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A Review on Minimal Processing of Fruits and Vegetables

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Abstract. Even though food industry employs various processing and preservation methods still there is an enormous peak season postharvest loss of fruits and vegetables. Minimal processing is a very effective method of minimizing postharvest loss at a lower cost. Peeled and sliced fruits and vegetables, cleaned and packed leafy vegetables are some of popular minimally processed products. Cleaning, pealing, slicing, shredding, cooling and modified atmospheric packaging are some of common processes in this industry. Controlling ethylene production and respiration, maintaining proper sanitary conditions, best suited packaging and proper storage are the key factors affecting quality and shelf life of the products as increased respiration and ethylene production, enzymatic browning, increased microbial susceptibility are the main challenges of the industry. Freshness and ease of preparation are the most preferable qualities of these products which has led to its popularity. This review includes a summary of key physiological changes of minimally processed fruits and vegetables and some modern processing techniques used in industry to improve quality and shelf life of minimally processed products.

Key words: Fruits and vegetables processing, Advances in minimal processing, physiology of minimal processed products, Natural sanitizers, Modified atmospheric packaging

Introduction

Minimally processed products are also referred as “lightly processed”, “fresh cut”, “freshly processed” or “partially processed” etc. With the busy lifestyles in industrialized societies, there is an increasing demand for minimally processed horticultural products. As most of the people are busy in modern world, they are very concern on easiness of cooking and also on safety, nutritional status and taste (Dharmasena et al., 2002). As a response to this trend, food industry directed towards the minimal processing of horticultural produces (Froeder et al., 2007). These freshly processed products became very popular all over the world within a very short period of time due to time saving, freshness, easiness, labor saving and cleanliness like consumer and producer preference qualities in it. Minimal processing is done for consumer convenience while maintaining the freshness of the product. Cleaning and disinfection, pealing, slicing, shredding, cooling and modified atmospheric packaging are the most common treatments in minimal processing. Lightly processed fruits and vegetables include peeled, sliced and chilled fruits such as mango, pineapple; peeled, cleaned, diced young and mature Jackfruit and cleaned, diced and packaged leafy vegetables etc. Minimally processed products have greater advantages to the consumers as well as to the producers over fresh whole produce. For example, in exporting minimally processed products requires less space thus lower transport costs due to their low volume compared to fresh whole produce (Sirichote et al., 2008). But the most critical aspect of minimal processing is maintaining the product quality and shelf life at a desirable level. Respiration rate, sanitary condition of the processing environment, packaging quality, storage conditions are some key factors affecting the shelf life and the quality of minimally processed fruits and vegetables (Zagory & Kader, 1988). As described later in this review, minimal processing industry adhere to several practices in processing to produce a quality product with a desirable shelf life.

Physiology of Minimal Processed Fruits and Vegetables

Minimally processed products are usually subjected to washing, cutting, peeling, grating, chilling, modified atmospheric packaging (MAP) like processes. Minimally processed plant tissues behave similar to a plant tissue which has been exposed to wounding or a stress (Bretch, 1995). Therefore, increased respiration rate and ethylene production and also induction of wound healing processes can be observed in those tissues thus, increase the perishability of the products. Loss of product quality aspects of color, flavor and texture of minimally processed fruits and vegetables could be observed due to physiological aging, microbial spoilage and biochemical changes. Controlling of this wound response is the major concern in minimally processed food industry. Therefore, preparation and handling of these products require a sound knowledge in food science and technology and postharvest physiology (Dharmasena et al., 2002) as minimally processed plant tissues behave similar to a wounded plant tissue those are very perishable and having a high risk of deterioration. Enhanced oxidative browning, enhanced water losses and lipid oxidation are some of other adverse effects of minimal processing (Bretch, 1995). Thus, should pay attention during manufacturing, distribution and retail sale (Martinez et al., 2005). Proper temperature control, packaging and storage could be useful in minimizing wound and bruising induced metabolic activities and enhance shelf life of the product. Quality of minimally processed Rambutan is highly affected by the factors like processing method, storage temperature and packaging film (Sirichote et al., 2008).

