Chapter 1
Introduction to Minimally Processed Refrigerated (MPR) Fruits and Vegetables

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1.1 Introduction

Minimally processed refrigerated (MPR) fruits and vegetables are an important and rapidly developing class of foods. These convenience foods are being produced by unique applications of the basic and food sciences and their supporting technologies and engineering. MPR fruits and vegetables have attracted the interest of many facets of the food industry including such diverse areas as food manufacturers, retail food stores (deli departments), restaurants, carry-out establishments, and commissary units. Much of the developmental work in this field is now being carried out in western Europe, Japan, and the United States in response to strong consumer demand, both individual and institutional, for new types of like-fresh high-quality convenience and safe foods. The purpose of MPR foods is to deliver to the consumer a fresh-like fruit or vegetable, product with an extended shelf-life, and at the same time ensure food safety and "maintain sound nutritional and sensory quality. MPR fruits and vegetables received their original impetus from institutional users, but retail applications are gaining favor and are expected to expand rapidly.

Many countries are making significant strides toward solving the myriad of problems associated with the manufacturing, distribution, and marketing of MPR fruits and vegetables.

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This progress appears to be due to strong governmental and food industry support for MPR food applications, a conducive regulatory climate in preparation for the expanding food markets that will be available within the European Community (EC) since the trade and monetary barriers are removed.

It is clear that investigators in the fields of food science, nutrition, technology, related disciplines, and engineering have studied and conducted research on the various facets of MPR food for many years, especially in the cold preserved and raw fresh foods areas (Fig. 1.1). The early work by Smock and Neubert (1950) on controlled atmosphere (CA) storage of apples is a good example of the type of research that is now utilized and is being greatly refined with regard to MPR fruits and vegetables. It is now time to look at this field as a concise discipline investigating the continuum of product flow from harvest to consumption (Fig. 1.2). As seen in Fig. 1.2, the discipline effectively links product production (horticulture production) with manufacturing, packaging, distribution, and consumption. See Morris (1991) and Anon (1991) for good manufacturing practices (GMP) and Hazard Analysis Critical Control Point (HACCP) Systems for MPR fruits and vegetables and chilled foods in general. A unified approach and thinking of MPR foods as a specific food preservation industry/method as contrasted to canning, freezing, or drying would greatly assist in its development, which is now growing rapidly in many parts of the world.

As shown in Fig. 1.1, the major differences between MPR fruits and vegetables and raw fruits and vegetables are the rather specific processing and preservation steps taken with MPR foods. The MPR fruits and vegetables are usually living respiring tissues (Rolle and Chism 1987), but respiration is greatly "increased by cutting, slicing, low temperature heat treatments, and preservatives (Figs. 1.3 and 1.4, Anon 1989a). As seen in Fig. 1.3, the intact cell is expected to be much more resistant to oxidative browning and entrance of bacteria as compared to the cut cell. Figure 1.4a shows the intact vegetable product in a package, and Fig. 1.4b shows the condition of some cut surface cells with the majority of intact interior cells. The latter situation may greatly complicate the modeling of gas exchange in polymeric packages as suggested by Mannapperuma and Singh (1990). Refrigeration and packaging may be optional for raw fresh intact fruits and vegetables but are mandatory for MPR fruits and vegetables.

In this book, the attempt is made to differentiate between intact fresh fruits and vegetables and MPR fruits and vegetables even though the latter are somewhat difficult to define exactly. For example, whole intact apple fruit in CA storage, described by Smock and Neubert (1950), would not be considered an MPR product, whereas sliced, refrigerated apple slices treated with ascorbic acid and calcium salts (Ponting et al. 1972) would easily fall into the MPR category. As seen in Fig. 1.5, the vacuum-infused peeled oranges prepared using pectinase are a good example of minimally processed fruit Baker and Bruemmer (1989). The fruit can be segmented or handled in a tray pack as a whole fruit. Waldorf salad with diced apples, celery, walnuts, etc., in a dressing and sous vide with a portion of prepared fruits or vegetables would be considered an MPR fruit and vegetable product to carry the concept

