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Mature Fruit Vegetables

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I. INTRODUCTION

Many vegetables are classified botanically as fruit, that is, as the product of a ripening ovary and its associated tissue. Fruit vegetables are consumed when they are immature or mature. This distinction is useful because each division has similar postharvest behavior and storage requirements (Table 1). Examples of immature fruit vegetables include cucumbers (*Cucumis sativus* L.), summer squash (*Cucurbita pepo* L.), and sweetcorn (*Zea mays* L. var. *rugosa* Bonaf.), while examples of mature fruit vegetables are chili peppers (*Capsicum annum* L. var. *annum* Longum Group), melons (*Cucumis melo* L.), pumpkins (*Cucurbita pepo* L. and *C. maxima* Duchesne ex Lam.), tomatoes (*Lycopersicon esculentum* Mill.), watermelons [*Citrullus lanatus* (Thunb.) Matsum. & Nak.], and winter squash (*Cucurbita maxima* L.). These mature fruit vegetables are derived from a taxonomically diverse number of families, but the major mature fruit vegetables are dominated by species from the Cucurbitaceae (melons, pumpkins, and winter squash), and Solanaceae (peppers and tomatoes). (See Table 2.) Mature fruit vegetables can be berries (peppers, tomatoes) and pepos (cucurbits) (Rubatzky and Yamaguchi, 1997). Melons comprise a diverse group of fruits, with the two major groups being those that have a netted surface (Reticulatus group: cantaloupe, muskmelon) and those that are smooth (Inodorus group: honeydew, winter melons).

Most fruit vegetables are warm-season crops that are subject to chilling injury (CI). (See Chap. 19.) Exceptions include sweetcorn and such cool-season crops as peas (*Pisum sativum* L.), broad beans (*Vicia faba* L.), and dried chili peppers. Immature fruit vegetables share many similarities with mature fruit vegetables, but there are also many differences (Table 3). The rate of respiration and development is rapid in both immature and mature fruit vegetables, but whereas the quality of most mature fruit vegetables improves with

Table 1 Classification of Fruit Vegetables on the Basis of Their Maturity When Harvested and "Horticulturally Mature"

I. Immature fruit vegetables
   A. Fleshy fruits: cucumber, summar squash, eggplant, green pepper
   B. Nonfleshy fruits: snap beans, lima beans, southern peas (cowpeas), peas, broad breans, sweetcorn, okra
II. Mature fruit vegetables
   A. Fleshy fruits: tomato, red pepper, winter squash, pumpkins, muskmelons, watermelons
   B. Nonfleshy fruits: dry peas, dry beans

Table 2 Taxonomic Classification of Some Important Mature Fruit Vegetables

Common name	Genus and species (group)
Cucurbitaceae	
Pumpkin, acorn squash, ornamental gourds	*Cucurbita pepo* (pepo)
Winter squashes and pumpkins ('Boston Marrow,' 'Hubbard,' 'Banana,' 'Turk's Turban,' 'Delicious')	*Cucurbita maxima*
Winter squashes and pumpkins (green striped cushaw, Japanese pie, 'Tennessee Sweet Potato')	*Cucurbita argyrosperma*
Winter melons, casaba, honeydew, 'Crenshaw,' 'Juan Canary,' 'Santa Claus'	*Cucumis melo* (Inodorus group)
Netted muskmelon, cantaloupe, Persian melon	*Cucumis melo* (Reticulatus group)
Watermelon	*Citrullus lanatus*
Solanaceae	
Pepper, sweet and pungent (Ancho, bell, cayenne, cheese, cherry, chiltepin, Cuban, jalapeno, long wax, New Mexican, pimiento, serrano)	*Capsicum annuum* var. *annuum*
Tomato	*Lycopersicon esculentum*
Cherry tomato	*Lycopersicon esculentum* var. *cerasiforme*

Table 3 Comparison of Postharvest Characteristics of Immature and Mature Fruit Vegetables

Immature fruit vegetables	Mature fruit vegetables
Warm-season crops.[a]	Warm-season crops.
Chilling sensitive.[b]	Chilling sensitive.
High respiration rates.	High respiration rates.
Rapidly developing.	Rapidly developing, or completed development.
Nonclimacteric.	Some are climacteric.
Morphological changes after harvest are detrimental.	Morphological changes after harvest may be desirable.
Chlorophyll loss is detrimental.	Chlorophyll loss and pigment synthesis may be desirable.

[a] Except peas, broad beans.
[b] Except peas, broad beans, sweetcorn.

Table 4 Composition of Mature Fruit Vegetables (Amount per 100-g Edible Portion Raw Product)

Vegetable	Water (%)	Calories	Protein (g)	Fat (g)	Ca (mg)	K (mg)	Vitamins A (IU)	Vitamins C (mg)
Tomato	94	22	1.1	0.2	13	244	900	23
Squash, winter	85	50	1.4	0.3	22	369	3,700	13
Pepper, chili	74	93	3.7	2.3	29	564	21,600	370
Melons								
Cantaloupe	91	30	0.7	0.1	14	251	3,400	33
Honeydew	91	33	0.8	0.3	14	251	40	23

Source: Watt, 1963.

their continued development (e.g., ripening of tomatoes), it declines with continued development of immature fruit vegetables (e.g., yellowing of cucumbers). Such morphological changes as softening and pigment changes are generally detrimental to the quality of immature fruits, while they may be necessary to improve the quality of mature fruit vegetables. For example, chlorophyll loss is detrimental to the quality of such harvested immature fruit vegetables as green beans (*Phaseolus vulgaris* L.) and okra [*Abelmoschus esculentus* (L.) Moench.], while it is necessary for such mature fruit vegetables as peppers and tomatoes). Mature fruit vegetables are generally not adapted to long-term storage (melons and tomatoes), but exceptions include dry chili peppers and hard-rind (winter) squash and pumpkin.

Most mature fruit vegetables are consumed fresh (e.g., melons and tomatoes). A large percentage of some mature vegetables are processed, however (tomatoes, pumpkin, winter squash) (Rubatzky and Yamaguchi, 1997). Over half of all tomatoes are consumed in the form of a processed product (e.g., paste, ketchup). Pumpkins and winter squash are used for holiday ornaments and processed for canned "pumpkin" pie filling. Chili peppers are consumed as dried or processed products.

Mature fruit vegetables supply a significant amount of nutrients to our diet (Table 4). Tomatoes rank first in relative contribution to nutrition, not because tomatoes are so nutritious but because so many tomatoes and tomato products are consumed (Rick, 1978; Rubatzky and Yamaguchi, 1997). They are an excellent source of vitamins A and C, as are peppers (Watt, 1963). Apart from their color and taste, peppers are also valued for their pungency. A single major gene controls the production of capsaicin, the pungent principal in peppers. This compound is produced in the septa and placental tissue, but not in the fruit walls or seeds. Red peppers usually contain several times the vitamin A content of green fruit and about twice as much vitamin C (Rubatzky and Yamaguchi, 1997). Orange-fleshed cantaloupes contribute significant amounts of vitamin A.

II. MATURITY AND QUALITY INDICES

The harvest index for mature fruit vegetables is usually based on size and color (Rubatzky and Yamaguchi, 1997). Chili peppers, pumpkins, winter squash, and ripe tomatoes are picked when they attain full size and show color. Tomatoes, however, are often picked at the mature-green stage and ripened after harvest. Melons should be harvested when they have attained sufficient sugars to be acceptable as dessert fruit, since they do not contain appreciable starch for conversion to sugars. The ripening and softening of tomatoes and some melons is assisted by the application of ethylene after harvest.

