

EFFECTS OF POSTHARVEST HANDLING PROCEDURES ON TOMATO QUALITY

A. A. Kader
Department of Pomology
University of California
Davis, CA 95616
U.S.A.

Summary

Tomato quality components include appearance (color, size, shape, freedom from defects and decay), firmness, flavor, and nutritional value. Color, firmness, flavor, nutritive value, and safety of tomatoes are related to their composition at harvest and compositional changes during postharvest handling. There are large genotypic variations in tomato quality attributes and it is possible to develop new cultivars which have good eating quality and maintain their firmness when fully ripe so that they can withstand the postharvest handling procedures.

Postharvest losses in quality and quantity are related to immaturity at harvest, inadequate initial quality control, incidence and severity of physical damage, exposure to improper temperatures, and delays between harvest and consumption. Shortening the time between harvest and consumption can minimize loss of the characteristic tomato aroma and development of off-flavors. Tomatoes subjected to bruising usually have less "tomato-like" flavor and more off-flavors than those without physical damage. Exposure to chilling temperatures adversely affects tomato flavor before other symptoms of chilling become apparent. Temperature also influences color uniformity and softening rate of tomatoes.

Reduced oxygen atmospheres can delay ripening of tomatoes kept within the optimum temperature range (12 to 20°C). Ethylene treatment results in faster and more uniform ripening of green tomatoes by reducing their "green-life". Since ethylene treatment reduces the time between harvest and consumption, it may have positive effects on flavor quality and vitamin C content relative to tomatoes picked green and ripened without ethylene application.

Although significant improvements in tomato quality and its maintenance between harvest and consumption can be made using existing information, additional research is needed to continue to provide solutions to tomato quality problems. Some examples of such research are discussed in this paper.

1. Quality components

The various components of tomato quality listed below are used in relation to specifications for grades and standards, selections in breeding programs, and evaluation of fruit responses to various environmental factors and postharvest handling procedures.

Although appearance quality has been emphasized in the past, increasing attention is being given to other quality attributes in response to consumer demands. Consumers buy tomatoes on the basis of appearance and firmness, but their satisfaction and repeat purchases depend upon good flavor quality.

1.1. Appearance factors

Color, size, shape, defects, and decay are influenced by both genetic and environmental factors, such as temperature, light, nutrients and water supply, and the presence of diseases and insects. Color and the severity of defects and decay are also affected by postharvest handling conditions.

1.1.1. Color

External color of tomatoes is the result of both flesh and skin colors. A pink tomato has a colorless skin and red flesh while a red tomato has a yellow skin and red flesh. Fruits of some tomato genotypes have pink, purple, orange, dark yellow, light yellow, yellow with pink end, and other colors. However, most consumers prefer the deep, uniform red-colored tomatoes. Color is an indicator of tomato ripeness stage. Several subjective rating scales and color charts have been developed for classifying ripeness stages of tomatoes, such as the six classes of tomato ripeness included in the U.S. Standards (USDA, 1976). Objective methods of tomato color evaluation include light reflectance measurement (Kader and Morris, 1978b) and light transmittance techniques (Worthington, 1974; Chen and Studer, 1977). Determination of pigment content (e.g., chlorophyll, lycopene, beta-carotene) can also be used to indicate tomato color changes. Such determinations can be done nondestructively by light absorbance techniques (Watada et al., 1976b).

1.1.2. Size

Preference for a given size of tomatoes varies among consumers and depends, to some extent, on the intended use of the fruits. The range of fruit sizes varies among cultivars. Within each cultivar when tomatoes are picked green, the smaller fruits will likely be more immature. Thus, ripening and ethylene production rates are highly correlated with fruit size within a given cultivar. But if fruits are harvested at the breaker stage or more advanced stages of ripeness, no effect of size is noticeable on the ripening rate or composition and flavor at the table-ripe stage.

1.1.3. Shape

Tomato cultivars differ greatly in fruit shape and may be spherical, oblate, elongated, pear-like, etc. In addition to these descriptive terms for shapes, the ratio of polar diameter to equatorial diameter and the ratio of maximum and minimum equatorial diameters can be used as indices of shape. Fruit shape has no direct effect on flavor or textural quality of tomatoes. It may

have an indirect effect because of the internal fruit structure (pericarp/locular material ratio) associated with a given shape. An angular shape is undesirable because it reflects immaturity or puffiness. Shape defects are usually related to poor pollination and irregular development of some locules. Such misshapen or rough, ridged fruits are considered defective and usually are discarded at shipping point.