Food Preservation and Processing Categories	Not Preserved, May be home Cooked	Minimally Processed, Refrigerated,May Be Home Cooked	Cold Preserved, Processed Frozen Storage, May be Home Cooked	Irradiation, electronic processing methods	Dehydrated	Heat Processing Canning,Sterilization, Pasteurization,Ultra High Temperature Processing,Frying	*Non-thermal and Electrotechnologies of food processing and preservation
Food Quality Color,Flavor, texture	Fresh	Like-Fresh	Slightly to fully Modified**	Slightly Modified**	Slightly to Fully Modified**	Fully Modified**,but Safe, no microbial contamination	Slightly Modified**
Storage, Shelf-life	May not be refrigerated	Requires Refrigerated, Transportation, Storage	Requires Frozen or Refrigerated storage,Transportation, and Market display	Requires Refrigerated storge	Shelf Stable at Ambient Temperatures	Long Shelf life at Ambient Temperatures	Shelf Stable, requires Refrigerated Transportation, Storage
Packaging	May not be Packaged	Requires Packaging	Requires Packaging	Requires Packaging	Requires Packaging	Requires Hermetic, Aseptic packaging	Requires Packaging
Cell Integrity	No Change	No change	Changes	Changes	Changes	Total destruction	Changes
Enzymes(Activity and structure)	No Change	No Change	Changes	Changes	Changes	Total destruction	Changes
Phytochemicals, Vitamins, Proteins	No Change	No Change	Changes	Changes	Changes	Highly changed	Changes
Dietary Advanced Glycation End Products(dAGEs), Formation before home cooking	None	None	Some dAGEs formation	dAGEs formation	dAGEs formation	High Quantity of dAGEs Formation	Some dAGEs formation
Free Radical Formation	None	None	Some Free radical	Free radicals formation	Some Free radicals fomation	Free radicals formation	Free radicals formation

*Non-thermal and electrotechnologies of food processing and preservation includes:
a-High Pressure, Ultra-high Pressure(HPP), b-Plasma, c-Pulsed Light and Pulsed electric fields, d-Ohmic Heating, e-Ionizing radiation, f-Pulsed X-ray, g-Ultrasound, h-High-voltage arc discharge, i-Magnetic fields, j-Dense phase carbon dioxide, k-Microvawes, l-Electron Beam Processing.
**Product Freshness

Fig. 1.1 Spectrum of food preservation systems related to minimally process refrigerated (MPR) fruits and vegetables (*Product freshness)

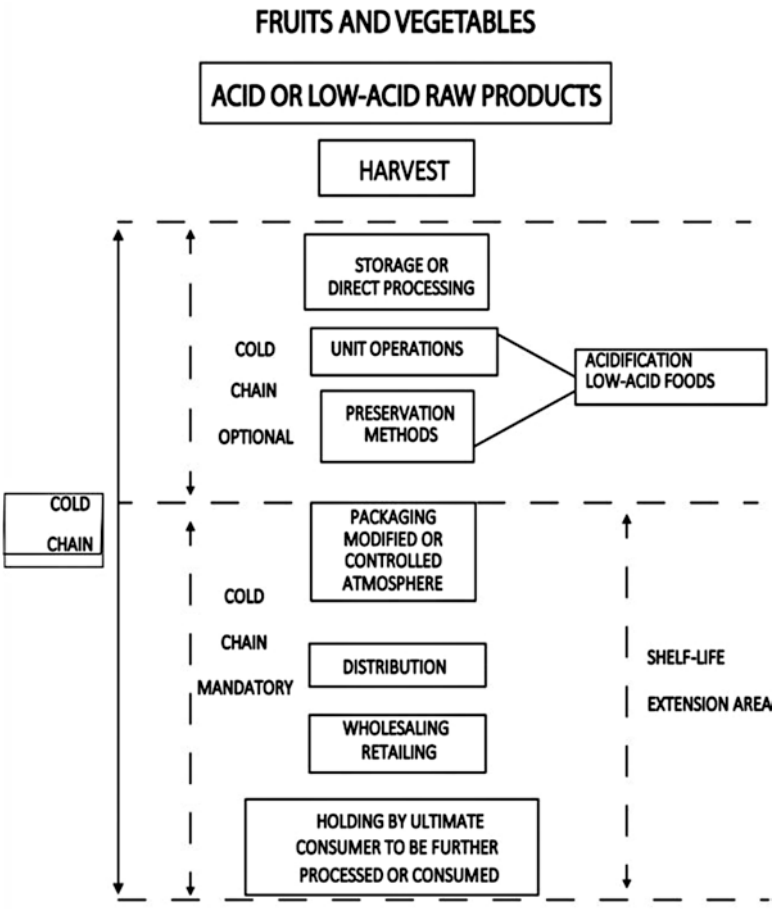

Fig. 1.2 General flow sheet for minimally processed refrigerated fruits and vegetables

into prepared foods. See Part 2 for an extensive listing of MPR fruits and vegetables.

