Kader, A.A. 2002. Pre- and postharvest factors affecting fresh produce quality, nutritional value, and implications for human health. Proceedings of the International Congress Food Production and the Quality of Life, Sassari (Italy), September 4-8, 2000, Volume 1, pp. 109-119.

PRE- AND POSTHARVEST FACTORS AFFECTING FRESH PRODUCE QUALITY, NUTRITIONAL VALUE, AND IMPLICATIONS FOR HUMAN HEALTH

FATTORI CHE INFLUENZANO LA QUALITÀ, L'ASPETTO NUTRIZIONALE E LA SALUTE UMANA NEL PRE E POST-RACCOLTA DEI PRODOTTI VEGETALI

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Summary

Fresh fruits and vegetables play a very essential role in human nutrition and health, especially as sources of vitamins, minerals, and dietary fiber. Other constituents that may lower risk of cancer, cardiovascular disease, and other diseases include carotenoids, flavonoids and other polyphenols, phenolic acids, and other phytonutrients. Nutritional value varies greatly among commodities and cultivars of each commodity. Using plant breeding and biotechnology approaches it is possible to develop genotypes that have enhanced nutritional quality and improved flavor quality to encourage consumers to eat more fruits and vegetables (at least five servings per day). This can have a major positive impact on human health and should be given high priority in research and extension programs worldwide. Climatic conditions, especially temperature and light intensity, have a strong effect on the nutritional quality of fruits and vegetables. Soil type, the rootstock used for fruit trees, mulching, irrigation, fertilization, and other cultural practices influence the water and nutrient supply to the plant, which can affect the composition and quality attributes (appearance, texture, taste and aroma) of the harvested plant parts. Maturity at harvest and harvesting method influence the commodity's quality and extent of physical injuries. Delays between harvest and consumption or processing can result in losses of flavor and nutritional quality. The magnitude of these losses increases with exposure to temperatures, relative humidities, and/or concentrations of oxygen, carbon dioxide, and ethylene outside the ranges that are optimum for each com-

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modity during the entire postharvest handling system. Furthermore, processing and cooking methods can greatly affect the nutritional value of fruits and vegetables.

Riassunto

Frutta e verdura fresca svolgono un ruolo essenziale nella nutrizione e nella salute umana, specialmente in quanto fonti di vitamine, minerali, e fibre. Altri costituenti che possono abbassare il rischio di cancro, malattie cardiovascolari, e altre malattie comprendono carotenoidi, flavonoidi e altri polifenoli, acidi fenolici, e altri fitonutrienti. Il valore nutrizionale varia fortemente tra prodotti e varietà di ciascun prodotto. Usando la coltivazione vivaistica e le biotecnologie è possibile sviluppare genotipi che hanno qualità nutrizionali esaltate e miglior qualità di sapore per incoraggiare il consumo di più frutta e verdura (almeno cinque porzioni al giorno). Questo può avere un impatto altamente positivo sulla salute dei programmi a livello mondiale. Le condizioni climatiche, in particolare la temperatura e l'intensità della luce, hanno un forte effetto sulla qualità nutritiva di frutta e verdura. Il tipo di terreno, il portainnesto usato per gli alberi da frutta, la pacciamatura, l'irrigazione, la fertilizzazione, e altre pratiche culturali influenzano la fornitura di acqua e di agenti nutritivi alla pianta, che può influenzare la composizione e la qualità (aspetto, consistenza, gusto e aroma) delle parti raccolte. La maturazione al momento della raccolta e il metodo di raccolta influenzano la qualità del prodotto e l'estensione dei danni fisici. I ritardi tra la raccolta e il consumo o la lavorazione possono portare a perdita di sapore e qualità nutrizionali. La dimensione di queste perdite aumenta con l'esposizione a temperature, umidità relative, e/o concentrazioni di ossigeno, anidride carbonica, ed etilene al di fuori degli intervalli ottimali per ciascun prodotto nel corso dell'intero sistema di lavorazione post-raccolta. Inoltre, la lavorazione e il modo di cucinare possono influire fortemente sul valore nutrizionale di frutta e verdura.