1.1.4. Defects

Appearance quality of tomatoes is greatly influenced by the presence and magnitude of defects. Minor blemishes that would not detract from eating quality are acceptable, but more serious defects can influence appearance, firmness, shriveling, and susceptibility to decay. Defects originating before harvest include puffiness, catfacing (blossomed-end scab) and other scabs, gold fleck/pox syndrome (Ilker et al., 1977), radial and concentric growth cracks, insect and bird damage, sunscald, excessive softening, and irregular ripening (Ryall and Lipton, 1979). Physical damage can occur during harvest and postharvest handling steps. It includes surface injuries such as scuffing, abrasions, cuts and punctures, and internal bruising due to impact, vibration, or compression (Kasmire and Kader, 1978). Physical damage is not only unsightly, but also increases rates of respiration, ethylene production, moisture loss, and decay, and can result in less desirable flavor (MacLeod et al., 1976a, b).

Numerous disorders can occur on tomatoes before or after harvest (McColloch et al., 1968; Hobson et al., 1977; Ryall and Lipton, 1979). The incidence and severity of preharvest disorders influence the percent of discarded fruit at the packinghouse, which is usually between 15 and 30% depending on cultivar, production area, season, and cultural practices. Postharvest losses result from various physiological, physical, or pathological disorders which occur before, during, or after harvest. The magnitude of these losses varies greatly with production area, handling and distribution system, and duration between harvest and consumption. In a survey of tomato losses at the retail and consumer levels in the New York area, Ceponis and Butterfield (1979) found that losses ranged from 11.4 to 14.2%. The major causes of losses were diseases; principally alternaria, rhizopus, and gray mold rots and bacterial soft rot; followed by physical injuries and physiological disorders.

1.1.5. Decay

The presence of decay is a very serious defect which renders tomatoes unmarketable. Most pathological disorders found during postharvest handling of tomatoes originate in the field before harvest. Incidence and severity of decay are increased by physical damage and chilling injury which make the fruits more susceptible to decay. The important postharvest diseases of tomatoes include alternaria rot, gray mold rot, phytophthora rot, rhizopus rot, and bacterial soft rot (McColloch et al., 1968).

1.2. Firmness

Next to visual appearance, the most important factor in tomato quality is firmness which is closely associated with ripeness stage. Most consumers prefer firm fruits which do not lose too much juice when sliced and which do not have tough skins. Firmness affects susceptibility of tomatoes to physical damage and consequently their shipping ability. The textural quality of tomatoes is influenced by skin toughness, flesh firmness, and internal fruit structure (pericarp/locular material ratio) which vary greatly among cultivars.

Sensory evaluation of textural quality involves both finger feel and mouth feel. Slicing characteristics are related to firmness. Objective evaluation methods for tomato firmness can be destructive or nondestructive. Destructive methods measure tissue resistance to force of penetration (fruit firmness testers, penetrometers), shearing (shear press), cutting, compression, or their combinations. The Instron Universal Testing Machine can be used to measure any of these parameters. Instruments for nondestructive determination of fruit firmness measure resistance to compression (deformation) force applied at a single point or at multipoints on the fruit (Stenvers et al., 1973; Kader et al., 1978c).

1.3. Flavor

Tomato flavor involves perception of the tastes and aromas of many chemical constituents. Sugars, acids and their interactions are important to sweetness, sourness, and overall flavor intensity in tomatoes (DeBruyn et al., 1971; Stevens et al., 1977b). Fructose and citric acid are more important to sweetness and sourness than glucose and malic acid, respectively. High sugars and relatively high acids are required for best flavor. High acids and low sugars will produce a tart tomato while high sugars and low acids will result in a bland taste. When both sugars and acids are low, the result is a tasteless, insipid tomato.

