Tomato

Steven A. Sargent and Celso L. Moretti
Sargent is with the Horticultural Sciences Department, University of Florida, Gainesville, FL; Moretti is with EMBRAPA, National Vegetable Crop Research Center, Brasilia, Brazil.

Scientific Name and Introduction

Tomato (*Solanum lycopersicum* L.) is a warm-season crop with origins in elevated regions of Peru and Ecuador. A member of the Solanaceae family, tomato is the second most produced vegetable in the United States, behind the potato. The round, red-fleshed tomato predominates in the fresh market, but red- and yellow-fleshed round, plum (roma), cluster, cherry, grape, and minipear types are also available. Domestic production is year round, though winter and spring imports from Mexico are increasing. Most tomatoes are grown in the field, but the use of protected culture is on the rise around the world. Dominant suppliers of greenhouse-grown tomatoes to U.S. markets are Holland, Spain, Israel, and Canada.

Quality Characteristics and Criteria

High-quality fruit have a firm, turgid appearance; uniform and shiny color; and no signs of mechanical injury, shriveling, or decay. Principal causes for postharvest losses are decay, external damage incurred during harvest and handling, and harvest at an improper maturity stage.

Horticultural Maturity Indices

Depending on the market and production area, tomatoes are harvested at stages of maturity ranging from physiological maturity (mature-green stage) through full-ripe. Immature tomatoes are available for certain regional dishes. It is difficult to accurately determine the completion of physiological maturity. Depending on the growing area and time of harvest, the percentage of immature tomatoes (M-1) in lots of green-harvested tomatoes can range from 20 to 80% (Sargent and VanSickle 1996). Tomatoes harvested at the mature-green stage (M-3 or M-4) will ripen to high quality if handled properly (Maul et al 1998). Tomatoes harvested at the M-2 stage will ripen to moderate quality, while those harvested at M-1 stage will not ripen to acceptable levels of quality.

Maturity Stage	**Internal Appearance (equatorial section)**
M-1	Seeds immature (white) and can be cut when the tomato is sliced; no gel in the locule.
M-2	Seeds mature (tan); gel formation in at least two locules.
M-3	Seeds pushed aside when tomato sliced; all locules have gel; internal color is still green.
M-4	Appearance of red color in gel and pericarp tissue.

Adapted from Kader and Morris (1976).

Ripeness stages are defined according to the following standards for red-fleshed tomatoes (AMS 1991):

Ripeness Stage	**External Color**

(1) Green	Fruit surface is completely green; the shade of green may vary from light to dark.
(2) Breaker	There is a definite break in color from green to tannish-yellow, pink, or red on not more than 10% of the surface.
(3) Turning	10 to 30% of the surface is not green; in the aggregate, shows a definite change from green to tannish-yellow, pink, red, or a combination thereof.
(4) Pink	30 to 60% of the surface is not green; in the aggregate, shows pink or red color.
(5) Light red	60 to 90% of the surface is not green; in the aggregate, shows pinkish-red or red.
(6) Red	More than 90% of the surface is not green; in the aggregate, shows red color.

Tomato Color Standards are based on the USDA Visual Aid TM-L-1, which consists of a chart containing twelve color photographs illustrating the color classification requirements.

Grades, Sizes, and Packaging

Grades for field-grown tomatoes include U.S. No. 1, U.S. , No. 2, U.S. Combination, and No. 3, with tolerances established for defects at shipping point and en route or at destination (AMS 1991). Fruit within a grade should have similar varietal characteristics and be uniformly mature, not overripe or soft, clean, well developed, fairly well formed, fairly smooth, and uniform in color. Fruit should be free from decay, freezing injury, sunscald, and damage caused by bruising, discoloration, sunken scars, cuts and broken skins, puffiness, catfaces, other scars, radial or concentric growth cracks, and hail or insect injury.