1. Quality attributes of fresh fruits and vegetables

Quality is the composite of product characteristics that impart value to the buyer or consumer [26]. Consumers consider good quality fruits and vegetables to be those that look good, are firm, and offer good flavor and nutritive value. Although consumers buy on the basis of appearance and textural (based on feel) quality, their satisfaction and repeat purchases are dependent upon good eating (flavor) quality. In contrast, producers and handlers are concerned first with appearance and textural quality along with long postharvest-life. The challenge is to encourage the producers and handlers to pay more attention to flavor and nutritional quality and to encourage consumers to be willing to pay a little more for varieties and picking maturities that are superior in flavor because they often have lower yield and require

more careful handling. It is also important to determine postharvest-life and "best if used by date" on the basis of flavor and nutritional quality rather than appearance and textural quality only of intact and fresh-cut fruits and vegetables.

Many pre-and postharvest factors influence the composition and quality of fruits and vegetables [7, 8, 14, 25, 26]. These include genetic factors (selection of cultivars, rootstocks used for fruit species), preharvest environmental factors (climatic conditions and cultural practices), maturity at harvest, harvesting method, postharvest handling procedures, and processing and cooking methods. In this review, I will discuss briefly the effects of each of these factors on quality attributes of fresh fruits and vegetables.

2. Importance of fruits and vegetables in human nutrition and health

Fresh fruits and vegetables play a significant role in human nutrition, especially as sources of vitamins (C, A, B_6, thiamine, niacin), minerals, and dietary fiber [21, 22, 32]. Their contribution as a group is estimated at 91% of vitamin C, 48% of vitamin A, 27% of vitamin B_6, 17% of thiamine, and 15% of niacin in the U.S. diet. Fruits and vegetables also supply 16% of magnesium, 19% of iron, and 9% of the calories. Legume vegetables, potatoes, and tree nuts (such as almond, filbert, pecan, pistachio, and walnut) contribute about 5% of the per capita availability of proteins in the U.S. diet, and their proteins are of high quality as to their content of essential amino acids. Nuts are a good source of essential fatty acids, fiber, vitamin E, and minerals. Other important nutrients supplied by fruits and vegetables include folacin, riboflavin, zinc, calcium, potassium, and phosphorus. For more information on food composition and nutritional value access the following Internet website: http://www.nal.usda.gov/fnic/foodcomp.

Fruits, nuts, and vegetables in the daily diet have been strongly associated with reduced risk for some forms of cancer, heart disease, stroke, and other chronic diseases [19, 20, 21, 22, 28, 30, 32]. Some components of fruits and vegetables are strong antioxidants and function to modify the metabolic activation and detoxification/disposition of carcinogens, or even influence processes that alter the course of the tumor cell [32]. Although antioxidant capacity varies greatly among fruits and vegetables [19] it is better to consume a variety of commodities rather than limiting consumption to a few with the highest antioxidant capacity. The USDA 2000 Dietary Guidelines [31] encourage consumers to: (1) enjoy five a day, i.e., eat at least 2 servings of fruits and at least 3 servings of vegetables each day, (2) choose fresh, frozen, dried, or canned forms of a variety of colors and kinds, and (3) choose dark-green leafy vegetables, orange fruits and vegetables, and cooked dry beans and peas often. In some countries, consumers are encouraged to eat up to 10 servings of

Table 1. Constituents of fruits and vegetables that have a positive impact on human health and their sources [20, 31].

