allowed making the state of the art of available literature assessing the impact of processing operation during minimally processing on quality of fresh-cut produce.

The extent of the damage was shown to vary with the different type of equipments and different operation modes Moreover, while some processing steps as washing and cutting are well studied, less is known about others. Further studies may be aimed to study drying control parameter effect on final quality of cut produce, also in relation to minimizing energy cost. Regarding to packaging, most of the literature focus on gas optimization, and generally of a single species, while when different products are mixed several issues related to compatibility and tolerance thresholds to oxygen and carbon dioxide need to be assessed. Moreover in relation to packaging biological fluctuation of respiration rate of raw material should be better investigated. Finally, while the impact of processing on sensorial and microbial quality have been more extensively covered, however, the study on those effects on phytonutrient retention are less abundant and thus need more investigation.

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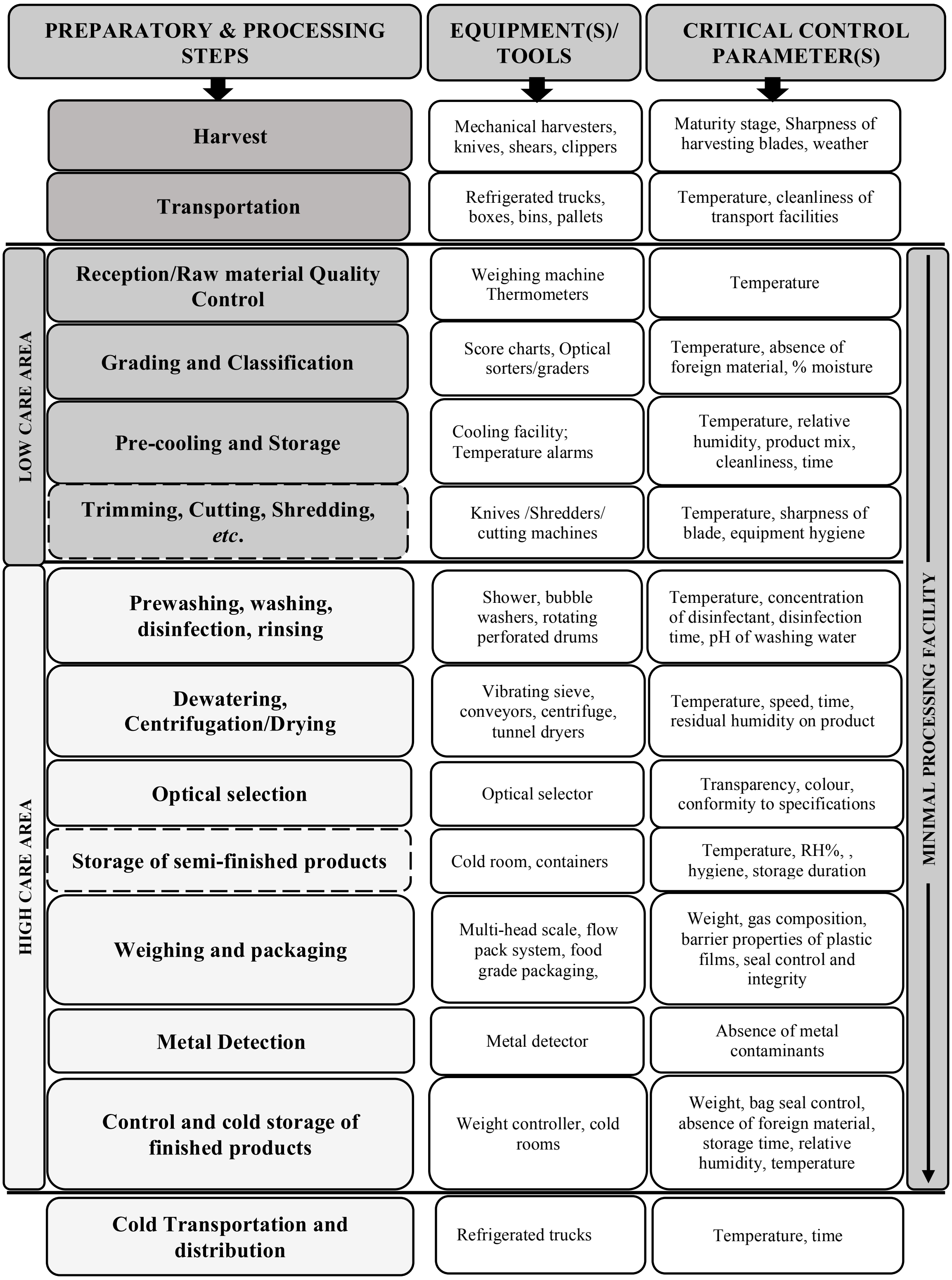
Table 1. Overview of existing literature on the effect of different Operation ster.