Tomatoes are rigorously sized with a 0.8 mm (1/32-in) overlap permitted between sizes, according to the following dimensions (AMS 1991):

Size	Minimum Diameter[1]	Maximum Diameter[2]
Small	5.40 cm (2 4/32 in)	5.79 cm (2 9/32 in)
Medium	5.72 cm (2 8/32 in)	6.43 cm (2 17/32 in)
Large	6.35 cm (2 16/32 in)	7.06 cm (2 25/32 in)
Extra Large	7.00 cm (2 24/32 in)	

[1] Will not pass through a round opening of the designated diameter when tomato is placed with the greatest transverse diameter across the opening.
[2] Will pass through a round opening of the designated diameter in any position.

Field-grown tomatoes are typically packed in lidded, 11.4-kg (25-lb) cartons, 30×40×24 cm (12×16×9.5 in) (W×L×H), that stack 10 cartons per layer on a 100×120 cm (40×48 in) pallet.

Grades for greenhouse tomatoes include U.S. No. 1 and No. 2 (AMS 2007). Ripeness stages and defects are similar to field-grown tomatoes. These fruit are sized as follows:

Size	Weight
Small	<99.4 g (<3.5 oz)
Medium	99.4 to 256 g (3.5 to 9 oz)
Large	>256 g (>9 oz)

Greenhouse-grown tomatoes are generally harvested at turning stage or later and packed according to ripeness and size (count) in single- or double-layer cartons, with or without bottom trays. Cluster tomatoes are usually picked when the least mature tomato begins to show red

color. Uniformity of fruit color, stem freshness, and fruit attachment to the stem are important quality characteristics for this tomato type. Cluster tomatoes are usually packed in single-layer cartons but sometimes in netted bags. Foam bottom pads may be inserted to reduce abrasion and bruising.

There are currently no U.S. grade standards for other types of tomatoes. They are all typically harvested once ripening has started and are sorted by defect and color. Roma-type tomatoes are normally packed in 11.4-kg (25-lb) cartons by color, while cherry, grape, and minipear tomatoes are packed in 227- to 454-g (8- to 16-oz) baskets or clamshell containers and placed in larger master cartons to facilitate palletizing.

Precooling Conditions

Following commercial packing, tomatoes are routinely palletized and cooled to 20 °C (68 °F) for ripening or to 12 °C (54 °F) for storage. While room-cooling is common, forced-air cooling is more uniform and produces better quality fruit. Packed, palletized tomatoes with pulp temperature of 28 °C (83 °F) actually increased 2 °C (4 °F) immediately after being stored at 20 °C (68 °F), and only cooled to 23 °C (73 °F) after 24 h using room-cooling (Brecht 1996). However, with forced-air cooling, tomatoes cooled to 20 °C (68 °F) in 2.5 h and ripened more uniformly throughout the pallet than those room-cooled.

Optimum Storage Conditions

Optimal storage temperatures depend on the maturity stage of the tomatoes. Ideal conditions for ripening are 19 to 21 °C (66 to 70 °F) with 90 to 95% RH. Storage at temperatures >27 °C (81 °F) reduces intensity of red color, while storage at <13 °C (55 °F) retards ripening and can lead to development of chilling injury, particularly in tomatoes at the mature-green stage. Red tomatoes can be stored at 7 °C (45 °F) for a couple of days, though tomatoes stored at 10 °C (50 °F) were rated lower in flavor and aroma than those held at 13 °C (55 °F) (Maul et al 2000).

Controlled Atmosphere (CA) Considerations

Tomatoes can be stored under CA to extend product quality (see below). The exact combination of CO_2 and O_2 varies among maturity stages and cultivars; but a satisfactory CA is 3% O_2 and 2% CO_2 (Wills et al. 1998). Storage under CA delays quality loss as measured by several factors, such as lycopene synthesis and sugar and chlorophyll degradation (Goodenough and Thomas 1980, Nakhasi et al. 1991). Storage in 3% O_2 and 97% N_2 extended postharvest life of mature-green tomatoes for 6 weeks at 13 °C (55 °F) without the development of off flavors (Parsons et al. 1970). Storage under CA may reduce development of undesirable symptoms caused by mechanical injury (Kader 1986). However, Moretti et al. (1999) observed that CA storage did not alleviate development of internal bruising (disruption of locular gel ripening) following impacts.