Enhanced Ethylene Production

Ethylene is the key plant hormone responsible for fruit ripening in climacteric fruits and senescence in plant tissues. Once tissues get damaged, wounded or under stress, ethylene synthesis is prompted. An elevated rate of ethylene synthesis could be seen in minimal processed plant tissues within 1hr of processing and the peak rate within 6 – 12 hours. Also in some fruits, the ethylene level increase is proportional to the amount of wounding (Abeles et al., 1992). Ethylene produced in wounded plant tissues leads to tissue deterioration and senescence while promoting the ripening of climacteric fruits like kiwifruit (*Actinidia deliciosa* L.), banana (*Musa* spp.) etc. (Abe & Watada, 1991). Physiological changes such as softening could be observed in minimally processed products as ethylene is responsible for ripening. Apart from softening, ethylene synthesis induces respiration rate as well. Therefore, controlling the ethylene production is critical in minimal processing of fruits and vegetables. A special care has to be given in minimizing tissue damage during cutting and peeling. Proper packaging and temperature control during storage also play an important roles in regulating wound response thus, the ethylene production and extending shelf life of minimally processed products.

Elevated Respiration

Respiration is the process of breakdown of stored organic materials like carbohydrates, fats in to simple end products by releasing of energy at cellular level (Kader, 2002). In wounded plant tissues respiration rate is increased which thought to be a consequence of elevated level of ethylene production which simulates respiration rate. In order to slow down the cellular senescence of fruits and vegetables after detaching from the tree, the respiration must be continued. But peeling and cutting during minimal processing leads to tissue wounding and trigger the respiration, microbial susceptibility and higher water loss compared to intact tissues (Kader, 2002). According to the literature, the respiration rate of minimally processed products may increase up to 1.2 – 7 folds or more depending on the factors like processing or storage temperature, cutting grade, type of produce etc. (Varoquaux & Wiley, 1994). Due to anaerobic respiration under anaerobic packaging conditions, production of ethanol, aldehydes and ketones could be observed (Powrie & Skura, 1991). In order to protect the freshness and quality of minimally processed products by controlling cellular respiration, storage conditions must be well planned. These products must be processed under proper hygienic conditions and store around 0 – 5°C until consumption. Modified atmospheric packaging is well suited technique for minimally processed products which controls micro climate inside the package controlling the cellular respiration of the product.

Lipid Oxidation and Enzymatic Browning

Oxidative browning requires the presence of four essential components: oxygen, an oxidizing enzyme, a suitable substrate and copper. Browning reactions or substrate biosynthesis increases after the tissue wounding as it enhances the production of some enzymes involve in those reactions (Rolle & Chism, 1987). Phospholipids and galactolipids are the main components of plant cell membranes and sub cellular organelles. These lipid components undergo rapid depletion by extensive enzymatic degradation (Feys et al., 1980) due to injuries of tissues caused by cutting and peeling during minimal processing. Therefore, a distinguishable discoloration occurs at the cut or peeled surface due to disruption of cells allowing relevant enzymes to come in to contact with the substrates. Therefore, in order to minimize browning of minimally processed foods, removal of at least one of these components from the system is a must. According to Hansche and Boynton (1986), browning intensity depends on substrate concentration and relative oxidative activities thus vary according to the tissues and crop types.

Phenols and anthocyanins are oxidized by phenolase enzymes like polyphenoloxidase (PPO) or peroxidases during phenylpropanoid metabolism resulting oxidative browning (Hanson & Havir, 1979). Polyphenol oxidase which leads to oxidative browning is one of the most important enzymes regarding minimally processed fruits and vegetables. Also, lipooxidase enzyme which catalyzes peroxidation reactions leads to formation of aldehydes and ketones which emits various bad odors (Varoquaux & Wiley, 1994). Minimum tissue damage and control of the cut surface, proper packaging, and storage conditions including optimum storage temperatures are very important in controlling oxidative browning in minimally processed fruits and vegetables. Degree of color change, flavor change and odor are higher at higher lipid oxidation thus, reducing the quality and shelf life of the product. And also makes food unpalatable and unacceptable due to rancid flavor and aroma, and production of harmful compounds.

