Pre-cut Fruits and Vegetables: Pre- and Post Harvest Considerations

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ABSTRACT

Development of minimal processing (MP) and storage protocols for pre-cut fruits and vegetables is an emerging area with immense commercial potential. The advantages include convenience for various end uses and reduction in packaging as well as transportation costs. The pre- and postharvest considerations stress on various aspects i.e. selection of appropriate varieties with necessary sensory and physiological stability with emphasis on texture, color and the inbuilt resistance against browning and microbial attacks. Pre-cut fresh produce as such is highly vulnerable in terms of physiological and microbiological stability due to the elimination of thermal process to inactivate deteriorative enzymes and latent infections. A minimal process is essential for the removal of field heat by pre-chilling techniques of the pre-cut produce and necessary surface sanitation needs to be carried out to ensure microbial stability during storage. The physiological and microbiological stability can be imparted by the application of anti-respiratory, anti-browning and anti-microbial agents. MP is a "process strategy" to maximize the beneficial effects obtained through synergistic affects of pre-chilling, surface sanitation through non-thermal means, additives and modified atmosphere storage conditions. All the specific attributes described have a pronounced effect on the stabilization of the pre-cut produce. In addition to the pre-conditioning by physico-chemical methods, a modified atmosphere contributes to restrict degenerative physiological changes and microbial profiles in pre-cut produce. MP as a pre-conditioning measure helps to maximize the beneficial effects of low O₂ and high CO₂ atmospheres with humidity regulation within the packages/containers. The process and storage of the pre-cut produce need to address statutory specifications besides ensuring food safety.

Keywords: minimal processing, pre-cut, pre-harvest, post-harvest, storage

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Invited Review
INTRODUCTION

The postharvest technology of fruits and vegetables has undergone several changes with respect to changes in the lifestyles of consumers and the growing demands of modern times. Core technologies i.e. canning, freezing, dehydration, aseptic processing and filling, among others have played a stellar role in providing microbiologically safe fruits and vegetable products which could be stored for longer durations under ambient as well as refrigerated conditions. Agro-processing still depends on the core technologies for bulk processing. However, there are new developments in secondary and tertiary processing as per the consumer demands. One of the latest developments is minimal processing of pre-cut fruits and vegetables.

The postharvest technologies for fresh commodities differ drastically from those for processed ones since fresh fruits and vegetables are actively respiring biological entities unlike fully processed commodities, having undergone complete termination of biological activities inclusive of respiration, enzymatic and other physiological activity. Therefore, the strategies and objectives of the specific technologies are fundamentally different. The concept of minimal processing (MP) effectively bridges the two polarized technologies. MP involves the principles of post-harvest handling i.e. restriction in metabolic rate, surface sanitation and restricted moisture loss in addition to some of the concepts of fully processed fresh commodities i.e. use of texturizing, anti-microbial and anti-browning agents, modulation of cell physiological conditions to maximize pigment and vitamin retention as well as the judicious use of a thermal process without impeding the fresh-like sensory attributes of the products.

NATURE AND DEFINITIONS

The initial debate with regards to definition and boundaries of MP revolves around the notion of retention of respiratory activity upon the process. However, it has been widely agreed upon to define MP as ‘a light process’ with minimal changes in quality characteristics and at the same time rendering sufficient shelf life to the product for the purposes of storage and distribution (Huis in’t Veld 1996).

Rice (1987) coined the term “minimally processed” to denote the lightly processed foods. The category includes partially processed foods and high moisture refrigerated foods. Later on, a number of workers extended the horizons of this area by their interpretations and extensions of the frontiers of the process. Fellows (2000) considered the retention of minimal and sensory quality by reduced reliance on thermal process. Initially, the unit operations in MP were restricted to washing, selection, peeling, slicing, chopping, coring etc. to keep the produce close to the fresh commodities in terms of sensory attributes (Shewfelt 1987). Later on, several workers highlighted the physiological changes in response to the size reduction operations (Huxsoll and Boatman 1989).

Apart from the physiological changes, the microbiological profiles influenced the categorization of minimally processed foods. In terms of the microbiological hazards, the nature of minimally processed fresh commodities warrants:

1. Appropriate refrigerated storage and distribution to prevent the growth of pathogenic microorganisms.
2. Restriction of use-by period to facilitate food safety by appropriate quick marketing strategies.

Keeping the above aspects in mind, the frontiers of minimally processed products include actively respiring fruits and vegetables in pre-cut form and also products without or insignificant respiratory activity. The process includes products with variable microbiological levels without the incidence of pathogenic organisms.

ADVANTAGES OF MINIMALLY PROCESSED PRODUCTS

The advantages of MP products are manifold. The major advantage is the satiation of the consumer with a fresh-like product with some of the advantages associated with fully processed products. The advantages of MP products could be listed as follows:

1. Provision of fresh to fresh-like nature of products as the modern consumer demands natural flavor, texture and color of the products which are otherwise restricted in the case of processed foods.
2. Removal of inedible portions resulting in restriction in packaging and transportation costs.
3. Excellent convenience offered by MP products. The convenience also lies in the fact that the products could be made end-use specific to suit different culinary requirements.
4. Reduction in kitchen drudgery and saving time forms a part of the convenience offered by the products.
5. The process facilitates integration of the fresh commodity market with that of processed foods. Many developing countries lack appropriate accountability for the fresh market in terms of food safety as the fresh commodity market lies in the domains of a disorganized sector. The minimally processed products ensure food safety as the products need to be governed under the realms of processed products.
6. The storage of minimally processed products offers operational ease as the products are graded materials with uniform characteristics in terms of physico-chemical composition and microbiological load.

The above advantages make minimally processed fruits and vegetables in pre-cut and packaged form a much sought after commodity in off-the-shelf markets. The product design has plenty of flexibility to obtain a variety of products for different end uses.

TYPES OF PRODUCTS

The different types of products could be listed as follows keeping in view the end use of the product. The differences amongst the various products include the type of commodity, variation in size reduction, assortment of commodities and inclusion of allied ingredients.

Vegetables

1. Snack vegetables: Pre-cut carrots, cucumbers, celery strips, sliced onions, roasted jackfruit seeds, roasted sweet potato slices, etc.
2. Stew vegetables: Diced potatoes, sliced onions, pre-cut green beans, peas, diced mushrooms, crinkle sliced cabbage and brussel sprouts, pre-cut okra, etc.
3. Salad vegetables: Shredded cabbage, carrots and radish, diced onions, shredded lettuce and capsicum, trimmed parsley and onion sprouts.
4. Soup vegetables: Shredded capsicum, diced mushrooms and onions, strip-cut parsley, cross-cut leaks and diced beet-root, etc.
5. Sandwich vegetables: Sliced tomatoes, onions, cucumber, cored and pre-cut capsicum, etc.
6. Ready-to-cook vegetables: Sliced potatoes, strip cut potatoes for french fries, pre-cut cauliflower, shredded cabbage, etc.
7. Sauce and gravy vegetables: Diced mushrooms, capsicum, strip cut peppermint, diced onions and tomatoes, etc.
8. Puree and juice vegetables: Diced tomatoes, carrot, beet, ash gourd, etc.
9. Pizza topping and stuffing vegetables: Strip cut mushroom, sliced tomatoes, mushrooms, cabbage, brussel sprouts, etc.
Fruits
1. Fruit pies: Apple and pineapple rings, peeled apricot and peach halves etc.
2. Fruit cocktails: Diced pineapple and apple, pitted cherries, etc.
3. Fruit salads: Seedless grapes, sliced bananas, orange segments, diced pears and peaches, etc.
4. Sliced water melon, musk melon, peeled oranges, pitted plums, etc.
5. Fruit puddings and cakes: Sliced bananas, pitted cherries and sliced strawberries and apricot.
6. Fruit sauce/puree/juice: Sliced apples, prunes, pre-cut oranges, lemons and grape fruit.

