Chapter 3
Initial Preparation, Handling, and Distribution of Minimally Processed Refrigerated Fruits and Vegetables

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3.1 Introduction

There is a continuous demand for fresh, convenient, high-quality, and safely prepared minimally processed refrigerated (MPR) fruits and vegetables throughout the world, but consumption is concentrated in certain areas. On the other hand, most MPR food raw material production is seasonal, usually remote from consumption areas, and concentrated at certain geographical regions where yield and quality can be optimized. In addition, the raw material remains a living entity and highly perishable, bulky, price, and quantity variable commodity Anon (1990a).

New fruit and vegetable production, storage, processing/packaging, and preparation technologies made year-round availability possible for most products, except perhaps apricots, blueberries, cherries, blackberries, tangerines, carambola, and some others in a global marketing system. An optimum integrated distribution system for MPR foods will minimize energy use, environmental pollution, food waste, and cost, while maximizing the overall quality and convenience of fruits and vegetables, for optimum health of consumer.

Uneven production and processing will be equalized with new cultivars, improved storage, and MPR technologies, which will make year-round availability of almost all fruits and vegetables possible in fresh form around the world.

There are over 500,000 species of plants known on which animal and human survival depends. However, if animals and humans ceased to exist on earth, plants would continue not only to survive but also to thrive very well. There are 5000 genera of plants and 5000 cultivars (varieties) that might be used to feed the world's

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people either directly or indirectly. The species is the fundamental unit used to designate groups of plants that can be recognized as distinct kinds. In nature, individuals within one species interbreed, but they do not interbreed with other species because they are separated by some physiological, morphological, or genetic barrier that prevents the interchange of genes between the two species (Hartmann et al. 1990). A cultivar denotes individuals that are distinguished by morphological, physiological, cytological, chemical, or other characteristics significant for the purpose of horticulture and retain their distinguishing features when reproduced. An example of cultivar is the Jonathan apple. Cultivars also represent different food quality attributes such as color, flavor, texture, and nutritional value. A strain includes those plants of a given cultivar that possess the general varietal characteristics but differ in some minor characteristic or quality. A cultivar with early maturation may be considered a strain within the cultivar. An example of strain is "gray zucchini." As another example, some 70 strawberry cultivars are grown commercially in the United States; only about 10 are truly popular, but these changes from year to year as new cultivars are developed by plant breeders (Hartmann et al. 1988). Variations between species, cultivars, and strains can be due either to environmental or to genetic differences. Opportunity exists for a large number of desired transgenic cultivars or strain developments. However, some 200 species of fruits and vegetables are of major importance in world trade.

3.2 Raw Materials Characteristics and Classification for Food Purposes

Commercially fruits and vegetables are classified as follows:

Classification of fruits: Mostly fruits are tree-grown, perennial crops.

Drupes: Has one large pit or seed and grows on trees. Examples: apricot, cherry, nectarine, and peach.

Pomes: Has a core that contains seeds and grows on trees. Examples: apples, pears, and quince.

Citrus fruits: Has a leathery skin, many segments filled with juicy pellets, and grows on trees. Examples: grapefruit, lemon, lime, and orange.

Berries: Small juicy fruits that contain tiny seeds. Grows as shrub. Examples: blackberry, cranberry, blueberry, grape, raspberry, and strawberry.

Melons: Large juicy fruits that grow on vines and contain seeds and have a thick skin that may be rough and smooth. Examples: cantaloupe, casaba, honeydew, and watermelon.

Tropical and subtropical fruits: Grows only in warm sunny climate of tropics or subtropics, as trees. Examples: avocado, banana, coconut, guava, kiwi, mango, and pineapple.

Classification of vegetables: Mostly seed-grown, annual crops.

Bulbs: The underground structure where the plant's nutrient reserves are stored. Round bud with a stem and overlapping leaves. Examples: chive, garlic, onion, leek, and shallot.

Flower: The blooms or flower buds of plants eaten as vegetables. Examples: artichoke and broccoli.
Fruit: Contains the seeds of the vegetable. Examples: cucumber, eggplant, pepper, squash, zucchini, and tomato.
Leaves: Leaves of edible plants consumed as vegetables. Examples: Brussels sprouts, cabbage, lettuce, kale, and spinach.
Root: The fleshy roots of edible plants consumed as vegetables. Examples: beets, carrots, jicama, parsnips, turnip, and sweet potatoes.
Seeds: Vegetables grown and eaten from seeds. Examples: corn, green beans, and peas.
Stem: Edible stalk and leaves of plants consumed as vegetables. Examples: asparagus, bok choy, celery, and rhubarb.
Tubers: Grown underground. Examples: potatoes and yams.

Raw fruit and vegetable quality and shelf life depend to a great extent on the preharvest, harvest, and postharvest conditions (Nonnecke 1989). These include:

1. Genetically controlled factors (cultivar, strain)
2. Climatic conditions (light, temperature, percent relative humidity, wind, rain fall, etc.)
3. Soil conditions (type of soil, pH, percent moisture, microflora, mineral composition, etc.)
4. Agricultural practices (use of fertilizers, pesticides, growth regulators, irrigation, and pollination, etc.)
5. Harvesting (mechanical harvest, hand harvest, harvest temperature, etc.)

Currently, most fruits and vegetables are grown in fields, gardens, and greenhouses; however, three very different production (organic, hydroponic, and aeroponics) systems are becoming more common.

Before harvest, fruits and vegetables must meet certain minimum maturity requirements (Burton 1982). These requirements may vary from one producing area to another and from one product to another but are usually based on (1) color break, (2) minimum juice content, (3) minimum acid content, (4) minimum percentage of total soluble solids, (5) brix/acid ratio, (6) optimum flavor development, (7) abscission (detachment from parent plant), (8) development of wax on the skin, (9) softening (changes in composition of pectic substances), (10) size and shape, and (11) heat units (Pantastico 1975; Wills et al. 1989).

Fruits and vegetables can be classified in different ways for purposes of postharvest storage and processing operations. Classifications of fruits and vegetables according to the use of different plant organs were outlined by Weichmann (1987) as follows:

Root, tuber, and bulb vegetables: carrot, celeriac, garlic, horseradish, Jerusalem artichoke, onion, parsnip, potato, radish, rutabaga, salsify, scorzonera, sweet potato, beet, turnip, and yam
Leafy vegetables: Brussels sprout, cabbage, celery, chard, chicory, Chinese cabbage, collard, cress, dandelion, endive, green onion, kale, leek, chive, lettuce, spinach, and parsley

Flower vegetables: artichoke, broccoli, and cauliflower
Immature fruit vegetables: bean, cucumber, eggplant, okra, peas, pepper, squash, and sweet corn
Mature fruit vegetables: melon and tomato
Seed vegetables: shelled peas, shelled beans, corn, and lentils
Simple fleshy berry fruits: banana, grape, date, papaya, avocado, and kiwifruit
Simple fleshy hesperidium fruits: orange, lemon, lime, tangerine, and grapefruit
Simple drupe (stone) fruits: peach, plum, cherry, apricot, almond, and olive
Simple pome fruits: apple, pear, and quince
Multiple fleshy berry fruits: strawberry, blackberry, raspberry, mulberry, fig, pineapple, and pomegranate

The variation in rates of respiration and transpiration among different commodities is enormous. The various respiration and transpiration properties and temperature sensitivities of horticultural products are compiled in Appendix tables. In Table 3.1 a list of some climacteric and nonclimacteric fruits according to their respiration patterns is given (Hardenburg et al. 1986; Kays 1991).

All vegetables and fresh herbs can be considered to have a nonclimacteric type of respiratory pattern. Most climacteric fruits, and some nonclimacteric fruits such as pineapple, continue to ripen after separation from the plant Rolle and Chism (1987). The task in this case is to deliver the fruit to the consumer at an optimal level of quality. Most nonclimacteric and some climacteric products do not ripen after harvest, such as apples, berries, cherries, grapefruit, grapes, lemons, limes, oranges, strawberries, tangerines, and watermelon. In nonclimacteric commodities, quality is optimal at harvest. The task is to minimize quality loss. "Quality specifications" must be reestablished for the final product by the retailers. The following is a list of changes occurring in fruits and vegetables during harvesting, preparation, and handling:

1. Respiratory, metabolic, and enzymatic activities:

   Heat production climacteric crisis after harvest nonclimacteric metabolism
   Ethylene-induced physiological disorders – russet-spotting
   Reduced O_2- or elevated CO_2-induced physiological disorders, CO_2 injury, and blackheart in potatoes

   a. Anaerobic respiration (ethanol-acetaldehyde accumulation causing off-flavors and off-odors)
   b. Lactic acid fermentation at low O_2 concentration in cut products (Juliot et al. 1989)

   Adverse effects of polyphenol oxidases, cellulases, pectolytic enzymes, amylases, and peroxidases (discoloration, softening, off-flavors, and off-odors)

2. Transpiration (moisture loss, weight loss):

   Loss of turgidity (firmness), withering, and wilting in leafy vegetables

Table 3.1 Classification of some edible fruits according to their respiratory behavior during ripening

Climacteric fruits	Nonclimacteric fruits
Apple	Blackberry
Apricot	Cacao
Avocado	Cashew
Banana	Cherry, sour
Biriba	Cherry, sweet
Bitter melon	Cucumber
Blueberry, highbush	Grape
Blueberry, lowbush	Grapefruit
Blueberry, rabbiteye	Java plum
Breadfruit	Lemon
Cantaloupe	Litchi
Cherimoya	Mountain apple
Chinese gooseberry	Olive
Corossol fruit	Orange
Feijoa	Pepper
Fig, common	Pineapple
Guava, purple strawberry	Rose apple
Guava, strawberry	Satsuma mandarin
Guava, yellow strawberry	Star apple
Guava	Strawberry
Honeydew melon	Surinam cherry
Kiwi	Tree tomato
Mammee apple	
Mango	
Papaw	
Papaya	
Passion fruit	
Peach	
Pear	
Persimmon	
Plum	
Sapote	
Soursop	
Tomato	
Watermelon	

Source: Hardenburg et al. 1986; Kays 1991

3. Growth phenomena:

   Sprouting
   Root growth (rooting)
   Lignification (toughening)
   Ripening
   Senescence (yellowing, pithiness, feathering opening or floral buds, pink rib in lettuce)

Color changes (greening)
Elongation (asparagus)
Sloughing (skin loss)
Wound healing
Warts

4. Pest and microbial spoilage (nematode, insect, bacteria, yeast, mold, and virus attack and cause physiological disorders):

   Psyllid yellows, insect infestation, root knot, brown rot, stem-end rot, gray mold rot, rusty brown discoloration, downy mildew, blossom-end rot, and blue mold rot

5. Temperature-induced injuries:

   Chill injury (CI), freeze injury, high-temperature injury, and solar injury (sunscald, sunburn)

6. Mechanical injuries:

   Wounding
   Latent damage
   Cracking
   Broken tips
   Surface browning
   Cut or bruised products
   Vibrational cell wall and cell membrane ruptures

Temperature is a major, invisible, ever-present factor controlling respiratory metabolic and enzymatic activities, transpiration, and the growth of pests and microorganisms. Proper temperature management in the storage of MPR fruit and vegetable tissues can inactivate or retard the physiological defects. A theory developed (Parkin et al. 1989) to explain chill injury was based on low-temperature-induced membrane lipid phase transitions leading to a loss of membrane integrity and physiological dysfunction.

