22

Quality and Safety Factors: Definition and Evaluation for Fresh Horticultural Crops

Adel A. Kader

Quality is defined as any of the features that make something what it is, or the degree of excellence or superiority. The word *quality* is used in various ways in reference to fresh fruits and vegetables such as market quality, edible quality, dessert quality, shipping quality, table quality, nutritional quality, internal quality, and appearance quality.

The quality of fresh horticultural commodities is a combination of characteristics, attributes, and properties that give the commodity value for food (fruits and vegetables) and enjoyment (ornamentals). Producers are concerned that their commodities have good appearance and few visual defects, but for them a useful cultivar must score high on yield, disease resistance, ease of harvest, and shipping quality. To receivers and market distributors, appearance quality is most important; they are also keenly interested in firmness and long storage life. 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 feel, their satisfaction and repeat purchases are dependent upon good edible quality. Assurance of safety of the products sold is extremely important to the consumers. If the product is not safe it does not matter what its quality is; it should be eliminated from the produce distribution system.

COMPONENTS OF QUALITY

The various components of quality listed in table 22.1 are used to evaluate commodities in relation to specifications for grades and standards, selection in breeding programs, and evaluation of responses to various environmental factors and postharvest treatments. The relative importance of each quality factor depends upon the commodity and its intended use (fresh or processed). Appearance factors are the most important quality attributes of ornamental crops.

Many defects influence the appearance quality of horticultural crops. Morphological defects include sprouting of potatoes, onions, and garlic; rooting of onions; elongation of asparagus; curvature of asparagus and cut flowers; seed germination inside fruits such as lemons, tomatoes and peppers; presence of seed stems in cabbage and lettuce; doubles in cherries; floret opening in broccoli; and so on. Physical defects include shriveling and wilting; internal drying of some fruits; mechanical damage such as punctures, cuts and deep scratches, splitting and crushing, skin abrasions and scuffing, deformation (compression), and bruising; growth cracks (radial, concentric); and so on. Physiological defects include temperature-related disorders (freezing, chilling, sunburn, sunscald); puffiness of tomatoes; blossom-end rot of tomatoes; tipburn of lettuce; internal breakdown (chilling injury) of stone fruits; water core of apples; and black heart of potatoes. Pathological defects include decay caused by fungi or bacteria and virus-related blemishes, irregular ripening, and other disorders. Other defects result from damage caused by insects, birds, and hail; chemical injuries; and scars, scabs, and various blemishes (e.g., russeting, rind staining).

The texture of horticultural crops is important for eating and cooking quality and is a factor in withstanding shipping stresses. Soft fruits cannot be shipped long distances without extensive losses due to physical injuries. In many cases, this necessitates harvesting fruits at less than ideal maturity for flavor quality.

Table 22.1. Quality components of fresh fruits and vegetables

Main factors	Components
Appearance (visual)	Size: dimensions, weight, volume
	Shape and form: diameter/depth, ratio, compactness, uniformity
	Color: uniformity, intensity
	Gloss: nature of surface wax
	Defects: external, internal
	Morphological
	Physical and mechanical
	Physiological
	Pathological
	Entomological
Texture (feel)	Firmness, hardness, softness
	Crispness
	Succulence, juiciness
	Mealiness, grittiness
	Toughness, fibrousness
Flavor (taste and smell)	Sweetness
	Sourness (acidity)
	Astringency
	Bitterness
	Aroma (volatile compounds)
	Off-flavors and off-odors
Nutritional value	Carbohydrates (including dietary fiber)
	Proteins
	Lipids
	Vitamins
	Minerals
Safety	Naturally occurring toxicants
	Contaminants (chemical residues, heavy metals)
	Mycotoxins
	Microbial contamination

Evaluating flavor quality involves the perception of tastes and aromas of many compounds. Objective analytical determination of critical components must be coupled with subjective evaluations by a taste panel to yield meaningful information about flavor quality. This approach can be used to establish a minimum acceptable level. To learn consumer flavor preferences for a given commodity, large-scale testing by a representative sample of consumers is required.