EFFECT OF PRE-CUTTING ON PRODUCE PHYSIOLOGY

It is well known that plant tissues respond towards external and internal stress factors inclusive of biotic and abiotic factors. Unit operations like peeling, trimming, pitting, coring, etc. have a pronounced effect on the physiology of pre-cut commodities. Plant tissues were reported to show pronounced enzymatic changes in response to mechanical injuries (Radclyffe and Canny 1987; Watada et al. 1990). Watada et al. (1996) reported that respiration rates of the fresh-cut fruits and vegetables were generally higher than those of the intact products. The increase in respiration rate of fresh-cut compared with the intact product ranged from only a few per cent for green beans, grape and courgettes to >100% for kiwifruit and lettuce. In the 0–10°C range, Q10 of respiration rates ranged from 2.0 to 8.6 among various fresh-cut fruits and vegetables. Severe mechanical injury was also found to enhance the accumulation of ethanol and acetaldehyde besides causing enhanced coliforms and Pseudomonas sp. growth in carrots (Barry-Ryan and O’Beirne 1998).

Karakurt and Huber (2003) studied activities of several membrane and cell-wall hydrolases, ethylene biosynthetic enzymes and cell wall polyuronide degradation during low-temperature storage of intact and fresh-cut papaya (Carica papaya) fruit and found significantly higher levels of α-galactosidase, β-galactosidase, phospholipase D, lipoxigenase, ACC (1-aminoacyclopropene-1-carboxylate) synthase, ACC oxidase, phospholipase C and pectin methyl esterase in cut than in intact fruits during storage. Decreases in firmness and molecular weight of polyuronides were more rapid in cut than intact fruits. However, certain exceptions do exist as in the case of ‘ Bartlett’ pears which do not show enhanced ethylene production in response to pre-cutting (Gorny et al. 2006). The physiological responses induced by wounding during pre-cutting highlights the repair physiology caused by the accumulation of secondary metabolites and enhanced lignification. Ke and Saltveit (1989) were of the opinion that wounding increased phenylalanine ammonia-lyase (PAL, EC 4.3.1.5) activity in iceberg lettuce (Lactuca sativa L.) which was a function of the degree of injury. Wound-induced PAL activity appeared after 4 h and reached maximum activity in about 24 h before slowly declining to normal levels in about a week. A signal for PAL induction was transmitted at about 0.5 cm h-1 from the site of injury to cells up to 2.5 cm away. Wounding also increased peroxidase (EC 1.11.1.7) activity and lignin content, with cell wall lignification localized in wounded and adjacent cells. Although wounding alone did not induce russet spotting, it did greatly increase susceptibility to ethylene-induced russet spot development. Sulfur metabolism was also reported to become enhanced in pre-cut cabbage (Brassica oleracea var. capitata) in response to wounding (Chin and Lindsay 1993). In spite of the plant tissues, response towards repair and protection against microbial attacks, the shelf life of produce upon pre-cutting becomes drastically reduced and the minimal process aims to reduce the physiological degeneration of the pre-cut produce by partial stabilization achieved through temperature regulation, use of anti-senescence agents and modulation of storage atmosphere.

PRE-HARVEST FACTORS

A number of pre-harvest factors influence the behaviour of fruits and vegetables. The suitability of fruits and vegetables towards development of pre-cut and minimally processed products, pest and disease management, irrigation and calcium nutrition play an important role as pre-harvest factors (Toivonen and de Ell 2002). Establishment of suitable genetic lines is also an important pre-harvest factor as different genetic lines respond variably towards wound-induced stress factors. This could be attributed to varied response potentials in terms of physiology linked with secondary metabolites, stress-induced respiration, texture, color and flavor-related metabolisms. Moor et al. (2004) studied the effects of mulch (plastic and straw), fertilization, water and calcium nutrition play an important role in the quality of MP products (Soliva-Fortuny et al. 2004). Mature citrus commodities such as lemon, oranges etc. are more firm and less susceptible to injury-induced degradation (Nagy 1980). The cultivar differences also influence the initial levels of vital nutrients. Ogbadu and Easmon (1989) studied the influence of inorganic and organic fertilizers on the chemical composition of three eggplant cultivars and reported that fertilizer application significantly reduced the total hemicellulose content whilst crude fiber, titratable acid and total protein content were significantly increased. With the exception of the cv. ‘Samaru striped’, fertilizer application caused a significant decrease in the nitrate-nitrogen content. Significant increases in ascorbic acid content as a result of fertilizer application were observed in cvs. ‘Samaru stripe’ and ‘Baluro’, but not in cv. ‘White large’. Calcium ammonium nitrate (CAN) and nitrogen-phosphorus-potassium (NPK) fertilizers were found to cause significant decreases in soluble carbohydrates, whilst hemicelullose content was significantly decreased by poultry manure application. Na, K and P contents were also significantly increased by fertilizer application. Therefore, it is highly essential to select suitable cultivars with appropriate maturity indices for the development of MP products.