High-temperature and solar injury has been more a concern during the growth and development of plants than in postharvest handling. Hot-water dipping with fungicides is used in certain products to reduce microbial load without injuring the fruit (Harvey 1978; Salunkhe et al. 1991).

Mechanical injuries speed up the deterioration of fresh produce by disrupting membranes and increasing enzymatic activity which causes undesirable reactions to occur (Shewfelt 1987).

Objectionable quality changes are accelerated by the mechanical rupturing of the cells that occurs during preparation operations such as peeling and cutting, allowing enzymes to intermix with substrates. In addition, cuts and punctures allow for microbial contamination of products as well as moisture loss. Mechanical damage may take place any time a product is handled during harvesting, loading, transportation, sorting, and grading operations. Mechanical stress also stimulates peroxidase activity in cucumbers (Eckert and Ogawa 1988).

Table 3.2 Susceptibility categories of fresh fruits and vegetables to freeze injury

Group 1	Group 2	Group 3
Most susceptible	Moderately susceptible	Least susceptible
Apricots	Apples	Beets
Asparagus	Broccoli, sprouting	Brussels sprouts
Avocados	Cabbage, new	Cabbage, old
Bananas	Carrots	Savoy
Beans, snap	Cauliflower	Dates
Berries (except cranberries)	Celery	Kale
Cucumbers	Grapefruit	Parsnips
Eggplant	Grapes	Rutabagas
Lemons	Onions (dry)	Salsify
Lettuce	Oranges	Turnips
Limes	Parsley	
Okra	Pears	
Peaches	Peas	
Peppers, sweet	Radishes	
Plums	Spinach	
Potatoes	Squash, winter	
Squash, summer		
Sweet potatoes		
Tomatoes		

Cuts, punctures, and vibrations can be reduced by selecting varieties less susceptible to bruising and by proper shock-absorbing packaging. Harvested fruits and vegetables exhibit considerable resistance to pathogens and decay processes during most of their postharvest life if they are not mechanically damaged.

Most perishable crops increase in susceptibility to infection as they approach senescence, which is a progressive loss of membrane integrity. Treatments that inhibit or delay these processes reduce postharvest decay losses (Eckert and Ogawa 1988).

It is essential to understand the nature of the harvested fruits and vegetables and the effects of handling practices, to maintain optimum condition of the product at the market. Due to the diversity of products, it is impossible to suggest a single solution for all fruits and vegetables; rather, the most appropriate practices must be worked out by the individual operator for each commodity and particular situation.

Susceptibility of fresh fruits and vegetables to freezing injury was summarized by Hardenburg et al. (1986) in Table 3.2.

3.3 Optimal System Analysis

A systems approach to processing and distribution of MPR fruits and vegetables is essential to optimize storage and handling conditions for individual crops. This offers a challenge and an opportunity for food scientists to develop systems that will attain the low overall cost for the system, as a whole, while attaining optimum overall quality of fresh horticultural products.

In a systems approach, (1) the steps of unit operations are documented within defined boundaries, (2) the system is analyzed, (3) the system is optimized, and (4) the system coordination and controls are studied. It will be necessary to, standardize some components such as container sizes, product size and shapes, labels, etc. for automation of the system.

An analysis of the system must begin with a survey of where the crops are grown and where the products are consumed for specific product and market situations. Each cultivar or closely related cultivars may be considered, a system. "For minimally processed fruits and vegetables," harvesting, processing, storage, and distribution are accomplished in a fast, highly integrated system to maintain product quality. As a result, postharvest losses have been reduced to a few percentages and manageable transportation distances have been increased up to thousands of kilometers (Meffert 1990). One of the disadvantages of the systems approach is that the understanding of the entire system is emphasized much more than the detailed understanding of each step.

Processing and distribution systems for MPR fruits and vegetables include such issues as processing at the location of production versus at the location of consumption, large versus small processing plants, and bulk transportation versus prepackaged shipment; other issues include controlled atmosphere (CA)/modified atmosphere (MA)/vacuum/air packaging and storage at the location of production or in the region of consumption of a single commodity versus a multiple fruit and vegetable processing plant.

The alternative processing and distribution systems of minimally processed products affect the kind of initial preparation and distribution that may be used. Once the postharvest handling system has been diagrammed for a specific product, quality attributes are measured at each step. Where the greatest quality losses are occurring, they can then be subjected to more intense investigation under controlled conditions. An improved technique can then be evaluated within the context of the entire system and assessed for economic feasibility. In general, quality deterioration occurring in MPR food systems is cumulative (Bogh-Sorensen 1990).

The location of the storage facility will depend greatly on the type of marketing operation and the location of the orchard or field. It is desirable to have wholesale bulk refrigerated storages as close to the production area as possible to dispose of or utilize the waste at nearby areas. On the other hand, retail storage and displays should be in the consumption area (Figs. 3.1 and 3.2).

The following type of information should be developed for each product in a systems approach. An example of systems approach to a fresh sliced strawberry processing operation should include at least the following parameters (Rosen and Kader 1989):

1. Cultivar selection: Allstar is a June-bearing strawberry cultivar, ideal for fresh market.
2. Harvest: Hand or mechanical harvesting at full bright red or pink, in shallow tray.

Fig. 3.1 A retail display shelf for MPR fruits and vegetables

Fig. 3.2 Living potted culinary herbs and sprouts

3. Precooling: Rapid forced air or hydro precooling to below 7 °C (44.6 °F) within 8 min or maximum 2 h.
4. Field processing: Dump-wash tank to remove sand, trash eliminator to separate berry from plant, and mechanical stemming to remove calyx.
5. Transportation: To packing house with dry ice in shallow tray around 0 °C (32 °F).
6. Sorting and grading: Defectives and color sorting, separation into two sizes (small, large) by a tapered-finger sizing device.
7. Processing: Slicing into quarters, water washing to remove all exudates, dipping into $CaCl_2$ solution, and spin drying.
8. Packaging: Controlled atmosphere (CA) packaging at 12% CO_2, 2% O_2, and 95% relative humidity and 0 °C (32 °F) packaging into portion 1-lb, 2-lb, and 11-lb (5 kg) size re-sealable plastic pail packaging for fresh or strawberry shortcake.

9. Storage at warehouse: 95% relative humidity, 0 °C (32 °F) wholesale warehousing on standard pallets; maximum 7 days.
10. Storage and display at retail: Display cabinets 1 day at 18–20 °C (64–68 °F); the first noticeable quality defect is loss of volatiles.

The ideal system will be a completely integrated, computerized, and automated one.

3.4 Major Initial Unit Operation of MPR Fruits and Vegetables

The industrial harvesting, handling, processing, preparation, and distribution of fruits and vegetables require a number of steps that are primarily physical in nature, although their effects may contribute to biological, chemical, and physical changes in the products. Many individual processes are required to change or separate horticultural products into various MPR foods. By systematically studying these operations, all processes are unified, simplified, and speeded up. Batch operation requires that theory and equipment be considered together. The understanding of the basic physical principles of an operation and the formulation of these principles into a mathematical expression are the first requirements for the application of the unit operation concept. The design and operation of the equipment and the material and energy balance calculations are based on unit operation principles. Major unit operations involved in MPR processing of fruits and vegetables are given in Table 3.3. Packaging and preservation operations are given in other chapters in this book.

3.4.1 Raw Material Handling Operations

Materials handling is movement of MPR foods from the field to the retail display cabinets. It involves the conveying (in all directions) and storage of materials. Hydraulic flow, pneumatic or air flotation methods, conveyors, and forklift trucks are basic to many materials handling systems. An understanding of the characteristics of produce, such as shape, size, density, and hardness, is necessary in designing process and equipment. Rapid handling, along with precooling and without damage to the product, preserves quality. The product should not be transferred from different containers to the field or in storage that will increase the chance of damage to the product. Palletized unit loads, mobile racking, and lift trucks reduce the time and labor requirements in handling operations. Therefore, unit loads should be maintained until the final sales point. *Unitizing* refers to various methods of grouping together shipping containers, whereby they can be mechanically handled as a unit load. The most common unitizing method is palletizing; that is, containers are stacked on a pallet. The standard pallet size most commonly used is 1.0 m × 1.2 m and has a thickness of 15 cm. Some of the methods of increasing efficiency in material handling are (1) to minimize movement, (2) handle in bulk or unit loads, (3) concentrate the

Table 3.3 Major unit operations of MPR fruit and vegetable processing

A. Materials handling operations	
1. Harvesting	
2. Field processing	
3. Transportation	
4. Receiving	
B. Preparation operations	
1. Separation and multiphase contacting operations	
a. Separating operations:	
Grading	Cleaning
Sorting	Husking
Screening	Heading
İnspection	Topping
Brine separation	Shelling
Culling	Snipping
Dewatering	Silking
Draining	Trimming
Cluster separation	Stemming
Flotation	Skinning
Centrifugation	Peeling
De-stoning	Pitting
Dusting	Coring
b. Mixing operations:	
Blending	Mixing with solids
Emulsification	Mixing with liquids
2. Size reduction operations:	
Chopping	Slicing
Cutting	Dicing
Strip cut	Segmenting
V cut	Shredding
Flat cut	Pulping
Crinkle cut	Mashing
Halving	Juicing
C. Distribution and utilization operations	
1. Wholesaling: storage and control	
CA/MA/air/vacuum storage (O_2, CO_2, N_2, CO, C_2H_4, H_2O controls)	
Computer-controlled warehousing	
Wholesale storage	
Retail storage	
Labeling	
2. Physical distribution or movement	
3. Retailing and foodservice	
4. Communications network	

products to minimize the quantity of material to be moved, (4) make the operation continuous and mechanized if possible, and (5) make units in the proper size. Perishable MPR foods may be damaged by excessive temperature fluctuations, severe vibration, or microbial contamination during the handling stage.