The factors used to measure the maturity and quality of the commodity depends on how it will be handled and used. Growers are interested in disease resistance, high yield, uniform maturity, desirable size, ease of harvest, and so on. Postharvest characteristics have not been one of their main interests. On the other hand, shippers and handlers are concerned with shipping quality and market quality. Hard fruit that can endure inexpensive handling and transport (i.e., rough treatment) and still maintain high market quality are desired. In contrast, consumers care about appearance, price, and table quality; the latter includes texture, flavor, and nutritive value. These often competing requirements must be balanced to produce an economical return to producers and marketers while at the same time ensuring a quality product for the consumer.

Maturity at harvest is a very important determinant of the final quality. For fruits consumed immature, overmaturity results in inferior quality. Fruits consumed ripe are best when ripened on the plant. Immaturity in this group results in inferior quality. Quality factors and maturity indices for selected fruit vegetables that are use in U.S. standards for grades and California code are summarized in Table 5.

Table 5 Quality Factors for Selected Mature Fruit Vegetables in the U.S. Standards for Grades and the California Food and Agricultural Code

Vegetable Standard (date issued)	Quality factors
Cantaloupe	
United States (1968)	Uniformity of size, shape, color and netting, maturity, soluble solids (>9%), turgidity, freedom from sunscald and other defects.
California (1976)	Maturity (soluble solids >8%), freedom from bruises, sunburn, growth cracks, and decay.
Honeydew	
United States (1967)	Maturity, firmness, shape, freedom from defects (sunburn, bruising, etc.) and decay.
California (1976)	Maturity (soluble solids >10%), freedom from sunscald, bruises, growth cracks, and decay.
Watermelon	
United States (1978)	Maturity, shape, uniformity of size (weight), freedom from anthracnose, decay, sunscald, white heart, and other defects. Internal quality; SS 10% (very good), 8% (good).
California (1976)	Maturity (arils around the seeds absorbed and flesh color is >75% red), freedom from decay, mechanical damage, sunburn, and discoloration.
Tomato	
United States (1976)	Maturity (contents of two or more seed cavities have developed jelly-like consistency and seeds are well developed (ripeness color chart), firmness, shape, size, freedom from defects (mechanical injury, freezing injury, sunscald, scars, catfaces, growth cracks, insect injury, puffiness) and decay.
California (1976)	Mature but not overripe; no defects or decay.

III. FACTORS AFFECTING QUALITY

There are many pre- and postharvest external and internal factors that affect the quality of mature fruit vegetables. They include temperature extremes, physical damage, water loss, physiological disorders, and pathological disorders.

A. Temperature Extremes

Because of their relatively large size, small surface-to-volume ratio, and well-developed cuticle that limits water loss, mature fruit vegetables are prone to damage from exposure to intense solar radiation. The limited evaporative cooling in these crops allows localized heating that can damage tissue, prevent normal ripening, and in severe cases kill the tissue. Whitewashes (water suspension of aluminum silicate and a surfactant) can be applied to exposed fruit in the field to reduce solar injury. Plant architecture can be modified to provide shading for developing fruit.

All mature fruit vegetables are susceptible to CI when exposed to temperatures above freezing, and depending on the commodity, below 5–12°C. Chilling injury can occur in the field, during transport, at the market, or in the home. Quality is reduced and shelf life shortened by both the tissue's responses to chilling and the subsequent changes in the commodity's susceptibility to diseases. Accelerated water loss, failure to ripen, and the production of abnormal metabolites, which alter the commodity's flavor and aroma, are some of the symptoms of chilling (Table 6).

Although avoiding chilling temperatures is the best preventative, elevated CO_2 (5–10%) atmospheres may alleviate chilling symptoms in chili peppers (Saltveit and Morris, 1990). Other treatments, such as intermittent warming and calcium dips, are also effective but none is used commercially on these crops.

B. Physical Damage

Physical damage is a major source of quantity and quality loss during postharvest handling and marketing of mature fruit vegetables. Although there is a slight amount of wound healing after harvest (i.e., curing in winter squash and pumpkins), the effect of injuries

Table 6 Visual Symptoms of Chilling Injury on Some Mature Fruit Vegetables

Vegetable	Symptoms
Muskmelons	Softening, pitting, increased decay incidence. Also failure to ripen, water-soaked rind, sticky surface due to juice exudation in severe chilling injury on honeydews.
Peppers	Surface pitting, shriveling, softening.
Pumpkins	*Alternaria* rot.
Tomatoes	Delayed and uneven ripening, increased susceptibility to *Alternaria* rot, shriveling, softening, seed discoloration. Susceptibility to chilling decreases with ripening.
Watermelons	Surface pitting and sunken areas that become dry upon removal to nonchilling temperature, internal rusty-brown spots in the rind, objectionable flavor, fading of red flesh color.
Winter squash	*Alternaria* rot

is usually cumulative, with the damage done at each handling step adding to the overall level of injury. Physical injury stimulates respiration and disrupts the natural protective barriers, which allows accelerated water loss and the entry of pathogens.

Symptoms of physical injury may not be visible at the time of injury, but become noticeable during transit and subsequent handling. Injuries that damage skin tissues (cuts, punctures, abrasions, scuffing) are usually more serious on immature fruits, which have thinner skin than more mature fruits, and these injuries can lead to abnormal cellular growth, surface scaring, altered ripening at the site of injury, and loss of visual quality. Bruising and deformation are more severe on partially ripened and ripe fruits since they are usually softer than unripe fruits.

C. Water Loss

Water loss is not as important a factor in quality loss among mature fruit vegetables as it is among immature fruit and leafy vegetables. The cuticle is much thinner and more easily damaged in immature than in mature fruit. In a mature fruit, such as tomatoes, a well-developed cuticle limits water loss so that although the stem scar comprises around 10% of the fruit's surface area, it accounts for about 65% of water loss. Mature fruit vegetables picked before they have developed their mature cuticle are more susceptible to water loss than those picked fully mature. Mature fruit vegetables have a low surface-to-volume ratio since many are spherical or cylindrical in shape, and their susceptibility to water loss is therefore moderate. The presence of trichomes and breaks in the cuticle (i.e., injuries), however, greatly influences water loss. Even small amounts of water loss can produce changes in texture and reduce quality.

D. Physiological Disorders

There are a number of disorders that result from stress during growth, harvesting, and postharvest handling (Table 7). Foremost among the postharvest disorders are those associated with exposure to ethylene (Abeles et al., 1992). While ethylene is beneficial in its promotive effect on ripening of tomatoes and melons, it can also cause the unwanted yellowing and softening of peppers and the senescence of other mature fruit vegetables.

E. Pathological Disorders

Healthy mature fruit vegetables are relatively resistant to attack by pathogenic microorganisms (Kader et al., 1985; McColloch et al., 1968). Added stress resulting from physical injury, exposure to high or chilling temperatures, or to injurious levels of O_2 or CO_2,

Table 7 Physiological Disorders of Mature Fruit Vegetables

Blotchy ripening of tomatoes
Blossom-end rot of tomatoes and peppers—related to water stress and calcium deficiency
Growth cracks in tomatoes and squash—related to irrigation practices
Puffiness of tomatoes
Internal rind spot on watermelons
Yellowing of peppers and watermelons—related to ethylene exposure
Watersoaking of watermelons—related to ethylene exposure

Table 8 Common Diseases of Mature Fruit Vegetables

Disease	Vegetables
Anthracnose	Watermelon
Bacterial soft rot	Cucurbits, tomatoes, peppers, melons
Gray mold rot	Peppers, tomatoes
Rhizopus rot	Peppers, melons, tomatoes, pumpkins
Fusarium rot	Melons, tomatoes, pumpkins
Phytophthora rot	Tomato, watermelon
Cladosporium rot	Melons, peppers
Alternaria rot	Tomatoes, follows chilling injury
Phythium spp	Cottony leak in squash

however, increases the susceptibility to disease (Table 8). In fact, the appearance of a specific disease is often a good indicator that the commodity has experienced a specific type of stress. For example, *Alternaria* rot in tomatoes often follows chilling (Hardenburg et al., 1986; Saltveit and Morris, 1990).