Agronomic practices also play an important role in the quality of MP products in terms of nutritional and sensory values as well as the extent of latent infections and micro-biological loads as such. Excess irrigation was found to increase the susceptibility of strawberry tissues to bruising and injuries (Prange and de Ell 1997). Herath et al. (2003) studied the effects of pre-harvest Ca (as lime) application on the control of internal browning (IB) development and fruit quality in cold-stored cv. ‘Mauritius’ pineapple (Ananas comosus L. Merr.). Excess irrigation has also been reported to affect respiration rate and reduce soluble solid...
content in berry crops (i.e. strawberry, raspberry and related species, blackcurrant, redcurrant, blueberry, cranberry), kiwifruit and grapes (Prange and DeEll 1997). Effect of pre-harvest factors such as genotype; climate; nutrient management; water management and other cultural practices; pests and diseases; and bioregulators at postharvest quality attributes such as size; shape; colour; weight loss; firmness; decay; soluble solids conc.; titratable acidity; flavour; aroma; and nutritional value of the fruits were also investigated. Adequate calcium nutrition was found to enhance firmness, delay membrane deterioration and ripening in apples cv. ‘Golden Smoothee’ (Benavides et al. 2001). Apple trees were sprayed over 2 growing seasons with STOPIT, a commercial product, at a Ca rate of 0.15%, in two patterns throughout the growing season, i.e. 10 applications at 15-day intervals starting 10 days after full bloom (DABF), or 6 applications starting 60 DABF at intervals of 15 days. Control trees remained unsprayed. It was observed that Ca applications throughout the growing season appeared to offer no advantages over applications in the later stages of growth, in regard to apple Ca levels and fruit quality. A Ca increase was strongly correlated with an increased firmness at harvest, but levels achieved did not always imply improvements in firmness after prolonged storage. Agronomic conditions such as shaded cultivation could also result in decreased levels of sucrose and higher accumulation of acetaldehyde and ethanol in muskmelons (*Cucumis melo* L. cv. ‘Andesu’) (Nishizawa et al. 1998). It was observed that acetaldehyde and ethanol production by muskmelon fruit were promoted by short-term shading of the plants for 5 days from 10 to 15 days prior to fruit maturation. Sucrose concentration in the fruit flesh was reduced by shading, while fructose and glucose concentration did not differ. Shading also accelerated the development of a ‘water-soaked’ appearance in the flesh. Geographic variations in addition to seasonal variations also play an important role in stress-induced wound physiology of MP products (Babic et al. 1993). Frank et al. (2005) described that vine nitrogen nutrition affected the arginine-mediated Maillard reactions improvements in firmness after prolonged storage. Agronomic conditions such as shaded cultivation could also result in decreased levels of sucrose and higher accumulation of acetaldehyde and ethanol in muskmelons (*Cucumis melo* L. cv. ‘Andesu’) (Nishizawa et al. 1998). It was observed that acetaldehyde and ethanol production by muskmelon fruit were promoted by short-term shading of the plants for 5 days from 10 to 15 days prior to fruit maturation. Sucrose concentration in the fruit flesh was reduced by shading, while fructose and glucose concentration did not differ. Shading also accelerated the development of a ‘water-soaked’ appearance in the flesh. Geographic variations in addition to seasonal variations also play an important role in stress-induced wound physiology of MP products (Babic et al. 1993). Frank et al. (2005) described that vine nitrogen nutrition affected the arginine-mediated Maillard reactions during storage of low moisture ‘Australian sultanas’. Maintenance of phytotoxicant conditions is of paramount importance in maintaining the microbiological quality of produce meant for MP. The presence of pathogens especially on ready-to-eat products could be highly dangerous in terms of food safety. Fresh commodities meant for MP as such need to be grown under ideal agronomic and phytotoxicant conditions.

Biotechnological methods to improve the eating quality of fresh produce in terms of sensory attributes, intrinsically by building the tissues towards express and reduction in susceptibility towards microbial infections in a pre-cut condition and the ability towards withstanding unfavorable storage conditions could be introduced by adopting suitable methods of breeding or by genetic engineering. Agronomic practices i.e. organic farming also play an important role as reservations of consumers towards the growing menace of pesticide and heavy metal residues is on the increase.

**MICROBIOLOGICAL CONSIDERATIONS**

MP of fruits and vegetables has to counter the adverse effects of pre-cutting on the physiology of the plant tissue and also the increased susceptibility of the tissue towards microbial spoilage. Fresh fruits and vegetables are contaminated at the farm environment and also during post-harvest handling and processing (Beuchat 1996). Destruction of surface tissues during preparatory stages of MP exposes cytoplasm and provides a potentially richer source of nutrients for the microorganisms than intact produce. This aspect together with the high water activity facilitates microbial growth in minimally processed fruits and vegetables. A number of contaminating microorganisms including spoilage organisms and pathogens were isolated from pre-cut fruits and vegetables. The organisms include coliforms, fecal coliforms, pectinolytic species, lactic acid bacteria (LAB), yeasts and molds (Brackett 1987). The standard plate counts range from 10² to 10⁴ cfu/g depending upon the product (Haerd 2002). Most of them were from Gram-negative rods, predominantly *Pseudomonades* (Benick et al. 1998). In the case of total mold count, the range could be 10⁴ cfu/g on cut lettuce to 10⁵ cfu/g in shredded carrots. Fungal pathogens are the major cause of post-harvest spoilage of fruits and vegetables (Sommer et al. 1990). *Fusarium sp.*, *Alternaria tenuis*, *Mucor sp.*, *Rizopus nigricans*, *Aureobasidium pullulans* among others were among the most frequently molds isolated from cut fruits and vegetables (Webb and Mundt 1978). Yeast populations could be as much as 10⁴ to 10⁶ cfu/g in processed fruits (Nguyen and Carlén 1994). Heard (2002) described the presence of LAB at 10⁵ cfu/g in shredded chiecy to 10⁶ cfu/g in mixed vegetables. The bacterial pathogens included *Clostridium botulinum*, *Pseudomonas* *Enterobacter* spp, *Versinia enterococolitica*, *Escherichia coli*, *Listeria monocytogens* and *Aeromonas hydrophila* (Palumbo 1986). Storage temperature also plays an important role as mesophilic pathogens i.e. *Salmonella*, *Shigella*, and *E. coli* 0157:47 do not grow under refrigerated conditions (4°C) but they remain viable for a longer duration. *Listeria monocytogens* growth remained constant or decreased on fresh cut fruits and vegetables at 4°C, while at 8°C growth of *L. monocytogens* was observed on the cut vegetables. By reducing the temperature, growth of mesophilic *E. coli* 0157:H7 decreased. However, viable population remained at the end of 4°C storage period. Francis (2004) reported temperature fluctuations during refrigerated storage of cut fruits and vegetables as the main reason for the growth of these organisms. Incidence of enteric viruses such as hepatitis A, Rota virus and Norwalk like viruses had also been reported from isolates of fresh-cut lettuce, chopped tomatoes and strawberries, yet, none have been linked specifically to MAP produce (Beuchat 1996). Out of the 14 reports of viral gastroenteritis salad was implicated as the vehicle in 36%. However, the degree of spoilage does not always correlate with a large total population and the spoilage symptoms could be organism-specific (Heard 2002). The spoilage could cause soft rot, wilting, brown discoloration and fermentative spoilage.

The microbiological profile of minimally processed fruits and vegetables needs an authentic monitoring and controlling schedule. Implementation of Hazard Analysis and Critical Control Points (HACCP) could authenticate the process to ensure food safety.

**MINIMAL PROCESS PROTOCOLS**

Minimal process protocols involve the following unit operations. The selection and sequencing depends on the specific nature of the produce, expected shelf life, storage conditions and marketing network, etc.