Ripeness Stage	Temperature	O_2(%)	CO_2(%)	Benefit
Mature green	12 to 20 °C	3 to 5	2 to 3	slight
Red	10 to 15 °C	3 to 5	3 to 5	moderate

From Saltveit (1997).

Retail Outlet Display Considerations

Tomatoes are normally displayed at the retail level in single-layer, corrugated cartons or in plastic clamshell containers at about 20 °C (68 °F). Grading, sizing, and packing fruit adds value and convenience to the final product. An important issue in the marketing of high-quality tomatoes is uniformity of size, grade, firmness, and color. Consumers tend to avoid packages of fruit with different colors, decay, or external blemishes. Some distributors also offer tomatoes in bulk containers, giving the consumer the option to choose among different maturities, sizes, and types of tomato. However, since tomato fruits are sensitive to compression stress, care must be taken to avoid overloading the display.

Chilling Sensitivity

Tomato fruit are chilling sensitive, and the recommended storage temperature varies with the maturity stage. Mature-green fruit will ripen normally at 13 to 21 °C (55 to 70 °F). On the other hand, ripe tomato fruits can be stored at 10 °C (50 °F) without visible symptoms of chilling injury, though flavor and aroma are negatively affected (Maul et al. 2000). Visual symptoms of chilling injury include pitting, nonuniform ripening, and storage decays (see *Postharvest Pathology*) (Wills et al. 1998).

Ethylene Production and Sensitivity

Tomato fruit produce moderate amounts of ethylene: 1 to 10 µL kg^{-1} h^{-1} at 20 °C (68 °F). Tomatoes are sensitive to ethylene exposure: As little as 0.5 µL L^{-1} ethylene is sufficient to trigger ripening and other associated metabolic processes (Abeles et al. 1992). For commercial ripening, green tomatoes should be held at 20 to 21 °C (50 to 52 °F) with 90% RH and 50 µL L^{-1} ethylene; this will promote uniform ripening. Upon reaching breaker stage, tomatoes produce sufficient ethylene and no longer require gassing. Highest quality tomatoes are those reaching the breaker stage within 3 days of ethylene exposure. These fruit were harvested at the mature green stage and will ripen with quality similar to tomatoes harvested at the breaker stage or later (Maul et al 1998).

Respiration Rates

Tomatoes are climacteric and show a pronounced increase in respiration during ripening. The intensity and duration of the climacteric varies among cultivars (Wills et al. 1998). Respiration also varies with temperature and atmospheric composition.

Temperature	Air*	3% O_2 /97% N_2 †
	---------mg CO_2 kg^{-1} h^{-1}--------	
10 °C	13 to 16	6
15 °C	16 to 28	-
20 °C	28 to 41	12
25 °C	35 to 51	-

*Data from Scholz et al. (1963). Storage at 10 °C (50 °F) is only recommended for red-ripe tomatoes.

†Data from Robinson et al. (1975).

To get mL CO_2 kg^{-1} h^{-1}, divide the mg kg^{-1} h^{-1} rate by 2.0 at 0 °C (32 °F), 1.9 at 10 °C (50 °F), and 1.8 at 20 °C (68 °F). To calculate heat production, multiply mg kg^{-1} h^{-1} by 220 to get BTU ton^{-1} day^{-1} or by 61 to get kcal $tonne^{-1}$ day^{-1}.

Physiological Disorders

Blotchy ripening is characterized by randomized development of green or green-yellowish areas on the surface of red tomato fruit. Apparently the development of this disorder is related to the availability of potassium and inorganic nitrogen in the soil. Areas showing blotchy ripening have less organic acids, SSC, and starch (Moretti et al. 2000).

Sunburn is associated with excessive exposure to sunlight and the resultant elevated tissue temperature during fruit development, disrupting lycopene synthesis and resulting in the appearance of yellow areas that remain during ripening.

