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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 O_2 and high CO_2 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

CONTENTS

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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 fruit 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 technological domains. MP involves the principles of postharvest 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 nutritional 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 Bolin 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. Snack fruits: Sliced water melon, muskmelon, peeled oranges, pitted plums, etc.
5. Fruit pudding 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 (Rolle and Chism 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, lipoxygenase, ACC (1-aminocyclopropane-1-carboxylate) synthase, ACC oxidase, phospolipase 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*. 2000). 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 and plant age (2, 3 and 4 yr) on yield and quality of strawberries (cv. 'Bounty') and reported that mulch type had a significant effect on total yield, with straw mulch increasing the total yield by 73%, but had no significant effect on yield of 1st grade fruits. Fertilization had no significant effect on total yield, but had a positive effect on the yield of 1st grade fruits with both mulches. Vitamin C content was not significantly affected by mulch type. Fertilization increased vitamin C content in fruits grown on plastic mulch but decreased it in fruits grown on straw mulch. Vitamin C content was negatively influenced by plant age, and in the 3-yr-old plantation, smaller fruits contained more vitamin C than larger fruits. With straw mulch, fertilization decreased the number of cracked fruits by 12%. Taehyun *et al*. (2005) studied the effects of phosphorus fertilizer supplementation on the activity of antioxidant enzymes such as superoxide dismutase, guaicol peroxidase and ascorbates peroxidase in tomato fruits and reported that antioxidant activities in tomatoes is influenced by the availability of P, but are subject to variation depending on developmental stage and season. However, Oke *et al*. (2005) is of the view that phosphorus supplementation during cultivation has no significant effects upon tomato processing quality.

Maturity of different fruits and vegetables also plays an important role in the quality of MP products (Soliva-Fortuney *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 moisture content whilst crude fibre, titratable acidity and total protein content were significantly increased. With the exception of the cv. 'Samaru stripe', 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 hemicellulose 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 microbiological 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 cosmosus* 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 on 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 (DAFB), or 6 applications starting 60 DAFB 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 during storage of low moisture 'Australian sultanas'. Maintenance of phyto-sanitary 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 phyto-sanitary conditions.

Biotechnological methods to improve the eating quality of fresh produce in terms of sensory attributes, intrinsically built ability of the tissues towards physiological stress 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 10^1 to 10^9 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 10^2 cfu/g on cut lettuce to 10^8 cfu/g in shredded carrots. Fungal pathogens are the major cause of post-harvest spoilage of fruits and vegetables (Sommer *et al*. 1992). *Fusarium* sp., *Alternaria tenuis*, *Mucor* sp., *Rizopus nigricans*, *Aureobasidium pullunans* 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 10^3 to 10^4 cfu/g in processed fruits (Nguyen and Carlin 1994). Heard (2002) described the presence of LAB at 10^2 cfu/g in shredded chicory to 10^6 cfu/g in mixed vegetables. The bacterial pathogens included C*lostridium botulinum*, *Pseudomonas*, *Enterobactor* sp., *Yersinia enterocolitica*, *Escherichia coli*, *Listeria monocytogens* and *Aeromona 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 3-4°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 rots, 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 alternate 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 vale, 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/cm^2. The effective wavelength was found to be 253.7 nm to achieve significant reduction in *E. coli* 0157.H7 to an extent of 3.3 logs at 24 mW/cm^2 (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. Gariepy and Raghavan (1991) described the effects of various types of pre-cooling i.e. forced air, CO_2 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 CO_2 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 strawberries (**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.

Harvesting fruits or vegetables
↓
Pre-cooling
↓
Sorting and grading
↓
Washing with chilled, chlorinated water
↓
Trimming fruits or vegetables in cold, chlorinated water flume
↓
Dewatering
↓
Size reduction/slicing/cutting
↓
Washing in chilled chlorinated water
↓
Soaking fruits or vegetables slices in solution containing citric acid, ascorbic acid etc.
↓
Draining of water
↓
Drying in the current of dehumidified air
↓
Packing in trays over-wrapped with breathable film
↓
Labeling
↓
Palletizing in cartons and cooling

Fig. 1 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 man power 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 losses, browning of tissue and also for antimicrobial activity 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 keeping quality of minimally processed shredded cabbage. Rocha *et al* (1998) treated cut apples for 5 min in 0.75% ascorbic acid; 0.75% ascorbic acid and 0.75% CaCl2; or 0.75% ascorbic acid, 0.75% CaCl2 and 0.75% citric acid and reported a number of beneficial effects of citric acid and ascorbic acid in terms of anti-PPO activity. Another area which received significant attention is the restriction of browning through sulfur derivatives and sulfur substitutes as such 4-hexyl resorcinol (Son *et al*. 2001), ascorbic acid alone or in combination with sodium hexametaphosphate (Pilizota and Saper 2004) in apple slices and cysteine derivatives in pineapple slices (Gonzalez-Aguilar *et al*. 2005).