Microbiological Aspects

In intact fruits and vegetables, peel act as a physical and chemical barrier to most of the microorganisms as it contains anti-microbial compounds. Acidity of pulp in peeled fruits also controls the growth of microorganisms except acid tolerant species. Minimally processed foods provide an excellent environment for microbial growth (Nguyen & Carlin, 1994). *Clostridium*, *Yersinia*, *Listeria*, *Erwinia* and *Pseudomonas* are some of very common pathogens in minimal processed products (Dharmasena et al., 2002). Contamination of these fruits and vegetables can occur at many stages during processing and due to high moisture content in packages and the presence of wounded tissues increase the risk of microbial contamination and spoilage due to microbial activities. Also high pH values, low salt content, high storage temperatures and environment with high RH and low oxygen increase the risk of microbial growth. Even though low RH reduces the risk of bacterial growth leads to excessive moisture loss/drying of the product.

Polluted cultivation environment and poor hygienic conditions during processing increase the risk of microbial contamination (Nguyen & Carlin, 1994). Proper sanitation practices are essential in order to minimize spoilage and to improve shelf life and quality of products (Beuchat, 1996). Shelf life of 15 days can be ensured for cantaloupe and honey dew pieces by selecting good quality raw materials and maintaining proper hygienic conditions along the processing (Ayhan et al., 1998). Therefore, in achieving extended shelf life, quality of whole fruit or the raw material is a very important in both physiological and microbiological point of views. Maintaining proper hygienic conditions throughout processing line, proper packaging and storage are essential to minimize microbial loads and their activities in minimal processed products.

Techniques of Minimal Processing

Techniques used to produce minimally processed fruits and vegetables depend on the manufacturer’s shelf life expectation of that product. If the product is prepared today and consumed tomorrow (catering purposes), requires a shelf life of a day or two. Thus, very simple processing techniques can be used. But if the product is expected to have a shelf life of several days to a week or more (Retailing marketing), it requires the use of relatively high tech and sensitive process and a relatively higher investment. The preservation in minimal processing is achieved by combining several treatments.

Preliminary Cleaning

In order to remove sand, mud or inert materials preliminary washing of raw materials is a must in any food processing chain. Even though cleaning is done before peeling and/or cutting a second washing is also essential to remove tissue fluid and microbes to reduce microbial activities and enzymatic oxidation during processing and storage (Ahvenainen & Hurme, 1994). Microbiological quality, sensory aspects of washing water including temperature and contact time are very important factors affect the quality and shelf life of product. Dipping the produce in water is the simplest way of washing. But washing with flowing or air bubbling water is preferable than simple dipping in water (Ahvenainen & Hurme, 1994). Washing helps to flush out potentially damaging enzymes away from wounded surface tissues. This is a very critical step in minimal processing industry as it supplies ready to eat products. Usually, gentle removal of water at the surface after washing is recommended. According to the literature, centrifugation is the best method and careful selection of centrifugal speed and time is a must (Bolin & Huxsoll, 1991). Basket type centrifuge at 1000 rpm for 30 s resulted the best shelf life for shredded lettuce (Ohta & Sugawara, 1987).