Blossom-end rot involves a calcium deficiency caused by either poor uptake or poor translocation into the fruit. Symptoms begin in the green fruit as a small discoloration at the blossom end that increases in size and becomes dry and dark brown. Occurrence increases dramatically when calcium levels in the soil system drop below 0.08% (Moretti et al. 2000). Eventually, secondary decay organisms colonize weakened tissues.

Graywall is noticeable as necrotic vascular tissue in the pericarp fruit wall (Jones et al. 1999). It begins developing at the green stage and has been associated with marginal growing conditions such as cool weather, low light levels, poor nutrition, saturated soils, tobacco mosaic virus, and bacteria; however, the cause is still undetermined. Graywall can be a serious disorder in both field and greenhouse production systems.

Irregular ripening is characterized by the appearance of nonuniform ripening and white internal tissue. It has been associated with feeding of sweetpotato whitefly *(Bemisia argentifolii)* on tomato fruit (Hanif-Khan et al. 1997).

Internal bruising is recognized by the appearance of yellow to green locular gel in ripe tomatoes. It is caused by an impairment of normal ripening of the locular gel following a physical impact at the green or breaker stage of ripeness (MacLeod et al 1976). Fruit with internal bruising show significant reductions in vitamin C content, TA, consistency, and total carotenoids (Moretti et al. 1998). Besides altering quality attributes, internal bruising also affects flavor (Moretti et al. 2002). Breaker-stage tomatoes are more sensitive to internal bruising than those handled at the green stage (Sargent et al 1992).

Postharvest Pathology

Tomatoes are susceptible to numerous fruit decays from the field through postharvest handling. Postharvest decay often develops in wounds and bruised tissue and during fruit softening. Sound tomatoes can be inoculated by plant pathogens via cross-contamination from diseased fruits,

dirty harvest containers, and poorly sanitized water handling systems and packing line components. Populations of decay pathogens can be adequately controlled through a regular sanitation program in the field and during handling, packing, and ripening-storage operations.

Causes of bacterial decay include soft rot *(Bacillus* spp., *Erwinia carotovora* ssp., *Pseudomonas* spp., and *Xanthomonas campestris)* and lactic acid decay (bacterial sour rot) *(Lactobacillus* spp. and *Leuconostoc mesenteroides)* (Bartz et al 1995, Conn et al 1995).

Fungal decay sources include alternaria rot (black rot) *(Alternaria alternata),* fusarium rot (*Fusarium* spp.), gray mold rot *(Botrytis cinerea),* mucor rot *(Mucor mucedo),* phoma rot (*Phoma* ssp.), phomopsis rot (*Diaporthe* spp.), phytophthora rot (buckeye rot) (*Phytophthora* spp.), pleospora rot (*Pleospora herbarum, Stemphylium botryosum* imp. stage), rhizopus rot *(Rhizopus stolonifer, R. oryzae),* ring rot *(Myrothecium roridum),* sclerotium rot *(Sclerotium rolfsii),* sour rot *(Geotrichum candidum),* target spot *(Corynespora cassiicola),* and watery soft rot *(Sclerotinia minor, S. sclerotiorum).* Tomato spotted wilt virus induces a mottled coloration at red stage.
(Information adapted from Jones et al. [1991] and Snowdon [1992].)

Quarantine Issues

Tomato fruit are a host for fruit flies and are subject to inspection in quarantined areas. Methyl bromide has been employed on a wide range of fruits and vegetables; however, its use is being phased out. Tomatoes have a phytotoxic response, characterized by delayed ripening and reduced sensitivity to exposure to ethylene (Brecht 1994). Vapor heat and hot water treatments are effective alternatives to treatment with methyl bromide.