3.4.2 Harvesting

Fruit and vegetable harvesting and handling operations are varied and highly dependent on the particular commodity. Lack of uniform ripening can make a one-time-mode harvest difficult but quite manageable. Harvesting at the proper stage of maturity is an extremely exacting operation. Harvest dates may be estimated in advance by crop scheduling systems or the heat unit system. Harvesting at the lowest possible temperature (night or early morning) is advantageous for maintaining fruit quality during handling and storage. Morris (1990) reported that grapes harvested when fruit temperature was high (above 30 °C) had a poor color and produced high levels of alcohol and acetic acid, indicating microbial spoilage. The delicate nature of many fruits and vegetables requires careful handling, and many products for the fresh and MPR processed market are hand harvested. Frequently, mechanical harvesting aids are used. Hydraulic platforms or ladders enable workers to be lifted while harvesting tree fruits. Bulk collection containers or conveyors are used to transfer the harvested products rapidly from fields to the processing unit. Machine harvesting may improve quality over that obtained by hand harvesting because it is faster and reduces holding time in the fields. In one study, mechanical and hand-harvesting systems bruised 11–40% and 0–18% of apples, respectively (Tennes et al. 1969).

3.4.3 Field Processing

Shelling and threshing of peas, beans, and lentils are done in the field by combines. Beets and carrots are harvested and topped mechanically at the field. Large boom conveyors have been used to carry the harvested pineapple from the pickers to the loading trucks. Potato harvesters dig, lift, clean, and load the product. Field processing includes inspecting for size, defects, maturity, and precooling in the field. Dry sorting in the field removes gross contamination and defective fruit which would otherwise contaminate wash waters. Insects in machine-harvested fruits can be removed by a tank washing technique in which infested fruits pass through water containing a 0.1% nonalkaline anionic wetting agent (Crandall et al. 1966). A water spray is then used to remove insects, debris, and wetting agents. Ninety-five percent of the chemical residues such as those arising from the use of pesticides can be removed by this method with no loss of quality. Precooling may be performed in the field or at the packing house on bulk loads, pallets, bin boxes, or shipping containers. Rapid precooling of fruits and vegetables to remove the field heat and the heat of respiration can be achieved by (1) forced air cooling, (2) hydrocooling, (3) hydro-air cooling (fine-mist spray combined with forced air cooling), and (4) vacuum cooling.

Significant losses in market life of fresh broccoli were noted (Brennen and Shewfelt 1989) within the 3-h cooling delay after harvest. Some MPR products, such as oranges, strawberries, and honeydew melons, may be hydro-cooled in the field, but green pepper will fill with water if hydro-cooled. However, efficient immediate handling techniques need to be established for chill-sensitive products at the field. Curing or preconditioning, which is holding produce at moderate temperature for a period, prior to low-temperature storage, is effective to prevent chill injury for some fruits such as grapefruit. All harvesting equipment should be maintained in clean condition to prevent deterioration caused by fungi and bacteria. Knives, belts, and other surfaces should be cleaned daily to remove accumulated dirt and soil. Boxes, trays, sacks, and other receptacles for harvested produce should be cleaned daily to reduce microbial load. Metal and plastic receptacles are more easily cleaned than wooden boxes. There are distinct advantages to do as much processing, such as cleaning, trimming, and coring, as possible at the production field as can be done without greatly increasing perishability. This prevents costly disposal problems at metropolitan consumption areas.

3.4.4 Transportation

It is obvious that perishable MPR fruits and vegetables must be quickly and carefully handled during transportation. The choice of shipping in packages or in bulk depends on the product and on market requirements and economics. Bulk transport of some vegetables, such as peas, beans, and sweet corn, presents problems with self-heating due to respiration, and cooling may be required before transport. In bulk packaging of leafy and stem vegetables, application of ice slush lowers the temperature while maintaining high relative humidity in transportation. The containers used in the transport of horticultural products must be so used to avoid any mechanical damage to their contents, both through particle-to-particle or particle-to-container contacts, by load shifting, shock, overhead weight, and vibration. Fleshy berry fruits are placed in shallow boxes to prevent crushing by packing under their own weight. Fast, reliable transportation by air, sea, truck, and rail is an important element in the distribution of minimally processed foods. Mechanically refrigerated CA/MA/air/vacuum intermodal containers can be transported by truck, rail, ship, or air. Internationally standardized, dry, and refrigerated intermodal containers of truck load capacity (20,000–30,000 kg) are now available. Mechanical refrigeration systems consist of a compressor- condenser-evaporator unit that is separated from the load compartment by an insulated bulkhead. The machine section also contains a thermostat for temperature control and an air temperature indicator.

The air distribution system in a rail car uses a fan to draw air through the evaporator coil and discharge it into a ceiling duct above the load. Air distribution in all refrigerated trailers is normally from front to back. Liquid nitrogen and solid CO_2 have been used for transit refrigeration and modified atmospheres of fresh produce. However, a prepared atmosphere with a specified mixture of N_2, CO_2, O_2, C_2H_2,

H_2O, and CO should be tailored to meet the requirements and tolerances of the product treated in airtight transport vehicles. It is sometimes desirable to initiate the ripening of pears, apples, plums, and tomatoes with a low concentration of ethylene at a controlled temperature during the transit period so that the product is ready for retail sale when it arrives at the market. Regardless of the method of loading, provision should be made for refrigerated, controlled, or modified air to circulate uniformly to all parts of the load. Kays (1991) reported the specific requirements of commodities being transported. The refrigeration requirement is higher during transport than in static storage due to infiltration of air through the container walls, floor, and ceiling. Highly perishable commodities, such as strawberries, apricots, figs, cherries, grapes, lettuce, and mushrooms, may be transported by air in refrigerated cargo containers. Less perishable commodities, such as citrus fruits, potatoes, pears, apples, bananas, tomatoes, and cabbage, may be shipped by sea in refrigerated holds of insulated ships. Fruits and vegetables that require different temperatures, relative humidity (RH) conditions, fumigation, and those that are ethylene producing and non-ethylene producing, odor absorbing, odor projecting, and possessing different chemical properties should not be loaded into the same container. Grouping of compatible loads is essential in mixed load transportation and storage. Containerization, modulization, unitization, and metrication allow delivery of MPR foods with a minimum of handling and physical injury to the product and a short transit time.

3.4.5 Receiving

At the receiving of MPR product, the cold chain is interrupted; consequently, proper care must be exercised not to lose the quality that has been retained in harvesting and transporting. The efficiency of the receiving operation will be increased by the use of palletized loads. In receiving, produce must be properly segregated to permit adequate grading. Materials should be moved rapidly through the shortest distance possible from the unloading to the storage point to reduce costs. Batch and continuous automatic digital weighing have replaced manual weighing, saving time and labor. Accurate weighing is necessary for proper cost accounting, product formulation, planning, and quality control. Contracts between the supplier and the MPR product processing plant include the required standards. In some cases, contract growing may be necessary as in canning. There is a need to be able to rapidly and nondestructively evaluate the quality of fresh produce at the receiving (Dull 1986) for such safety aspects as pesticide residues, heavy microbial loads, toxic metals, naturally present undesirable compounds, and plant growth regulators.

After products have been received, they should be transferred immediately to the proper (−1 °C to +6 °C, +6 °C to 13 °C, or +13 °C to 18 °C) storage areas depending on the chill characteristics of the product.

Table 3.4 Raw or cooked yield of edible portion (EP) per pound of selected fruits and vegetables as purchased (AP)

Food items	Yield (pounds of EP)
Apples, fresh peeled	0.92
Bananas, with peel	0.65
Beans, green (cooked)	0.88
Broccoli	0.81
Cabbage	0.87
Cantaloupe	0.52
Carrots	0.70
Carrots (cooked)	0.60
Lettuce (head)	0.55
Mushrooms	0.76
Onions	0.98
Peaches	0.88
Pears, pared	0.76
Pineapple	0.78
Plums	0.54
Potato, baked with skin (cooked)	0.94
Potato, mashed (cooked)	0.81
Spinach (cooked)	0.81
Sweet potato, baked with skin (cooked)	0.81
Tomato	0.61
Watermelon	0.99

Source: USDA 1984

3.4.6 Preparation Operations

Ready-to-cook, ready-to-eat, and ready-to-use type convenience fruits and vegetables require many preparation operations. Most of these involve physical changes, but chemical reactions also take place. The weight of the prepared cooked final product may be 50–99% of the raw material as shown in Table 3.4 (USDA 1984). Vegetables in the following food groups are prepared for ready-to-use, ready-to-cook, MPR products (Figs. 3.3, 3.4, and 3.5).

Snack vegetables: whole and sliced onion, celery strip, cut carrots, sliced cucumbers, and whole lettuce

Stew vegetables: cut green beans, sliced onions, diced potatoes, corn, diced tomatoes, asparagus, riba, diced peppers, peas, diced broccoli stalks, diced mushrooms, Brussels sprouts, crinkle-sliced eggplants, and whole okra

Salad vegetables: shredded carrots, shredded cabbage for coleslaw, halved and cored pepper, diced onions, sliced red cabbage, shredded lettuce, whole parsley, sliced tomatoes, endive, and chicory

Grill vegetables: zucchini, red pepper, and eggplant

Fig. 3.3 Minimally processed fresh-cut salads in a retail display

Fig. 3.4 Fresh-cut ready-to-cook vegetables: carrots, green beans, zucchinis, and pumpkins

Soup vegetables: diced peppers, diced mushrooms, diced onions, strip-cut parsley, crinkle-cut celery, diced garlic, and crosscut leeks

Sandwich vegetables: sliced tomatoes and shredded lettuce

Ready-to-cook vegetables: sliced potatoes, strip cuts for French fries, and stir-fry vegetables

Souve and gravy vegetables: diced peppers, diced mushrooms, diced onions and garlic, strip-cut peppermint, diced tomatoes, etc.

Puree and juice vegetables: shredded potatoes, mashed potatoes, diced tomatoes, diced carrots, diced celery, diced beets, and diced eggplants

Pizza topping vegetables: strip-cut peppers, sliced mushrooms, and sliced tomatoes

Fruits in the following groups are prepared for MPR products in the end-use form (Figs. 3.5 and 3.6).