IV. GENERAL POSTHARVEST PHYSIOLOGY

A. Control of Ripening in Fruit Harvested Mature but Unripe

Satisfactory ripening of tomatoes and melons occurs only within about 12–25°C, with the rate of the ripening increasing with temperature within that range (Hardenburg et al., 1986; Ryall and Lipton, 1979). The optimal range for ripening tomato fruit is 20–22°C. Ethylene treatment (100 ppm for 24 to 48 h) is used commercially to accelerate and achieve more uniform ripening of mature fruit vegetables such as mature-green tomatoes and some winter melons (e.g., honeydew).

B. Respiration and Ethylene Production

Some fruit vegetables are climacteric (i.e., produce increased amounts of CO_2 and ethylene coincident with ripening), while others are nonclimacteric (Biale and Young, 1981). Usually fruit vegetables harvested immature are nonclimacteric, while fruit vegetables harvested mature can be either climacteric or nonclimacteric. For example, harvested mature fruit of green (bell) peppers (*Capsicum annuum* L. Grossum Group) are nonclimacteric, while tomatoes, cantaloupes, and watermelon are climacteric. Muskmelons are a diverse group that may exhibit climacteric (cantaloupe, Crenshaw) or nonclimacteric (casaba) ripening behavior (Kendall and Ng, 1988). Hybrids between netted and nonnetted cultivars were intermediate to the parents in rates and time of ethylene production. Honeydew melons exhibit a climacteric pattern of respiration and ethylene production when harvested mature, but a nonclimacteric pattern when harvested immature (Pratt et al., 1977).

The concept that the respiratory climacteric is an integral part of the ripening of climacteric fruit has been accepted for over 60 years and has greatly affected the direction and focus of research on fruit ripening (Shellie and Saltveit, 1993). Almost all this research on fruit ripening has been done with harvested fruit, however. A different pattern can appear when the respiratory and ethylene production are measured on ripening fruit attached to the plant. The fruit of some melon and tomato cultivars do not exhibit a respiratory climacteric (e.g., an increase in the internal concentration of CO_2) when allowed to ripen on the plant (Saltveit, 1993; Shellie and Saltveit, 1993). The rise in the ethylene production with ripening occurred in both attached and detached fruit, but the rise in respiration only occurred in attached fruit once they abscised. Other studies by Knee (1995) on tomato and Hadfield et al. (1995) on melon, however, have failed to confirm these observations.

C. Response to Controlled Atmospheres

Mature fruit vegetables show slight benefits from controlled atmospheres (CA) (Isenberg, 1979; Saltveit, 1997). A 3–5% O_2 atmosphere without added CO_2 retards ripening and can be tolerated by all fruit vegetables. Tolerance for elevated CO_2 varies among these vegetables. While tomatoes and bell peppers show CO_2 injury if exposed to more than 2% CO_2, cantaloupes tolerate and benefit from CO_2 in the range of 10–15%. Adding carbon monoxide (CO; 5–10%) to atmospheres low in O_2 controls decay on tomatoes. Controlled atmospheres or modified atmospheres (MA) are not commonly used with mature fruit vegetables except for export marketing, when they are used mainly to reduce incompatibilities with other commodities shipped in the same container.

D. Recommended Storage Conditions

Optimum temperatures for mature-green tomatoes, watermelons, pumpkins, and hard-rind squash are 12–14°C, while it is 10–12°C for partially ripe tomatoes and muskmelons (except cantaloupes, which can be held at 2–5°C) (Hardenburg et al., 1986). The optimum temperature is 8–10°C for fully ripe tomatoes and most ripe muskmelons. As expected, there are slight differences among cultivars, seasons, and production locations. The relative humidity (RH) must be around 90%, except for pumpkins and hard-rind squashes, for which it should be lower (65%). If CA or MA is used, O_2 concentration should not be allowed to drop below 3% and CO_2 should not be allowed to rise above 2%.

E. Compatibility Considerations

Mixing commodities that are sensitive and insensitive to chilling should be avoided, unless transit periods at the chilling temperature are shorter than the time required to produce injuries (usually less than 2 days). Ripening tomatoes and melons produce ethylene that can influence the ripening rate of other commodities, and enhance yellowing and senescence of immature fruit and leafy vegetables. Pungent odors from ripening cantaloupes can be absorbed and alter the flavor of other commodities.

F. General Postharvest Handling Procedures

The handling procedures for mature fruit vegetables are very similar to those used for other fruits and vegetables (Table 9). Noticeable differences include a step to cure winter squash and pumpkins (step 9a), and a step to use ethylene to promote ripening (step 9b) (Kader et al., 1985). Because of the large size of some melons, watermelons, winter squash, and pumpkins, hand sorting and packing is preferred to mechanical handling to minimize physical injuries.

Table 9 Generalized Postharvest Handling Procedure for Mature Fruit Vegetables

Step	Function
1	Harvesting
2	Hauling to the packinghouse or processing plant
3	Cleaning
4	Sorting to eliminate defects
5	Waxing (tomato, pepper)
6	Sizing and sorting into grades
7	Packing—shipping containers
8	Palletization and unitization
9a	Curing of winter squashes and pumpkins
9b	Ripening of melons and tomatoes with ethylene
10	Cooling (hydrocooling, room cooling, forced-air cooling)
11	Temporary storage
12	Loading into transport vehicles
13	Destination handling (distribution centers, wholesale markets, etc.)
14	Delivery to retail
15	Retail handling

V. POSTHARVEST PHYSIOLOGY OF SELECTED MATURE FRUIT VEGETABLES

A. Tomatoes (*Lycopersicon esculentum* Mill.)

The growth characteristics of tomato plants range from indeterminate to highly determinate (Rick, 1978). Indeterminate plants produce fruit over an extended period of time and require multiple harvests, while determinate plants produce fruit over a short period of time and can be harvested once economically. Most processing varieties are determinate so that once-over mechanical harvesting of the ripe fruit is practical (Gould, 1974). Processing varieties have many moderately sized, tough-skinned fruit that are firm and thick-walled with few and small locules (Fig. 1). Yields are increased because fruit do not

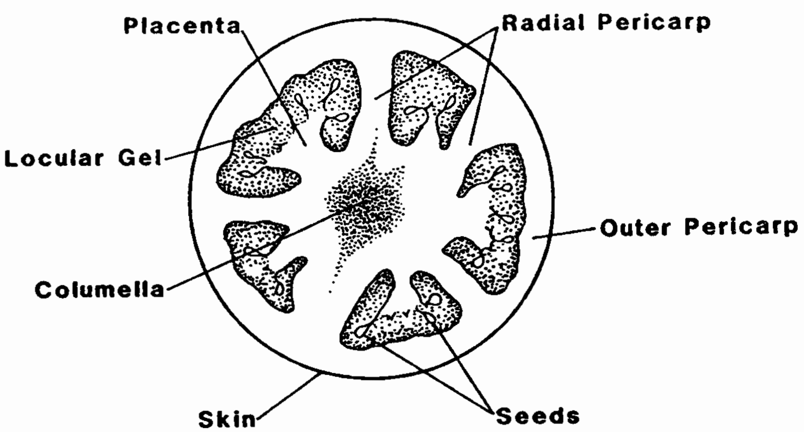


Figure 1 Cross section through a mature-green tomato fruit. (From Brecht, 1987.)

abscise and even red-ripe fruit remain attached to the plant until harvested. A spray application of ethephon (2-chloroethyl-phosphonic acid) at 2000 ppm 7 to 10 days before harvest accelerates maturation and color development. Mechanically harvested fruit are handled in bulk and processed within a day, so minor mechanical damage has minimal effect on product quality.