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. 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 26% of magnesium, 19% of iron, and 9% of the calories consumed. Legume vegetables, potatoes, and tree nuts contribute about 5% of the per capita availability of proteins in the United States, and their proteins have a good content of essential amino acids. Other important nutrients supplied by fruits and vegetables include folacin, riboflavin, zinc, calcium, potassium, and phosphorus. Other constituents that may lower risk of cancer, heart disease, and other diseases include carotenoids, flavonoids, isoflavones, phytosterols, and other phytochemicals (phytonutrients). Postharvest losses in nutritional quality, particularly vitamin C content, can be substantial and increase with physical damage, extended storage, high temperatures, low RH, and chilling injury.

Safety factors include levels of naturally occurring toxicants in certain crops (such as glycoalkaloids in potatoes), which vary according to genotype and are routinely monitored by plant breeders so they do not exceed safe levels. Contaminants such as chemical residues and heavy metals are also monitored by various agencies to assure compliance with established maximum tolerance levels. Sanitation throughout harvesting and postharvest handling operations is essential to minimize microbial contamination; procedures that reduce the potential for growth and development of mycotoxin-producing fungi must be used. For more details about safety factors, see chapter 24.

INTERRELATIONSHIPS AMONG THE COMPONENTS OF QUALITY

It is important to define the interrelationships among each commodity's quality components and to correlate subjective and objective methods of quality evaluation. This information is essential for selecting new cultivars, choosing optimal production practices, defining optimal harvest maturity, and identifying optimal postharvest handling procedures. The point of all this effort is to provide high-quality fruits and vegetables to the consumer.

In most commodities, the rate of deterioration in nutritional quality (especially vitamin C content) is faster than that in flavor quality, which in turn is lost faster than textural quality and appearance quality. Thus, the postharvest life of a commodity based on appearance (visual) quality is often longer than its postharvest life based on maintenance of good flavor.

Quality criteria used in the U.S. standards for grades and the California Agricultural Code (tables 23.1 to 23.5 in chapter 23) emphasize appearance quality factors in most commodities. In many cases, good appearance does not necessarily mean good flavor and nutritional quality. A fruit or vegetable that is misshapen or has external blemishes may be just as tasty and nutritious as one of perfect appearance. For this reason, it is important to include quality criteria other than appearance that more accurately reflect consumer preferences. Such quality indices must be relatively easy to evaluate, and objective methods for evaluation should be developed.

FACTORS INFLUENCING QUALITY

Many pre- and postharvest factors influence the composition and quality of fresh horticultural crops. These include genetic factors (selection of cultivars and rootstocks), preharvest environmental factors (climatic conditions and cultural practices), maturity at harvest, harvesting method, and postharvest handling procedures.

Climatic conditions

Climatic factors, especially temperature and light intensity, have a strong influence on the nutritional quality of fruits and vegetables. The location and season in which plants are grown can determine their ascorbic acid, carotene, riboflavin, and thiamine content. Light is one of the most important climatic factors in determining ascorbic acid content of plant tissues. Researchers consistently find much higher ascorbic acid content in strawberries grown under high light intensity than in the same varieties grown under lower light intensity. In general, the lower the light intensity, the lower the ascorbic acid of plant tissues.

Although light does not play a direct role in the uptake and metabolism of mineral elements by plants, temperature influences the nutrient supply because transpiration increases with higher temperatures. Rainfall affects the water supply to the plant, which may influence composition of the harvested plant part.

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 composition of the harvested plant part. The effect of fertilizers on the vitamin content of plants is much less important than variety and climate, but their effect on mineral content is more significant. 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 supply increases their acidity and ascorbic acid content.

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

Maturity at harvest

This is one of the main factors determining compositional quality and storage life of fruits and vegetables. All fruits, with few exceptions, reach peak eating quality when fully ripened on the tree. However, since they cannot survive the postharvest handling system, they are usually picked mature but not ripe. Tomatoes harvested green and ripened at 20°C (68°F) to table ripeness contain less ascorbic acid than those harvested at the table-ripe stage.