Fruit cocktail: diced peaches, diced pears, whole seedless grapes, diced pineapples, pitted cherries, and diced apples

Fruit pies: apple slices, peeled peach halves, and peeled apricot halves

Fig. 3.5 Ready-to-eat mixed snack vegetables with dip

Fig. 3.6 Ready-to-eat fruit salad; watermelon, grape, and honeydew mix and honeydew chunks on a display cabinet

Fruit salads: diced peaches, diced pears, seedless grapes, diced pineapple, pitted cherry halves, sliced bananas in syrup, citrus salads, segmented oranges, segmented mandarins, halved grapefruits, etc.
Fruit soups: pitted prunes, pitted cherries, sliced peaches, sliced apricots, etc.
Fruit cakes: sliced strawberries, peeled bananas, pitted cherries, and sliced apricots
Fruit jellos: whole strawberries, sliced bananas, pitted cherries, seedless grapes, and sliced oranges
Fruit puddings: cut strawberries, sliced bananas, and pitted cherry halves
Snack fruits: sliced melons, pitted plums, and peeled oranges
Fruit sauce/puree/juice: shredded apples for puree or sauce, prune sauce, whole or cut oranges, lemons, and grapefruits for juice

The preparation functions may be simplified by using assembly line concepts and related equipment to enable mass production. The primary objective of industrial food preparation is to ensure ultimate consumer safety (nutritional and health), quality, convenience, and innovation at minimum cost. Preparation of MPR fruits and vegetables for ready-to-use form involves washing, cutting, rinsing, conditioning, packaging, and storage operations as illustrated in Fig. 3.7 (Anon. 1988d).

In addition to general methods of doing these operations for some products, specialized equipment is required such as green bean snippers and centrifugal spin driers, special cutters, and aseptic assembly and filling rooms. In the design of a processing line for MPR products, the major economic consideration is the cost of operation and amount of the time the equipment is being utilized. The initial investment cost is usually secondary to the costs of operation. Operating costs on a per unit of product processed basis take into account the type and use of energy, the labor employed, the amount and type of water used, and the cost of effluent disposal and innovation at minimum cost.

3.4.7 Separation and Multiphase Contacting Operations

In MPR food preparation, solid-solid, solid-liquid, and solid-gas contacting systems are utilized for separation and mixing operations. Process equipment for such systems is designed to achieve the appropriate transfer operations with a minimum expenditure of energy and capital investment. Screening is the solid-solid separation of a mixture of various sizes of fruits. Blending of ingredients may be the main objective of a solid-solid mixing. Leaching or simple washing is a separation of solid-liquid system which consists of the displacement of dirt by a liquid in which it is soluble. Separation and multiphase contacting operations of this kind are carried out in single or multiple steps or stages. A stage may be defined as a unit of equipment in which two dissimilar phases are brought into contact with each other and then are mechanically separated. Gravity sedimentation operations are also solid-liquid separations. Solid-liquid mixing is involved in fruit juice and puree preparations. Modified and controlled atmosphere storage and packaging involves

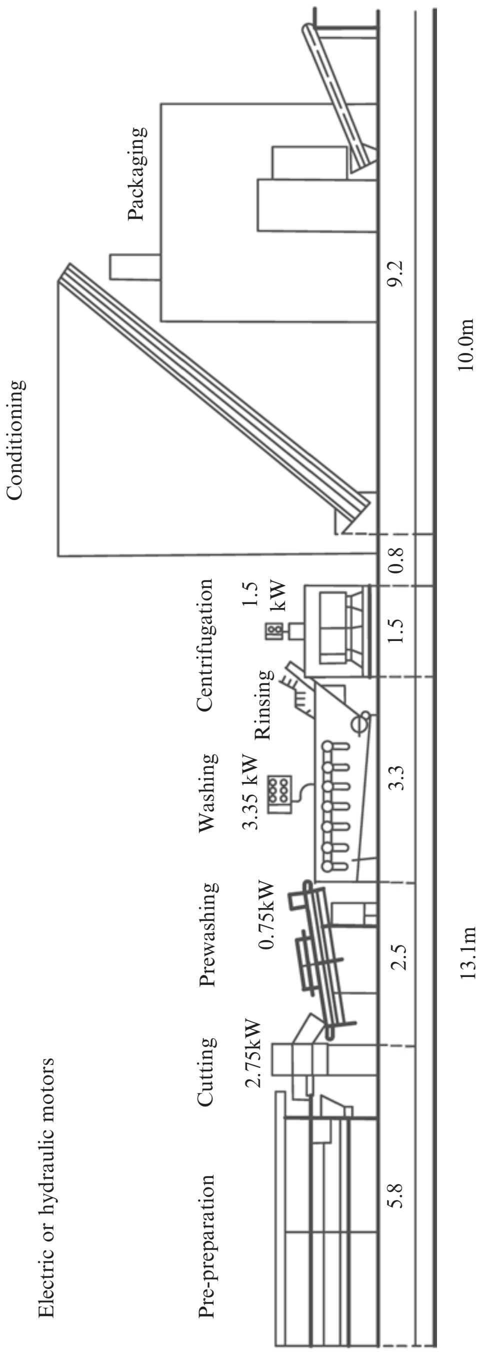

Fig. 3.7 Diagram of an MPR salad production line

gas-solid mixing operations. The solid phase is usually in a static condition. The gas phase flows or circulates more or less freely around the solid particles. Gas-solid separation is involved in dust collection, aspiration, dewatering, O_2 scavenging, CO_2 scavenging, and ethylene emitting.

Solid materials such as horticultural produce may be separated by virtue of differences in density, shape, size, color, surface characteristics (surface area, electrostatic charge), and solubility. In general, separating includes the following operations: grading, cleaning, washing, screening, sorting, peeling, coring, draining, paring, pitting, stemming, sedimenting, trimming, and centrifuging. The MPR products processing industry uses separators of various kinds. Solid-solid separators include screens, sizers, classifiers, magnetic separators, and cluster separators. Solid-liquid separators are exemplified by the commonly used clarifiers, basket centrifuges, strainers, and percolators. Also, solid-gas separators such as driers, dehumidifiers, aspirators, cyclone separators, air filters, electrical precipitators, dust collectors, and ethylene-removing catalyzers are used.

3.4.8 Sorting, Sizing, and Grading

Figures 3.8 and 3.9 show separation of raw materials into size and weight quality groups. This provides uniformity and standardization of the finished products for buying and selling. The most important grade factors are size, shape, color, firmness, flavor, friability, bruises, cut surfaces, chemical composition, disease, and soundness. Overripe, undersized, and blemished products are separated from those of acceptable quality. Grading and sorting comprise the last separation stage before processing. Damage and spoilage therefore are likely to be transmitted to the

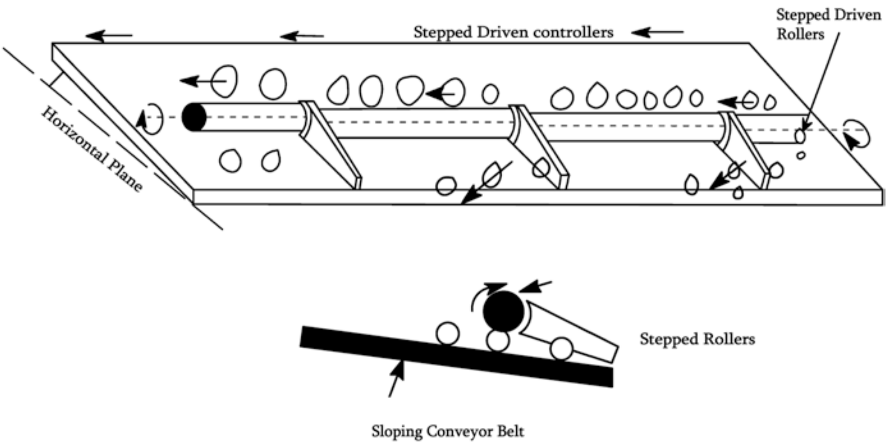

Fig. 3.8 The operating principle of a belt and roller sorter: **a** oblique view, **b** section across conveyor belt (From Brennan et al. 1990)

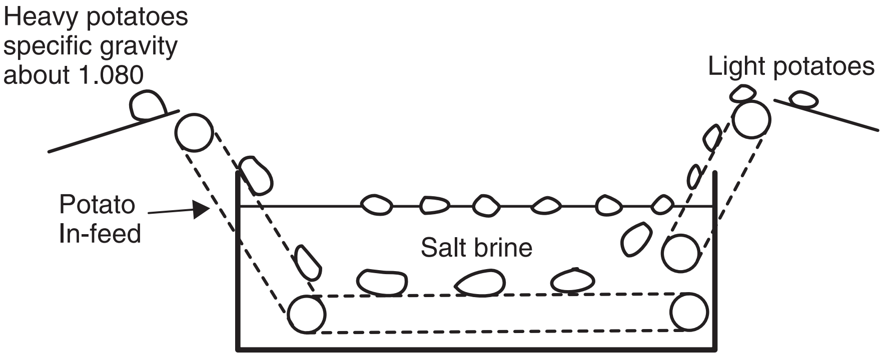

Fig. 3.9 Potato handling system (From Farrel 1976)

finished product if the bad products are not removed. The emptying of field containers onto sorting belts and dropping of product units from sorters can cause extensive damage if it is not controlled. Screening is the separation of a mixture of various sizes of produce such as peaches, strawberries, apricots, or oranges into two or more portions by means of a screening surface. Material that remains on a given screening surface is the normal size and that passing through the screening surface is the undersize material. Vibrating bar screens are used for coarse size separation and dewatering at 4 mesh (4.76 mm) and larger screening operations. Smaller than 4 mesh and larger than 48 mesh (0.29 mm or 297 μm) is referred to as fine separation. Ultrafine separation screens are smaller than 48-mesh size (Perry et al. 1989). In the grading and sorting of fruits and vegetables, various devices and types of apparatus are used to facilitate and mechanize grading operations. Screens of various designs are used. Flatbeds, drums, rollers, vibrating screens, and belt and roller sorters are a few examples of industrial operations. Light reflectance and transmittance sorting are used for nondestructively sorting and internal examination of foods (Dull 1986). Some grading is carried out manually by trained personnel who are able to assess a number of grading factors simultaneously. Automated grading has the advantages of speed, reliability, and low labor cost. The consumer recognizes, in descending order of preference, fancy, choice, standard, and seconds for most fruits and vegetables. A fancy product is normally one that can be secured only from the most nearly perfectly grown crop in a given season.