Pre-cut produce tend to soften due to enhanced activity of cellulolytic and pectin degrading enzymes which needs remedial action in the form of reduction in physiological activity by lowered temperature or use of texturizing agents. Chauhan *et al*. (2006a) described the synergistic effects of calcium infiltration, mild acidification to pH 4.5 and presence of MAs on the keeping quality and maintenance of optimum texture of pre-cut papaya (*C. papya* 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 SO_2 should adhere to the latest specifications and ready-to-eat pre-cut products can not have more than 50 ppm SO_2 residue (Chassery and Gormley 1994).

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 a number of fruit and vegetable products in pre-cut form. Nisin is highly effective against Gram-positive bacteria e.g. *Clostridium* sp. in general and also holds potential for the stabilization of minimally processed products in addition to pediocin, ruterine and microgard (Mahapatra *et al*. 2005). Ukuku and Fett (2004) tested nisin (50 mug/ml), EDTA (0.02 M, disodium salt), sodium lactate (NaL, 2%) and potassium sorbate (KS, 0.02%) alone and in various combinations as sanitizer treatments for reducing *Salmonella* on whole and fresh-cut cantaloupe and found that combination treatments of nisin-EDTA, nisin-NaL, nisin-KS, NaL-KS or nisin-NaL-KS resulted in reductions of approx. 3 log cfu/cm^2 for whole melons at day 0, but were less effective after 3 and 7 days storage. They further suggested that treatment of whole cantaloupe with nisin-EDTA, nisin-NaL, nisin-KS or NaL-KS, and fresh-cut pieces with nisin-NaL or NaL-KS could help ensure the safety of fresh-cut cantaloupe. Another potential area of bio-preservatives for application in MP products includes spices and oleoresins which are potential natural antioxidants and antimicrobials (Ahn *et al*. 2004). The use of spices and derivatives could be judiciously made use of as an integral part of end product composition. 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**).

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-

Table 1 Functional pH and target organisms.

Antimicrobial agent	Functional pH	Target microorganism
Benzoates	2.5-4.0	Bacteria, yeast and molds
Sulfites	Acidic pH (<4.0)	Bacteria, yeast and molds
Sorbates	Acidic pH	Mostly yeast and molds, some bacteria
Nitrites	Acidic pH	Mostly bacteria
Parabens	3-8	Bacteria and fungi
Dimethyl dicarbonate	3.7	Yeast and some bacteria
Lysozyme	5.5-6.0	Gram-positive bacteria
Natamycin	5-7	All molds and yeasts; No effect on bacteria and viruses
Nisin	3	Gram-positive bacteria

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 O_2 and CO_2; 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 alginates (Moldão *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 (Huating 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. 'Delicious', 'Empire', 'Idared' 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 Elche' 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 O_2 and elevated CO_2 concentrations achieved through produce-generated passive mode or through active modes using an external source of gas mixtures. Low O_2 and high CO_2 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% CO_2 and 2-5% O_2 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

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

Commodity	MA requirements	Reference
Apple	<1kPa O_2	Soliva-Fortuny *et al.* 2002
Papaya	3 kPa O_2 + 6 kPa CO_2	Chauhan *et al.* 2006a
Mango	2 kPa O_2 + 10 kPa CO_2	Rattanapanone *et al.* 2001
	3 kPa O_2 + 8 kPa CO_2	Chauhan *et al.* 2006c
Pear	2 kPa O_2	Soliva-Fortuny *et al.* 2004
Peach	0.25 kPa O_2 + 10 kPa CO_2	Gorny *et al.* 1999
Watermelon	3 kPa O_2 + 15 kPa CO_2	Cartaxo *et al.* 1997
Strawberry	1-2 kPa O_2 + 10 kPa CO_2	Watada *et al.* 1996
Citrus	Air	Palma *et al.* 2003
Honeydew melon	2 kPa O_2 + 10 kPa CO_2	Qi *et al.* 1999
Tomato	0 kPa O_2 + 12 kPa CO_2	Gil *et al.* 2002
	7.5 kPa O_2 + 0 kPa CO_2	Artes *et al.* 1999
Potato	3 kPa O_2 + 9 kPa CO_2	Gunes and Chang 1997
Cabbage and lettuce	1.2-5.0 kPa O_2 + 3.5 kPa CO_2	Koseki and Itoh 2002
Broccoli	2.54 kPa O_2	Talasila *et al.* 1994
Carrot and cucumber	2.0-2.1 kPa O_2 + 5.5-5.7 kPa CO_2	Lee *et al.* 1996
Mushrooms	10-20 kPa O_2 + 2.5 kPa CO_2	Simon *et al.* 2005
Peeled garlic	0% O2, 5-15% CO2	Dong *et al.* 2000