When held at the appropriate temperature and RH, mature-green fresh-market tomatoes pass through an orderly sequence of developmental stages (Table 10). Exposure to ethylene stimulates the ripening of mature-green fruit in a log-linear sequence with days to breaker being halved for every 10-fold increase in concentration (Table 11). Although many changes take place during ripening, most of these stages are based on external color as the fruit turns from green to red with the destruction of chlorophyll and the synthesis of lycopene (Hobson and Davies, 1971). Internal changes include seed maturation and the liquefaction of locular tissue. At maturity, the seeds are surrounded by a gelatinous material that fills the locules. In addition to external color changes, these changes in internal color and tissue firmness can also be used with the appropriate instruments to nondestructively evaluate fruit maturity.

Even though most fresh-market tomatoes are still hand harvested, a significant volume of mature-green fruit destined for the fresh market is mechanically harvested (Rubatzky and Yamaguchi, 1997). Fruit at the breaker or more advanced stages of maturity, however, will probably be hand harvested for some time because their softer texture is less resistant to mechanical damage than the firmer mature-green fruit. Many recent cultivars have a "jointless" characteristic, whereby the abscission layer does not develop in

Table 10 Maturity Stages for Fresh-Market Tomato Fruit

Number	Stage	Description
0	Immature	The fruit is not sufficiently developed to ripen to an acceptable level of horticultural quality. Seeds will not germinate. Fruit do not color properly.
1	Mature-green (MG)	The fruit will ripen to an acceptable level of horticultural quality under proper conditions. Seeds are mature and can germinate. The entire surface of the fruit is either green or white. No red color is visible. There are four stages within the mature-green classification.
	MG1	Firm locular tissue; knife cuts seeds.
	MG2	Softened locular tissue; seeds not cut with knife.
	MG3	Some gel in the locule, no red color in columnella tissue.
	MG4	Locular tissue predominately gel, some red in the columnella tissue.
2	Breaker	There is a definite break in color from green to tannish-yellow, pink, or red at the blossom end of the fruit.
3	Turning	More than 10% but less than 30% of the fruit surface shows a definite color change to tannish-yellow, pink, or red, or a combination of colors.
4	Pink	More than 30% but less than 60% of the fruit surface is pink or red.
5	Light red	More than 60% but less than 90% of the fruit surface is red.
6	Red ripe	More than 90% of the fruit surface is red.

Note: Each successive stage after mature-green takes about 2 days at 20°C.

Table 11 Effect of Various Ethylene in Air Mixtures on the Rate of Ripening of Mature-Green Tomato Fruit

Ethylene concentration (ppm)	Days to breaker
0.0	15.4
0.3	8.8
1.0	7.3
3.0	6.3
10	4.7
30	4.3
100	3.8

Source: Kader et al., 1978.

the pedicel. These fruits are easily separated from the plant without the attached pedicel that can puncture other fruit during postharvest handling. Since quality (i.e., color, flavor, and aroma) increases with ripening on the plant (Kader et al., 1978), there is an economic incentive to harvest and market fruit at a riper stage.

The numerous changes that take place during tomato fruit ripening have been extensively studied (Davies and Hobson, 1981; Hobson and Davies, 1971). Major changes involve pigment synthesis, tissue softening, increased flavor and aroma, and a climacteric rise in respiration and ethylene production. The red color of ripe fruit is due to the synthesis of lycopene, other carotenoid pigments, and the destruction of chlorophyll. Ripening starts in the columnella and progresses outward and from the blossom to the stem ends of the fruit (Brecht, 1987). Pigment changes occur in three distinct phases during ripening (Hobson and Davis, 1971). Chlorophyll is the predominant pigment during growth and development up to the mature-green stage (chlorophyll:carotenoids, 10:1). From mature-green to breaker there is a destruction of chlorophyll accompanied by an increase in carotenoids (chlorophyll:carotenoids, 1:1). From breaker to red-ripe there is a surge in lycopene synthesis as chlorophyll content falls to zero. Ripeness classifications of fresh-market tomato fruit are based almost entirely on color. The six levels of maturity are described in Table 10.

Tomato fruit are classified as climacteric, with the onset of the climacteric rise in respiration and ethylene production coincident with the first appearance of red color at the breaker stage (Rick, 1978) (Fig. 2). Fresh-market cultivars at about 93% final size (about 42 days after antithesis) are able to go through a normal climacteric and ripen to an acceptable level of quality after harvest. Fruit harvested smaller are unable to ripen to an acceptable level of quality. Fruit that are older than 31 days after anthesis develop red color without added ethylene, while younger fruit require ethylene to develop red color. Application of 1,000 ppm ethylene in air to fruit as young as 17 days after anthesis induces respiratory and ethylene climacterics, color change, and softening. These fruit do not develop into good quality fruit, however. Since ethylene can promote some ripening changes even in immature fruit, the danger exists that repeated or prolonged exposures to ethylene will be used to ripen inferior-quality green fruit.

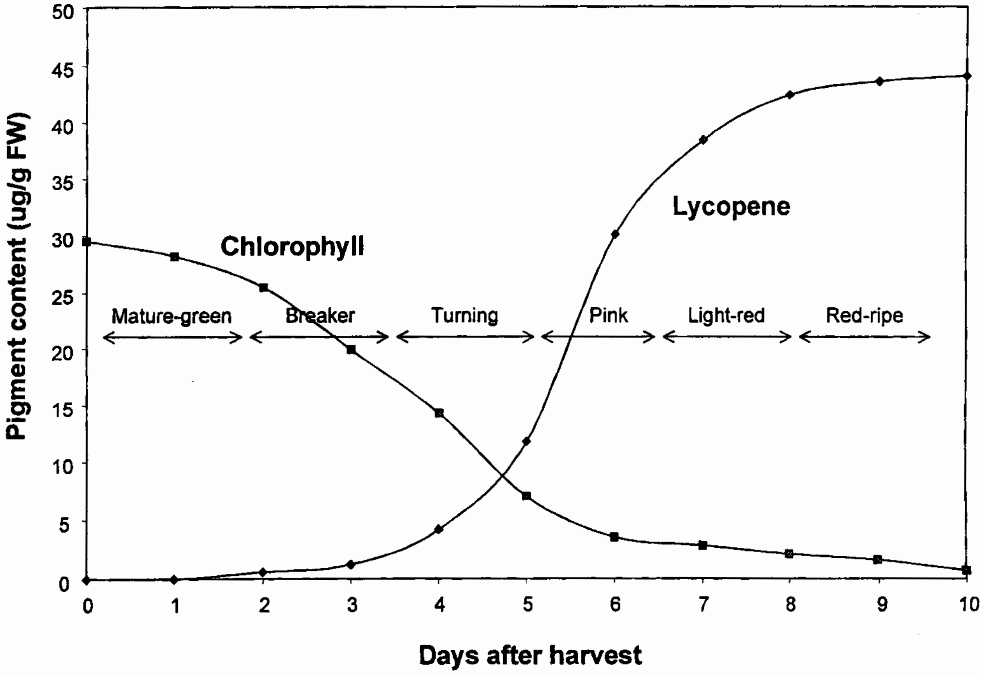


Figure 2 Changes in chlorophyll and lycopene during the ripening of tomato fruit. The ripeness stages are described in Table 10.

When measured in ripening fruit attached to the plant, the respiratory climacteric is greatly reduced while the ethylene climacteric remains unaffected (Fig. 3). Fruit ripening while attached to the plant also continue to accumulate soluble solids and organic acids (the two major components of flavor quality), in contrast to harvested fruit, in which both decline (Fig. 4). Continued import of phototsynthate from the plant is probably the main reason for the continued increase of soluble solids and organic acids in attached fruit, while the elevated respiration of harvested fruit may contribute to the decline of these components.