**Surface sanitation**

Surface sanitation is highly essential for minimally processed produce as thermal treatments are restricted in the process. The commonly used sanitizers include sodium hypochlorite at a concentration of 50-200 ppm (Pirovani et al. 2001) and 5% solution of hydrogen peroxide (Sapers et al. 1999). The limitation of chlorination in eliminating a wide range of organisms (Sapers and Simons 1998) and its reactivity with some food constituents necessitates the inclusion of certain alternative methods of surface sanitation i.e. ozonization and non-thermal treatments (Hurst 1993). Ozone at a concentration of 0.1 to 1.0 ppm in gaseous form for a period of 360 min was found extremely useful in the inactivation of a number of organisms including *E. coli* and *Bacillus cereus* in pistachio nuts (Akbas and Ozdemir 2006). It was found that the effectiveness of ozone against these organisms increased with increase in exposure time and ozone concentrations. However, the physico-chemical properties i.e. pH, free fatty acids, peroxide value, colour and
fatty acid composition did not change significantly. The non-thermal treatments acquire significance in MP and their use in large-scale production depends largely on scaling up of the equipment and costs. UV-C light as such is an effective disinfectant in reducing the *Salmonella* spp. and *E. coli* O157: from the surface of 'Red Delicious' apples, green leaf lettuce and tomatoes. The produce were treated at constant intensity and variable exposure time were then employed to allow for different doses ranging from 1.5 to 24 mW/cm². The effective wavelength was found to be 253.7 nm to achieve significant reduction in *E. coli* O157:H7 to an extent of 3.3 logs at 24 mW/cm² (Yaun et al. 2004). Use of chlorinated water as sodium hypochlorite in the range of 50-200 ppm is practiced widely and in synergism with ozonization would be helpful in minimizing the concentration of chlorine to acceptable levels. Certain detergents i.e. tri-sodium phosphates are also extensively used for surface sanitation in commodities like cantaloupes melons (*Cucumis melo*) (Sapers et al. 2001).

**Pre-cooling**

MP of pre-cut fruits and vegetables involves physical conditioning of the produce which is under a physiologically stressed condition. The physical conditioning includes removal of field heat through the process of pre-cooling. Ga-riepy and Raghavan (1991) described the effects of various types of pre-cooling i.e. forced air, CO₂ and water pre-cooling. A reduction in post harvest losses by more than 20% was reported for a highly perishable commodity viz. green asparagus. The cooling rates obtained by using chilled water in the presence of ice blocks was found comparable to that of forced air and CO₂ pre-cooling techniques. The same techniques could be used for the removal of field heat of pre-cut fruits and vegetables. Minimally-processed lettuce is being successfully marketed by using pre-cooling techniques to minimize the upsurge in respiration and associated enzymatic discoloration and softening of plant tissues (Wolfe and Tani 2002). The methodology also includes use of cold water current which causes pre-cooling of the produce besides facilitating transportation within the process plant. Such water-born transportation restricts the physiological stress and also restricts the surface microflora. The produce could be trapped by suitable filters at specific points to enable pre-packaging of the produce in a pre-cooled and hygienic condition. Tompkins *et al.* (1997) described a process for the prepackaging of pre-coated straw-berries (Fig. 1). Water-based pre-cooling also facilitates restriction in enzymatic browning besides causing removal of field heat from the pre-cut produce. Pre-cooling also helps in restricting moisture condensation within the packages during chilled storage. Restricting moisture condensation is an important quality parameter for minimally processed pre-cut produce and appropriate packaging with higher water vapor transmission rates (WVTR) and needs to be carried out. The display of the pre-cut product in cabinets, made up of transparent and rigid plastics, also needs restriction in moisture condensation which could be achieved by the process of pre-cooling in addition to other humidity regulatory measures such as use of moisture traps or placement of diffusion windows. However, humidity controlled low temperature cabinets are costly, though highly effective in restricting excessive moisture condensation within the cabinets.

**Size reduction**

Size reduction is an important unit operation in the MP of fruits and vegetables. Since, minimal process is basically perceived as the provisioning of edible parts of a fruit or vegetable in an appropriately pre-cut form followed by mixing of various ingredients to make a wholesome food towards ready-to-eat or ready-to-cook purposes, the specified unit operations attain paramount significance in the process. Size reduction includes a number of operations i.e. peeling, chopping, coring, slicing, dicing, etc. (Bolin and Huxsoll 1991). However, methods need to be selected keeping in view certain requirements to minimize the physiological stress and also the requirements of consumers for specific end uses. It has been well proved that the quality of cutting determines the extent of physiological stress. Barry-Ryan and O’Beirne (1998) reported the effectiveness of razor blades in minimizing physiological stress in pre-cutting of carrot compared with machine blades either with sharp or blunt edges. Similarly, care needs to be taken to avoid excessive abrasion of the tissue which may result in excessive physiological stress. The particulate size also matters in achieving restricted physiological stress and susceptibility towards microbial infections. Certain end uses require shredding and crinkle cutting etc. which may result in higher stress conditions restricting the shelf life of the minimally processed product.

![Fig. 1](image-url) Method for processing fresh-cut fruits or vegetables.
Mixing

Mixing involves solid-solid, solid-liquid and solid-gas contacting systems. Process equipments for such systems are designed to achieve the appropriate operations with a minimum expenditure of energy and capital investment. Blending of ingredients is usually achieved by solid-solid mixing. Certain screening procedures are also employed for the separation of mixtures to select appropriately sized units of pre-cut produce by using vibrating bar screens. Composite foods essentially require mixing and assembling prior to packaging. Blending, coating and dipping operations require solid to solid mixing. Salad dressings are emulsions that are a mixture of liquids. Appropriate mixing technique is required to obtain stable emulsions which could be surface coated on the fruit or vegetable segments involved in salad making.

Chemical pretreatments

MP over the years centered on physical conditioning of the pre-cut produce inclusive of surface sanitation, pre-cooling during processing followed by modified atmosphere (MA) storage. This classical approach adheres to the fundamentals of MP where marginal to minimal stabilization of the produce takes place. The produce remains very close to the fresh-like quality and exhibits limited shelf life for over a few days at low temperature. The important requirements for the adaptation of such a classical process includes microbial contamination levels on the produce, environmental conditions i.e. temperature and humidity of ambient air, extent of automation of the process, presence of adequate cold chain, socio-economic conditions of the manpower involved, infrastructure and market chain. Tropical, developing countries have deficiencies with regards to the above. Therefore, attempts have been made to impart stability to the produce by chemical conditioning without resorting to harsh heat preservation methods. A number of food additives were reported to have potential in restricting textural degradation of pre-cut produce. Several acidulants like acetic acid, citric acid and malic acids were used in minimally processed cabbage for restricting the microbiological loads (Fantuzzi et al., 2004). Raju et al. (2002) described beneficial effects of citric acid (0.6%) in combination with class II antimicrobials i.e. benzoate and sorbate (0.025%) for enhancing the anti-PPO activity by lowered temperature or use of texturizing agents. Spicing is an essential process for many products i.e. stews vegetables, salads and steamed products such as fresh sweetcorn. Spicing of these products could render preservative functions besides contributing to the sensory attributes of the product (Chauhan et al., 2006b).

The functional pH of different antimicrobial agents needs to be matched with the product characteristic along with the target organisms to maximize the beneficial effects (Table 1).

