Recent Advances and Future Research Needs in Postharvest Technology of Fruits

by

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I. INTRODUCTION

Worldwide availability of fresh fruits and their products continues to increase in terms of the number of species and cultivars (varieties) as well as their expanded season of availability. Continued consolidation and vertical integration among producers, shippers, and marketers plus increased use of modern communications characterize the global marketing systems for fresh produce and related value-added products. Both retail and foodservice produce buyers are demanding more services, including the application of "Product Look Up" (PLU) codes and "Electronic Data Interchange" (EDI) to facilitate category management and "Efficient Consumer Response" (ECR). This will most likely result in increased need for short-term storage of fresh fruits and vegetables close to the location of the retail and foodservice distribution centres. Massmarketers are becoming more serious competitors to traditional food retailers. Both domestic consumption and exports of fresh fruits and vegetables are increasing. People are interested in healthier diets, natural foods, organic produce, convenience, and diversity of foods. The produce industry is responding to consumers' demand for convenience by increasing the quantity and range of "ready-to-eat" and "ready-to-cook" fresh-cut fruit and vegetable products and combining them with pasta and other food products in "home meal replacement" marketing programmes.

The primary goals of research on postharvest biology and technology of fresh produce are to reduce losses in quantity and quality between harvest and consumption. The strategies for attaining these goals include selection of genotypes with good quality when harvested at optimum maturity, use of an integrated crop management system that maximizes yield without sacrificing quality, and use of optimum postharvest handling procedures to maintain the quality and safety of the produce. The most useful technological changes in the production, harvesting, and postharvest handling systems for horticultural crops have resulted from interdisciplinary research and development approaches and this is likely to continue to be true in the future.

II. FLAVOUR AND NUTRITIONAL QUALITY

Until recently most produce marketers and postharvest researchers paid more attention to appearance and textural attributes than to flavour and nutritional attributes of fruit quality. It is time for a paradigm shift in our thinking about quality because without good flavour, consumption of fresh fruits and their products will not increase. We need to pay more attention to the role of fresh produce in promoting good health by providing not only essential vitamins, minerals, and dietary fibre, but also phytonutrients (such as...
carotenoids and flavonoids) that play a role, as antioxidants, in the prevention of cancer, cardiovascular disease, and other chronic diseases. Additional research is needed in order to evaluate the effects of preharvest and postharvest factors on the nutritional quality and antioxidant activity of various fruits.

Flavour quality of most fruits is influenced by their contents of sugars (sweetness), organic acids (acidity), phenolic compounds (astringency), and organoleptically-important volatiles (aroma). More information is needed about the optimum concentration ranges of these constituents to assure good overall flavour (based on sensory evaluation) of each kind of fruit (to satisfy the majority of consumers). Also, future research and development efforts on objective quality evaluation methods must include non-destructive assessment of fruits on the basis of their contents of sugars, acids, phenolics, and/or odour-active volatiles. In many cases, consumers are willing to pay a higher price for fruits with good flavour and there is a growing trend of high-quality-based stores that serve this clientele.

### III. PREHARVEST FACTORS

#### III.1 Genotypic variation in quality and storage potential

Using classical breeding and molecular-based methods for varietal development, there are many opportunities to develop genotypes that have lower respiration and ethylene production rates, less sensitivity to ethylene, slower softening rate, improved flavour quality, enhanced nutritional quality (vitamins, minerals, dietary fibre, and phytonutrients including carotenoids and polyphenols), reduced browning potential, decreased susceptibility to chilling injury, and increased resistance to postharvest-decay-causing pathogens. In some cases, the goals may be contradictory, such as lowering phenolic content and activities of phenylalanine ammoniase and/or polyphenoloxidase to reduce browning potential versus increasing polyphenols as antioxidants with positive effects on human health. Another example is reducing ethylene production versus maintaining or increasing flavour volatiles production capacity in fruits.