Control of tomato fruit ripening has received much attention over the years. Genetic control was first introduced by breeding lines that stored well. Later, mutant lines (e.g., *rin*, *nor*, and *Nr*) with altered ripening characteristics were used in breeding programs, and finally genetic engineering is being used to specifically alter certain ripening characteristics, such as softening and climacteric ethylene production. A number of cell wall hydrolytic enzymes, including polygalacturonases, pectinmethylesterases, and carboxymethylcellulases, contribute to fruit softening (Fischer and Bennett, 1991). Antisense plants have been produced in which the activity of these enzymes is significantly reduced. Fruit from some of these constructs soften more slowly than normal, but softening in others was unaffected. Control of fruit softening appears to involve more than simply altering the activity of one or two enzymes.

The metabolic pathways for ethylene synthesis and action in ripening fruit are apparently much simpler than those pathways responsible for tissue softening. Ethylene synthesis and action in fruit ripening has been modified by altering the two enzymes responsible

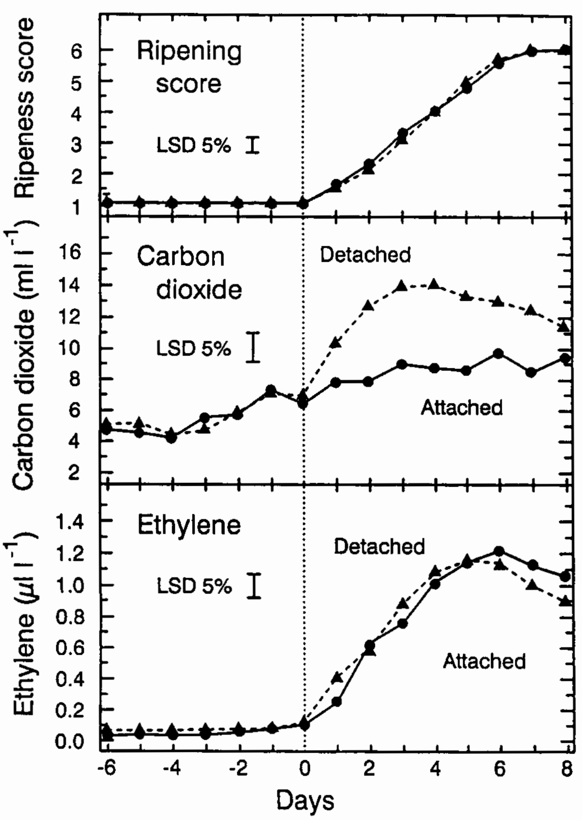


Figure 3 Ripening score and carbon dioxide and ethylene production from a ripening tomato fruit attached to the plant or detached (harvested). (From Saltveit, 1993.)

for its biosynthesis (ACC synthase and ACC oxidase) (Lelievre et al., 1997; Yang, 1987) and the complex of molecules and pathways involved in its perception (Picton et al., 1993). Ripening is uniformly delayed by both approaches. Adding ethylene to the storage atmosphere overcomes these imposed genetic limitations and promotes natural ripening.

Modification of the atmospheric composition through CA and MA techniques offers a moderate to slight benefit. Oxygen levels of 3–5% and CO_2 levels of 2–3% for mature-green and 3–5% for ripe fruit retard ripening and respiration and suppress ethylene synthesis and action. Altering the partial pressure of gases by storage at subatmospheric pressure also reduces the partial pressure of O_2 to that found in CA and MA, and facilitates diffusion of ethylene from the fruit. These changes mean that it takes longer for the endogenously synthesized ethylene to reach levels that stimulate ripening. Mature-green fruit can be held at 102 mmHg for up to 100 days and still ripen normally when returned to normal storage conditions (Fig. 5) (Wu et al., 1972). Fruit ripening can also be inhibited by a short exposure to a low concentration of ethanol vapor (Kelly and Saltveit, 1988) without affecting subsequent quality when ripened (Saltveit and Sharaf, 1992). Although this phenomenon was first observed with ethanol applications (Saltveit and Mencarelli, 1988), acetaldehyde is actually the causal agent responsible for the inhibition of tomato fruit ripening (Beaulieu et al., 1997).

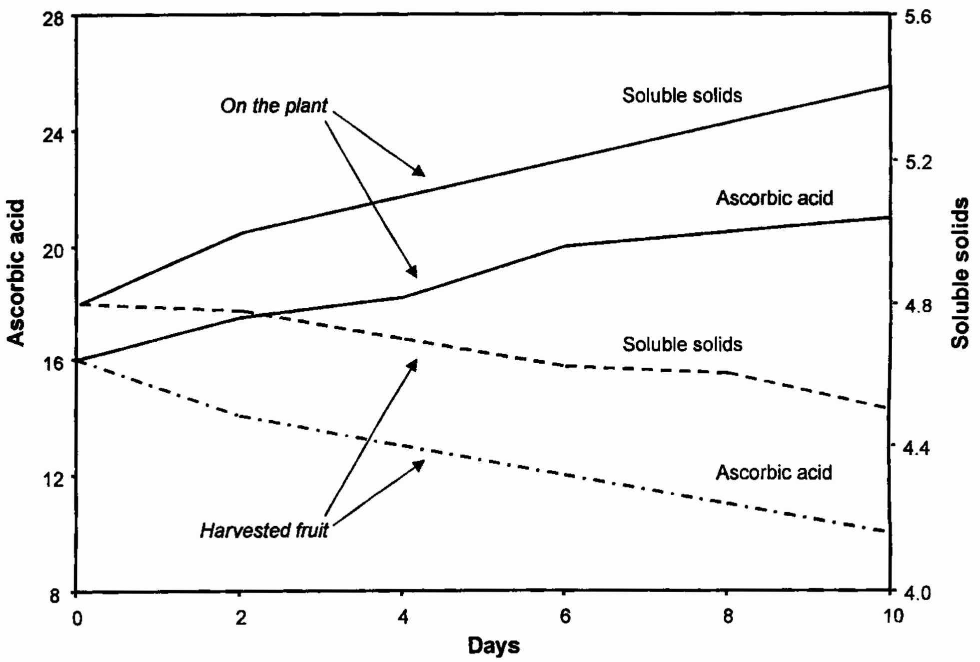


Figure 4 Soluble solids and ascorbic acid content of tomatoes ripened while on the plant or after harvest. (From Rick, 1978.)

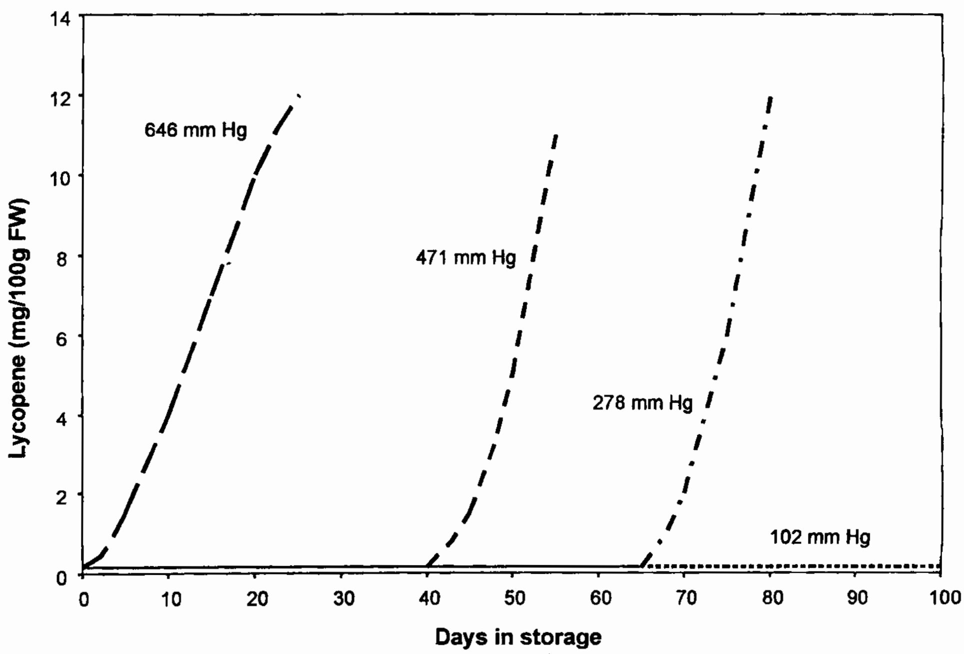


Figure 5 Lycopene content of mature-green tomato fruit ripened before and after hypobaric storage. (From Wu et al., 1972.)