### Table 1: Functional pH and target organisms.

<table>
<thead>
<tr>
<th>Antimicrobial agent</th>
<th>Functional pH</th>
<th>Target microorganism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzoylpenicillin</td>
<td>6.0</td>
<td>Bacteria, yeasts and molds</td>
</tr>
<tr>
<td>Sodium azide</td>
<td>8.0</td>
<td>Bacteria, yeasts and molds</td>
</tr>
<tr>
<td>Zanamivir</td>
<td>5.0</td>
<td>Mostly yeasts and molds, some bacteria</td>
</tr>
<tr>
<td>Ribavirin</td>
<td>7.0</td>
<td>Mostly bacteria</td>
</tr>
<tr>
<td>Fosfomycin</td>
<td>6.0</td>
<td>Yeast and some bacteria</td>
</tr>
<tr>
<td>Lysozyme</td>
<td>4.5</td>
<td>Gram-positive bacteria</td>
</tr>
<tr>
<td>Natamycin</td>
<td>5.0</td>
<td>All molds and yeasts; No effect on bacteria and viruses</td>
</tr>
<tr>
<td>Nisin</td>
<td>3.0</td>
<td>Gram-positive bacteria</td>
</tr>
</tbody>
</table>

### Use of bio-preservatives

Use of bio-preservatives is on the increase with regards to stabilization of pre-cut produce. The latest consumer choices include bio-preservatives inclusive of antimicrobials and antioxidants. Bacteriocins which are protein containing macromolecules with antimicrobial function could be used as such 4-hexyl resorcinol (Son et al., 2006) described the synergistic effects of calcium infiltration, mild acidification to pH 4.5 and presence of MA on the keeping quality and maintenance of optimum texture of pre-cut papaya (C. papaya L.) slices. However, certain requirements need to be kept in view during chemical conditioning of pre-cut product. Foremost amongst them, is the need to minimize the chemical additives so that they do not impede the sensory quality of the product in comparison to fresh produce. The use of SO₂ should adhere to the latest specifications and ready-to-eat pre-cut products can not have more than 50 ppm SO₂ residue (Chassery and Gormley, 1994).

### Moisture conditioning of pre-treated products

Since pre-cut produce has the tendency to ooze out water (Gorny, 1997), there is need to condition the produce prior to packaging. The usual methods employed include basket centrifugation, vibratory sieves and restricted hot air evaporation of surface moisture. However, the extent and intensity of these techniques need to be maintained below certain threshold levels so that the solid loss is minimized during the unit operation. Another concern could be the loss of in...
fused additives during the dewatering process. Therefore, it is highly essential to minimize these operations and use of dehumidified air currents could be highly useful in restricting the solid and textural losses during the process.

Use of edible coatings

Use of edible coatings on the surface of fruits and vegetables has a number of advantages:

1. Forms an efficient barrier to moisture loss;
2. Has a selective permeability towards respiratory gases such as O₂ and CO₂; water vapours and ethylene;
3. Controls migration of water-soluble solutes to retain the natural color and nutrients;
4. Facilitates food contact applications by holding additives i.e. flavors and preservatives.

Reports exist (Lewicki et al. 1984; Camirand et al. 1992; Baldwin et al. 1996; Mao and Holly 2000) that describe the useful effects of coatings in protecting the product quality during dewatering processes i.e. hot air/freeze/osmotic dehydration. The advantages are:

1. Reduction in loss of color and flavor compounds as well as nutrients;
2. Allowing the use of lower molecular weight osmotic agents with high osmotic pressures;
3. Reduction in amount of osmotic agents that enters the food;
4. Less microbial contamination during storage;
5. Less oxygen diffusion to food;
6. Greater aesthetic appeal for the products particularly those with clear polysaccharide coatings.

The polysaccharides frequently used in the coatings include alginites (Moldao et al. 2003), pectin (Vachon et al. 2003), chitosan (Baldwin et al. 1996), proteins (Perez-Gago et al. 2003), starches (Garcia et al. 1998), shellac (Huanting 2004) etc. and the cross linking of molecules enhance the barrier and mechanical properties of the coatings significantly. The composite coatings could be designed appropriately by inclusion of ingredients such as proteins and lipids to obtain optimum coating characteristics.

In the case of pre-cut produce, the surface coatings need to help the surface dewatering process and at the same time, they have a role in preventing oozing out of water during storage. Therefore, the coatings need to be sparingly soluble in water to restrict dissolution of the coatings during storage of the pre-cut produce.

Non-thermal treatments

Non-thermal pretreatments inclusive of advanced physical conditioning include high pressure processing, ionizing radiation, reduction in water activity, pulsed electric field and pulsed UV light. The application of non thermal treatments takes care of not only the surface micro flora but also that of the product.

High pressure processing

High pressure processing is extremely useful in inactivating a number of organisms such as bacterial sores, yeasts, molds and vegetative cells in the range of 600 MPa to 1200 MPa. Milder treatments at 300-600 MPa were found to be effective against the bacterial and fungal vegetative cells in terms of inactivation. However, most of the bacterial spores required 1200 MPa for their inactivation (Gomes and Ledward 1996). Pre-cut produce like chopped garlic (Allium sativum L.) in a mildly acidified (pH 4.4) condition could render excellent storage stability in terms of physico-chemical characteristics and keeping quality to the product (Hong and Kim 2001).

Ionizing radiation

Low does of γ-irradiation (0.2 kGy) was found to reduce bacterial population with a moderate increase in produce respiration in packaged cut lettuce and shredded carrot (Hagenmaier and Baker 1997). Irradiation at a mean doses of 0.19 kGy of commercially prepared fresh-cut iceberg lettuce resulted in a product that had, 8 days after irradiation, total microbial population of 290 cfu/g and yeast population of 60 cfu/g, compared with values of 2,20,000 and 1400 cfu/g respectively for non-irradiated control. The respiration rate of the irradiated lettuce was about 33% higher than that for the control samples after one day and 8 day of irradiation and slightly lower after 13 days at 2°C. Doses of >0.34 KGy could result in softening of tissues in apple ( cvs. ‘Delicios’, ‘Empire’, ‘Inedar’ and ‘Rome’) slices despite reduction in ethylene production (Gunes et al. 2000, 2001). Firmness was found to decrease with increase in irradiation dose beyond 0.34 kGy and the high dose rate initially resulted in less softening compared to low dose rate, but dose rate became insignificant upon storage. Therefore, there is a need to keep the radiation doses around the threshold level to minimize textural losses and discoloration of the product due to increased enzymatic browning. Irradiation was found to alter the cell wall permeability of cell compartments allowing contact between PPO and its substrates causing increased browning (Mayer and Harel 1991).

Reduction of water activity

Moisture conditioning of the product by osmotic dewatering at mild temperatures preserves the fresh-like characteristics of fruits and vegetables (Heng et al. 1990). Vacuum impregnation during the osmotic process increases rates of moisture and weight loss and solid gain besides conditioning the product in terms of water activity (Rastogi and Raghavrao 1996). A mathematical model was developed based on osmotic pressure; osmotic pressure ratios were calculated for drying under atmospheric conditions and under vacuum. The effect of vacuum application was examined on the basis of the diffusional osmotic transport parameter, the mass transfer coefficient and the interfacial area. Minimally-processed fruit and vegetable products with controlled water activity (a_w 0.92-0.97) shows stabilization in terms of metabolic activities and shelf life and the concept could be further extended to obtain products preserved with combination preservation techniques (Wiley 1994).