Harvesting method

The method of harvest can determine the variability in maturity and physical injuries and can consequently influence the nutritional composition of fruits and vegetables. Mechanical injuries such as bruising, surface abrasions, and cuts can accelerate loss of vitamin C. The incidence and severity of such injuries are influenced by the method of harvest, management of harvesting, and handling operations. Proper management to minimize physical damage to the commodity is required whether harvesting is done by hand or by machine.

Postharvest handling procedures

Delays between harvesting and cooling or processing can result in direct losses (due to water loss and decay) and indirect losses (lowering of flavor and nutritional quality). The extent of such losses is related to the condition of the commodity when picked and is strongly influenced by the temperature of the commodity, which can be several degrees higher than ambient temperatures, especially when exposed to sunlight. Temperatures higher than those that are optimum for the commodity increase the loss rate of vitamin content, especially vitamin C. In general, vegetables have more loss of ascorbic acid content in response to elevated temperatures than do fruits that are more acidic (pH 4.0 or lower), such as citrus.

Chilling injury causes accelerated losses in ascorbic acid content of sweet potatoes, pineapples, and bananas, but it does not influence ascorbic acid content of tomatoes and guavas.

METHODS FOR EVALUATING QUALITY

Quality evaluation methods can be destructive or nondestructive. They include objective scales based on instrument readings and subjective methods based on human judgment using hedonic scales.

APPEARANCE QUALITY (VISUAL)

1. Size

Dimensions: Measured with sizing rings, calipers.

Weight: Correlation is generally good between size and weight; size can also be expressed as numbers of units of commodity per unit of weight.

Volume: Determined by water displacement or by calculation from measured dimensions.

2. Shape

Ratio of dimensions: For example, diameter/depth ratio; used as index of shape in fruits.

Diagrams and models of shape: Some commodity models are used as visual aids for quality inspectors.

3. Color

Uniformity and intensity: Important appearance qualities.

Visual matching: Using color charts, guides, and dictionaries to match and describe colors of fruits and vegetables.

Light reflectance meter: Measures color on the basis of the amount of light reflected from surface of the commodity; examples include Minolta Colorimeter, Gardner and Hunter Color Difference Meters (tristimulus colorimeters), and Agtron E5W spectrophotometer.

Light transmission meter: Measures the light transmitted through the commodity; may be used to determine internal color and various disorders, such as water core of apples and black heart of potatoes.

Measurement of delayed light emission: Related to the amount of chlorophyll in the plant tissues; can be used to determine color-based maturity stages.

Determination of pigment content: Evaluates the color of horticultural crops by pigment content, i.e., chlorophylls, carotenoids (carotene, lycopene, xanthophylls), and flavonoids (anthocyanins).

4. Gloss (bloom, finish)

Wax platelets: Amount, structure, and arrangement on the fruit surface affect the gloss quality; measured using a Gloss-meter or by visual evaluation.

5. Presence of defects (external and internal)

Incidence and severity of defects are evaluated using a five-grade scoring system (1 = no symptoms, 2 = slight, 3 = moderate, 4 = severe, 5 = extreme) or a seven- or nine-point hedonic scale if more categories are needed. To reduce variability among evaluators, detailed descriptions and photographs may be used as guides in scoring a given defect. Objective evaluation of external defects using computer-aided vision techniques appears promising.

Internal defects can be evaluated by nondestructive techniques, such as light transmission and absorption characteristics of the commodity, sonic and vibration techniques associated with the mass density and elasticity of the material, X-ray transmission (which depends on mass density and mass absorption coefficient of the material), and nuclear magnetic resonance (NMR) imaging (also known as magnetic resonance imaging, or MRI), which detects the concentration of hydrogen nuclei and is sensitive to variations in the concentration of free water and oil.