The need for postharvest treatments to extend the market life of tomatoes may diminish in importance as genetic modifications produce fruit with naturally longer storage lives. Care must be exercised in the use of genetic engineering, however, so that appearance characteristics are not extended beyond the quality attributes of flavor, texture, aroma, and nutritive value.

B. Peppers (*Capsicum annuum* L. and *C. frutescens* L.)

The two *Capsicum* species that are most widely used are *C. annuum* (bell peppers and chili peppers) and *C. frutescens* (Serrano peppers and Tabasco peppers) (Rubatzky and Yamaguchi, 1997). They are indigenous to tropical and subtropical America and have been cultivated for more than five millennia. The more widely cultivated and economically important *C. annuum* includes a variety of sweet and pungent cultivars of different shapes and sizes. Chlorophyll (green), carotenoids (red and yellow), and anthocyanin (purple) pigments give the fruit their characteristic colors. During ripening, a brown color stage is sometimes encountered when the destruction of chlorophyll and the synthesis of lycopene and β-carotene occur simultaneously and have not yet been completed. As the fruit ripens, it becomes less sensitive to chilling (Lin et al., 1993).

The maturity of pepper fruit is not easily determined by appearance, but color and size are often used to decide when to harvest the fruit (Rubatzky and Yamaguchi, 1997). Like other fruit, peppers are considered mature when the seeds become capable of germination. Precocious seed germination within the fruit can be a problem (Marrush et al., 1998), but a few germinated seeds in a pepper fruit are not as objectionable, as in a tomato fruit. The locule in a pepper is dry and open.

Pepper plants are perennials that are grown as annuals and produce fruit throughout the season (Rubatzky and Yamaguchi, 1997). Multiple harvests are necessary to maximize yield since older fruit retard the growth of younger fruit. While the pedicel forms an abscission zone in some cultivars, many others are nonabscising, and the pedicel must be cut or broken to harvest the fruit. Pepper fruit are nonclimacteric (Saltveit, 1977). Hand harvesting is most common because too much injury occurs during mechanical harvesting for the fresh market. Fruit can be left on the plant to dry in the field, thereby reducing the time and energy required for final drying. Fruit coloration can be accelerated by the application of ethephon, but it also hastens softening of the fruit and senescence of the plant. Ethephon is commercially used to improve the color of dry chile and paprika types (Hardenburg et al., 1986).

C. Melons (*Cucumis melo* L.)

Multiple harvests are often necessary to obtain maximum yields because fruit set occurs over a prolonged period and developing fruit inhibit the set and growth of other fruit on the same vine (Pratt, 1971; Robinson and Decker-Walters, 1997; Rubatzky and Yamaguchi, 1997). Selecting mature fruit requires hand harvesting, which also helps to minimize mechanical damage because of the large size and delicate nature of melon fruit. Melons are sometimes harvested at night to reduce the heat load acquired during hot days (Kasmire, 1981). Immature melons have poor color and flavor and low sugar content. Besides the characteristic flavor and color, the most important quality attribute of melons is their sugar content. Melons do not store starch, nor do they synthesize sugars after harvest from other stored reserves. The last week or two of growth are therefore very important, because most of the soluble sugar is accumulated during that time and melons must be harvested with adequate levels of sugar (Pratt, 1971). Cantaloupe, for example, accumulates most of the sugar in the last 7 days of growth before harvest. In contrast to cantaloupes, honeydew melons have acceptable levels of sugar before they develop their characteristic flavor and taste. Ethylene treatment is deleterious for cantaloupe since it promotes overripening and senescence, while it is often necessary for honeydew to promote uniform ripening and good organoleptic quality.

Maturity of Reticulatus Group (cantaloupe) melons is gauged by the formation of an abscission zone or "slip" between the peduncle and its attachment to the fruit (Robinson and Decker-Walters, 1997; Rubatzky and Yamaguchi, 1997). A "full slip" denotes melons that detach naturally due to the abscission zone forming completely around the peduncle. Melons harvested before "half slip" are often of inferior quality. They can be recognized by the rough scar at the stem end of the fruit. Like tomatoes, the respiratory climacteric is greatly reduced when the fruit ripen on the vine, while the climacteric rise in ethylene is virtually unaffected (Fig. 6) (Shellie and Saltveit, 1993). This is true for both Reticulatus (Fig. 6) and Inodorus (Fig. 7) types of melons (Miccolis and Saltveit, 1991).

Inodorus Group melons do not form an abscission zone. Their maturity is more difficult to judge and is usually based on size, shape, firmness, surface appearance and color, and aroma. Although generally slow ripening, cultivars in this group have too short

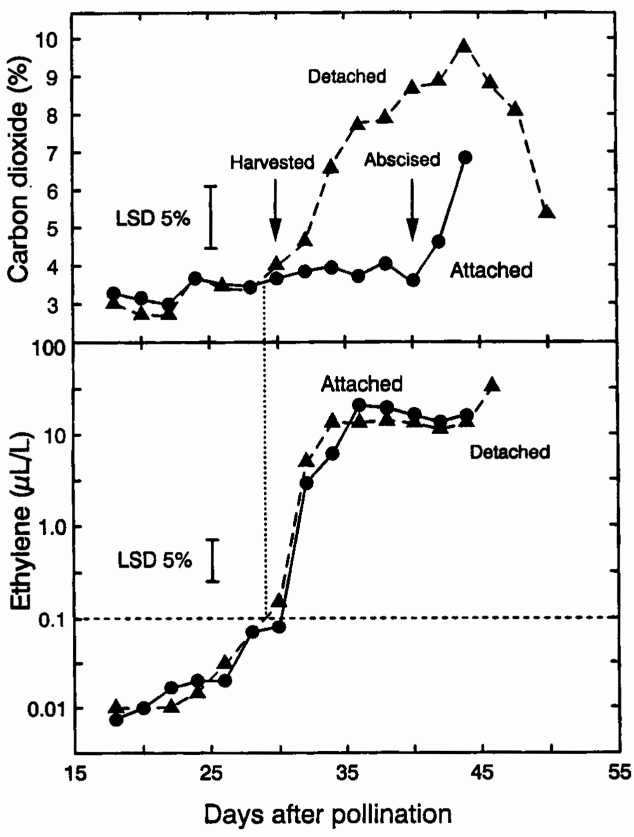
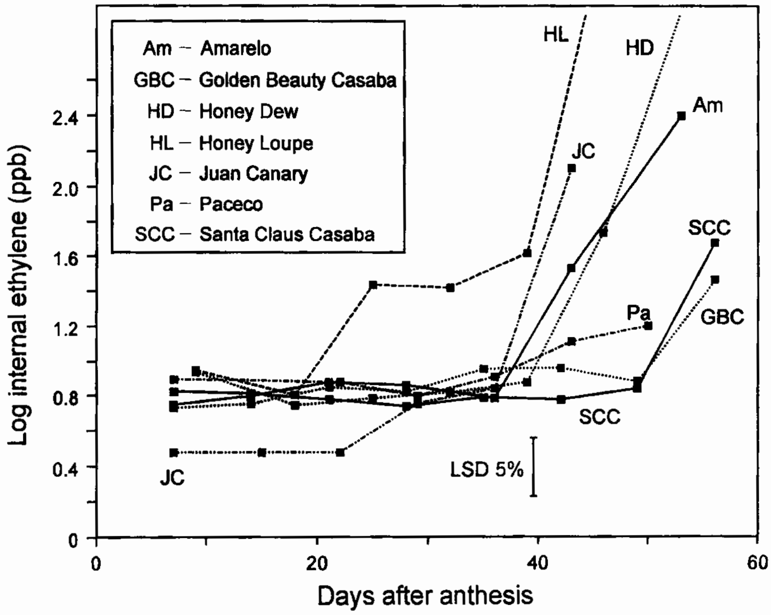
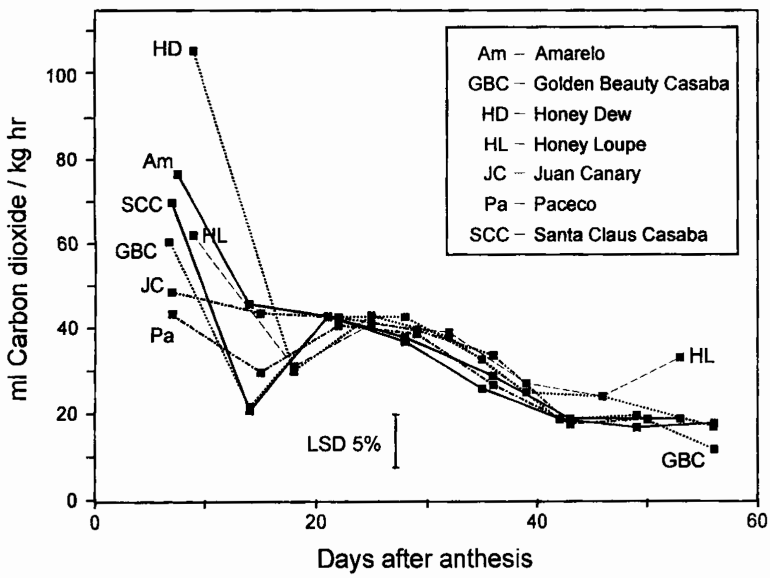