Tomato fruit pericarp portion contains more reducing sugars and less organic acids than the locular portion. Thus, cultivars with large locular portion and with high concentrations of acids and sugars have better flavor than those with small locular portion (Stevens et al., 1977a).

Differences in amino acid concentrations associated with fruit ripeness when picked do not appear to be directly related to flavor differences (Kader et al., 1978e). The possible contribution of other constituents, such as minerals, ascorbic acid, and alkaloids, has not been investigated.

Volatile compounds are important to not only the aroma but also the overall flavor of tomatoes. No single volatile compound or a small number of volatiles appear to be responsible for the characteristic aroma of fresh tomatoes (Buttery et al., 1971).

Dirinck et al. (1976) found panel evaluations of aroma quality to be related to the concentrations of n-hexanal, trans-2-hexenal, cis-3-hexen-1-ol, 2-isobutylthiazole, and some unidentified C₁₂-C₁₆ volatile compounds. Of more than 200 peaks on the gas chromatograph (GC), Hayase et al. (1984) identified 130 compounds. Hexanal, trans-2-hexenal, 2-isobutylthiazole, 2-methyl-2-hepten-6-one, geranylacetone, and farnesylacetone were identified by the GC-sniff method as those volatiles that are important contributors to fresh tomato aroma. Concentration of these compounds increased with ripening.

The "off-flavor" character found in tomatoes of certain cultivars when picked green and ripened off the plant appears to be related to higher concentration of some volatiles, especially 2-methyl-1-butanal which has a flavor threshold concentration of 0.1 to 1 ppm.

There is a relationship between tomato fruit color and its volatile composition, especially those volatile compounds which are formed by oxidation of carotenoids. High beta-carotene cultivars (e.g., 'Caro Red') and high delta-carotene cultivars (e.g., 'Gold Jubilee') have a distinctly different volatile composition and flavor than red cultivars.

1.4. Nutritional value

Tomatoes are important sources of vitamins A and C more because of the large amount consumed than their average content of these two vitamins. A 100-g tomato can supply about 20% and 40% of the U.S. recommended daily allowances of vitamins A and C, respectively, for adults. It is possible to select tomato genotypes that are rich in vitamins A and C. Cultivars with very high vitamin A content have been developed, but their orange color limits consumer acceptance.

1.5. Safety

Safety factors include naturally occurring toxicants and contamination with chemical residues, heavy metals, and microorganisms of public health significance. Tomatine is a steroidal glycoalkaloid which is found in all tomato genotypes (Davies and Hobson, 1981). Young developing tomato fruits accumulate tomatine, but as ripening begins, alkaloid degradation occurs and tomatine concentration declines to less than 0.04%, fresh weight basis. The LD₅₀ value for tomatine is estimated to be 0.5 g per kg body weight. Thus, tomatine does not pose a safety hazard in ripe tomatoes.

2. Factors influencing quality

Many preharvest, harvest, and postharvest factors influence the composition and quality of tomatoes. These include inherent (genetic) and environmental factors such as climatic conditions (temperature, light, pollutants) and cultural practices (soil type,

nutrient and water supply, use of agricultural chemicals, harvesting method). Maturity stage at harvest and postharvest handling procedures also affect tomato quality and its maintenance.

2.1. Preharvest factors

Stevens et al. (1979) found that differences among genotypes in sugars and acids are responsible for most of the differences in sweetness, sourness, and overall flavor intensity. They concluded that improved tomato flavor can be achieved via increased sugar and acid content.

While hybrid tomatoes heterozygous for the rin and nor non-ripening genes produce fruits with greatly extended shelf-life, they may have limitations in terms of flavor quality. In a comparison of rin and nor hybrids with their parents and standard cultivars, Strand et al. (1983) found the hybrids can have acceptable quality. Taste-life is extended by the nor gene, but not nearly as much as shelf-life, while the two rin hybrids tested did not have an extended taste-life. The effects of both rin and nor on firmness, flavor, shelf-life, and taste-life are dependent on the genetic background into which they are incorporated.

Genotypic variation in fruit firmness at harvest and softening pattern is an important factor in determining shipping ability and postharvest-life of tomatoes. Cultivars that maintain good firmness beyond the table-ripe stage will permit picking the fruits at more advanced ripeness stages which have better flavor.