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 microbiological proliferation with emphasis on yeasts and molds. The low O_2 and high CO_2 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 O_2 and elevated CO_2 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.

Table 3 Microorganisms associated with cut fruits and vegetables (Francis 2004).

Microorganism	Cut produce
Bacteria	
Listeria monocytogens	Cabbage, raw tomatoes, lettuce, celery, coleslaw
Salmonella spp.	Watermelon, tomatoes, cantaloupe melon, cress sprouts, mung sprouts
Clostridium botulinum	Garlic
Escherichia coli	Cantaloupe melon, radish sprouts
Bacillus cereus	Soy, mustard and cress sprouts
Yersinia enterocolitica	Bean sprouts
Shigella sonnei	Lettuce, parsley, watermelon
Campylobactor jejuni	Lettuce
Virus	
Hepatitis A virus	Lettuce, tomatoes, raspbesrry, strawberry
Norwalk virus	Fresh cut fruits, melon, raspberries
Parasites	
Cryptosporidium parvum	Green onion
Cyclospora cayetanensis	Blackberry, raspberry
Giardia spp.	Onions, lettuce

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*, *Ersinia*, *Campylobactor*, 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 (Beuchat 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 hurdles or barriers to maintain product safety and quality. As such, the GMP regulatory protocols need to be established yet 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 geographic 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 SO_2 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 SO_2 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 SO_2 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 feed back from the consumer forum to the industry to ensure comprehensive food safety in terms of biological hazards (Pabrua 1999). Some of the specifications adopted by European countries are given below (**Tables 4, 5**).

The above specifications take into consideration the local needs in terms of microbial loads. Sampling also plays a

Table 4 Suggested microbial specifications for prepared salad vegetables (Germany). (modified from Lund 1993).

Microbial counts	Limits (g^{-1})
Total counts at production	<5 x 10^6
Total counts at retail	<5 x 10^7
Escherichia coli	<10^2
Salmonella	Absent in 25 g sample
Listeria monocytogens	<10^2, no action
	>10^2, further investigations made
Recommended shelf life	7 days (including days of production)
Recommended temperature during transportation and sale	2-7°C

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

Microorganisms	Sample size	c[a]	Limit (cfu g^{-1}) m[b]	M[c]
Total counts at production				
Salad and shredded vegetables	5	2	5×10^5	5×10^6
Parsley, watercress and aromatic herbs	5	2	5×10^6	5×10^7
Total counts at use-by-date				
Salads	5	d	d	5×10^7
Coliforms at 44.5^{0}C	5	2	10	10^3
Salmonella in 25 g	5	None	None	None

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

major role in ensuring authentic monitoring of microbiological loads. Certain interesting features exist as in the case of coliforms which are acceptable to a level of 10^2 without the incidence of *E. coli*. The practice of prescribed low 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-to-batch 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.

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 produce (fruit and vegetable) markets in the USA and presented a survey of retail produce management regarding their perspectives on these changes and those in shipper-retailer relationships. Since the product range includes refrigerated foods with restricted shelf life, the network needs to be sophisticated with necessary infrastructure with regards to cold chain, warehousing, rapid transportation, communication and sound freight facilities. The lead period from farm to industry, to warehouse, to retail market, to consumer as the market chain need to be trimmed to shortest period possible. Marketing strategies towards commercial and non-commercial eating joints need to be subjected to specific product channelization and the process shall be framed based on market requirements and strategy. The technical awareness of entrepreneurs, marketing executives and consumers need to be oriented towards the specific nature of the products and shall not be deviated towards any complacency that is associated with marketing of conventionally processed stabilized products. A continuous relationship shall exist amongst the farming community, technology developers, industry, market and consumer to ensure successful marketing of pre-cut produce. The feed back from consumer on daily basis shall direct the whole process to adopt required remedial measures, if required.

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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