Constituent	Sources	Impacted human diseases
Antioxidants		cancer cataracts stroke
Vitamin C	broccoli, cabbage, cantaloupe, citrus fruits, kiwifruit, leafy greens, pepper, potato, strawberry, tomato	
Vitamin A	dark-green vegetables (such as collards, spinach, and turnip greens), orange vegetables (such as carrots, pumpkin, and sweet potato), orange-flesh fruits (such as apricot, cantaloupe, mango, and peach), tomato	
Vitamin E	nuts (such as almonds, filberts, pecans, and pistachios) red, blue, and purple fruits (such as blueberry, pomegranate, plum & prune, and strawberry)	
Fiber	most fresh fruits and vegetables, nuts, cooked dry beans and peas	diabetes heart disease
Folate	dark-green leafy vegetables (such as spinach, mustard greens, and romaine lettuce), legumes (cooked dry beans and peas, green peas), oranges	birth defects cancer heart disease
Potassium	baked potato or sweet potato, banana & plantain, cooked dry beans, cooked greens, dried fruits (such as apricots and prunes), winter (orange) squash	hypertension stroke

fruits and vegetables per day.

There is increasing evidence that consumption of whole foods is better than isolated food components (such as dietary supplements and nutracenticals). For example, increased consumption of carotenoid-rich fruits and vegetables was more effec-

tive than carotenoid supplements in increasing LDL oxidation resistance, lowering DNA damage, and inducing higher repair activity in human volunteers who participated in a study conducted in France, Italy, Netherlands, and Spain [28]. Similar comparative studies are needed on other constituents of fruits and vegetables and on the bioavailability of nutrients taken as dietary supplements or as foods that contain these nutrients.

Examples of the components of fruits and vegetables that have positive effects on human health and their important sources are shown in Table 1. Some changes in this table are likely as the results of additional studies on effects of phytonutrients and their bioavailability on human health become available in the next few years. Meanwhile it is important to evaluate the validity and dependability of the results of every study before reaching conclusions for the benefit of consumers.

3. Genotypic variation in composition and quality

Within each commodity there is a range of genotypic variation in composition, quality, and postharvest-life potential. Plant breeders have been successful in selecting carrot and tomato cultivars with much higher carotenoids and vitamin A content, sweet corn cultivars that maintain their sweetness longer after harvest, cantaloupe cultivars with higher sugar content and firmer flesh, and pineapple cultivars with higher contents of assorbic acid, carotenoids, and sugars. These are just a few examples of what has been accomplished in improving quality of fruits and vegetables by genetic manipulations. [3, 7, 21, 22]. However, in some cases, commercial cultivars, selected for their ability to withstand the rigors of marketing and distribution, tend to lack sufficient quality, particularly flavor [26].

Horticultural plant breeders have an unprecedented opportunity to address human nutritional needs by developing fruit and vegetable cultivars rich in nutrients [3]. A multidisciplinary research team is best suited to plan and carry out an improvement program, using classical breeding and molecular-based methods for varietal development [3]. Emphasis should be placed on nutritional quality for maximum impact on human nutrition and wellness. There are many opportunities in using biotechnology to maintain postharvest quality and safety of fresh produce. However, the priority goals should be: (1) to attain and maintain good flavor and nutritional quality to meet consumer demands and (2) to introduce resistance to physiological disorders and/or decay-causing pathogens to reduce use of chemicals.

A cost/benefit analysis (including consumer acceptance issues) should be used to determine priorities for genetic improvement programs. In some cases, increasing the consumption of commodities and/or cultivars that are already high in nutritive

value may be more effective and less expensive than breeding for higher contents of nutrients.

4. Preharvest factors influencing quality

The effects of preharvest factors on postharvest quality of fruits and vegetables have been reviewed by several authors [1, 5, 6, 7, 8, 12, 14, 15, 16, 18, 24, 25, 33]. A diverse range of biotic and abiotic factors can alter the appearance of fruits and vegetables prior to harvest. Even under optimum conditions, a portion of every crop is invariably downgraded due to appearance defects [12]. If poor management decisions are made during crop production, the texture of the product which reaches consumers may by undesirable [24]. Many preharvest factors impact flavor by influencing plant growth and development, but the influence may be insignificant if produce is harvested too early or the cultivar is not genetically capable of developing desirable flavor [15]. Preharvest factors which may predispose fruits for subsequent disorder development are dominated by position of the fruit on the tree, characteristics of the fruiting site, crop load, mineral and carbohydrate nutrition of the developing fruit, water relations, and response to temperatures [6].