Cutting and Peeling

This is a very common process for all most all minimal processing chains. As the natural cover of fruits and vegetables is removed during cutting and peeling, the product is very susceptible to oxidative browning, microbial spoilage and also impact damage during processing. It is recommended to use very sharp stainless steel knives, blades or trimming tools to progress cutting, peeling or trimming (Martin-Belloso et al., 2006). Ensuring proper sanitation throughout cutting and peeling of fruits and vegetables is important to avoid cross contamination (Heard, 2002). Controlled release of oxidizing enzymes is also another important phenomenon. Damaged cells which triggers the release of intracellular products at a faster rate which causes product decaying is a major consequence of improper cutting and peeling. As the cut surface is very susceptible to microbial growth, further product deterioration could occur thus lowering product quality (Laurila & Ahvenainen, 2002). Dipping cut slices in water with sulfite agents or non-sulfite agents is practiced to avoid discoloration and spoilage during further processing and storage. But non sulfite agents are recommended than sulfite agents for health reasons. Dipping in various concentrations (0.5 – 1.5%) of ascorbic acid, citric acid and calcium chloride for 10 – 15 minutes is very common in minimal processing industry (Zhu et al., 2007). Other than that, dipping cut slices in a disinfecting detergent is also an effective measure to prevent biofilm formation at cut surface (Ohlsson & Bengtsson, 2002).

But all the materials used for disinfection must be approved as 'Generally Recognized as Safe' (GRS) substances. Damage due to wounding and bruising could be minimized by cooling the product prior to processing.

'Water jet cutting' is a one of cutting approaches tested in France where cutting is taken place under water. In order to reduce browning of fruits and vegetables after cutting, Ultraviolet C (UV-C) light can be used during cutting to produce hypersensitive defensive mode within cuts (Lamikanra et al., 2010). Immersion therapy is another novel approach which is used to minimize spoilage of cut fruits and vegetables.

Chlorination

For washing of fruits and vegetables prior to cutting and peeling, chlorinated water is recommended over portable water (Madden, 1992). Effectiveness of chlorination to remove soil, inert material and microbes on fresh produce depends on pH and organic matter content of wash water (Dychdala, 1991). In order to ensure a satisfactory antimicrobial effect in chlorinated water, pH of 6 – 7, low organic matter content in water, concentration of chlorine (100 – 150 ppm) and contact time should be properly controlled. So that chlorination will be adequate to destroy fungi and vegetative bacteria. Chlorine has the advantages of high effectiveness together with comparatively lower cost and free availability as a common disinfecting agent. According to the US Environmental Protection Agency (EPA), use of chlorine gas, sodium hypochlorite, calcium hypochlorite are accepted (Ruiz-Cruz et al., 2010). But still the selection of chlorine sources, side effects of chlorination like some serious health concerns are associated with chlorination (Pasha et al., 2014).

Table 1. Effectiveness of chlorine on aerobic plate count (APC) on the surfaces of whole cantaloupe and honeydew melons

Treatment	Free available chlorine concentration (ppm)[2]	Surface population[1] ($\log_{10}$ CFU cm^{-2})	
		Cantaloupe	Honeydew
Unwashed	0	5.76a	3.26a
Dipped in water	0	5.15a	2.89a
Dipped in 200[3] ppm, pH 6	93 – 101	3.73b	2.02b
Dipped in 500[3] ppm, pH 6	328 – 353	3.09bc	1.45b
Dipped in 1000[3] ppm, pH 6	438 – 470	2.48c	1.40b
Dipped in 2000[3] ppm, pH 6	814 – 841	2.43c	1.30b

Note. [1]Mean values in the same column that are not preceded by the same letter indicate significant difference ($p \leq O.05$); [2]Determination by DPD colorimetric method before addition of fruits, pH 6; [3]Concentrations of total available chlorine

Source: Ayhan and Chism (1998).

Ozonation

Use of ozone in food industry for disinfecting purposes over various other sanitizers is proven to be beneficial through many studies (Travagli et al., 2010; Ikeura et al., 2011a). Ozone is moderately soluble in water and destroys microbes via various means including cell membrane oxidation, bleaching and putrefaction, mycotoxin degradation, organic matter deodorization etc. (Karaca et al., 2010). Oxidation potential of ozone is 1.5 fold higher than that of chlorine. Therefore, it can be effective over a wider range of microbes than chlorine and other sanitizers.