TEXTURAL QUALITY

1. Yielding quality (firmness, softness)

Hand-held testers: Determine penetration force using testers such as the Magness-Taylor Pressure Tester and the Effegi penetrometer. The plunger (tip) size used depends on the fruit and varies from 3 mm (1/8 in) for cherry, grape, and strawberry; 8 mm (5/16 in) for stone fruits (other than cherries), kiwifruit, and pear; to 11 mm (7/16 in) for apple.

Stand-mounted testers: Determine penetration force using testers with a more consistent speed of punch such as the UC Fruit Firmness Tester and the Effegi penetrometer mounted on a drill stand.

Laboratory testing: Fruit firmness can be determined by measuring penetration force using an Instron Universal Testing machine or a Texture Testing system, or by measuring fruit deformation using a Deformation Tester.

It is inappropriate to use the term "pressure" in association with firmness measurements using the devices described above. While pounds-force (lbf) or kg-force (kgf) are preferred in the industry, Newton (N) is the required unit for scientific writing. The conversion factors are as follows:

pound-force (lbf) × 4.448 = Newton (N)

kilogram-force (kgf) × 9.807 = Newton (N)

2. **Fibrousness and toughness**

Shear force: Determined using an Instron or a Texture Testing system.

Resistance to cutting: Determined by using a Fibrometer.

Chemical analysis: Fiber content or lignin content.

3. **Succulence and juiciness**

Measurement of water content: An indicator of succulence or turgidity.

Measurement of extractable juice: An indicator of juiciness.

4. **Sensory textural qualities**

Sensory evaluation procedures: Evaluate grittiness, crispness, mealiness, chewiness, and oiliness.

FLAVOR QUALITY

1. **Sweetness**

Sugar content: Determined by chemical analysis procedures for total and reducing sugars or for individual sugars; indicator papers for quick measurement of glucose in certain commodities, such as potatoes.

Total soluble solids content: Measured using refractometers or hydrometers; can be used as indicator of sweetness because sugars are major component of soluble solids. Other constituents that contribute to total soluble solids include soluble pectins, organic acids, amino acids, and ascorbic acid.

2. **Sourness (acidity)**

pH (hydrogen ion concentration) of extracted juice: Determined using a pH meter or pH indicator paper.

Total titratable acidity: Determined by titrating a specific volume of the extracted juice with 0.1 *N* NaOH to pH 8.1, then calculating titratable acidity as citric, malic, or tartaric acid (depending on which organic acid predominates in the commodity).

3. **Saltiness**

Fresh vegetables and fruits: Usually not applicable.

4. **Astringency**

Determined by taste testing or by measuring tannin content, solubility, and degree of polymerization.

5. **Bitterness**

Determined by taste testing or measurement of the alkaloids or glucosides responsible for the bitter taste.

6. **Aroma (odor)**

Determined by sensory panels in combination with identification of volatile components responsible for specific aroma of a commodity (using gas chromatography–mass spectrometry).

7. **Sensory evaluation**

Human subjects: Judge and measure combined sensory characteristics (sweetness, sourness, astringency, bitterness, overall flavor intensity) of a commodity.

Laboratory panels: Detect and describe differences among samples; determine which volatile compounds are organoleptically important in a commodity.

Consumer panels: Indicate quality preferences.

NUTRITIONAL VALUE

Various analytical methods are available to determine total carbohydrates, dietary fiber, proteins and individual amino acids, lipids and individual fatty acids, vitamins, and minerals in fruits and vegetables. Several public and private laboratories have automated equipment for food analysis for use in situations where nutritional labeling is required and large numbers of samples have to be analyzed routinely.