Pulsed electric field/UV light

Pulsing of electric field or UV-C light maximizes the energy dissipation which enables reduction in the microbial population with minimal use of energy. Barbos et al. (1996) described the inactivation of a wide range of bacteria and yeasts in terms of their susceptibility towards pulsed electric fields. Similarly, pulse UV-C light has also been described as a highly effective non-thermal mode of microbial inactivation with respect to mesophilic, psychrotrophic, lactic acid and Enterobacteriaceae counts in minimally processed pomegranate (Punica granatum cv. ‘Molar of Éléche’ arils (Lopez-Rubira et al. 2005). However, the yeasts and moulds were found unaffected by the UV-C treatments.

Modified/controlled atmosphere (MA/CA) packaging

Modified atmosphere (MA) packaging is an important unit operation to obtain physiological and microbiological stability to the pre-cut produce. MA as such is based on lowered O₂ and elevated CO₂ concentrations achieved through produce-generated passive mode or through active modes using an external source of gas mixtures. Low O₂ and high CO₂ environments in the package of fresh cut produce can extend the shelf life by slowing respiration rate, browning reactions, water loss and ethylene biosynthesis (Gorny 1997). A concentration of 5-10% CO₂ and 2-5% O₂ has been suggested for modified atmosphere packaging of cut fresh produce (Kader et al. 1989). Chauhan et al. (2006c) reported reduction in respiratory activity of pre-cut mango slices and
attributed the same to the synergistic effects of pre-conditioning of the slices with acidulants and modified and controlled atmospheres. The best results were obtained by the synergistic effects. The MA alone could not show significant anti-respiratory function. The maintenance of MAs within the packages had also helped in restriction of microbial proliferation with emphasis on yeasts and molds. The low O2 and high CO2 atmospheres result in restriction of enzymatic browning and activity of cell wall degrading enzymes i.e. pectin methyl esterase and polygalacturonase. The debate continues with regards to specific roles of lower O2 and elevated CO2 concentrations for their antimicrobial activity. The presence of MAs in polypropylene over wrapped trays was found to influence the color and aroma profiles of pre-cut mangoes (Beaulieu and Lea 2003). However, the onset of anaerobic condition needs to be avoided which is a common problem in unconditioned pre-cut produce. The pre-conditioning of pre-cut produce in the form of a minimal process could be carried out with a variety of additives i.e. acidulants, ascorbic acid, browning inhibitors and texturizing agents. However, the process needs to be optimized keeping in view the requirement to keep the product in a fresh like condition without impeding the sensory attributes significantly.

SAFETY OF MINIMALLY PROCESSED PRODUCT

A pre-cut surface offers an ideal site for microbial attacks. The plant tissues respond spontaneously by a series of biochemical events i.e. lignification, formation of polyphenolic compounds and increase in detoxifying enzymes such as peroxidase. Minimally processed fruits and vegetables could be contaminated by a number of organisms including pathogens i.e. Clostridium, Salmonella, E. coli, Pseudomonas, Aeromonas, Listeria, Erwinia, Campylobacter, etc. Minimal process primarily aims at decreasing the microbiological load by appropriate surface sanitation and maintenance of optimized MAs at low temperature. Maintenance of hygiene at the produce and process levels holds the key in ensuring authentic provision of minimally processed fruits and vegetables. Following precautions can help in ensuring phytosanitary conditions in the process plant and in the distribution chains:

- Minimizing handling frequency;
- Providing continued control of temperature, RH, CA conditions during storage and transport;
- Transferring product from truck to refrigerated storage immediately;
- Rotating products on a first-in/first-out basis;
- Stacking individual cases no more than five cases high.

The major sources of microbiological contamination are animal feces, bio-solids or contaminated water used (Beaulieu 1996). The pH of many fruits is lower than 4 and this low pH combined with presence of organic acids generally prevents the growth of pathogenic bacteria. Temperature and MA abuses during storage are major concerns in extending the shelf life of pre-cut fresh commodities. The temperature and MA requirements of some of the pre-cut fruits are given in Table 2. However, it is important to notice that the MA requirements for whole and pre-cut produce could differ as the pre-cut produce undergoes stressed physiology with an increased susceptibility towards microbial infections and quality deterioration as such.

The growth of microorganisms need specific and necessary precautions to be taken to restrict them by phytosanitary measures or by the use of additives used as aids to preservation (Table 3).

REGULATORY MODE AND MICROBIOLOGICAL SPECIFICATIONS

Regulation

Besides the basic provisions of the Food Drug and Cosmetic act, the US food and Drug administration has promulgated (good manufacturing practices (GMP) designed to minimize risk to public health from improper handling, storage, distribution or processing of fruits and vegetables. All MP refrigerated foods include refrigeration as one of the

<table>
<thead>
<tr>
<th>Commodity</th>
<th>MA requirements</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple</td>
<td>&lt;1kPa O2</td>
<td>Soliva-Fortuny et al. 2002</td>
</tr>
<tr>
<td>Papaya</td>
<td>3 kPa O2 + 6 kPa CO2</td>
<td>Chauhan et al. 2006a</td>
</tr>
<tr>
<td>Mango</td>
<td>2 kPa O2 + 10 kPa CO2</td>
<td>Rattanapane et al. 2001</td>
</tr>
<tr>
<td>Pear</td>
<td>2 kPa O2</td>
<td>Chauhan et al. 2006c</td>
</tr>
<tr>
<td>Peach</td>
<td>0.25 kPa O2 + 10 kPa CO2</td>
<td>Gorny et al. 1990</td>
</tr>
<tr>
<td>Watermelon</td>
<td>3 kPa O2 + 15 kPa CO2</td>
<td>Cartaxo et al. 1997</td>
</tr>
<tr>
<td>Strawberry</td>
<td>1-2 kPa O2 + 10 kPa CO2</td>
<td>Watada et al. 1996</td>
</tr>
<tr>
<td>Citrus</td>
<td>Air</td>
<td>Palma et al. 2003</td>
</tr>
<tr>
<td>Honeydew melon</td>
<td>2 kPa O2 + 10 kPa CO2</td>
<td>Qi et al. 1999</td>
</tr>
<tr>
<td>Tomato</td>
<td>0 kPa O2 + 12 kPa CO2</td>
<td>Gil et al. 2002</td>
</tr>
<tr>
<td>Potato</td>
<td>3 kPa O2 + 9 kPa CO2</td>
<td>Gunes and Chang 1997</td>
</tr>
<tr>
<td>Cabbage and lettuce</td>
<td>1.2-5.0 kPa O2 + 3.5 kPa CO2</td>
<td>Koseki and Itoh 2002</td>
</tr>
<tr>
<td>Brussels sprouts</td>
<td>2.54 kPa O2</td>
<td>Tan et al. 1994</td>
</tr>
<tr>
<td>Carrot and cucumber</td>
<td>2.0-2.1 kPa O2 + 5.5-5.7 kPa CO2</td>
<td>Lee et al. 1996</td>
</tr>
<tr>
<td>Mushrooms</td>
<td>10-20 kPa O2 + 2.5 kPa CO2</td>
<td>Simon et al. 2005</td>
</tr>
<tr>
<td>Peeled garlic</td>
<td>0% O2, 5-15% CO2</td>
<td>Dong et al. 2000</td>
</tr>
</tbody>
</table>

Table 2 Suggested modified atmosphere conditions for some fresh-cut produce.