Washing fruits and vegetable with ozonated or ozone micro-bubbled water is an effective method for maintaining and improving fresh produce safety. Ozone is very effective on destruction of *E. coli* which is a very destructive pathogen in food industry. Also slow downing fruit and vegetable ripening at low temperatures is another advantage of ozonation (Ikeura et al., 2011b, 2011a). By using ozone in minimal processing antioxidant level in products can be increased (Alothman et al., 2010). Auto decomposition without accumulated toxicity is a very manufacturer and consumer friendly property of ozonation. Use of chlorine and ozone together for disinfection purposes is a new approach which results higher microbial destructions than disinfection with chlorine.

Chilling

Storing at low temperature is commonly practiced to retard microbial growth and spoilage, reduce respiration rate and enzymatic browning which leads poor quality and shorter shelf life in minimally processed fruits and vegetables. In general fresh cut produces are recommended to be stored at 0°C, but commercially those are stored at 0 – 5°C to maintain their quality, shelf life and safety (Cantwell & Suslow, 1999). Fresh cut produce should be stored as cold as possible to ensure microbial safety. It has found that 2 °C is the best storage temperature for preserving fresh cut tomato (Gil et al., 2002).

Freezing

The food preservation technology in which temperature of the food is lowered below the freezing point thus restrict microbial growth and enzymatic activities. There are main three freezing methods used in fruits and vegetables processing industry as individual quick freezing, immersion freezing and freezing in the container. Freezing ensures better texture, taste and nutritional value compared to the other preservation methods. Freezing converts water within food in to ice crystals and ensure that water is no longer available either as a solvent or as a reactive component in the cells. But size and location of ice crystals is very important to achieve desired outcome of the freezing as large ice crystals could damage the cell membrane and break down physical structure of the cell (Delgado & Sun, 2001).

In individual quick freezing (IQF), freezing is achieved with direct contact of the food with a cryogenic agent (Ex: liquid nitrogen). This method is very suitable for small food items like diced carrots, peas, berries etc. (Archer, 2004). Very low cold losses (about 3%) and avoidance of dehydration are main advantages of this freezing technique. (Chourot et al., 2001). Compared to other freezing methods immersion freezing provides many advantages including energy saving, individual freezing, high heat transfer coefficient with high product quality etc.

Edible Coatings

Edible coating is a thin layer of an edible substance which is applied on the exterior surface of fruits and vegetables (Ghasemzadeh et al., 2008). Dipping, spraying or brushing to obtain a modified atmosphere are used to apply these edible coatings on foods (Mchugh & Senesi, 2000). These edible coatings could contain polysaccharides, proteins, lipids or a mixer of few of these and act as a barrier for oxygen, oil and aroma while protecting and maintaining structural integrity of products.

Also edible coatings help to retain color, flavor, aroma, acids and sugars of the products. Thus, protect sensory properties of products, enhance consumer appeal and improve shelf life of products (Duan et al., 2011). Also coating adds a value to the product and reduce the requirement of special packaging of products. Edible coatings with many additives serves different purposes such as reducing microbial decay, minimizing water loss from the product and enhance appearance etc. (Olivas et al., 2003). Antioxidant agents like N-acetylcysteine and glutathione can be mixed with edible coatings to reduce browning in fresh cut apples, papaya, pears etc. (Tapia et al., 2005; Rojas-Grau et al., 2007). Also edible coatings mixed with Vitamin A, Vitamin D, iron and zinc can be considered as an approach where fortification is coupled with edible coating.

Modified Atmosphere Packaging

Major factors limiting shelf life of minimally processed products include ethylene production, enhanced respiration, microbial spoilage, discoloration and off-flavors etc. (Amanatidou et al., 2000; Sandhya, 2010). Purpose of packaging is to protect the product from external environment while maintaining sterile conditions around the product enhancing shelf life. In order to maintain products' sensory properties as much as natural and to have an extended shelf life, there are various modern packaging types including Modified Atmosphere Packaging (MAP), smart packaging etc.