SAFETY FACTORS

Analytical procedures, using thin-layer chromatography, gas chromatography, and high-pressure liquid chromatography, are available for determining minute quantities of the following toxic substances:

- naturally occurring toxicants, such as cyanogenic glucosides in lima beans and cassava, nitrates and nitrites in leafy vegetables, oxalates in rhubarb and spinach, thioglucosides in cruciferous vegetables, and glycoalkaloids (solanine) in potatoes
- natural contaminants, such as fungal toxins (mycotoxins), bacterial toxins and heavy metals (mercury, cadmium, lead)
- synthetic toxicants, such as environmental contaminants and pollutants, and residues of agricultural chemicals

QUALITY CONTROL AND ASSURANCE

An effective quality control and assurance system throughout the handling steps between harvest and retail display is required to provide a consistently good-quality supply of fresh horticultural crops to the consumers and to protect the reputation of a given marketing label. Quality control starts in the field with the selection of the proper time to harvest for maximum quality. Minimum acceptable flavor of fruits can be assured by determining their soluble solids content and titratable acidity (table 22.2). Careful harvesting is essential to minimize physical injuries and maintain quality. Each subsequent step after harvest has the potential to either maintain or reduce quality. Few postharvest procedures can improve the quality of individual units of the commodity.

Many attempts are currently being made to automate the separation of a given commodity into various grades and the elimination of defective units. The availability of low-cost microcomputers and solid-state imaging systems has made computer-aided video inspection on the packing line a practical reality. Solid-state video camera or light reflectance systems are used for detection of external defects, and X-ray or light transmittance systems are used for detecting internal defects. Further development of these and other systems to provide greater reliability and efficiency will be very helpful in quality control efforts.

Table 22.2. Proposed minimum soluble solids content (SSC) and maximum titratable acidity (TA) for acceptable flavor quality of fruits

Fruit	Minimum SSC%	Maximum TA%
Apple	10.5–12.5 (depending on cultivar)	
Apricot	10	0.8
Blueberry	10	—
Cherry	14–16 (depending on cultivar)	
Grape	14–17.5 (depending on cultivar) or SSC:TA ratio of 20+	
Grapefruit	SSC:TA ratio of 6+	
Kiwifruit	14	—
Mandarin	SSC:TA ratio of 8+	
Mango	12–14 (depending on cultivar)	
Muskmelon	10	—
Nectarine	10	0.6
Orange	SSC:TA ratio of 8+	
Papaya	11.5	—
Peach	10	0.6
Pear	13	—
Persimmon	18	—
Pineapple	12	1.0
Plum	12	0.8
Pomegranate	17	1.4
Raspberry	8	0.8
Strawberry	7	0.8
Watermelon	10	—

FUTURE RESEARCH AND EXTENSION NEEDS

- Identify the important components of quality and the interrelationships among these quality factors for the various horticultural commodities and products for which such information is not available.
- Develop objective and nondestructive methods of determining quality attributes, especially those related to flavor and nutritional quality of fresh fruits and vegetables.
- Work with agencies responsible for standardization and inspection of fresh horticultural commodities to develop methods to improve the enforcement of current minimum maturity and quality standards to ensure better quality for the consumer. Also, consideration should be given to revising some of the existing quality and maturity standards with more emphasis on the eating quality of fruits and vegetables.
- Conduct consumer acceptance research aimed at relating maturity indices at harvest to the final organoleptic acceptability by the consumer.
- Continue efforts aimed at development of new genotypes with better flavor and nutritional quality in all the major fruits and vegetables and genotypes with improved appearance quality and vase life of cut flowers.

- Study the effects of preharvest factors (climatic conditions, cultural practices, etc.) on quality attributes of fresh fruits, vegetables, and flowers.
- Evaluate the effects of currently used and alternative postharvest handling practices on flavor and nutritional quality (including phytonutrients contents) and safety attributes of fresh fruits and vegetables.
- Develop alternatives to currently used chemicals as part of integrated pest management strategies for control of postharvest diseases and insects of fresh horticultural crops.
- Expand the current Extension programs to reach more of the handlers, receivers, marketers, and consumers and provide them with information about proper procedures for maintaining quality and safety of fresh produce.
- Identify strategies to improve the efficiency of the distribution system for fresh fruits, ornamentals, and vegetables at the local, national, and international levels.

REFERENCES

Abbott, J. A. 1999. Quality measurement of fruits and vegetables. Postharv. Biol. Technol. 15:207–225.