<table>
<thead>
<tr>
<th>Microorganism</th>
<th>Cut produce</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacteria</td>
<td>Cabbage, raw tomatoes, lettuce, celery, coleslaw</td>
</tr>
<tr>
<td>Listeria monocytogenes</td>
<td>Watermelon, tomatoes, cantaloupe melon, cress sprouts, mung sprouts</td>
</tr>
<tr>
<td>Salmonella spp.</td>
<td>Garlic</td>
</tr>
<tr>
<td>Clostridium botulinum</td>
<td>Cantaloupe melon, radish sprouts</td>
</tr>
<tr>
<td>Escherichia coli</td>
<td>Soy, mustard and cress sprouts</td>
</tr>
<tr>
<td>Bacillus cereus</td>
<td>Bean sprouts</td>
</tr>
<tr>
<td>Yersinia enterocolitica</td>
<td>Lettuce, parsley, watermelon</td>
</tr>
<tr>
<td>Campylobacter jejuni</td>
<td>Lettuce</td>
</tr>
<tr>
<td>Virus</td>
<td>Lettuce, tomatoes, raspberry, strawberry</td>
</tr>
<tr>
<td>Norwalk virus</td>
<td>Fresh cut fruits, melon, raspberries</td>
</tr>
<tr>
<td>Parasites</td>
<td>Blackberry, raspberry</td>
</tr>
<tr>
<td>Cryptosporidium parvum</td>
<td>Green onion</td>
</tr>
<tr>
<td>Cyclospora cayetanensis</td>
<td>Onions, lettuce</td>
</tr>
<tr>
<td>Giardia spp.</td>
<td></td>
</tr>
</tbody>
</table>

Table 3 Microorganisms associated with cut fruits and vegetables (Francis 2004).
hurdles or barriers to maintain product safety and quality. As such, the GMP regulatory protocols need to be established and a sort of umbrella GMP exists to address plant, equipment and personal hygiene. Presence of time-temperature indicators as smart indicators for possible storage temperature and ESL (expected shelf life) abuses could come handy in ensuring better food safety. Another important issue is regarding the safety of chemical substances involved in cut fruit and vegetable processing is GRASS (generally recognized as safe) listed additives by the USFDA. The list of additives and their specifications of the Codex Alimentarius Commission is also a world reference on the subject. The HACCP approach should be considered and practiced by all MP food manufacturers to ensure food safety. United States Food and Drug Administration (FDA) together with the Institute of Food Technologies (IFT) issued a document ‘Analysis and Evaluation of Preventive Control Measures for the Control and Reduction/elimination of microbial hazards on fresh and fresh cut produce’ (FDA 2001). This document presents a comprehensive guide about potential microbial risks in fresh cut produce and how to handle them through out production, processing and distribution. Maintenance of the keeping quality of pre-cut fruits and vegetables by minimal process is in vogue in many developed countries including the United States. However, the process strategy had been physical conditioning oriented inclusive of removal of field heat, stringent phyto-sanitary conditions, automated unit operations, minimization of manual handling etc. The technology is often backed by a marketing chain with adequate cold storage and transportation facilities. HACCP protocols are followed and a continuous feed back on the quality of the produce is obtained from the consumers to have authentic control and remedial measures in the process. The process is basically strategy oriented rather than mere technology as such.

Specifications

The specifications pertaining to MP fruits and vegetables are largely geographical location specific. Many European countries make use of certain arbitrary specifications to ensure food safety in terms of biological hazards. However, the additives in the form of preservatives i.e. antimicrobial, antibrowning and texturizing agents need to be regulated to ensure comprehensive food safety.

Food additives

Pre-cutting of fruits and vegetables induces physiological stress and renders the cut surface highly susceptible to microbial infections. Though the classical approach to MP does not make use of food additives for the stabilization purpose, the horizons of the technology developed new frontiers in the form of minimal use of additives to impart stability to the products without impeding the sensory attributes of the pre-cut produce. The commonly used additives include ascorbic acid, sulfur dioxide, salts of benzoic and sorbic acids, calcium salts and acidulants i.e. citric, malic and lactic acids. The role of sulfur dioxide in the preservation of ready-to-eat fruits and vegetables had undergone drastic changes over the years. U.S. FDA considers use of sulfur dioxide and sulfite salts on fruits and vegetables intended to be served raw to consumers as illegitimate and therefore, the use of SO₂ or sulfites need to be subjected to closure scrutiny in terms of regulations. As a rule of thumb colored vegetables are subjected to MP without the use of SO₂ whereas, the vegetables with white flesh are usually restricted to a maximum permitted level of 50 mg/kg. However, the labeling requirements are stringent and specific mention need to be present for any use of SO₂ above 10 mg/kg. Ascorbic acid is the most commonly used additive in MP and the regulation gives it the status of ‘quantum satis’ (to an extent satisfactory to the consumer). The primary objectives for the use of ascorbic acid include antibrowning activity in addition to function as vitamin C supplementation. Pre-cutting of fresh produce and also germination of pulse seeds result in excessive losses of ascorbic acid and could be a major drawback for the nutritional quality of pre-cut produce. Use of ascorbic acid in MP has the status of quantum satis and the vitamin C requirement is met with the inclusion of L-isomeric form of ascorbic acid (erythrobate). The practice also includes inclusion of D-isomeric form of ascorbic acid along with L-ascorbic acid as the former is readily oxidizable though, devoid of vitamin C activity resulting in better retention of L-ascorbic acid or its salts. Use of benzoates and sorbates is not wide spread to render microbial stability to the pre-cut produce (Baldwin et al. 1996). However, since the ADI levels, these substances are significantly high at 5 and 25 mg/kg body weight, the maximum permissible levels could be 200 mg/kg for single or combined use of the specific antimicrobials. In the case of texturizing agents, use of calcium salts could be restricted to a calcium level of 50 mg/kg as in the case of canned products for diced potatoes. The use of other texturizing agents i.e. hydrocolloids could be an area of intensive research to impart fresh like textural quality to the pre-cut produce (Lamikanra and Watson 2003). Several acidulants have been successfully used as means of protection against excessive bacterial levels and also to render suitable functional pH for class II antimicrobials i.e. benzoates. Commercial sources of malic and lactic acids are preferred in the industry as the additives have lesser tartness compared to citric acid. Use of glucono-δ-lactone also needs higher attention as the acidulant has the tendency to yield progressively increasing acidity upon hydrolysis during storage of the product and could also contribute significantly in decreasing the tartness of the product (Martinez et al. 1997). Though the chemical conditioning of pre-cut produce render significant shelf stability and endow the produce with intrinsically built resistance towards spoilage under ambient storage, the sensory attributes need to be kept close to the fresh like quality. In the case of ready-to-cook products, the acidification of the produce shall be restricted to a minimal level so that the cookability of the products is not affected adversely.