Climatic conditions (temperature and light intensity) influence the sugar, ascorbic acid, and pigment content of the fruit. Reduced soil moisture and salt stress increase sugar content in tomatoes while high nitrogen decreases it. Fruit color and firmness are also affected by environmental conditions (Davies and Hobson, 1981).

2.2. Harvesting factors

Harvesting method (hand versus mechanical) can influence the incidence and severity of physical injuries and the percentage of immature fruits. These factors, in turn, can adversely affect tomato quality.

Maturity at harvest is very important to composition and quality of tomatoes. This is especially a problem with tomatoes picked green since it is difficult to differentiate between mature- and immature-green fruits. Typical and advanced mature-green tomatoes will usually attain a much better flavor at the table-ripe stage than those picked at the immature or partially mature stages. The latter are also much more susceptible to physical injuries and water loss because of their thin cuticle.

Ripeness stage at harvest affects fruit composition and quality. Tomatoes accumulate acids, sugars, and ascorbic acid

during ripening on the vine (Sakiyama and Stevens, 1976; Betancourt et al., 1977). Field-ripened tomatoes have better flavor and overall quality than room-ripened tomatoes (Bisogni et al., 1976). Tomatoes picked at less than table-ripe and ripened at 20°C were evaluated by panelists as being less sweet, more sour, less "tomato-like" and having more "off-flavor" than those picked at the table-ripe stage. The magnitude of these differences varied greatly among cultivars (Kader et al., 1977). Watada and Aulenbach (1979) found that the intensities of sensory attributes were similar in table-ripe tomatoes harvested at the mature-green and breaker stages. Intensities of sweetness, saltiness, and "fruity-floral" flavor were higher in tomatoes harvested at the table-ripe stage than at earlier stages.

2.3. Postharvest factors

Postharvest losses in quality are related to immaturity at harvest, inadequate initial quality control, incidence and severity of physical damage, exposure to improper temperatures, and delays between harvest and consumption. Shortening the time from harvest to consumption can minimize loss of the characteristic aroma and development of off-flavors. Tomatoes subjected to bruising usually have more off-flavor and less "tomato-like" flavor than those without physical damage (Kader et al., 1978d).

A summary of the effects of temperature on deterioration and ripening is shown in Figure 1.

Exposure to chilling temperatures adversely affects tomato flavor (increased acidity, loss of characteristic aroma) before other symptoms of chilling become apparent. Temperature also influences softening and color uniformity of tomatoes. Adequate air exchange in storage and ripening rooms is important in reducing off-flavors.

The lowest temperature at which ripening, with good color and flavor development, occurs is 12.5°C. Above 30°C, lycopene formation (red color) is inhibited and the tomatoes turn yellow. Between 12.5°C and 25°C, the higher the temperature the faster the ripening (Table 1). The optimum ripening temperature in terms of quality maintenance is 20°C.

Ethylene treatment to accelerate ripening of green tomatoes at 20°C results in higher ascorbic acid content at the table-ripe stage when compared with fruits ripened without added ethylene (Watada et al., 1976a; Kader et al., 1978d).

The effects of modified atmospheres on postharvest behavior of tomato fruits picked at the mature-green or partially ripe stage are summarized in Table 2. Using a low-O₂ atmosphere to retard tomato ripening has less of an effect on flavor than ripeness stage at harvest. If O₂ concentration is reduced to 2% or lower increased off-flavors and uneven color development will result. Controlled atmospheres reduce the loss of chlorophyll and the

synthesis of lycopene, carotenoids and xanthophylls (Goodenough and Thomas, 1980). Carbon monoxide at 5 to 10% in combination with 4% O₂ reduces postharvest decay incidence and severity without influencing flavor of tomatoes (Kader et al., 1978a). Mature-green tomatoes can be stored at 12.8°C for up to 7 weeks under 4% O₂, 2% CO₂, and 5% CO and still retain an adequate marketing life at acceptable quality for 1 to 2 weeks at 20°C. However, the flavor of these tomatoes is likely to be inferior to that of mature-green tomatoes ripened soon after harvest.