A more difficult to define, gray area might involve the classification of washed, waxed cucumbers. These products would probably not be considered MPR foods because although they are packaged (waxed), they are also intact." Waxed intact cucumbers could be contrasted with precut or sliced cucumbers which have a relatively short shelf-life and are considered MPR foods. MPR fruits and vegetables should not include fresh intact fruits and vegetables which may undergo normal postharvest handling treatments such as sizing, grading, washing, waxing, CA, or modified atmosphere (MA) storage (see Fig. 1.1).

Frozen foods make up a portion of products normally classified as cold preserved foods. However, MPR foods are dissimilar to frozen foods in that frozen foods must be transported and stored at −10 °C or lower, whereas MPR foods require cold-chain

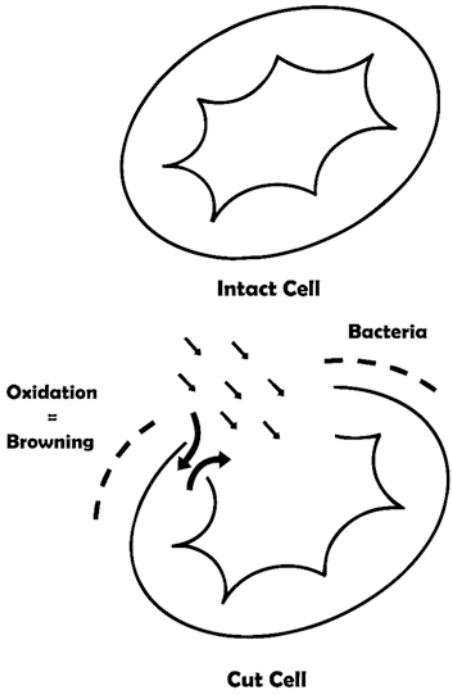

Fig. 1.3 Diagrams of intact and processed (cut) fruit or vegetable cell (From CTIFL, France)

refrigerated or slightly higher temperatures depending on the commodity or mixtures of commodities (Anon 1989b). The overall quality of frozen food is different than the like-fresh quality of MPR food. Many times the consumer can discern differences in texture between frozen and MPR foods. Some manufacturers of sous vide meals, for example, freeze their product, which makes the meal little less than a frozen food in most respects.

MPR fruits and vegetables are different from dehydrated fruits and vegetables in terms of texture and water activity (a_w). MPR fruits and vegetables which normally have a_w around 0.97–0.99 are very sensitive to a_w reduction. However, preservatives such as ascorbic acid and citric acid used on dehydrated fruits and vegetables are also used on MPR fruits and vegetables. Dehydrated foods are considered shelf-stable at ambient temperatures and thus do not require the cold-chain delivery system used for MPR foods (Fig. 1.2).

An important difference between MPR and thermally processed foods is that MPR foods do not exhibit "commercial sterility" as defined for thermally processed foods. This definition states thermally processed foods are free of microorganisms capable of reproducing under nonrefrigerated conditions and that no viable microorganisms (including spores) of public health significance can reproduce. This "sterility" may be acquired by control of water activity, reducing pH, or application of heat. There is some likelihood that the "commercially sterile" concept may be assigned to those MPR fruits and vegetables that are deemed to be safe. The microbial and