Microbiological specifications

The microbiological specifications of fresh cut/minimally processed fruits and vegetables are largely dependent on the agro-climatic conditions, environmental and hygiene standards in the process plants and the storage temperatures adopted at wholesale/retail markets in different countries. Some of the European countries have established certain mandatory microbiological specifications for the marketing of the pre-cut produce to ensure food safety to the consumers. However, batch and seasonal variations warrant a continuous feedback from the consumer forum to the industry as the additives have lesser tartness compared to citric acid. Use of glucono-δ-lactone also needs higher attention as the acidulant has the tendency to yield progressively increasing acidity upon hydrolysis during storage of the product and could also contribute significantly in decreasing the tartness of the produce (Martinez et al. 1997). Though the chemical conditioning of pre-cut produce render significant shelf stability and endow the produce with intrinsically built resistance towards spoilage under ambient storage, the sensory attributes need to be kept close to the fresh like quality. In the case of ready-to-cook products, the acidification of the produce shall be restricted to a minimal level so that the cookability of the products is not affected adversely.

| Table 4 Suggested microbial specifications for prepared salad vegetables (Germany). (modified from Lund 1993). |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Microbial counts | Limits (g⁻¹) | Total counts at production | <5x10⁶ | Total counts at retail | <5x10⁷ | Escherichia coli | <10¹² | Salmonella | Absent in 25 g sample | Listeria monocytogenes | <10⁻¹, no action | Recommened shelf life | 7 days (including days of production) | Recommended temperature | 2-7°C | during transportation and sale |
are restricted to 10^2 and it is a common experience that incidence of pathogens. The tolerance levels for coliforms could be high with tolerance levels of coliforms without the draw from these case studies. A noteworthy feature is SPC. The available literature is scarce except a few case-mounted to pre-cut commodities as the profiles largely depend on initial loads, the prevailing climatic conditions at pre as well as post harvest stages, season of growth etc. The batch-totraditions for pre-cut commodities as the profiles largely depend on market requirements and the specific nature of the products and shall not be deviated from the specific process, storage and transportation schedules as any deviation could be deleterious in terms of public health and brand reputation.

FUTURE PROSPECTS

Marketing of pre-cut produce is largely restricted to developed countries with a well established infrastructure and assured phytosanitary conditions at farm and industry levels. Since tropical countries are the major producers of several exotic tropical fruits and vegetables with vast export potential, these countries need greater attention and integration with the global marketing network. Minimal process plants with low capital investments and as cottage industry need to be developed in close proximity to scientifically managed farms. The energy inputs need to be minimal and the required phytosanitary conditions standardized by appropriately addressed mechanisms, including extension services to areas of production to generate socio-economic awareness required for tapping the huge resources of fresh produce available. Cooperative processing and adoption of HACCP protocols can promote entrepreneurship and successful marketing inclusive of exports. Organically grown produce could be highly conducive for marketing in pre-cut and packaged form. It is highly essential to adhere to the specific process, storage and transportation schedules as any deviation could be deleterious in terms of public health and brand reputation.

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Table 5: Suggested microbial specifications for prepared salad vegetables. (modified from Nguyen and Carlin 1994).

<table>
<thead>
<tr>
<th>Microorganisms</th>
<th>Sample size</th>
<th>c*</th>
<th>Limit (cfu g^-1)</th>
<th>m^n</th>
<th>M^o</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total counts at production</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salad and shredded vegetables</td>
<td>5</td>
<td>2</td>
<td>5 x 10^2</td>
<td>5 x 10^3</td>
<td></td>
</tr>
<tr>
<td>Parsley, watercress and aromatic herbs</td>
<td>5</td>
<td>2</td>
<td>5 x 10^3</td>
<td>5 x 10^4</td>
<td></td>
</tr>
<tr>
<td>Total counts at use-by-date</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salads</td>
<td>5</td>
<td>d</td>
<td>d</td>
<td>5 x 10^4</td>
<td></td>
</tr>
<tr>
<td>Coliforms at 44.5°C</td>
<td>5</td>
<td>2</td>
<td>10^1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salmonella in 25 g</td>
<td>5</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td></td>
</tr>
</tbody>
</table>

a: maximum allowable number of samples between m and M for acceptance; b: value separating good quality from marginally acceptable quality; c: unacceptability value and d: at use-by-date, m = M

MARKETING

A sound marketing network is absolutely essential for the successful marketing of pre-cut and minimally processed produce. Schaffner (2002) reviewed the factors implicated in the transition of tens to expected shelf life as a mandatory requirement eliminates the potential biological hazards. However, the generalized requirements adopted by different countries include zero tolerance towards pathogens and coliforms. Detection of fungal spores of potential toxigenic species is also objectionable. Adoption of the HACCP protocol is mandatory for international trade concerning pre-cut produce and the protocol as such ensures elimination of biological hazards which may cause threat to food safety and public hygiene. As such, it is difficult to draw microbiological specifications for pre-cut commodities as the profiles largely depend on initial loads, the prevailing climatic conditions at pre as well as post harvest stages, season of growth etc. The batch-tobatch variations are large across different geographic entities. The available literature is scares except a few case studies (Nguyen and Carlin 1994; Phillips 1996). Certain commonalities keeping public hygiene in focus could be drawn from these case studies. A note-worthy feature is SPC could be high with tolerance levels of coliforms without the incidence of pathogens. The tolerance levels for coliforms are restricted to 10^2 and it is a common experience that these levels are attained within a limited period and therefore, ideally, the produce need to be free from coliforms.

Bulk: A sound marketing network is absolutely essential for the successful marketing of pre-cut and minimally processed produce. Schaffner (2002) reviewed the factors implicated in the transition of tens to expected shelf life as a mandatory requirement eliminates the potential biological hazards. However, the generalized requirements adopted by different countries include zero tolerance towards pathogens and coliforms. Detection of fungal spores of potential toxigenic species is also objectionable. Adoption of the HACCP protocol is mandatory for international trade concerning pre-cut produce and the protocol as such ensures elimination of biological hazards which may cause threat to food safety and public hygiene. As such, it is difficult to draw microbiological specifications for pre-cut commodities as the profiles largely depend on initial loads, the prevailing climatic conditions at pre as well as post harvest stages, season of growth etc. The batch-tobatch variations are large across different geographic entities. The available literature is scares except a few case studies (Nguyen and Carlin 1994; Phillips 1996). Certain commonalities keeping public hygiene in focus could be drawn from these case studies. A note-worthy feature is SPC could be high with tolerance levels of coliforms without the incidence of pathogens. The tolerance levels for coliforms are restricted to 10^2 and it is a common experience that these levels are attained within a limited period and therefore, ideally, the produce need to be free from coliforms.

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