Processing step	**Object of the study**	**Produce/Material**	**Reference**
Cutting	Blade sharpness	Bobby Beans	Grout *et al.*, 2002
		Cantaloupe Melon	Portela and Cantwell 2001
		Carrots	Barry-Ryan and O'Beirne 1998
		Eggplant	Mishra *et al.*, 2012
	Blade sharpness/rotating and stable blades	Fresh-cut vegetables	O'Beirne D. 1995
	Cutting mode (direction)	Banana	Abe *et al.*, 1998.
		Lettuce	Deza-Durand and Petersen 2011
	Cutting mode (number of cuts)	Carrots	Surjadinata and Cisneros-Zevallos 2003
		Lemons	Artés-Hernández *et al.*, 2007
		Pumpkin	Lee *et al.*, 2008
		Radish	Saavedra del Aguila *et al.*, 2006
	Cutting mode (type of cut)	Melons	Aguayo *et al.*, F. 2004.
	Mechanical slicing (SammicCA300, Barcelona, Spain)	Lettuce	Barry-Ryan and O'Beirne 1999
	Waterjet and blade-cut	Lettuce	Wulfkuehler, *et al.*, 2014; Cantwell *et al.*, 2016
Washing/Cutting	Water jet cut and Sanitizer comparison	Watermelon	Mcglynn *et al.*, 2003
Washing	Industrial or laboratory scale plants (prevalence of contamination, cross-contamination)	Lettuce	Holvoet *et al.*, 2012; Buchholz *et al.*, 2012
	Sanitizer comparison	Cabbage, iceberg lettuce and leek	Vandekinderen *et al.*, 2009
		Carrots	Gonzalez *et al.*, 2004
		Escarole and lettuce	Allende *et al.*2008
		Lettuce	Baert *et al.*. 2009; López-Gálvez *et al.*, 2009
		Red chard	Tomás-Callejas A *et al.*, 2012
		Rocket leaves	Martínez-Sánchez *et al.*, 2006
		Spinaches	Gómez-López V *et al.*, 2013
		Potato	Beltrán D *et al.*, 2005

	Sanitizer comparison/washing mode	Fresh-Cut fruit and vegetables	Vandekinderen *et al*., 2007; Gil *et al*., 2009
		Leafy vegetables	Kim *et al*., 2016
		Lettuce	Luo *et al*., 2011; Lopez-Fernandez *et al*., 2013
	Washing mode	Artichoke and borage	Sanz *et al*., 2002
		Peppers	Toivonen and Stan 2004
	Additional sanitizing treatments	Baby Leaf Brassica	Martínez-Sánchez *et al*., 2008
		Lettuce	Kim J *et al*.1999
	Additional sanitizing treatments/Sanitizer comparison	Carrots	Gómez-López *et al*., 2007
Washing/Packaging	Washing mode/gas optimization	Rocket Leaves	Rux *et al*., 2017
Drying	Centrifugation time	Carrot	Moretti *et al*., 2007
Packaging	Gas optimization	Artichoke	la Zazzera *et al*.. 2012 and 2015
		Basil	Amodio *et al*., 2005
		Broccoli raab	Cefola *et al*., 2016a
		Carrots	Izumi *et al*., 1996; Amanatidou *et al*., 2000
		Coconut	Amodio *et al*., 2004
		Fennel	Rinaldi *et al*., 2010.
		Fresh-Cut fruit and vegetables	Gorny J.R., 2003.
		Mushrooms	Capotorto I., Amodio M.L. Colelli, G. 2015.
		Lettuce	Mateos *et al*., 1993; Oliveira *et al*., 2010; Baldassarre *et al*., 2013; Ansah *et al*., 2015;
		Mushroom, celeriac and chicory endive	Jacxsens *et al*., 2001
		Peaches	Colantuono *et al*., 2015
		Pumpkin	Amodio *et al*., 2010
		Rocket leaves	Cornacchia *et al*., 2006; Amodio *et al*., 2015; Inestroza-Lizardo *et al*., 2016; Mastrandrea *et al*., 2017b
		Strawberry	Almenar *et al*., 2007

		Zucchini flowers	Cefola *et al*., 2016b
	Gas optimization/chemical preservative	Pears	Gorny *et al*., 2002
	Gas optimization/temperature	Baby Spinach	Kou *et al*., 2014
	Peelability optimization	Adhesive, cohesive and delamination films	Baker 2009
	Seealability optimization	LLDPE	Mueller *et al*., 1998; Mihindukulasuriya and Lim 2012
	Vertical-Form-Fill-and-Seal Machines with biodegradable film	Lettuce	Brown *et al*., 2009
Entire process	Equipment requirements	Fresh-cut fruit	Turatti 2015
	Process design, facility and equipment requirements	Fresh-cut fruit and vegetable	Turatti A. 2011
	Process design, facility and equipment requirements	Fresh-cut fruit and vegetable	Artés and Artés-Hernández 2003

Figure 1. Minimal processing steps, equipments used and quality control parameters; processing steps encircled with broken lines may be optional (Adapted from Artés-Hernández *et al*., 2013)