#### III.2 Climatic conditions and cultural practices

The extent of variation in quality and postharvest storage potential depends upon climatic conditions (especially temperature and light intensity) and cultural practices (especially water and nutrient supply). High calcium content in fruits has been related to longer postharvest life as a result of reduced rates of respiration and ethylene production, delayed ripening, increased firmness, and reduced incidence of physiological disorders and decay. In contrast, high nitrogen content is often associated with shorter postharvest life due to increased susceptibility to mechanical damage, physiological disorders, and decay. Future research should be focused on identifying the optimum production conditions to maximize flavour and nutritional quality at harvest and minimize incidence and severity of physiological disorders and decay during postharvest handling of fruits.

#### III.3 Maturity at harvest and harvesting method

Maturity and ripeness stage at harvest have a major impact on quality and postharvest-life potential of fruits. Harvesting method influences the extent of mechanical injuries and variation in maturity and ripeness stages at harvest. Future research needs include the following objectives:

a. establishing minimum requirements for acceptable eating quality and using these criteria in evaluating the interactions of genetic, preharvest, harvest, and postharvest factors with the quality of fresh fruits;

b. identification of organoleptically important volatiles produced by each kind of fruit;

c. continuing development of nondestructive procedures and instrumentation for fruit maturity and quality evaluations to be used as tools for quality control and for sorting fruits according to their external and internal quality.

### IV. POSTHARVEST FACTORS

#### IV.1 Packing and packaging

Automation of packinghouse operations, including separation of fruits according to size, colour, external defects, and internal quality (in a few cases), has increased in most production areas and this trend will likely continue in the future. There is an increased use of plastic containers that are used to display produce at retail markets and can be reused and recycled in order to reduce waste disposal problems. These containers measure 40 x 60 cm, vary in depth (depending on the commodity) and can be rented from various companies that rent plastic containers and pallets (120 x 100 cm). There is continued increase in use of modified atmosphere
and controlled atmosphere packaging (MAP and CAP) systems at the pallet, shipping container (fibreboard box liner), and consumer package levels. Use of absorbers of ethylene, carbon dioxide, oxygen and/or water vapour as part of MAP and CAP is increasing.

**IV.2 Cooling and storage**
The trend is towards increased precision in temperature and relative-humidity management to provide the optimum environment for fresh fruits and vegetables during cooling and storage. Precision temperature management (PTM) tools, including time-temperature monitors, are becoming more common in cooling and storage facilities. Forced-air cooling continues to be the predominant cooling method for horticultural perishables. Operators can ensure that no produce shipments leave the cooling facility above or below about 0.5°C of the optimum storage temperature. Periodic ventilation of storage facilities is effective in maintaining ethylene concentrations below 1 ppm, which permits mixing of temperature-compatible, ethylene-producing and ethylene-sensitive commodities. More research is needed to develop instruments that can detect prior, cumulative exposures of fruits and other perishables to chilling temperatures and to ethylene.

**IV.3 Ethylene**
Recent developments in postharvest technology to reduce detrimental effects of ethylene include improved methods of monitoring ethylene concentrations around produce, avoiding exposure to exogenous sources of ethylene, and increased use of ethylene scrubbers (mainly those using potassium permanganate) during postharvest handling of produce. While the ethylene action inhibitor, 1-methylecyclopropene (MCP) is used commercially on ornamentals, approval of its use on edible products is pending. Meanwhile, many researchers worldwide are investigating the efficacy of MCP in reducing ethylene-induced deterioration of fruits and vegetables. MCP at 0.1 to 1.0 ppm for 6 to 24 hours at 0 to 20°C has been shown to be effective in delaying fruit ripening (as indicated by colour, firmness, acidity, and other compositional changes), but there are indications of potential negative effects on subsequent ripening uniformity and flavour quality (reduced production of aroma volatiles). Once MCP is approved for use on fruits it will be important to evaluate its effects on flavour quality (by sensory evaluation panels) before recommending it for commercial application.