3.4.9 Cleaning, Washing, and Disinfection

Cleaning and washing may be the only preservation treatments in most of the MPR fruits and vegetables. Cleaning refers to the removal of foreign materials. As a unit operation, cleaning is a form separation concerned with the removal of twigs, stalks, dirt, sand, soil, insects, pesticides, and fertilizers residues from fruits and

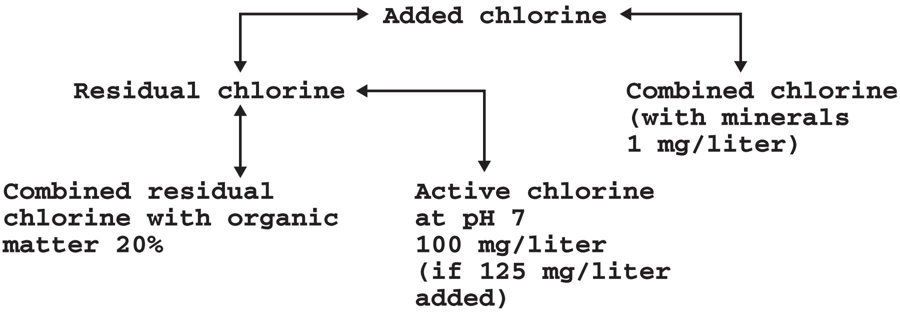

Fig. 3.10 Chlorination of wash water for MPR fruits and vegetables (Anon. 1988d)

vegetables, as well as containers and equipment, as the first step in processing. The cleaning process also involves separation of light from heavy materials by gravity, de-stoning, flotation, picking, screening, dewatering, and others Robinson and Hills (1959).

In an MPR fruit and vegetable process line, washing is generally done in an isolated chamber with a restricted number of entrances; human contact to product is limited which is in sharp contrast with the previous operations. At this stage the product becomes ready-to-eat and ready for preservation. To this end, the product is washed and freed of the majority of microorganisms by chlorine treatment up to 200 ppm allowed in the United States. The MPR product is immersed in a bath in which bubbling is maintained by a jet of air. This turbulence permits one to eliminate practically all traces of earth and foreign matter without bruising the product. The addition of various forms of chlorine to wash waters helps to prevent microbial contamination. Chlorine is the only technological washing aid permitted (Anon. 1988d); it is eliminated from the product by a final step (Fig. 3.10).

Water is one of the key elements in the quality of the MPR products. The source and quality of water must be considered. Three parameters are controlled in washing MPR fruits and vegetables (Anon 1990b): mushrooms, potatoes, and sweet potatoes are never washed or are washed after storage since added moisture is undesirable. Dry cleaning methods such as screening, brushing, aspiration, abrasion, and magnetic separation can be applied. The automatic aeroseparator for spinach and leafy vegetables removes foreign matter such as worms, insects, stones, wood pieces, etc. (Femia Industries, S. A., France, Anon. 1990b).

The washing operation has been studied for specific products (Gould 1974), and such steps as the soak period, spray pressure, and use and concentration of detergents added to the soak tank have been optimized. Rotary drum washers are used for cleaning apples, pears, peaches, potatoes, turnips, and beets; high-pressure water is sprayed over the product and it never comes in contact with dirty water. In wire-cylinder leafy vegetable washers, medium-pressure sprays of fresh water are used for washing spinach, lettuce, parsley, and leeks.

Fig. 3.11 Continuous spin drier for salads and vegetables

Because free moisture and cellular exudates on the surface of horticultural products tend to stimulate the growth of yeasts, molds, and bacteria, many types of driers (dewaterers, centrifuges, screens, dehumidifiers) have been used to remove water after washing (Fig. 3.11).

3.4.10 Peeling

The removal of the outer layer of a fruit or vegetable is referred to as peeling, paring, skinning, husking, shelling, etc. Peeling may be done (1) by hand, (2) with steam or boiling water, (3) with lye or alkalies (NaOH, KOH), (4) by dry caustic peeling with infrared heat, (5) by flame, (6) by mechanical means, (7) by high-pressure steam, (8) by freezing, and (9) with acids (Lopez 1987). Industrial peeling of large volumes of products can be accomplished mechanically, chemically, or in high-pressure steam peelers. Root vegetables such as potatoes, beets, carrots, turnips, and onions may be peeled mechanically or lye peeled. Lye peeling of peaches, pears, apricots, and tomatoes causes less loss of fruit and permits rapid handling but requires a large water supply, NaOH, and a source of heat. Hand peeling is slow, costly, and wasteful of the product. Husking of corn, shelling of peas, and snipping of beans may be done by high-speed machines. Silking is an operation applied exclusively to corn. An apple preparation system has been developed by FMC (Anon. 1988a) that automatically peels, cores, and slices apples in a high-speed continuous operation (Fig. 3.12).

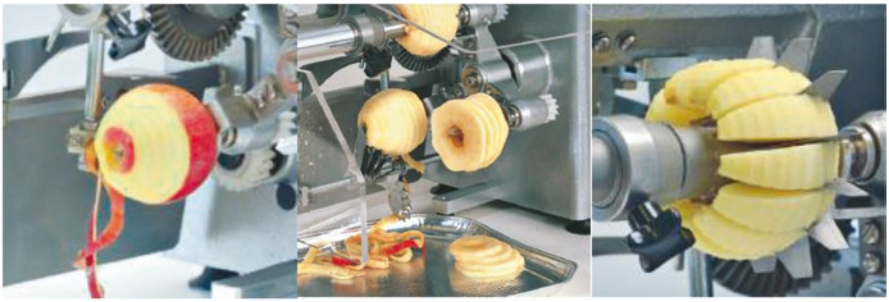

Fig. 3.12 Automatic apple washing, peeling, coring, and slicing machine

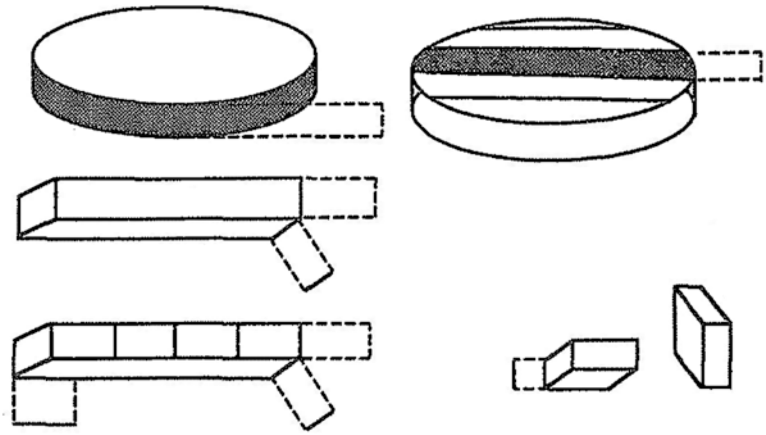

Fig. 3.13 Cutting, giving a definite size and shape to the product

3.4.11 Size Reduction Operation

Size reduction describes all means by which fruits and vegetables are cut or broken into smaller and uniform pieces of definite shape and size (Fig. 3.13). Size reduction may be an essential step to improve taste, digestibility, ease of handling, and effective heat transfer, but it has accompanying disadvantages.

3.4.12 Cutting

Cutting accelerates respiration, causes mechanical damage, and softens plant tissue. Cut tissues have lower barriers to gas diffusion, and they tolerate higher concentrations of CO_2 and lower O_2 levels than intact commodities. Therefore, the products

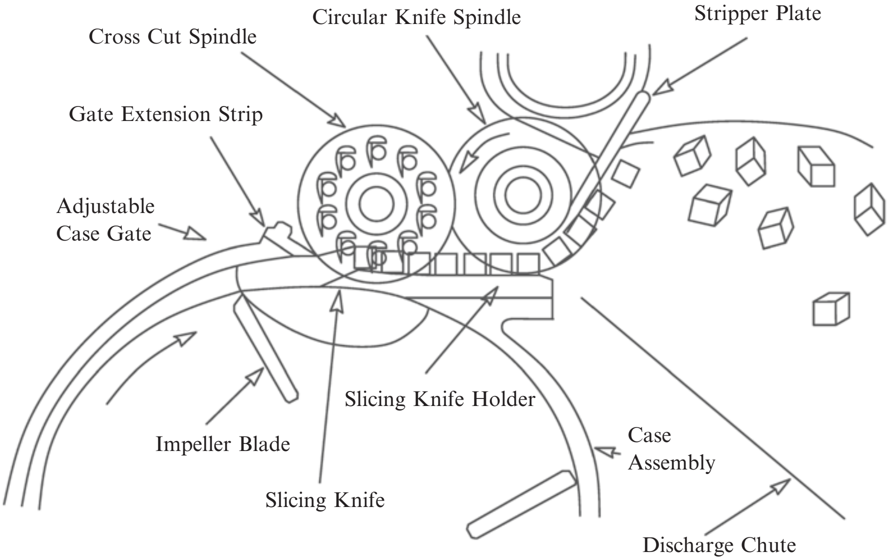

Fig. 3.14 Automatic high-speed centrifugal slicing, dicing, and strip cutting machine (Urschel Laboratories, Inc.; Anon. 1988b)

must be taken to a 4 °C room immediately after cutting. Four types of force are generally recognized in cutting machines.

They are (1) compression, (2) impact, (3) attrition, and (4) cutting. The performance of a machine for reducing the size of material is characterized by the capacity, the power required per unit of material, shape and surface characteristics of the product, and the optimum size (Perry et al. 1989).

MPR fruits and vegetables are moved on a belt or centrifugally to vertical or horizontal cutting blades (Fig. 3.14). Size reduction equipment is divided into grinders for grinding, pulping, mashing, and juicing. Cutting machines are divided for chopping, slicing, dicing, and shredding of horticultural products. Grinders break large pieces, then the products pass through a 200-mesh screen that cuts them into particles 1–50 μm in size. The smallest size attainable by wet grinding with suitable surfactants is 0.5 μm, but in dry grinding, it is 1 μm (Perry et al. 1989).

Fresh horticultural products are automatically sliced, diced, and strip cut with high-speed centrifugal machines. A slicing knife, circular knife, spindle, and cross-cut knife spindle are used for dicing. Changing the size of the cubes is done by using the required cutting spindles and adjusting the slice thickness. Strip cuts of any product can be made by removing the crosscut knife from the machine. The length of the strips will depend on the size of the original product (Fig. 3.14, Anon. 1988b).

The use of power is a major expense in size reduction operations. Cutters give products of definite size and shape (fixed dimensions). The most satisfactory cutting device is a knife of extreme sharpness and as thin as structurally possible. In general, impact and shearing forces applied via a cutting edge are used in the disintegration

Fig. 3.15 A various size and shape cutting machine for fruits and vegetable

of fibrous materials. Cutting machines are constructed of 18–8 stainless steel that contacts the product. The slicing knives are made of high-carbon stainless steel alloys. Most knives are ground to one of the three shapes: fully tapered, partially tapered, or hollow ground. The knives of a cutter must be kept sharp and usually must be sharpened after each 8-h operation. The effects of cutting angle, cutting speed, and core diameter on energy requirement have been studied. It was concluded that the energy and the peak force are not affected by the cutting speed (Kulshreshtha et al. 1988). The energy requirement is minimum for a cutting angle of about 21°. The cutting angle corresponding to the minimum peak force is dependent on the diameter. Cutting and grinding equipment must be thoroughly washed after each operation. It is possible to produce aseptically diced or sliced products by using sterile knives and aseptic conditions. Thorough washing with water alone to remove the free cellular contents that are released by cutting was found to be important in prolonging the shelf life of cut carrots (Bolin and Huxsoll 1991) (Fig. 3.15).