Suitability as Fresh-Cut Product

Despite efforts to commercialize fresh-cut tomatoes, such products are still only available in limited quantities to the food-service industry, particularly fast-food restaurants and catering services. After processing, loss of the gel-like locule tissue, desiccation, water-soaking, and the development of decay are the principal constraints challenging the worldwide fresh-cut industry. Crossing commercial varieties with mutants that express delayed softening and slicing less ripe tomatoes (in the breaker stage, for instance) for subsequent application of ethylene are strategies being researched in different parts of the world to obtain a fresh-cut tomato with sufficient postharvest life to be readily commercialized. Mature-green sliced tomatoes ripen normally at 20 °C (68 °F) (Mencarelli and Saltveit 1988). Sliced red tomatoes maintain good quality for 14 days when stored in MAP at 5 °C (Hong and Gross 2001).

Special Considerations

Ethylene used to ripen tomatoes can be catalytically generated from ethanol using commercially available units or supplied from compressed cylinders. Because air mixtures of 3 to 32% ethylene are explosive (Abeles et al. 1992), ethylene for ripening rooms is supplied from a compressed cylinder containing a <3% ethylene in N_2. A metered flow of ethylene from either a

catalytic unit or compressed cylinder is used to produce a diluted, active concentration of ethylene in the ripening room.

References

Abeles, F.B., P.W. Morgan, and M.E. Saltveit. 1992. Ethylene in Plant Biology, 2nd ed. Acad. Press, Waltham, MA.

AMS [USDA Agricultural Marketing Service]. 2007. United States standards for grades of tomatoes on the vine. *At* http://www.ams.usda.gov/AMSv1.0/getfile?dDocName=STELPRDC5065392

AMS [USDA Agricultural Marketing Service]. 1991. United States standards for grades of fresh tomatoes. *At* http://www.ams.usda.gov/standards/tomatfrh.pdf.

Bartz, J.A., N.C. Hodge, Y. Perez, and D. Concelmo. 1995. Two different bacteria cause a decay in tomatoes that is similar to sour rot. Phytopathology 85:1123.

Brecht, J.K. 1994. Vegetables. *In* R.E. Paull and J.W. Armstrong, eds., Insect Pests and Fresh Horticultural Products: Treatments and Responses, pp. 309-328. CAB International, Wallingford, U.K.

Brecht, J.K. 1996. Tomato response to ethylene at high temperatures: are pressure ripening systems worth considering? *In* C.S. Vavrina, ed., Proceedings of the Florida Tomato Institute, pp. 11-13. Pub. no. PRO 108, University of Florida, Institute of Food and Agricultural Science, Gainesville, FL.

Conn, K.E., J.M. Ogawa, B.T. Manji, and J.E. Adaskaveg. 1995. *Leuconostoc mesenteroides* subsp. *mesenteroides,* the first report of a coccoid bacterium causing a plant disease. Phytopathology 85:593-599.

Goodenough, P.W., and T.H. Thomas. 1980. Comparative physiology of field grown tomatoes during ripening on the plant or retard ripening in controlled atmospheres. Ann. Appl. Biol. 94:445-455.

Hanif-Khan, S., R.C. Bullock, P.J. Stoffella, et al. 1997. Possible involvement of altered gibberellin metabolism in the induction of tomato irregular ripening in dwarf cherry tomato by silverleaf whitefly. J. Plant Growth Reg. 16(4):245-251.

Hong, J.H., and K.C. Gross. 2001. Maintaining quality of fresh-cut tomato slices through modified atmosphere packaging and low temperature storage. J. Food Sci. 66(7):960-965.

Jones, J.B., J. Jones, R. Stall, and T. Zitter. 1991. Compendium of Tomato Diseases. APS, St. Paul, MN.

Kader, A.A. 1986. Biochemical and physiological basis for effects of controlled and modified

atmospheres on fruits and vegetables. Food Technol. 40(5):99-104.

Kader, A.A., and L.L. Morris. 1976. Correlating subjective and objective measurements of maturation and ripeness of tomatoes. *In* Proceedings of the 2nd Tomato Quality Workshop. Vegetable Crop Series no. 178, University of California, Davis, CA.

MacLeod, R.F., A.A. Kader, and L.L. Morris. 1976. Stimulation of ethylene and CO_2 production of mature-green tomatoes by impact bruising. HortScience 11(6):604-606.