**IV.4 Postharvest integrated pest management (IPM)**
One of the most common and obvious symptoms of deterioration results from the activity of fungi. Attack by most organisms follows physical injury or physiological breakdown of the commodity. In a few cases, pathogens can infect apparently healthy tissues and become the primary cause of deterioration. In general, harvested fruits exhibit considerable resistance to potential pathogens during most of their postharvest life. The onset of ripening in fruits results in their becoming susceptible to infection by pathogens. Controlled atmosphere (CA) conditions delay senescence, including fruit ripening, and consequently reduce susceptibility of fruits to pathogens. On the other hand, CA conditions unfavourable to a given commodity can induce physiological breakdown and enhance susceptibility to decay. Calcium treatments have been shown to reduce the incidence and severity of decay. Biological control agents are being used alone or in combination with reduced concentrations of postharvest fungicides, heat treatments, and/or fungistatic CA for control of postharvest diseases. The potential of using superatmospheric O₂ levels plus 15-20% CO₂ for decay control without detrimental effects on fruit quality merits further investigation.

Chemical fumigants, especially methyl bromide, are still the primary method used for insect control in harvested fruits when such treatment is required by quarantine authorities in importing countries. Many studies are under way to develop alternative methods of insect control that are effective, are not phytotoxic to the fruits, and present no health hazard to the consumer. These alternatives include: cold treatments, hot water or air treatments, ionizing radiation (0.15-0.30 kiloray), safer chemical fumigants, and exposure to reduced (less than 0.5%) oxygen and/or elevated carbon dioxide (40-60%) atmospheres. This is a high-priority research and development area because of the possible loss of methyl bromide as an option for insect control.

**IV.5 Use of controlled atmospheres**
Several refinements in CA storage have been made in recent years to improve fruit quality maintenance; these include creating nitrogen by separation from compressed air using molecular sieve beds or membrane systems, low O₂ (1.0-
1.5%) storage, low ethylene CA storage; rapid CA (rapid establishment of the optimum levels of O₂ and CO₂), and programmed (or sequential) CA storage (e.g., storage in 1% O₂ for 2 to 6 weeks followed by storage in 2-3% O₂ for the remainder of the storage period). Other developments, which may expand use of MA during transport and distribution, include using edible coatings or polymeric films with appropriate gas permeabilities to create a desired MA around and within the commodity. Modified-atmosphere packaging is widely used in marketing fresh-cut fruits and vegetables. Future research needs include the following:

a. continuing studies to better understand the biological basis of oxygen and carbon dioxide effects on postharvest quality of fruits.

b. continuing investigations of the physiological and biochemical basis of CA-induced physiological disorders; reasons for genotypic differences in tolerance of fruits to reduced O₂ and/or elevated CO₂ concentrations.

c. elucidating the mode of action of elevated O₂, elevated CO₂, ethylene, and carbon monoxide on postharvest pathogens.

d. continued development of optimum modified atmosphere packaging technologies for various fruits, including evaluation of various types of O₂, CO₂, C₂H₄, and water vapour absorbers for their effectiveness in helping maintain the desired microenvironment within modified atmosphere packages.

e. developing dynamic controlled-atmosphere procedures for use during transport and storage of fruits.

IV.6 Transportation

There are continued improvements in attaining and maintaining the optimum environmental conditions (temperature; relative humidity; concentrations of oxygen, carbon dioxide, and ethylene) in transport vehicles. Treating fruits with ethylene to initiate their ripening during transportation is feasible and is used commercially to a limited extent. Products are commonly cooled before loading and are loaded with an air space between the palletized product and the walls of the transport vehicles to improve temperature maintenance. In some cases, vehicle- and product-temperature data are transmitted by satellite to a control centre allowing all shipments to be continuously monitored. Some new trucks have air-ride suspension, which can eliminate transport vibration damage and as the industry realizes the value of air ride, its popularity will increase. Controlled-atmosphere and precision temperature management allow non-chemical insect control for markets that have quarantine restrictions against pests endemic to exporting countries and for markets that do not want their produce exposed to chemical fumigants.