Water knives are a new innovation where the fruits and vegetables are cut by a fine jet of high-pressure water (3000 kPa). Heiland et al. (1990) investigated the use of water knives as a high-capacity, high-speed, accurate, and automatically controlled cutting equipment for fruits and vegetables. Cell exudates were washed away by the very stream that produced them. The cost study showed that, at the high capacity, water knives may be economical.

3.4.13 Mixing and Assembling

Combined foods such as salads and ready-to-eat meals all require mixing and assembling before packaging. The object of mixing in fruit and vegetable processing is to ensure that a homogeneous mixture is formed and maintained with as low as energy input as possible at the lowest overall cost. Blending, coating, and dipping operations all require solid-solid mixing. Salad dressings are emulsions that are a mixture of liquids. Stable emulsions are formed by homogenizing. The three basic mechanisms by which solid particles are mixed are diffusive mixing, convective mixing, and shearing. There are several types of solid mixing machines. Tumblers are suitable for gentle blending of solids. Ribbon mixers are effective blenders for thin pastes and for solids that do not flow readily. The power they require is moderate. Agitators are used for slow-speed mixing with a number of paddles and baffles. The mixing efficiency of an industrial mixer is judged by the time required (mixing time) and power load (power consumption) and the properties of the product. If two or more gases are brought together, complete blending is achieved instantly. In gas-solid mixtures, the diffusion of gas molecules and the convective currents will cause slow but certain mixing. The simplest approach to mixing gases with liquid foods is to introduce the gas with a sparger at the bottom of the tank containing the liquid food and to permit it to bubble up through the liquid. Whippers and beaters are used for the mixing of gases with low-viscosity liquids. The colloid mill is a special mixing device for mixing extremely fine suspensions of either solids or liquids in a liquid. Mayonnaise, salad dressing, seasoning blends, fruit cocktail, and fruit and vegetable sauces all require mixing and emulsification.

The final operation in the processing of MPR foods takes place in the assembly and packaging room. Shredded lettuce, sliced carrots, peeled oranges, or mixtures of fresh vegetable or fruit ingredients are combined to produce a palatable mixture with dressing, mayonnaise, and other ingredients. Cook-chill meals and pizza mixes are prepared, portioned, plated, and filled in consumer packaging containers. The assembly room is the most critical zone in the processing chain and aseptic techniques are employed. A schematic diagram of an assembly and packaging room is given in Fig. 3.16. Operators working in the assembly room wear special dress, mouth masks, hair caps, and gloves. Inside the assembly room, a positive air pressure is maintained with filtered air; ambient temperature is controlled at 10–12 °C and humidity is 60–70% RH.

3.5 Distribution and Utilization of MPR Fruits and Vegetables

Distribution, in general, may be defined as the fast and efficient movement and handling of fruits and vegetables from the farm gate to the point of consumption. This involves collecting 46 million tons of produce from 350,000 farms and distributing into 37,459 food stores and 1 million foodservice establishments in the United

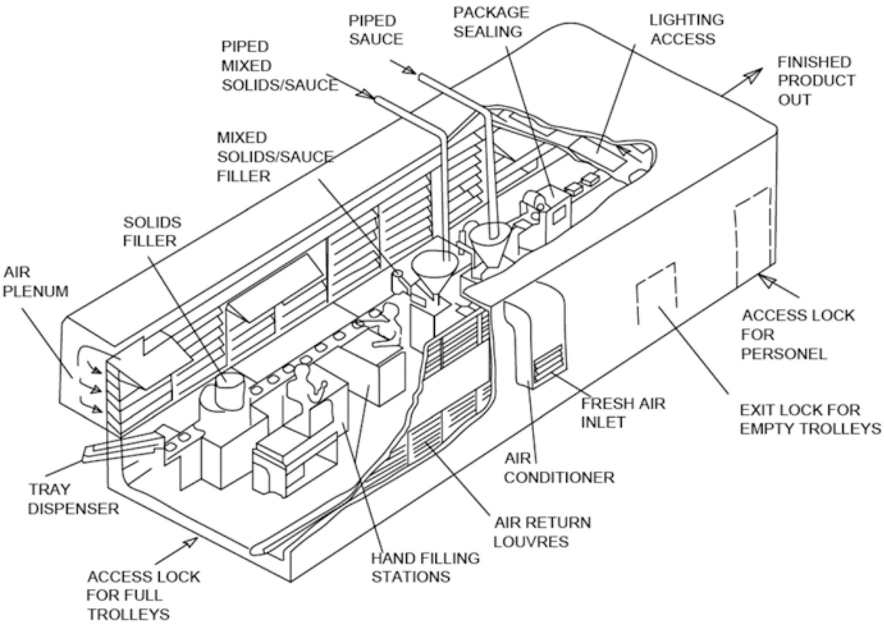

Fig. 3.16 An aseptic assembly and packaging room for MPR foods (Source: Knight 1991)

States (Fig. 3.17; Cook 2011). This involves 26.8 billion USD farm gate value to 150 billion USD consumer value (Cook 2011; News and Facts 2017). Distribution and utilization of MPR foods include the following operations:

1. Production center operations: raw and processed fruit and vegetable storage and control, central processing operations
2. Physical distribution: intra- and intercity transportation
3. Consumption center operations: food distribution centers, wholesaling, retailing, and foodservice operations
4. Communication network

MPR food distribution systems seek to maximize the time and place utility or economic value of products by getting and having the products where they are wanted, at the time they are wanted, and at a reasonable cost. The exact marketing channels differ with each commodity and change in pattern over the years. Quality and quantity of MPR food losses occur in the field, at the processing plants, in shipment to warehouses, and in the retail stores. Pilferage and tampering losses occur primarily in retail outlets and, to some extent, in truck and rail shipments. It has been reported (Kays 1991) that 3.62% of durable products such as dried fruits, nuts, and potatoes, 5.42% of fruits, and 10.3% of fresh vegetables are lost during transportation. Total distribution systems should reduce food losses and standardize the product in wholesale, retail, and consumer packaging. This would also increase the speed of distribution.

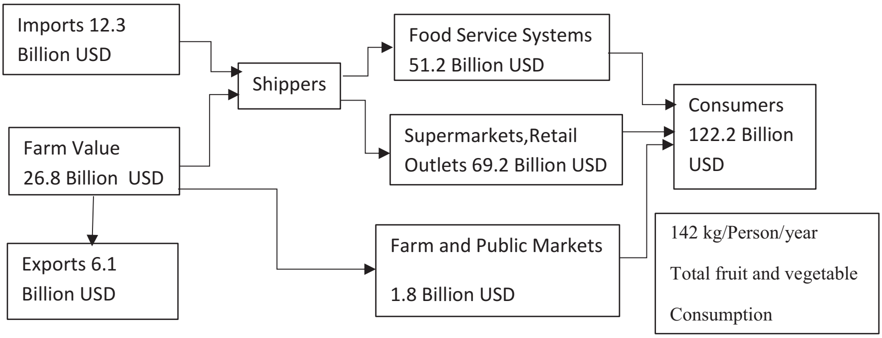

Fig. 3.17 US fresh fruit and vegetable value chain, estimated dollar sales, billions, in 2010 (Roberta Cook 2011)

The selection and establishment of a distribution system is a key decision area as it usually binds the firm long term, involves heavy investment, and can be the deciding factor in determining the success or failure of a marketing strategy. If a product is to sell, it must be made readily available to target segments such as fast-food chains, supermarkets, restaurants, hotels, institutional cafeterias, and caterers. The extensiveness of the distribution system is the foundation of marketing in the industrialized countries. The system must be able to adjust the supply of commodities to market demands quickly and easily as either supply or demand changes. During the 3–10-day distribution time, the product is often handled four to six times in loading, warehousing, and unloading at the retail outlet (Anon. 1978).

Quality maintenance is aided by the following procedures in distribution channels:

1. Minimize handling frequency.
2. Provide continued control of temperature, % RH, modified atmosphere (MA)/controlled atmosphere (CA) conditions (total environmental control) during storage and transportation.
3. Always transfer product from truck to refrigerated storage immediately.
4. Always rotate product on a first-in/first-out basis; rotate the complete inventory on a weekly basis.
5. Never stack individual cases more than five cases high.

Proper control of storage and transportation will extend the shelf life of MPR fruits and vegetables. Extended shelf life MPR foods can reduce number and magnitude of returned products, extend the distribution range of products, and will reduce the frequency of deliveries to retail from two or three per week to one per week.

Currently, the MPR food section offers at least 300–400 items in retail display cabinets. These items include:

Ready-to-eat fruits and vegetables
Ready-to-cook fruits and vegetables
Ready-to-cook mixed meals
Fresh ready-to-use herbs and sprouts
Fresh ready-to-eat specialty fruits and vegetables (tropical plants)