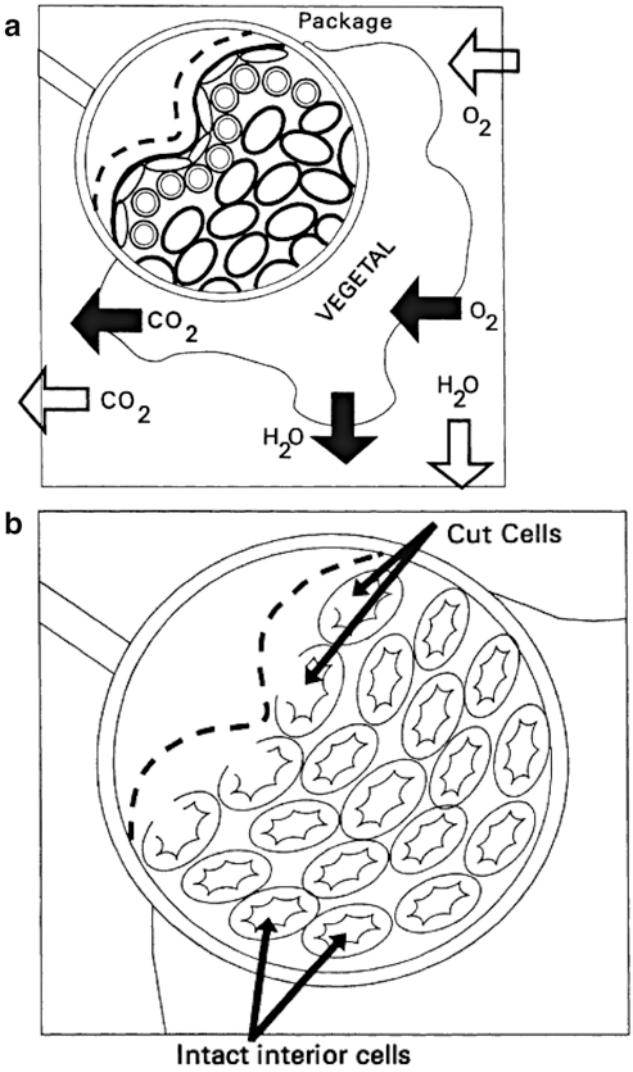

Fig. 1.4 Diagram of product in package and product with surface modification such as from peeling or slicing (From CTIFL, France)

enzyme limits for "commercial sterility" or "microbial and enzymatic safety" of MPR fruits and vegetables are yet to be developed, if in fact this term is accepted and is germane to these foods. Thermally processed food cannot be claimed to be like-fresh. Nevertheless, the tremendous amount of research conducted on handling, processing, and preservation of fresh, frozen, irradiated, dehydrated, and thermally processed fruits and vegetables can be applied where appropriate to the relatively new concept of MPR foods Kader (1986), Kantor (1989).

Fig. 1.5 Example of vacuum-infusion peeling of oranges by pectinase (From Agricultural Research Service, USDA)

A major advantage in the development and careful classification of MPR foods is that they provide a basis for separation of the traditional cold preservation field, as described by Potter (1968), into two distinct areas, that is, frozen foods and refrigerated foods. As shown in Fig. 1.1, separation of these two areas would greatly simplify the frozen food/refrigerated food classification by placing all frozen foods together and all refrigerated foods in a refrigerated category (Appendix 1). No doubt refrigerated as well as other preservation categories should be subclassed into commodity and prepared foods areas. One noticeable difference between MPR fruits and vegetables and many other refrigerated foods is the "living tissue" concept which must be considered in dealing with certain types of MPR fruits and vegetables. The shelf-life of MPR fruits and vegetables also should be limited to 3–6 months from harvest to consumption due to the living tissue and active enzymes concept.

There is a need to update and organize current information developed over many years of research in food science and technology that may apply to MPR foods. In addition, there are demands for research to make MPR foods comparable to the currently more actively used preservation methods for which so many food processing industries are named. The food industry seems interested in making the large family of MPR foods more intensively competitive. It would require several volumes to cover adequately the various food product types that could be interpreted as using the technologies and packaging systems required to produce MPR foods. To narrow the scope of this volume, emphasis will be placed on MPR fruits and vegetables, although in some chapters of the book, particularly in the regulatory and quality control areas, it is difficult to separate MPR fruits and vegetables from other MPR foods. This burgeoning area of food science requires the expertise of horticulturists, plant physiologists, molecular biologists and pathologists, biochemists, biotechnologists, microbiologists, food scientists, and food engineers and packaging experts, to name only a few specialties. A truly interdisciplinary effort will be needed to deliver to the markets MPR fruits and vegetables that will have extended high-quality shelf-life beyond 8–10 days, which is usually satisfactory for the retail European market. MPR fruits and vegetables will probably require a minimum shelf-life of 21 days to compete satisfactorily in US markets (Lioutas 1988). This author is likely referring to name-brand products requiring national distribution and not to regional operations.

1.2 Definitions of MPR Fruits and Vegetables

There have been a number of articles which have defined minimal processing. For example, Rolle and Chism (1987) suggest that minimal processing "includes all unit operations (washing, sorting, peeling, slicing, etc.) that might be used prior to blanching on a conventional processing line." They feel all these products are living tissues. A slightly different approach was taken by Huxsoll and Bolin (1989) in which they felt the "minimally processed product is raw and the cells of the tissues are alive but these characteristics are not required." There was no agreement on the definitions for minimally processed fruits and vegetables at a recent American Chemical Society symposium (Hicks and Sapers 1991). Cantwell (1991) for one, at the symposium, called these products "cut fruits and vegetables which are lightly processed."