4.1 Climatic conditions

Climatic factors, especially temperature and light intensity, have a strong influence on the nutritional quality of fruits and vegetables. Consequently, the location and season in which plants are grown can determine their ascorbic acid, carotene, riboflavin, thiamine, and flavonoids content [8]. In general, the lower the light intensity the lower the ascorbic acid content of plant tissues. Temperature influences uptake and metabolism of mineral nutrients by plants because transpiration increases with higher temperatures. Rainfall affects the water supply to the plant, which may influence composition of the harvested plant part and its susceptibility to mechanical damage during subsequent harvesting and handling operations.

4.2 Cultural practices

Soil type, the rootstock used for fruit trees, mulching, irrigation, and fertilization influence the water and nutrient supply to the plant, which can affect the nutritional quality of the harvested plant part [8]. The effect of fertilizers on the vitamin content of plants is less important than the effects of genotype and climatic conditions, but their influence on mineral content is more significant. For example, sulfur and selenium uptake influence the concentrations of organosulfur compounds in *Allium* and *Brassica* species [7]. High calcium content in fruits has been related to longer postharvest life as a result of reduced rates of respiration and ethyl-

ene production, delayed ripening, increased firmness, and reduced incidence of physiological disorders [6] 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. Increasing the nitrogen and/or phosphorus supply to citrus trees results in somewhat lower acidity and ascorbic acid content in citrus fruits, while increased potassium fertilization increases their acidity and ascorbic acid content [1, 14].

There are numerous physiological disorders associated with mineral deficiencies. For example, bitter pit of apples; blossom-end rot of tomatoes, peppers, and watermelons; cork spot in apples and pears; and red blotch of lemons are associated with calcium deficiency in these fruits. Boron deficiency results in corking of apples, apricots, and pears; lumpy rind of citrus fruits, and cracking of apricots. Poor color of stone fruits may be related to iron and/or zinc deficiencies. Excess sodium and/or chloride (due to salinity) results in reduced fruit size and higher soluble solids content.

Severe water stress results in increased sunburn of fruits, irregular ripening of pears, tough and leathery texture in peaches, and incomplete kernel development in nuts. Moderate water stress reduces fruit size and increases contents of soluble solids, acidity, and ascorbic acid. On the other hand, excess water supply to the plants results in cracking of fruits (such as cherries, prunes, and tomatoes), excessive turgidity leading to increased susceptibility to physical damage, reduced firmness, delayed maturity, and reduced soluble solids content.

Cultural practices such as pruning and thinning determine the crop load and fruit size, which can influence nutritional composition of fruit. The use of pesticides and growth regulators does not directly influence fruit composition but may indirectly affect it due to delayed or accelerated fruit maturity.

5. Maturity at harvest and harvesting method

Maturity at harvest has a major impact on quality and postharvest-life potential of fruits and vegetables [8, 9, 11]. All fruits, with a few exceptions like avocados, bananas and pears, reach their best eating quality stage when fully ripened on the tree. However, since such ripe fruits cannot survive the postharvest handling system, they are usually picked mature but not ripe. It is better to pick fruits partially-ripe than mature but not ripe to provide the consumer with better flavor and nutritional quality fruits.

Harvesting method can determine the extent of variability in maturity and physical injuries and consequently influence composition and quality of fruits and vegetables. Mechanical injuries (bruising, surface abrasions, cuts, etc.) can accelerate loss of water and vitamin C and increase susceptibility to decay-causing pathogens. The incidence and severity of such injuries are influenced by the method of harvest

(hand vs mechanical) and management of the harvesting and handling operations.

6. Postharvest factors influencing quality

The effects of postharvest handling procedures and conditions on quality and postharvest-life of fruits and vegetables have been discussed in books [9, 29] and review articles [2, 8, 10, 14, 17, 23, 27]. This section provides a brief overview of how postharvest factors influence produce quality and its maintenance.