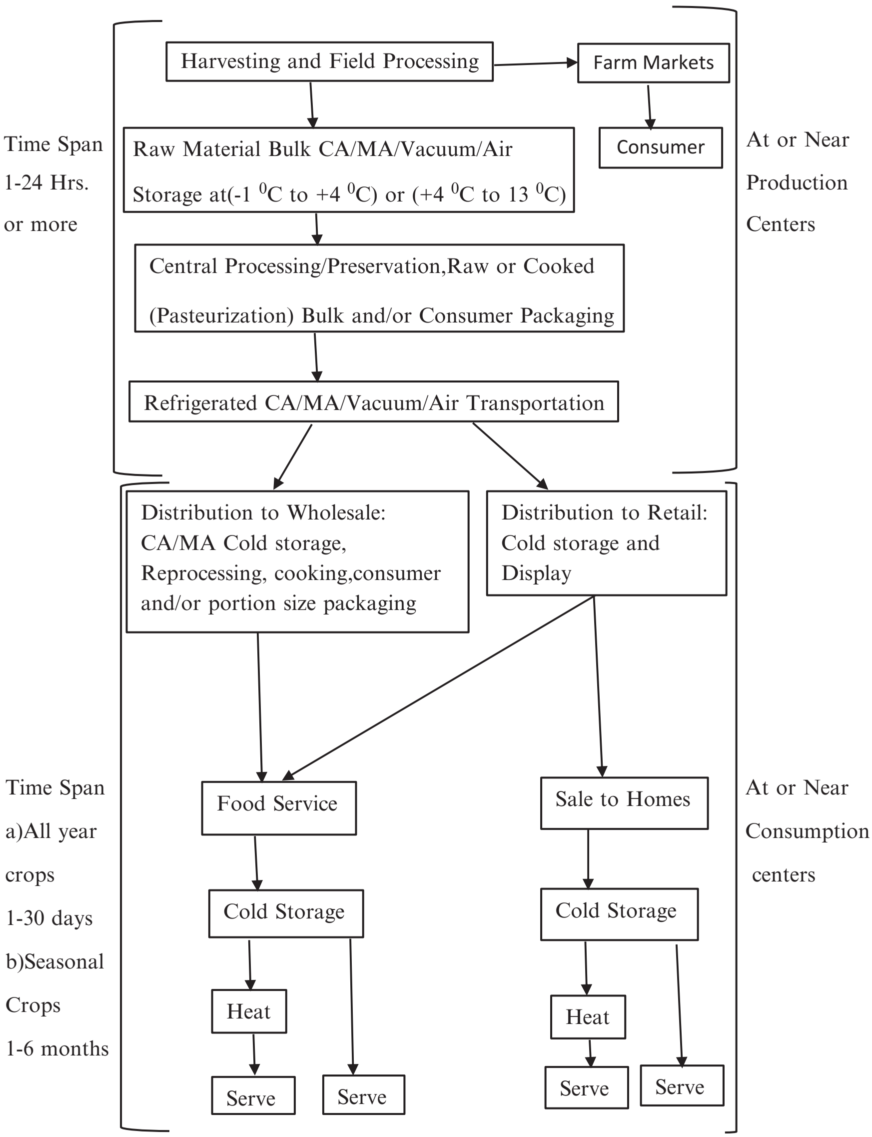

Fig. 3.18 An alternative processing and distribution system for MPR fruits and vegetables

An alternative processing and distribution system for MPR foods is given in Fig. 3.18. A single item or a few items may be more efficiently handled, but the more the produce items, the more complex the problems of distribution. The MPR foods are of low unit value and purchased frequently as convenience foods, which are usually eaten within 2 days of purchase. An intensive distribution system seeks maximum market penetration to increase, attract, or retain more customers.

However, the adoption of this system reduces the incentive for a retailer. On the other hand, an exclusive or selective distribution system may be used for some high-priced items to push the product to retail outlets. High-image products, for example, some tropical fruits, vegetables, or fresh herbs, may not be distributed to every retailer who is willing to buy but only to upscale retailers and restaurants. There may be a conflict of interest between fresh produce distribution channels and MPR foods distribution channels in local, regional, national, or even international markets.

3.6 Production Center Operations

Functions performed at production centers can be divided into two categories: first, physical operations which include harvesting, cooling, sizing, ripening, cutting, preservation, packaging, storing, and shipping and, second, related service operations which include buying, selling, financing, market finding, inspecting, and regulating. Production center operations will vary from product to product and from place to place. In the processing of MPR foods, two important functions may be distinguished: (1) raw material or processed products CA/MA/air/vacuum-packaged storage operations (storage and control) and (2) central processing and preservation operations.

3.7 Storage and Control Operations

Fresh fruits and vegetables are stored in bulk or in prepackaged forms in conventional refrigerated storage. In addition to refrigeration at certain relative humidity, CA/MA/air/vacuum and low-pressure or hypobaric storage methods are used for improving quality and shelf life. The latter methods involve a combination of lowering the O_2 level from the usual 21% level in air, raising the CO_2 level to 20% in a gas mixture, and controlling the level of ethylene (Wills et al. 1989, Robinson et al. 1975). Newer storage methods include the low-oxygen (LO) storage method which reduces the O_2 content to 2.0–1.5% by volume and maintains the CO_2 content at 0.1–0.2% below the O_2 value. The ultra-low-oxygen (ULO) storage method reduces O_2 content to the biological compatibility level of 1.2–0.8% by volume. The CO_2 content should be held at a lower level than O_2 concentration (Anon. 1989). All of these methods are practiced in completely airtight warehouses, in bulk containers, or in individual consumer packages. All storage methods also involve humidity control to prevent dehydration and maintain turgor. Stacking of unit loads must provide for free passage of gases surrounding the product during storage. Optimum levels of O_2, CO_2, % RH, and temperature must be established for each precut fruit or vegetable variety. Because CA/MA storage leaves no undesirable residues on the products, its use for minimally processed products will increase. Much research is needed to establish optimum conditions for each product.

The marketing of minimally processed fruits and vegetables requires storages for the long and short term and for bulk or packaged products at the wholesale and retail levels. The CA/MA storage can affect all forms of postharvest deterioration of fresh produce directly or indirectly and, consequently, its quality and postharvest shelf life. The composition of the gases in a closed space may be altered by increasing the concentration of some gases while reducing the concentration of others. This can be accomplished by scrubbing the atmosphere of CO_2 or O_2 by controlled venting and, if only O_2 is lowered, by continuous evacuation of the storage space. Individual gases can be added from pressurized cylinders or insulated tanks or by catalytic burners that consume O_2 and produce CO_2. Membrane air separation systems may be employed for lowering the O_2 level or increasing CO_2 level in CA storage. Air filtration is used in storage rooms to prevent microbial contamination.

The CA/MA storage rooms must be constructed similarly to conventional refrigerated storages with adequate insulation and vapor barriers and enough cooling surface to ensure high humidities and air circulation. The most reliable method of making a room gastight is to line the walls and ceiling with 28-gauge galvanized steel and connect it to the floor. The metal sheets must be fastened tightly to the walls and ceiling and the joints between sheets must be well sealed. A method of testing for gas tightness is to build up a pressure in the room 1 inch of water (gauge) and to observe the rate of pressure drop. If at the end of 1 h, 0.10–0.2 inch of water (gauge) remains, the room is tight enough (Anon. 1990b).

In cold storage rooms with ceiling evaporators, the following clearances should be respected: (1) between rows of pallets in the direction of air flow, 5–10 cm (2–4 inches); (2) wall to evaporator, 40 cm (15.7 inches); (3) under evaporator, 30 cm (11.8 inches); and (4) side walls, 40 cm (15.7 inches). Commodities should never be stacked higher than the lower edge of the evaporator.

Control systems are used to regulate mass, volume, temperature, pressure, time, % RH, % O_2, % CO_2, % C_2H_2 concentrations, and other controllable variables to minimize total cost and maintain product quality. The refrigeration system should be designed such that the thermostats work with very small switching differences if possible. Because new storage methods require drastic reduction in the O_2 level, as in the ULO process, while at the same time maintaining CO_2 at certain levels, highly accurate measuring and control systems are needed to ensure efficient control and to prevent damage to the stored products.

Microprocessor-controlled systems have been designed for the refrigeration CA/MA system to monitor the entire cooling installation and regulate cooling, ventilation, defrosting, and compressor utilization, balancing all of these different factors for maximum efficiency, which results in significant energy savings. The levels of C_2H_4, CO_2, and O_2 are measured by special analyzers and displayed digitally. At the same time, the stored data are compared with target set points for CO_2, C_2H_4, and O_2 levels for the relevant storeroom. Any differences between set points and actual levels are recorded, and the system sends instructions to the CO_2 adsorption, O_2 reduction, or ethylene removing units to make the necessary corrections. So far, no suitable sensors have been designed for measuring the relative humidity. The data recorded by the microcontrollers are continuously displayed on the terminal monitor. Besides temperature, all analytical data pertaining to the CA/MA refrigeration system, total defrosting time, temperature readings, set point values, adsorbers running times, and O_2 supply times are printed out automatically on the printer. The electronic analyzer should be checked once a week with portable electronic devices as a manual emergency control for a fully automatic system (Ryan and Lipton 1979).

The quality of minimally processed food products is dependent on their temperature history, from production through distribution and storage to consumption. Therefore, time-temperature indicator labels are an integral part of the storage and packaging; they monitor changes in food quality arising from poor temperature maintenance during storage and distribution of MPR foods (Labuza and Breene 1989).

3.8 Central Processing Operations

The processing and preservation center at the raw material production areas will expand or replace conventional packing house operation in the MPR food system. Certain economic scale of operation is required for the establishment of a central processing plant for single or multiple commodities. A minimum efficient scale plant is the smallest sized plant at which minimum unit cost is achieved (Marion 1986). At the processing center, MPR foods will go through the processing stages of handling, cleaning, and washing and many of the following operations:

Grading and inspection: Size, shape, and quality grading can be done mechanically or by hand.

Pesticide residue and other contaminants are tested. Preservation operations: Chemical preservatives, mild heat treatments, pasteurization, pH modification, water activity reduction, ionizing radiation, or other minimal treatments (National Food Processors Assoc. 1968).

CA/MA/vacuum packaging and storage: A few commodities, such as winter apples and potatoes, can be stored for long periods. However, most items must be shipped and sold as soon as possible.

3.8.1 Physical Distribution

Physical distribution refers to the portion of the total distribution system concerned with long- or short-distance transportation of MPR products from the producer to the consumer under the cold chain including local delivery. Knowledge of the available transportation systems and the ability to select the most appropriate mode of transportation for each product and destination are essential to minimize cost while optimizing quality and shelf life. Over 80% of produce is shipped by truck; the remainder travels mostly by rail, water, or air (Imming 1985). Sanitation is a major factor in food transportation. Inadequate cleaning of trucks or rail cars may lead to food spoilage and waste. Freight cars designed specifically for MPR foods need to be used. These are called “reefer containers.” The temperature range is adjustable, between −25 °C and +25 °C (−15 °F to +75 °F ± 1 °F). This degree of temperature control may be done by the use of platinum sensors and integrated circuits. The microbial risks in CA/MA/vacuum-packaged products are much greater in the absence of proper sanitation and temperature control (Jay 1992).

New multicomponent trailers and containers offer the possibility of combined, cold (−1 °C to +4 °C), chilled (+4 °C to +13 °C), and ambient (+13 °C to +18 °C) transportation. Radio-linked computers installed in all trucks give operators a direct link to the stock control computer telling them which pallets are required for each dispatch (Goad 1989).

When the transport vehicle travels over land, sea, or air at a constant speed, some degree of vibration and sudden compression impact (shock) is always present. Transportation shocks and vibrations are transmitted from the vehicle through the packaging to the product inside, causing injury during long journeys from production areas to markets. Therefore, optimum package design is essential for maximum protection of MPR products in transportation.