It is generally conceded that MPR fruits and vegetables are products that contain live tissues or those that have been only slightly modified from the fresh condition and are fresh-like in character and quality. These tissues do not exhibit the same physiological responses as normal (raw) untreated intact live plant tissues (Fig.1.3 and 1.4). The cutting, abrasion, or minimal heating of these tissues can cause broadly different responses in various environmental and packaging situations. However, some fruits and vegetables that show little or no physiological activity should also be included in the MPR category. The cold preservation category (Fig. 1.1) now encompasses some of these types of foods. MPR fruits probably should include products such as chilled peaches in glass containers in which complete inactivation of cellular metabolism has recently occurred, and the product has been quickly transferred to the market in the cold chain. Sous vide dishes which may include preheated vegetables or fruits should be included in the MPR food area. In terms of physical state, the tendency has been to include only solids, semisolids, and semiliquids as MPR fruits and vegetables, but refrigerated liquids both cloud and clarified juices should be included in this class of foods. The freshly squeezed orange juices and others that are chilled and packaged in plastics, paperboard, or glass are good examples of this type of product. This type of food should probably be included with refrigerated fruit and vegetable products under the like-fresh minimal processing column (Fig. 1.1). The USFDA is still considering whether these products should be labeled fresh.

MPR fruits and vegetables (for the purposes of this book) are defined as those prepared by a single or any number of appropriate unit operations such as peeling, slicing, shredding, juicing, etc., given a partial but not end-point preservation treatment including the use of minimal heat, a preservative, or radiation. The preservation or hurdle treatment may include pH control, antioxidants, chlorinated water dips, or a combination of these or other treatments (see Chap. 3). It is important to take advantage of the synergies of all preservation treatments. The initial preparation and preservation treatments are usually followed by some kind of controlled/modified atmosphere and vacuum packaging and subjected to reduced temperatures above the freezing point during storage, distribution, marketing, and just prior to

preparation for consumption. For safety and greatest retention of sensory and nutritional quality, these products must be distributed and marketed in the cold chain.

Some precut fruits and vegetables (examples are cucumber, eggplant, tomatoes, and tropicals, and subtropicals) have to be handled at higher temperatures to avoid chilling injury (Appendix, Tables 2 and 3). It should be clear that MPR fruits and vegetables are not intended for ambient shelf-life stability as expected from canned, retorted, or aseptic processed and packaged fruits and vegetables. Nor are they protected from spoilage or quality changes by freezing and being held in frozen storage. There is a need for *agreement* by workers in the food field as to the proper description (title) for these foods and definitions thereof. To be successful, MPR foods will have to be of high quality, convenient, healthier, fresh-like aroma, active phytonutrients, and safe and reduce the risk of chronic diseases. Currently, there is no other food processing methods that have all these properties.

1.3 Quality of Minimally Processed Fresh Produce and Other Plant Foods

Several parameters affect quality and shelf-life of MPR produce from field to the fork as summarized in Table 1.1 and Fig. 1.6. Quality aspects of MPR fruits and vegetables are studied and published by many researchers (Mercedes Diaz-Mendoza et al. 2016; Anna Kårlund et al. 2014). Leaf senescence is a physiological process critical for plant survival. It is characterized by the dismantling of cellular structures, massive degradation of macromolecules, and efficient relocation of nutrients from senescing leaves to growing tissues or sink organs. Shelf-life extension will be very closely related to the control of senescence and cell membrane peroxidations in MPR fruits and vegetables (Mercedes Diaz-Mendoza et al. 2016; Yildiz et al. 2007).