Principal of MAP is to create an environment with low oxygen (O_2) and high carbon dioxide (CO_2) content within the package. Almost all the deteriorative activities such as spoilage, ethylene production, ripening, senescence, chlorophyll degradation etc. are suppressed due to this changed O_2: CO_2: N_2 ratio inside the package (Ohlsson & Bengtsson, 2002; Farber et al., 2003; Xing et al., 2010). High CO_2 concentration inside the package is achieved by controlling permeability of the packaging for CO_2. But as plant material continually respire, CO_2 concentration inside the package could increase to a level which can adversely effects on the product. Therefore, gradual release of CO_2 from the packaged product is a must in such products. Increased CO_2 levels inhibit growth of microorganisms under refrigerated conditions as CO_2 requires refrigerated conditions to be effective. Therefore, packages with modified atmosphere should store under refrigerated conditions to be effective and improve the quality and shelf life of the product.

Ohmic Heating

Ohmic heating is an electro-heating technology used in food industry for processing a wide range of foods. An electric current is passed through foods in order to achieve sterile food with a preferable level of cooking. Principal of ohmic heating is to destroy microbes using heat produced in foods by the applied electric current. This has proven as very effective in food processing like blanching, fermentation, dehydration, extrusion etc. Also this ensures microbial destruction and retain the required quality characteristics of minimally processed fruits and vegetables (Leizerson & Shimoni, 2005). Specific heat capacity, thermal and electrical conductivity, size, shape and orientation of the food and the specific heat capacity of the carrier medium are key factors affecting heat transfer in the food while temperature, flow rate, holding time and heating rate are main factors affecting application of this technology in industrial scale (Ruan et al., 2001). Ohmic heating is comparably a cost effective treatment than freezing and retort treatments of low acid products. Still there are numerous problems to overcome before applying microwaves at operation in industrial scale.

Irradiation

Irradiation is the process which uses specific ionizing radiation on food to improve microbial safety and storability of foods. According to WHO, FAO and IAEA use of irradiation in food processing with appropriate technology is an internationally accepted, safe, effective and nutritionally adequate technology (Farkas & Mohacsi-Farkas, 2011). The major advantage of irradiation is the non-residual nature of ionizing radiation. Due to improved safety concerns of food processing, irradiation is a better way to minimize chemical exposure of foods (Manzocco et al., 2010). For fruits and vegetables 1 kGy (100 krad) of irradiation treatment is permitted by the Food and Drug Administration. Apart from maintaining postharvest quality of fruits and vegetables, UV-B radiation has the potential to improve antioxidant capacity (Food and Drug Administration, 2007). Other than microbial destruction, irradiation provides other advantages of less incidents of food borne illnesses, longer shelf life and better quality products. Irradiation technology is used for very limited range of foods at present due to consumer acceptability and legal considerations.

UV Treatment

UV light has been used over decades as a physical method of microbial disinfection in the fields of electronics, pharmaceutical and aquaculture etc. UV light effects on the DNA of microbial cells and damage reproduction systems of the cells leading to their death (Gardner & Shama, 2000). This method can effectively be applied for liquid food products (Sastry et al., 2000). The wavelength range of 220 – 300 nm is considered as lethal to most of the microbes such as bacteria, viruses, yeasts, protozoa etc. and wavelengths from 100 – 400 nm rage is used in UV processing (Bintsis et al., 2000). Main advantage of UV processing over thermal preservations like pasteurization is taste and flavor preservation of the product. It does not lead to change in sensory characteristics including flavor, odor and color of the product and does not produce any undesirable products. Therefore UV technology could be used as a promising food preservation method instead of application of synthetic antimicrobial agents or thermal treatments.

High-Pressure Processing

High pressure processing (HPP) is a promising alternative to thermal processing of food preservation in food industry. There is a high probability to develop products with longer shelf life, better sensory properties and higher nutritional values by using high pressure processing for food preservation (Perera et al., 2010). This technology was first practiced in Japan for pasteurization of chilled low-acid foods in early 1990's. Principle is to apply a high pressure (thousands of Pascal) on food and release it, and rupture microbial cells when pressure is released. Apart from microbial destruction, destruction of spores of bacteria, inactivation of enzymes could also achieved in high pressure processing.