Abbott, J. A., R. Lu, B. L. Upchurch, and R. Stroshine. 1997. Technologies for nondestructive quality evaluation of fruits and vegetables. Hort. Rev. 20:1–120.

Amerine, M. A., R. M. Pangborn, and E. B. Roessler. 1965. Principles of sensory evaluation of food. New York: Academic Press. 602 pp.

Arthey, V. D. 1975. Quality of horticultural products. New York: Halstead Press; Wiley. 228 pp.

Bourne, M. C. 1980. Texture evaluation of horticultural crops. HortScience. 15:51–57.

Chen, P., and Z. Sun. 1991. A review of non-destructive methods for internal quality evaluation and sorting of agricultural products. J. Agr. Eng. Res. 49:85–98.

Dull, G. G., G. S. Birth, and J. B. Magee. 1980. Nondestructive evaluation of internal quality. HortScience. 15:60–63.

Eskin, N. A. M., ed. 1989. Quality and preservation of vegetables. Boca Raton, FL: CRC Press. 313 pp.

———. 1991. Quality and preservation of fruits. Boca Raton, FL: CRC Press. 212 pp.

Francis, F. J. 1980. Color quality evaluation of horticultural crops. HortScience. 15:58–59.

Goddard, M. S., and R. H. Matthews. 1979. Contribution of fruits and vegetables to human nutrition. HortScience. 14:245–247.

Gould, W. A. 1977. Food quality assurance. Westport, CT: AVI. 314 pp.

Gunasekaran, S. 1990. Delayed light emission as a means of quality evaluation of fruits and vegetables. Crit. Rev. Food Sci. Nutr. 29:19–34.

Heintz, C. M., and A. A. Kader. 1983. Procedures for the sensory evaluation of horticultural crops. HortScience. 18:18–22.

Jen, J. J., ed. 1989. Quality factors of fruits and vegetables—Chemistry and technology. Washington, D.C.: Am. Chem Soc. Ser. 405. 410 pp.

Kader, A. A. 1983. Postharvest quality maintenance of fruits and vegetables in developing countries. In M. Lieberman, ed., *Postharvest physiology and crop preservation*. New York: Plenum. pp. 455–470.

Lee, S. K., and A. A. Kader. 200. Preharvest and postharvest factors influencing vitamin C content of horticultural crops. Postharv. Biol. Technol. 20:207–220.

Lipton, W. J. 1980. Interpretation of quality evaluations of horticultural crops. HortScience. 15:64–66.

O'Mahony, M. 1986. Sensory evaluation of food. Statistical methods and procedures. New York: Marcel Dekker. 487 pp.

Pattee, H. E., ed. 1985. Evaluation of quality of fruits and vegetables. Westport, CT: AVI. 410 pp.

Paull, R. E. 1999. Effect of temperature and relative humidity on fresh commodity quality. Postharv. Biol. Technol. 15:263–277.

Shewfelt, R. L. 1999. What is quality? Postharv. Biol. Technol. 15:197–200.

Shewfelt, R. L., and S. E. Prussian, eds. 1993. Postharvest handling: A systems approach. San Diego, CA: Academic Press. 358 pp.

Stevens, M. A., and M. Albright. 1980. An approach to sensory evaluation of horticultural commodities. HortScience. 15:48–50.

Tomas-Barberan, F. A., and R. J. Robins, eds. 1997. Phytochemistry of fruits and vegetables. Oxford, UK: Oxford Science. 375 pp.

U.S. Department of Agriculture (USDA). 2000. Composition of foods: Raw, processed, prepared. Available via Internet at http://www.nal.usda.gov/fnic/foodcomp

Watada, A. E. 1989. Non-destructive methods of evaluating quality of fresh fruits and vegetables. Acta Hort. 258:321–329.

Williams, A. A. 1979. The evaluation of flavour quality in fruits and fruit products. In D. G. Land and H. E. Nursten, eds., Progress in flavour research. Essex, UK: Applied Science. pp. 287–305.