Health-promoting quality of minimally processed fruits and vegetables has been emphasized by many researchers in many countries in the last 20 years (Crowe et al. 2011; Carter et al. 2010). There is an increasing epidemiological and experimental

Table 1.1 Summary of the factors affecting total quality of the MPR fruits and vegetables

Parameters	Affects
Preharvest agricultural practices	Composition, phytonutrients
Growing crops practices	Size, shape, scars, pesticide residues
Harvest practices	Maturity, brix/acid, color
Postharvest handling	Mechanical damage, biochemical changes
Processing	Microbial growth, browning, weight loss
Packaging, handling, and storage	Spoilage, weight, loss, softening, surface drying
Physiological changes from harvest to fork (respiration rates of F&V O_2/CO_2)	Senescence, changes in respiration rates, ethylene production, yellowing, loss of water, size changes, loss of phytonutrients, shelf-life

Fig. 1.6 Senescence of broccoli (changes in lipids, chlorophylls, chloroplast, ethylene, and proteins metabolism during postharvest storage, yellowing)

data indicating that the consumption of vegetables and fruits confers many health benefits (Hughes et al. 2010; Cho et al. 2010). There are more than 10,000 phytochemicals in plant foods which include antioxidants, anti-inflammatory substances, and many others (Trim 2006; World Cancer Research Fund/American MPR) fruits and vegetables:Institute for Cancer Research 2007). For example, polyphenols are antioxidants and cardioprotective in humans (Anna et al. 2014).

1.4 Approach to Studying MPR Fruits and Vegetables

It is becoming increasingly recognized that low temperatures are not the defenses against foodborne illnesses that were previously accepted by the food industry and governmental agencies. The emergence to prominence of non-spore-forming psychrophilic pathogens such as *Listeria monocytogenes* and *Yersinia enterocolitica* can cause enormous problems in refrigerated foods (Chap. 19). Many vegetables, mushrooms, and legume sprouts are considered to be low-acid foods by the USFDA (pH 4.6 and over); thus, special measures will have to be taken to make these types

of foods free from type B and type E C. *botulinum* toxin formation in anaerobic situations brought on by packaging, product density, deaeration, or inert gas injection.

MPR fruits and vegetables have necessarily been studied first on an individual commodity basis and not as mixtures such as precut salads, pizza vegetables, or stir-fry mixtures, sous vide, and the like. A good example of the individual approach is the work on grated carrots in modified atmosphere packaging in France (Carlin et al. 1990). In this research, only gaseous packs of thin strips 1.5 mm × 1.5 mm sections of carrots were studied. There is a need for studies of convenience foods, that is, complex food mixtures in salads and soup mixtures and the various new products being developed for the market. Also every commodity and its individual cultivars need to be investigated for their applications to MPR foods. It is not clear at this time, for example, whether strawberries for the fresh market or for freezing would be the best suited as a MPR product. Perhaps plant breeders, biotechnologists should be looking for cultivars that are especially suited for minimal processing and refrigerated products. This idea seems to be supported by Rolle and Chism (1987), who have stated that MPR fruits and vegetables are all living respiring tissues in an "energized state." The individualistic concept is also suggested by Labuza and Breene (1989), who feel that is all important to define the end point of high-quality life for each type of fruit and vegetable. Both cultivar and maturity play a very important role in determining these end-point values. It is necessary to collect data on individual commodities, their cultivars, and maturity levels before attempting to work with either simple or complex MPR food mixtures, although this will eventually have to be done by computer modeling. There is no question that complex minimally processed food mixtures are being found in the markets at this time, but little information seems to be available about their shelf-life characteristics.

Rolle and Chism (1987) suggested live tissues that have the largest energy reserves such as white potato, topped beetroot, and apple have the longest shelf-life (postharvest) and that the greatest problems are being found with those commodities such as sweet corn/eggplant, raspberries, and strawberries that have the smallest "reserves." Probably more important than the lack or presence of "reserves" is the physical injury received during size reduction operations and the series of preservation steps that will set up a complex series of physiological and microbiological events (Figs. 1.3 and 1.4).

It appears that MPR fruits and vegetables of the high-reserve type and high respiration rates will have a shorter shelf-life than the intact raw or fresh product, for example, controlled atmosphere stored apples vs. the presliced refrigerated MPR) fruits and vegetables:fruit. The former may exhibit 6–8 months or longer satisfactory storage period, whereas refrigerated presliced apples may not be usable for more than 2–3 weeks if untreated or up to the average of 10 weeks if treated with 0.5% ascorbic acid and 0.1% Ca (Ponting et al. 1972). Low-reserve fruits and vegetables are very sensitive" to further processing as a means to extend storage and shelf-life and present complex research challenges. There are currently research studies in many parts of the world to address these problems, but in most cases, the findings are not published or available to the public.

The study of MPR fruits and vegetables will be divided into introductory information, preparatory operations, preservation methods, packaging, biological aspects, and regulatory implications for MPR food products.

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