3. Future research needs

The potential for solving some of the problems related to tomato quality and its postharvest maintenance through genetic manipulations is excellent and should be given a high priority in future research. Plant breeders in collaboration with postharvest physiologists should continue to select genotypes that have good flavor (high sugars and acids contents and good potential for development of volatiles associated with desirable tomato flavor). Also, fruit firmness and softening pattern in relation to ripeness stage should be evaluated. Genotypes in which fruits maintain their firmness when fully ripe would permit harvesting tomatoes at the breaker to pink stages and marketing them successfully. Research is also needed to identify those organoleptically important volatiles and their mode of genetic control so that plant breeders can develop strategies for retaining the desirable volatiles and minimizing the undesirable ones from breeding lines. Work on improving the nutritional quality of tomatoes via increased ascorbic acid and beta-carotene (provitamin A) contents should be an integral part of tomato improvement programs.

Research on hybrids containing non-ripening genes such as nor and rin should continue. These hybrids could permit picking tomatoes when ripe and shipping them long distances without significant losses. In such studies and other research involving extension of postharvest-life, a distinction must be made between shelf-life based on appearance quality and shelf-life based on taste quality. All recommended handling procedures should be based on maintenance of flavor quality.

Additional efforts are needed to develop a dependable and practical method of eliminating immature fruits from those picked before the breaker stage. One possibility is to test the commercial feasibility of using ethylene treatment to initiate ripening of green tomatoes and discard any fruits that do not reach the breaker or riper stage after 5 days at 20°C. This would eliminate immature fruits which have poor flavor when ripe.

Further work on use of modified atmospheres should be directed towards investigating their possible use to permit postharvest handling of tomatoes picked partially ripe instead of green to assure better flavor quality to the consumer. Much effort is also needed to develop the technology of modified atmospheres application within consumer packages, pallets, and transport vehicles.

Bibliography

- Betancourt, L. A., Stevens, M. A., and Kader A. A., 1977. Accumulation and loss of sugars and reduced ascorbic acid in attached and detached tomato fruits. *J. Amer. Soc. Hort. Sci.* 102:721-723.
- Bisogni, C. A., Armbruster, G., and Brecht, P. E., 1976. Quality comparisons of room ripened and field ripened tomato fruits. *J. Food Sci.* 41:333-338.
- Buttery, R. G., Seifert, R. M., Guadagni, D. G., and Ling, D. G., 1971. Characterization of additional volatile components of tomato. *J. Agr. Food Chem.* 19:524-529.
- Ceponis, M. J., and Butterfield, J. E., 1979. Losses in fresh tomatoes at the retail and consumer levels in the greater New York area. *J. Amer. Soc. Hort. Sci.* 104:751-754.
- Chen, P., and Studer, H. E., 1977. Physical properties related to maturity and puffiness of fresh market tomatoes. *Trans. ASAE* 20:575-578.
- Davies, J. N., and Hobson, G. E., 1981. The constituents of tomato fruit--The influence of environment, nutrition, and genotype. *CRC Crit. Rev. Food Sci. Nutr.* 15(3):205-280.
- DeBruyn, J. W., Garretsen, F., and Kooistra, E., 1971. Variation in taste and chemical composition of the tomato (*Lycopersicon esculentum* Mill.). *Euphytica* 20:214-227.
- Dirinck, P., Schreyen, L., van Wassenhove, F., and Schamp, N., 1976. Flavour quality of tomatoes. *J. Sci. Food Agr.* 27:499-508.
- Goodenough, P. W., and Thomas, T. H., 1980. Comparative physiology of field-grown tomatoes during ripening on the plant or retarded ripening in controlled atmospheres. *Ann. Appl. Biol.* 94:445-455.
- Hayase, F., Chung, T-Y., and Kato, H., 1984. Changes of volatile components of tomato fruits during ripening. *Food Chem.* 14:113-124.
- Hobson, G. E., and Davies, J. N., 1971. The tomato. In: *The biochemistry of fruits and their products*, Vol. 2, A. C. Hulme (ed.). Academic Press, New York and London:437-482.
- Hobson, G. E., Davies, J. N., and Winsor, G. W., 1977. Ripening disorders of tomato fruit. *Growers' Bull. No. 4*, Glasshouse Crops Res. Inst., Littlehampton, UK, 24 pp.
- Ilker, R., Kader, A. A., and Morris, L. L., 1977. Anatomical changes associated with the development of gold fleck and fruit box symptoms on tomato fruit. *Phytopathology* 67:1227-1231.
- Kader, A. A., Chastagner, G. A., Morris, L. L., and Ogawa, J. M., 1978a. Effects of carbon monoxide on decay, physiological responses, ripening, and composition of tomato fruits. *J. Amer. Soc. Hort. Sci.* 103:665-670.
- Kader, A. A., and Morris, L. L., 1978b. Tomato fruit color measured with an Agtron E5-W reflectance spectrophotometer. *HortScience* 13:577-578.
- Kader, A. A., Morris, L. L., and Chen, P., 1978c. Evaluation of two objective methods and a subjective rating scale for measuring tomato fruit firmness. *J. Amer. Soc. Hort. Sci.* 103:70-73.