As microbial resistance to pressure varies, operating pressure and temperature, time duration of HPP varies depending on the type of target microbes. Usually HPP products are subjected to a pressure of 3000 – 8000 bars to inactivate enzymes and to destroy microbes (Hoogland et al., 2001). Main disadvantages of high pressure processing are starch swelling, proteins coagulation and changes in texture and sensory properties of food.

Pulsed Electric Field (PEF) Technology

This is comparatively a new but promising food preservation technology which uses short bursts of electricity to destroy microorganisms in liquid and semi-liquid products (Soliva-Fortuny et al., 2009). Product is placed between two electrodes and supply a high voltage electric pulses (up to 70 kV cm^{-1} with 50 – 200 kJ kg^{-1} energy) for a duration of a few micro seconds (Toepfl et al., 2007). Microbial destruction is achieved based on electromechanical instability of the cell membrane. Strength of the electric field applied and treatment duration are the most important factors of preservation method (Jeyamkondan et al., 1999). As PEF is a non-thermal food preservation method, preserve volatile compounds and thermolabile nutrients in processing foods compared to thermal food preservation methods (Jia et al., 1999). Major obstacle of utilizing this technology at industrial level is the high initial cost of establishing a PEF processing unit. Therefore, there is a need of developing continuous PEF process for a successful industrial application of this technology.

Hurdle Technology

Hurdle technology is the basis of mild processes of fruit preservation. This technology uses a combination of several different preservation techniques (hurdles) to combat food deterioration and microbial growth to have a good quality product with an acceptable shelf life. Major hurdles of food preservation include temperature, pH, water activity, preservatives, competitive microorganisms, redox potential (Leistner, 2000). This technology helps to produce safe, nutritious, economical foods with good sensory aspects by an intelligent combination of hurdles (Leistner, 1995). Homeostasis, stress reactions and metabolic exhaustion which are the physiological responses of microbes during food preservation are the basis of advanced hurdle technology. Hurdle technology is currently used for high moisture fruit processing. As the current trend in developing countries is to go for low moisture containing products, there is a need of applying an intelligent hurdle technology to fulfill that requirement. Main concern of this technique is microbes in the food should not be able to overcome the hurdles used.

Table 2. Applications of minimal processing methods

Process	Applications	Mechanism
Controlled-atmosphere storage	Bulk-stored fresh fruits and vegetables	Antimicrobial effect (inhibition of aerobic or anaerobic microorganisms): altered respiration rates in fruits and vegetables
Postharvest treatments:	Fresh vegetables	
Chlorinated water soaking		Antimicrobial effect
Reducing agents		Oxidation prevention
Preservatives		Antimicrobial effect
Divalent ions		Improved texture
Non-thermal processing methods:		
High-pressure treatment	Many products, currently especially fruit products	Microorganisms ruptured under high pressure
Gamma irradiation	Many products, particularly fresh fruits	Ability of microorganisms to reproduce eliminated
High electric field pulses	Many products, particularly fruits	Microbial cell rupture due to uneven distribution of electrical change across cell
New thermal processing methods:	Many products especially finished meals	Optimized heating regime reduces levels of undesired microorganisms while minimizing thermally induced quality losses (e.g. impaired flavor)
Ohmic heating		
High-frequency heating		
Microwaving		
New packaging technologies:		
Modified-atmosphere packaging and active packaging	Fresh meat and fish, prepared foods, baked goods, fresh fruit and vegetables	Antimicrobial effect (inhibition of aerobic or anaerobic microorganisms); altered respiration rates in fruits and vegetables
Edible films	Dry, frozen and semi-moist foods	Protection against oxygen ingress, moisture loss and flavor loss

Source: Ohlsson (1994).

Photosensitization

Use of thermal processing is widely used food preservation approach. It has the potential of destruction of most of the microbes in foods depending on the temperature and time combination applied. But it results in changes of sensory qualities as well as destruction of thermal sensitive nutrients in foods. Thermal preservation methods are fairly energy and tech intensive, and costly. Instead of using thermal preservation, photosensitization could be used as a promising technique for microbial destruction in food processing.