6.1. Temperature and relative humidity

Keeping fruits and vegetables within their optimum ranges of temperature and relative humidity is the most important factor in maintaining their quality and minimizing postharvest losses. Above the freezing point, (for non-chilling-sensitive commodities) and the minimum safe temperature (for chilling-sensitive commodities), every 10∞C increase in temperature accelerates deterioration and the rate of loss in nutritional quality by 2- to 3-fold. Delays between harvesting and cooling or processing can result in direct losses (due to water loss and decay) and indirect losses (losses in flavor and nutritional quality). The extent of these losses depends upon the commodity's condition at harvest and its temperature, which can be several degrees higher that ambient temperatures, especially when exposed to direct sunlight.

The distribution chain rarely has the facilities to store each commodity under ideal conditions and requires handlers to make compromises as the choice of temperature and relative humidity. These choices can lead to physiological stress and loss of shelf-life and quality [17]. The weakest link in the postharvest handling chain of fresh fruits and vegetables is the home handling system; greatest potential for improvement includes development of more sophisticated home-handling equipment and transfer of handling knowledge to the consumer [27].

6.2. Supplemental treatments applied to the commodity

These include curing of "root" vegetables, cleaning, sorting to eliminate defects, sorting by maturity/ripeness stage, sizing, waxing, treatment with fungicides for decay control, heat treatments for decay and/or insect control, fumigation for insect control, irradiation for preventing sprouting or insect disinfestation, and exposure of fruits to ethylene for faster and more uniform ripening. In most cases, these treatments are useful in maintaining quality and extending postharvest-life of the produce. Irradiation at doses below 1 kilogray has no significant effects on nutritional quality of fruits and vegetables [8, 14]. Ethylene treatment shortens the time between harvest and consumption which can result in maintaining a higher con-

centration of ascorbic acid in tomatoes [8].

6.3. Supplemental treatments involving manipulation of the environment

Responses to atmospheric modification vary greatly among plant species, organ type and developmental stage, and duration and temperature of exposure [2, 10]. Maintaining the optimum ranges of oxygen, carbon dioxide, and ethylene concentrations around the commodity extends its postharvest-life by about 50 to 100% relative to air control. In general, low O_2 atmospheres reduce losses of ascorbic acid in fresh produce. Elevated CO_2 atmospheres up to 10% also reduce ascorbic acid losses, but higher CO_2 concentrations can accelerate these losses [8, 14]. Exposure to ethylene can be detrimental to the quality of most vegetables [23].

6.4. Processing and cooking methods

Vitamin C of produce is subject to degradation during processing and cooking. Electromagnetic energy seems to have advantages over conventional heating by reduction of process times, energy, and water usage. Blanching reduces the vitamin C content during processing, but limits further decreases during the frozen-storage of horticultural products [14]. During processing, the antioxidant compounds may undergo physical and chemical changes that alter their potential benefits. Generally, thermal processing results in a decrease in ascorbate and tocopherols and an increase in available carotenes. Once processed, frozen or canned fruits and vegetables retain their ascorbate, carotene, and tocopherol levels for prolonged periods [13].

7. Conclusions

Selection of the genotype with the highest flavor and nutritional quality for a given commodity is much more important factor than climatic conditions and cultural practices in producing the best quality for consumers of that commodity. Producers should use an integrated crop management system to optimize yield and quality of each commodity. Buyers and consumers should be willing to pay more for higher flavor and nutritional quality products because often the producer sacrifices some yield to produce better quality fruits and vegetable. Postharvest opportunities for enhancing the quantity and quality of essential nutrients present in fruits and vegetables include: (1) increasing overall consumption of fruits and vegetables, (2) improving bioavailability of nutrients, (3) increasing levels of essential nutrients through fortification methods, and (4) reducing nutrient losses [4]. All these strategies require effective interdisciplinary cooperation in research, establishing policy, and education consumers and all those involved in produce production and marketing.

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