- Kader, A. A., Morris, L. L., Stevens, M. A., and Albright-Holton, M., 1978d. Composition and flavor quality of fresh market tomatoes as influenced by some postharvest handling procedures. *J. Amer. Soc. Hort. Sci.* 103:6-13.
- Kader, A. A., Stevens, M. A., Albright, M., and Morris, L. L., 1978e. Amino acid composition and flavor of fresh market tomatoes as influenced by fruit ripeness when harvested. *J. Amer. Soc. Hort. Sci.* 103:541-544.
- Kader, A. A., Stevens, M. A., Albright-Holton, M., Morris, L. L., and Algazi, M., 1977. Effect of fruit ripeness when picked on flavor and composition in fresh market tomatoes. *J. Amer. Soc. Hort. Sci.* 102:724-731.
- Kasmire, R. F., and Kader, A. A., 1978. Handling tomatoes at wholesale and retail: A guide for better quality and greater profits. *Outlook* 5(3):5-12.
- MacLeod, R. F., Kader, A. A., and Morris, L. L., 1976a. Stimulation of ethylene and CO₂ production of mature-green tomatoes by impact bruising. *HortScience* 11:604-606.
- MacLeod, R. F., Kader, A. A., and Morris, L. L., 1976b. Damage to fresh tomatoes can be reduced. *Calif. Agr.* 30(12):11-12.
- McColloch, L. P., Cook, H. T., and Wright, W. R., 1968. Market diseases of tomatoes, peppers, and eggplants. U.S. Dept. Agr., Agr. Handbook No. 28, 74 pp.
- Ryall, A. L., and Lipton, W. J., 1979. Handling, transportation, and storage of fruits and vegetables. Vol. 1, Second Edition, Vegetables and melons. AVI Publ. Co., Westport, CT.
- Sakiyama, R., and Stevens, M. A., 1976. Organic acid accumulation in attached and detached tomato fruits. *J. Amer. Soc. Hort. Sci.* 101:394-396.
- Stenvers, N., Rudolphij, J. W., and Bruinsma, J., 1973. Growth, ripening and storage of tomato fruits. I. The measurement of softening during the ripening of tomato fruits. *Gartenbauwissenschaft* 38:517-531.
- Stevens, M. A., Kader, A. A., and Albright, M., 1979. Potential for increasing tomato flavor via increased sugar and acid content. *J. Amer. Soc. Hort. Sci.* 104:40-42.
- Stevens, M. A., Kader, A. A., and Albright-Holton, M., 1977a. Intercultivar variation in composition of locular and pericarp portions of fresh market tomatoes. *J. Amer. Soc. Hort. Sci.* 102:689-692.
- Stevens, M. A., Kader, A. A., Albright-Holton, M., and Algazi, M., 1977b. Genotypic variation for flavor and composition in fresh market tomatoes. *J. Amer. Soc. Hort. Sci.* 102:680-689.
- Strand, L. L., Morris, L. L., and Heintz, C. M., 1983. Taste life of rin and nor hybrids. In: Proc. Fourth Tomato Quality Workshop, Veg. Crops Res. Rept. VEC-83-1. University of Florida, Gainesville:68-77.
- U.S.D.A., 1976. United States standards for grades of fresh tomatoes. U.S. Dept. Agr., Agr. Mktg. Serv., Washington, D.C., 10 pp.
- Watada, A. E., and Aulenbach, B. B., 1978. Chemical and sensory qualities of fresh market tomatoes. *J. Food Sci.* 44:1013-1016.