This is comparatively a novel, non-thermal, environmental friendly and effective antimicrobial technology used in food preservation. Principal of photosensitization is to obtain selective microbial cell destruction through an interaction between two non-toxic substances at the presence of oxygen. For an example, the interaction between photoactive compounds and light with the presence of oxygen could results the destruction of some selected microbes. Blood disinfection is an example for the application of photosensitization. This preservation method can be used to destroy viruses, yeast, micro fungi like many types of microorganisms. Major advantages of photosensitization over conventional thermal preservation methods include, cost effectiveness, environmental friendly nature, and inactivation of pathogen population by up to six orders, no bacterial resistance or mutagenicity developed in this method and no effect of antibiotic resistance pattern of the strain on treatment efficiency (Jori et al., 2006).

Natural Sanitizers

Natural sanitizers are a reliable replacement for synthesized chemical sanitizers used in food industry. There are three main types of natural sanitizers as antioxidants, antimicrobials and antibrowning agents which are produced by plants, animals and microbes like living organisms (Ohlsson & Bengtsson, 2002).

Antimicrobials are a group of natural chemical substances act on microorganisms mainly causing food poisoning and spoilage while suppressing their growth and ultimately destroying (Davidson et al., 2012). It has proven that addition of lime, lemon, citrus and mandarin like plant extracts (0.02% v v^{-1}) to minimally processed fruits can suppress the growth of microorganisms and improve shelf life without harming sensory properties of products (Pasha et al. 2014). Even though mechanism of microbial destruction by antimicrobials is not clear yet, it is assumed to be passive diffusion through plasma membrane brings microbial destruction.

Antioxidants are the substances prevent oxidation of other substances. Main type of oxidation causes quality losses in minimally processed products is lipid oxidation which leads foods to an inedible stage. Ascorbic acid, carotenoids, phenolic compounds and flavonoids are some of natural antioxidants in foods. Spices are a good source of antioxidants. It has found that flavonoids have the ability to inhibit lipoxygenase and cyclooxygenase enzymes which causes oxidative rancidity in foods (Embuscado, 2015). Demand for natural antioxidants is increasing at present over synthetic antioxidants due to safety concerns in food industry. Apart from antioxidant activity, natural antioxidants have health benefits like enhancing food nutritional status, readily assimilated by the body.

One of the main problems associated with minimally processed fruits and vegetables is browning which causes color change and poor appearance of products. Washing with water alone is not adequate to slow down this browning process. Even though sulphites have used as an antibrowning agent over past decades, citric acid, ascorbic acid like natural acids have now identified as very effective antibrowning agents. There is a need for further research on the use of natural sanitizers in minimal processed fruits and vegetables industry.

Conclusion

Minimal processing allows the food industry to fulfill consumer needs of instant, healthy and nutritious food supply. Demand for minimally processed fresh-alike products is increasing at present due to busy life styles. Also this is a promising solution to minimize huge fruit and vegetable losses around the world. Minimal processing increase product susceptibility to microbial spoilage, discoloration due to oxidative browning, increased respiration rates etc. There are various minimal processing techniques from low tech processes including simple cleaning and grading to advanced techniques such as heat preservation, UV treatment, etc. Apart from using high tech preservation methods, there is a huge potential to use natural sanitizers including antimicrobials, antibrowning agents and antioxidants which are safer for consumers and environment, and would reduce the cost of production of the industry as well. Even though there are a few well known application of these natural substances in minimal processing industry, there is an increasing need of more advanced researches on this sector. The most novel approach of lightly processed food industry to preserve produce is 'Hurdle technology' which is a combination of several different techniques to enhance desirable qualities of minimally processed products. But still there is a need for development of an intelligent combination of hurdles to have a cost effective, consumer and environment friendly approach. It will be a remarkable step in minimal processing fruits and vegetables industry as it could attract more entrepreneurs to the industry as it has the potential to produce good quality value added products with high market demand with the use of low tech processes with least investment.

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