Maul, F., S.A. Sargent, M.O. Balaban, et al. 1998. Aroma volatile profiles from ripe tomato fruit are influenced by physiological maturity at harvest: an application for electronic nose technology. J. Amer. Soc. Hort. Sci. 123(6):1094-1101.

Maul, F., S.A. Sargent, C.A. Sims, et al. 2000. Recommended commercial storage temperatures affect tomato flavor and aroma quality. J. Food Sci. 65(7):1228-1237.

Mencarelli, F., and M.E. Saltveit. 1988. Ripening of mature-green tomato fruit slices. J. Amer. Soc. Hort. Sci. 113(5):742-745.

Moretti, C.L., E.A. Baldwin, S.A. Sargent, and D.J. Huber. 2002. Internal bruising alters aroma volatile profiles in tomato fruit tissues. HortScience 37(2):378-382.

Moretti, C.L., A.G. Calbo, and G.P. Henz. 2000. Postharvest physiology and handling. *In* J.B.C. Silva and L.B. Giordano, eds., Processing Tomatoes, p.136-143. Embrapa/SCT, Brasilia, Brazil.

Moretti, C.L., S.A. Sargent, D.J. Huber, et al. 1998. Chemical composition and physical properties of pericarp, locule and placental tissues of tomatoes with internal bruising. J. Amer. Soc. Hort. Sci. 123(4):656-660.

Moretti, C.L., S.A. Sargent, D.J. Huber, et al. 1999. Delayed ripening does not alleviate symptoms of internal bruising in tomato fruit. Proc. Fla. State Hort. Soc. 112:169-171.

Nakhasi, S., D. Schlimme, and T. Solomos. 1991. Storage potential of tomatoes harvested at the breaker stage using modified atmosphere storage. J. Food Sci. 56(1):55-59.

Parsons, C.S., R.E. Anderson, and R.W. Penney. 1970. Storage of mature-green tomatoes in controlled atmospheres. J. Amer. Soc. Hort. Sci. 95:791-794.

Robinson, J.E., K.M. Browne, and W.G. Burton. 1975. Storage characteristics of some vegetables and soft fruits. Ann. Appl. Biol. 81:399-408.

Saltveit, M.E. 1997. A summary of CA and MA requirements and recommendations for harvested vegetables. *In* M.E. Saltveit, ed., 7th International Controlled Atmosphere Research Conference, July 13-18, 1997, University of California, Davis, vol. 4, pp. 98-117. University of California, Davis, CA.

Sargent, S.A., J.K. Brecht, and J.J. Zoellner. 1992. Sensitivity of tomatoes at mature-green and

breaker ripeness stages to internal bruising. J. Amer. Soc. Hort. Sci. 117(1):119-123.

Sargent, S.A., and J.J. VanSickle. 1996. Premium-quality tomato program for Florida. *In* C.S. Vavrina, ed., Proceedings of the Florida Tomato Institute, pp. 8-9. Pub. no. PRO 108, University of Florida, Institute of Food & Agricultural Science, Gainesville, FL.

Scholz, E.W, H.B. Johnson, and W.R. Buford. 1963. Heat-evolution rates of some [Lower Rio Grande Valley] Texas-grown fruits and vegetables. J. Rio Grande Valley Hort. Soc. 17:170-175.

Snowdon, A.L. 1992. Color Atlas of Postharvest Diseases and Disorders of Fruits and Vegetables, vol. 2, Vegetables. CRC Press, Boca Raton FL.

Wills, R.B.H., B. McGlasson, D. Graham, and D. Joyce. 1998. Postharvest: An Introduction to the Physiology and Handling of Fruits, Vegetables and Ornamentals. University of New South Wales Press, Sydney, Australia.

Acknowledgments

The authors wish to thank Dr. Jerry A. Bartz, Plant Pathology Department, University of Florida, Gainesville, for assistance with the Postharvest Pathology section.

The editors of this Handbook will appreciate your input for future editions of this publication. Please send your suggestions and comments to HB66.Comments@ars.usda.gov.