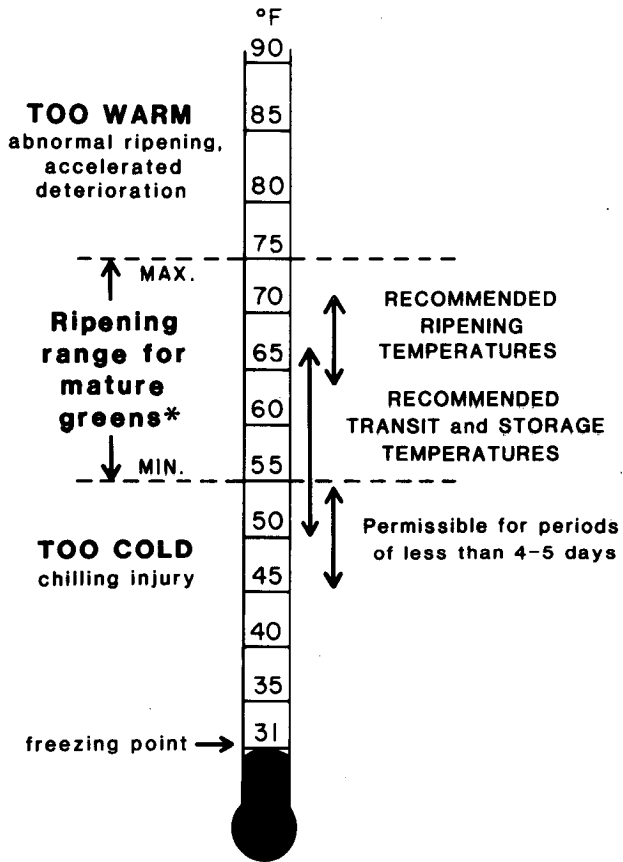
- Watada, A. E., Aulenbach, B. B., and Worthington, J. T., 1976a. Vitamins A and C in ripe tomatoes as affected by stage of ripeness at harvest and supplementary ethylene. *J. Food. Sci.* 41:856-858.
- Watada, A. E., Norris, K. H., Worthington, J. T., and Massie, D. R., 1976b. Estimation of chlorophyll and carotenoid contents of whole tomato by light absorbance technique. *J. Food Sci.* 41:329-332.
- Worthington, J. T., 1974. A light transmittance technique for determining tomato ripening rate and quality. *Acta Hort.* 38:193-215.

Table 1 - Effect of temperature on average ripening rate of mature-green, breaker, turning, and pink tomatoes.

Ripeness stage	Days to reach table-ripe at indicated temperatures (°C)					
	12.5	15	17.5	20	22.5	25
Mature-green	18	15	12	10	8	7
Breaker	16	13	10	8	6	5
Turning	13	10	8	6	4	3
Pink	10	8	6	4	3	2

Table 2 - Effects of modified atmospheres on tomato fruits picked at the mature-green (MG) or partially ripe (PR) stages and kept within the optimum temperature range (12-20°C for MG or 10-15°C for PR).

Parameter	Reduced O ₂	Elevated CO ₂
Beneficial level	3-5%	Less than 1%
Benefits	Retards ripening, respiration rate, C ₂ H ₄ production, C ₂ H ₄ response	None
Potential for benefit	Moderate	None
Injurious level	Below 2 to 3% depending on time	Above 2% (MG) or 5% (PR); depends on cultivar, temperature, and time
Injury symptoms	Brown discoloration, uneven ripening, off-flavors	Brown staining, uneven ripening, enhanced softening
Potential for injury	Moderate	Moderate to severe
Commercial use	Not in common use; potential is good for control of ripening during temporary storage and transport.	Avoid accumulation; use lime or other CO ₂ absorbers if CO ₂ is expected to exceed tolerance limits.



*The ripening range is somewhat wider (2° or 3°F)
on each side for partially-ripened fruit.

Figure 1. Effects of temperature on ripening and deterioration of tomato fruits.