PREPARATORY & PROCESSING STEPS	EQUIPMENT(S)/ TOOLS	CRITICAL CONTROL PARAMETER(S)
Harvest	Mechanical harvesters, knives, shears, clippers	Maturity stage, Sharpness of harvesting blades, weather
Transportation	Refrigerated trucks, boxes, bins, pallets	Temperature, cleanliness of transport facilities
Reception/Raw material Quality Control	Weighing machine Thermometers	Temperature
Grading and Classification	Score charts, Optical sorters/graders	Temperature, absence of foreign material, % moisture
Pre-cooling and Storage	Cooling facility; Temperature alarms	Temperature, relative humidity, product mix, cleanliness, time
Trimming, Cutting, Shredding, *etc*.	Knives /Shredders/ cutting machines	Temperature, sharpness of blade, equipment hygiene
Prewashing, washing, disinfection, rinsing	Shower, bubble washers, rotating perforated drums	Temperature, concentration of disinfectant, disinfection time, pH of washing water
Dewatering, Centrifugation/Drying	Vibrating sieve, conveyors, centrifuge, tunnel dryers	Temperature, speed, time, residual humidity on product
Optical selection	Optical selector	Transparency, colour, conformity to specifications
Storage of semi-finished products	Cold room, containers	Temperature, RH%, , hygiene, storage duration
Weighing and packaging	Multi-head scale, flow pack system, food grade packaging,	Weight, gas composition, barrier properties of plastic films, seal control and integrity
Metal Detection	Metal detector	Absence of metal contaminants
Control and cold storage of finished products	Weight controller, cold rooms	Weight, bag seal control, absence of foreign material, storage time, relative humidity, temperature
Cold Transportation and distribution	Refrigerated trucks	Temperature, time

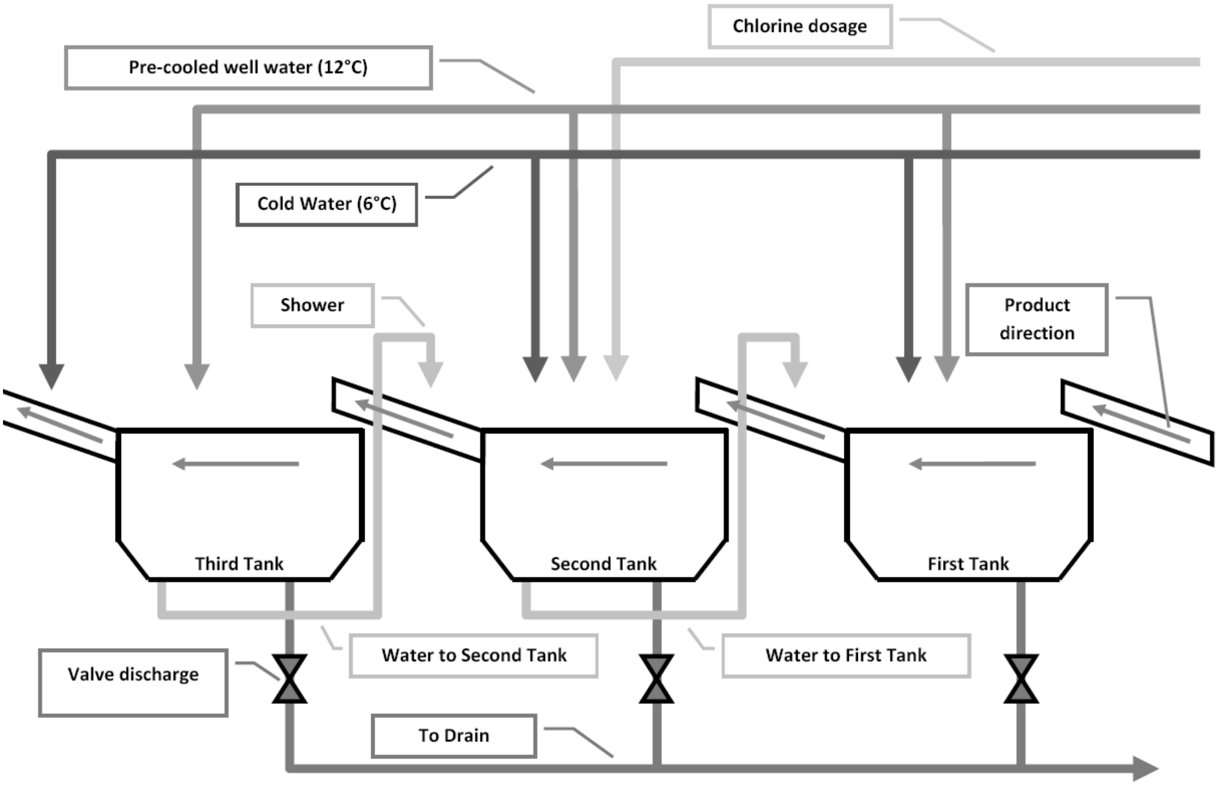


Figure 2. A typical washing system in the minimal processing industry.