Figure 6 Internal carbon dioxide and ethylene concentration in muskmelon fruit ripened while attached or detached (harvested) from the plant. (From Shellie and Saltveit, 1993.)



(a)



(b)

Figure 7 (a) Changes in the internal ethylene concentration during growth and maturation of 'Amarelo,' 'Golden Beauty Casaba,' 'Honey Dew,' 'Honey Loupe,' 'Juan Canary,' 'Paceco,' and 'Santa Claus Casaba' melons. Data are the average of measurements of five fruit from each of two harvests. The vertical bar represents the overall LSD 5% value. (From Miccolis and Salveit, 1991.) (b) Changes in the rate of carbon dioxide production during growth and maturation of 'Amarelo,' 'Golden Beauty Casaba,' 'Honey Dew,' 'Honey Loupe,' 'Juan Canary,' 'Paceco,' and 'Santa Claus Casaba' melons. Data are the average of measurements of five fruit from each of two harvests. The vertical bar represents the overall LSD 5% value. (From Miccolis and Salveit, 1991.)

a commercial shelf life if allowed to ripen on the vine. Honeydew melons become fully mature around 50 days after anthesis, but they are often harvested around 35 days after anthesis (Pratt et al., 1977). These fruits require a postharvest treatment with ethylene to ripen them sufficiently for market.

After harvest, melons should be quickly transported to a packing shed and cooled (Kasmire, 1981). Hydrocooling is the preferred method, but complete immersion of warm melons in cold water could cause contaminated water to be drawn into the fruit. Thin-skinned cultivars may be field packed and forced-air cooled at the packing shed. Properly cooled melons can be held for 1 to 6 weeks. Cultivars of the Reticulatus Group store well at 3–4°C and 85–90% RH for up to 2 weeks, while cultivars of the Inodorus Group can be held for longer periods (Hardenburg et al., 1986).

D. Watermelons [*Citrullus lanatus* (Thunb.) Matsum. & Nak.]

Watermelon fruit do not form an abscission zone and their maturity is difficult to gauge (Robinson and Decker-Walters, 1997; Rubatzky and Yamaguchi, 1997). Harvest should be delayed until they reach 10% or higher soluble solids. Because of their large size and propensity to split or crack under mechanical stress, watermelons should not be harvested in the early morning when they are most turgid. A short 2- to 3-cm length of peduncle should be left attached to the fruit when it is cut from the vine to deter stem end rot. Latent *anthracnose* infection is controlled by quickly cooling the fruit after harvest and maintaining the RH around 85%. Watermelons store well at 15°C for up to 2 weeks (Hardenburg et al., 1986). Longer-term storage at 12°C is limited by internal breakdown of the flesh around the seeds. Chilling injury with rind browning and fading of flesh color occurs below 10°C.

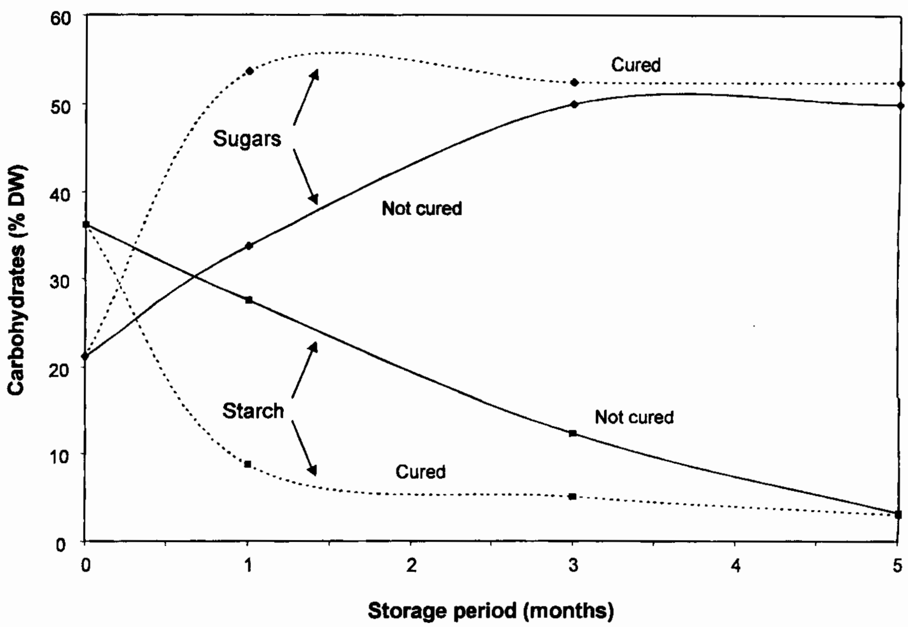


Figure 8 Changes in carbohydrates (starch and sugars) during storage of cured and uncured 'Buttercup' winter squash. (Redrawn from Schales and Isenberg, 1963.)

E. Winter Squashes and Pumpkins (*Cucurbita maxima* and *C. pepo*)

Although resistant to a light frost, pumpkins and winter squashes should be harvested before significant exposure to temperatures below 10°C causes CI and reduced storage life (Robinson and Decker-Walters, 1997; Rubatzky and Yamaguchi, 1997). The decline and death of the vine facilitate harvesting the mature fruit. A short 2- to 3-cm length of peduncle should be retained attached to the fruit when it is cut from the vine. If the fruit are harvested into large bins, peduncle length should be minimized to avoid damage to the other fruit. Bins should be designed to allow adequate ventilation to remove excess moisture and control temperature.