IV.7 Handling at wholesale and retail markets

There is a shift towards automated ripening where gas composition of the ripening atmosphere, room temperature and relative humidity, and fruit colour are continuously monitored, and modulated to meet desired ripening characteristics. Improved ripening systems will lead to greater use of ripening technology to deliver products that are ripened to the ideal eating stage. Better refrigerated display units, with improved temperature and relative humidity monitoring and control systems, are being used in retail markets, especially for fresh-cut fruit and vegetable products. Many retail and food service operators are using Hazard Analysis Critical Control Points (HACCP) programmes to assure safety of food products to the consumer.

IV.8 Fresh-cut fruits

Quality of fresh-cut fruits depends upon quality of the intact fruits and its maintenance until the time of preparation, ripeness stage at the time of cutting, method of preparation, and subsequent handling conditions. Temperature and relative humidity are the most critical factors in preserving quality of these products. Even under optimum preparation and handling conditions, postcutting life based on flavour is shorter than that based on appearance. More research is needed to identify the reasons for the flavour loss and possible treatments to slow it down and to restore the ability of the fruit tissue to produce the desirable esters and other aroma compounds.

Use of calcium chloride or calcium lactate in combination with ascorbic acid and cysteine as a processing aid (2-minute dip) has been shown to be effective in firmness retention and delaying browning of fresh-cut fruits. Ethylene scrubbing and modified atmosphere packaging (to maintain 2-5% O₂ and 8-12% CO₂) can be useful supplements to good temperature management in maintaining quality of fresh-cut fruit products. Additional research is needed to optimize preparation and subsequent handling procedures for maintaining quality and safety of each fruit product.
V. FOOD SAFETY ASSURANCE

During the past few years, food safety became and continues to be the number one concern of the fresh produce industry. The U.S. Food and Drug Administration published in October 1998 a "Guide to Minimize Microbial Food Safety Hazards for Fresh Fruits and Vegetables", which is based on the following principles: (1) Prevention of microbial contamination of fresh produce is favored over reliance on corrective actions once contamination has occurred; (2) To minimize microbial food safety hazards in fresh produce, growers, packers, or shippers should use good agricultural and management practices in those areas over which they have control; (3) Fresh produce can become microbiologically contaminated at any point along the farm-to-table food chain. The major source of microbial contamination with fresh produce is associated with human or animal feces; (4) Whenever water comes in contact with produce, its quality dictates the potential for contamination. Minimize the potential of microbial contamination from water used with fresh fruits and vegetables; (5) Practices using animal manure or municipal biosolid wastes should be managed closely to minimize the potential for microbial contamination of fresh produce; and (6) Worker hygiene and sanitation practices during production, harvesting, sorting, packing, and transport play a critical role in minimizing the potential for microbial contamination of fresh produce.

Chlorine dioxide and ozone-based systems for water sanitation are increasingly being used instead of chlorine-based systems. Researchers continue to evaluate the efficacy of various ultraviolet radiation treatments in reducing microbial contamination of fresh produce. Other active research areas include identification of relevant indices of microbial quality of intact and fresh-cut fruits and investigation of how various postharvest handling treatments and conditions influence survival of human pathogens on produce.

VI. VALUE OF POSTHARVEST RESEARCH

I estimate that about one third of fresh produce harvested worldwide is lost at various points in the distribution system between production and consumption sites. While it may be impossible and not economical to reduce these losses to zero, it is possible and desirable to reach a 50% loss-reduction level. Minimizing postharvest losses of already produced food is more sustainable than increasing production to compensate for these losses. Yet, less than 5% of the funding of agricultural research is allocated to postharvest research areas. This situation must be changed to increase the role of postharvest loss reduction in meeting world food needs.

Much more research is needed to determine the return on investment (ROI) or the cost/benefit ratio of postharvest research and various postharvest technologies (such as cooling, ethylene scrubbing, modified atmosphere packaging, and MCP treatment). Such information would be very valuable in convincing policymakers to increase funding of postharvest research and extension programmes and in encouraging produce handlers to use the postharvest technology procedures that have high ROI potential.

REFERENCES