3.9 Consumption Center Operations

Fresh, minimally processed products arrive at terminal market facilities which include food distribution centers, wholesalers, retailers, and foodservices.

3.9.1 Food Distribution Center Operations

National or international food distribution centers are important for MPR foods to extend the season and to facilitate the distribution. The typical distribution center operations include receiving, storing, order picking, wholesale packaging, and final shipment. The intermodal terminal food distribution centers are large facilities designed to receive unit trains of produce or MPR food containers, truck lots, and shipment by nearby air or water ports. The operation would require short-time storage and standardized or containerized shipment allowing for easy and efficient intermodal transfer for local distribution.

3.9.2 Wholesaling

The wholesaling function consists of procurement, ripening of some products, warehousing, repacking, and reselling smaller amounts to many different types of customers. Local warehouses stock items close to the consumers to provide immediate availability. Automating warehouse operations allows for faster handling of larger volumes of products with less labor. Repacking or some reprocessing of MPR products in consumer units is done at all marketing levels including warehousing.

3.9.3 Retailing and Foodservice

Retail stores and foodservice establishments are the final link in the distribution of MPR foods. A small portion (3–6%) of fresh produce are directly marketed by farmers to consumers. Retailing is a very specialized operation involving all business activities that are concerned with selling the MPR products to final consumers for at-home use. In general, MPR products are priced 10% above conventional produce at the retail level, but products are 100% useable and there is no waste (Swientek 1991). A retail storewide computer system that uses data derived from an automated checkout system and controls physical facilities for heating, lighting, refrigeration, and interfaces electronically with suppliers will increase efficiency and speed of operation. Standardization of retail packages, cases, and pallets has been advocated (Kadoya 1990) as a means for improving efficiency in handling products moving through the market channels by reducing the number of different sizes and shapes, improving modularity, and making palletizing more efficient. There is a need for a better design of the location and layout of the MPR produce section within the retail outlets. Figure 3.19 gives an alternative layout for an MPR produce section in the supermarkets.

Foodservice operation can be divided into commercial or noncommercial eating places. Commercial operations consist of cafeterias, catering, fast-food outlets, restaurants, and other places. Noncommercial places include schools, hospitals, military establishments, and other facilities. Sales of food to eat away from home are increasing (How 1991). Fast-food chains are good examples of mass production and service of certain MPR products, especially salad bar technology (Fig. 3.20). For example, McDonalds requires that its lettuce suppliers harvest a week earlier than normal to prevent the core from becoming too crunchy. A company grows lettuce year-round exclusively for McDonalds. About 175 acres of lettuce is cut each week, leaving about 25% in the field that failed to meet the quality standards. Following harvest the lettuce is promptly cooled and then shipped to McDonalds' ten central salad processing plants strategically located around the country. Lettuce and other salad vegetables are processed. Processing involves chopping, washing, drying, and packaging in 3 1/2-lb bags, each holding the equivalent of four heads. The product is then shipped to 1500 stores, some as far as 300 miles from the processing plant. To meet the quality standards, the lettuce must be used within 10 days. The lettuce is harvested and delivered to the processor within 5 days. Processing takes about 1 day, so the store must sell the product within 4 days.

Delivery of complete meals to the home is a possible extension of changing lifestyles and MPR technology. The sous-vide concept has been tried with several variations for feeding elderly or handicapped individuals and children in special programs (Schafheifte 1990).

BACK ROOM PREPARATION AND STORAGE,PACKAGING AREA		
SLIDING MIRROR WINDOWS AND LIGHTING MIST SPRAYING		
Cold Section (Ice-slush or mechanical) 0 ^{0}C to 3 ^{0}C % RH 85-95	Chilled section 6 ^{0}C to 10 ^{0}C % RH	Dry-cool section 13 ^{0}C to 18 ^{0}C % RH 55-
Fresh fruits/Vegetables,Juices Precut Fruits and Vegetables Fresh-cut fruits and vegetables Ready-to-cook meals Green salads	Cut Pepper, Tomatoes Cucumbers Fresh herbs	Bananas Avocado Tropical fruits Subtropicals Sweet potatoes

Seasonal ambient temperature display area

Potaoes Onions Cut Pumpkins	Oranges Limons Limes	Apples Pears Melons

Fig. 3.19 An alternative MPR foods display section layout within the store

Sous-vide processing involves vacuum packaging of prepared raw or par-cooked meals or meal components, pasteurizing them under controlled time-temperature conditions (closed-pack pasteurization), chilling, then storage under 3 °C until reheating and serving.

3.10 Communication Network

Communications provide the exchange of information among the distribution channel members. Information as accurate and up to date as possible on supply, demand, and price is essential for anyone directly or indirectly involved in the production, processing, and consumption of MPR foods. The ability to identify what information is important and how to use it will be the key for success of managers.

The National Agricultural Statistics Service (NASS) gathers and disseminates official information on the production, storage stocks, and seasonal average price of major commodities. Government grades and international standards provide impartial general information about the individual product.

MPR food prices fluctuate widely from day to day and between places due to many factors. However, knowledge of differences in price elasticities of demand for a commodity in different markets may be used to raise total returns in those markets.

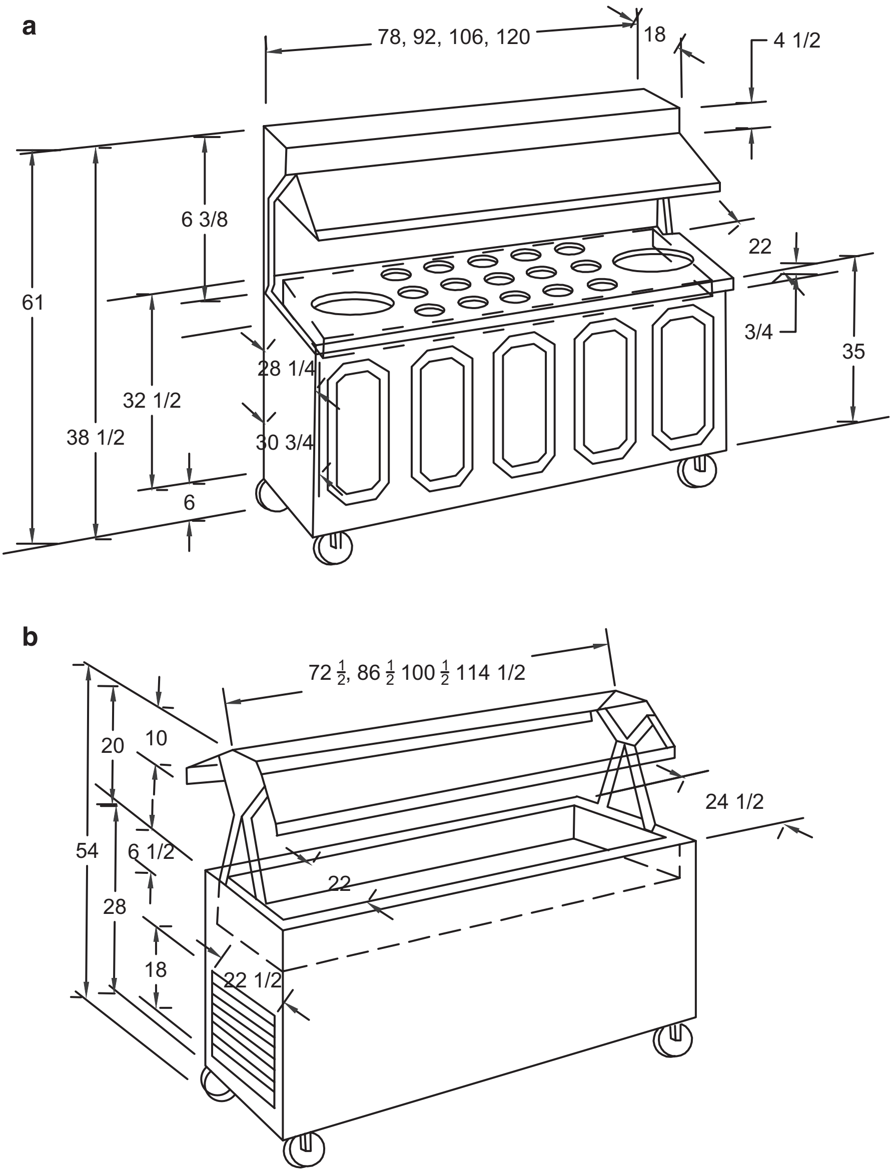

Fig. 3.20 Two types of mobile mechanically cooled salad serving equipment: **a** mirrored back salad bar, **b** two-sided salad bar (Source: Duke Manufacturing Co.; Anon. 1988c)

Information between firms needs to be exchanged for compatibility, transport type, scheduling, unit load requirements, warehousing, product availability, package size and type, delivery dates, and order quantity. Inventories exist as a necessary device to coordinate supply and demand. It is information that adjusts the relationship between orders, inventory, and production output (O'Shaughnessy 1988).

Advertising and promotion provides consumers with information and an incentive to purchase the advertised product. There are three major types of advertising programs directed specifically at buyers of MPR products. First, generic advertising is directed at expanding the market for a commodity or group of commodities grown in a specific area or countrywide, such as Washington State hazelnuts and the national potato program. Second, brand advertising seeks to increase sales and prices for a commodity or commodities sold by a specific company, such as Sunkist oranges. Third, private label advertising is used to expand sales of product under the label or brand of a chain retailer or foodservice wholesaler. The use of a private label does not bind retailers to purchase branded products from any particular seller, and so they can shop around for the best buy. The private label package does not have to support as heavy an advertising budget as branded products and so can be sold at a lower price.

The MPR fruit and vegetable processing company deals with a host of environmental elements that influence physical distribution planning and operations. Technological changes can have a great effect on distribution systems. Changes can be received through an appropriate information channel. The gross national product, population, inflation, economic growth, changing lifestyles, competition, changes in labor rates, and political changes all affect distribution in a variety of ways. Radio Frequency Identification (RFID): RFID tags are an advanced form of information carrier that can identify and trace a product. In a typical system, a reader emits a radio signal to capture data from an RFID tag. The data is then passed to a computer for analysis. RFID tags contain a microchip connected to a tiny antenna. This allows for the tags to be read for a range of 100 feet(30 m) or more in more expensive tags, to 15 feet(4 m) in less expensive tags. In contrast to a barcode, RFID does not need to be in a direct line of sight to be recognized by a scanner. Many RFID tags can be read simultaneously at a rapid rate. RFID tags could also store information such as temperature and relative humidity data, nutritional information and cooking instructions. They could be integrated with a time temperature indicator or a biosensor to carry time temperature information or microbiological and pesticide information. RFID technology in the food system is still evolving to be used in many applications.

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