Winter squashes and pumpkins can be cured prior to long-term storage by holding them at 20–30°C for 3 to 20 days (Hardenburg et al., 1986; Rubatzky and Yamaguchi, 1997). Curing promotes healing of wounds, the conversion of starch to sugars, and other physiological changes that increase storability. Curing improved the quality of 'Butternut,' had little effect on 'Blue Hubbard,' and was determined to both skin color and taste of 'Table Queen' (Schales and Isenberg, 1963). In 'Butternut' squash, curing accelerated the conversion of starch to sugar (Fig. 8), thereby improving quality and storability. Storage of cured and noncured squashes and pumpkins should be at 10–15°C and 50–70% RH. Higher RH of 70–80% reduces water loss, but favors microbial growth (Hardenburg et al., 1986). The susceptibility of 'Butternut' squash to develop hollow neck at the lower RH is reduced at the higher RH, and the enhanced decay can be controlled by a 2-min dip in 60°C water (Francis and Thomson, 1965).

The storage life of mature squash depends on the cultivar. 'Hubbard' squash can be stored for 6 months, while 'Turban' squash store for 3 months and 'Table Queen' and othe acorn squashes store well for 2 months (Hardenburg et al., 1986). During storage, starch-to-sugar conversion continues and β-carotene content may improve. The content

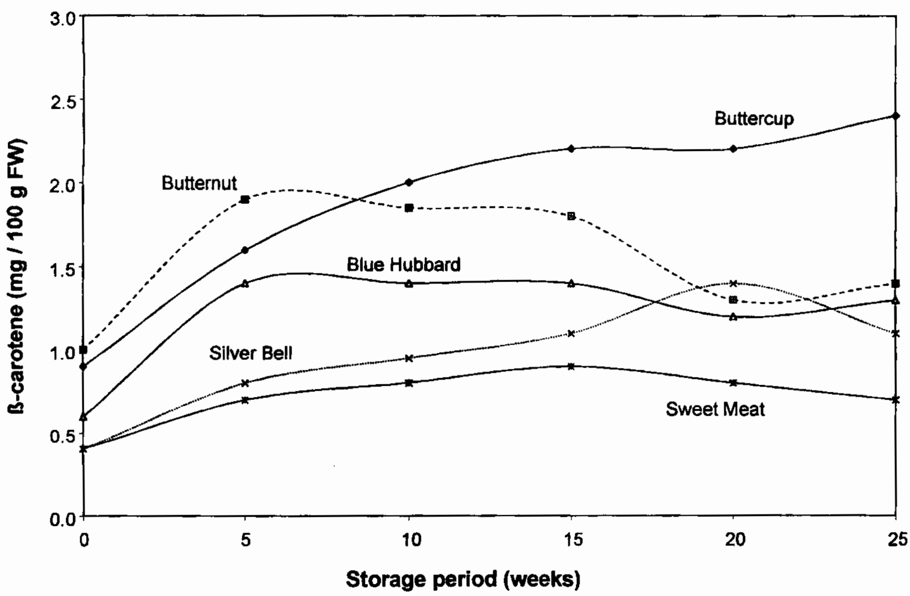


Figure 9 Changes in β-carotene during storage of five cultivars of winter squash. (Redrawn from Hopp et al., 1960.)

of β-carotene in five squashes increased during the first 5 weeks of storage, and then continued to increase ('Buttercup' and 'Silver Bell'), slightly declined ('Butternut'), or remained relatively unchanged during the remaining 20 weeks of storage (Fig. 9). Respiratory depletion of sugars and textural changes may reduce quality over time in storage, however. Storage at 5°C for 3 weeks caused CI, while storage at 10–15°C did not.

REFERENCES

Abeles FB, Morgan PW, Saltveit ME. Ethylene in Plant Biology. 2nd ed. San Diego, CA: Academic Press, 1992.

Beaulieu JC, Peiser G, Saltveit ME. Acetaldehyde is a causal agent responsible for ethanol-induced ripening inhibition in tomato fruit. Plant Physiol 113:431–439, 1997.

Biale JB, Young RE. Respiration and ripening in fruits—Retrospect and prospect. In: Friend J, Rhodes MJC, (eds.). Recent Advances in the Biochemistry of Fruit and Vegetables. New York: Academic, 1981, p. 1–39.

Brecht JK. Locular gel formation in developing tomato fruit and the initiation of ethylene production. HortScience 22:476–479, 1987.

Davies JN, Hobson GE. The constituents of tomato fruit—The influence of environment, nutrition and genotype. CRC Crit Rev Food Sci Nutr 15:205–280, 1981.

Fischer RL, Bennett AB. Role of cell wall hydrolases in fruit ripening. Ann Rev Plant Physiol Plant Molec Biol 42:675–703, 1991.

Francis FJ, Thomson CL. Optimum storage conditions for Butternut squash. Proc Amer Soc Hort Sci 86:451–456, 1965.

Gould WA. Tomato Production, Processing and Quality Evaluation. Westport, CT: AVI, 1974.

Hadfield KA, Rose JKC, Bennett AB. The respiratory climacteric is present in Charentais (*Cucumis melo* cv. Reticulatus F1 Alpha) melons ripened on or off the plant. J Exp Bot 46:1923–1925, 1995.

Hardenburg RE, Watada AE, Wang CY. The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks. Washington, DC: US Dept of Agriculture Agr Res Serv, Agr. Handbook 66, 1986.

Hobson GE, Davies JN. The tomato. In: Hulme AC, ed. The Biochemistry of Fruits and Their Products. vol. 2. New York: Academic, 1971, p. 437–482.

Hopp RJ, Merrow SB, Elbert EM. Varietal differences and storage changes in β-carotene of six varieties of winter squash. Proc Amer Soc Hort Sci 76:568–576, 1960.

Isenberg FMR. Controlled atmosphere storage of vegetables. Hort Rev 1:337–394, 1979.

Kader AA, Kasmire RF, Mitchell FG, Reid MS, Sommer NF, Thompson JF. Postharvest technology of horticultural crops. University of California, Coop. Ext. Special Pub. no. 3311. Oakland, CA: ANR, 1985.

Kader AA, Morris LL, Stevens MA, Albright-Holton M. Composition and flavor quality of fresh market tomatoes as influenced by some postharvest handling procedures. J Amer Soc Hort Sci 103:6–13, 1978.

Kasmire RF. Muskmelon Production in California. Berkeley, CA: University of California, 1981, Leaflet 2671.

Kelly MO, Saltveit ME. Effect of endogenously synthesized and exogenously applied ethanol on tomato fruit ripening. Plant Physiol 88:143–147, 1988.

Kendall SA, Ng TJ. Genetic variation of ethylene production in harvested muskmelon fruits. HortScience 23:759–761, 1988.

Knee M. Do tomatoes on the plant behave as climacteric fruit? Physiol Plant 95:211–216, 1995.

Lelievre J-M, Latche A, Jones B, Bouzayen M, Pech J-C. Ethylene and fruit ripening. Physiol Plant 101:727–739, 1997.

Lin WC, Hall JW, Saltveit ME. Ripening stage affects the chilling sensitivity of greenhouse-grown peppers. J Amer Soc Hort Sci 118:791–795, 1993.

Marrush M, Yamaguchi M, Salveit M. Effect of potassium nutrition during bell pepper seed development on vivipary and endogenous levels of abscisic acid. J Amer Soc Hort Sci 123:925–930, 1998.

McColloch LP, Cook HT, Wright WR. Market Diseases of Tomatoes, Peppers, and Eggplants. Washington, DC: U.S. Department of Agriculture, Agr Handbook 28, 1968.

Miccolis V, Saltveit ME. Morphological and physiological changes during fruit growth and maturation of seven melon cultivars. J Amer Soc Hort Sci 116:1025–1029, 1991.

Phan CT. Biochemical and physiological changes during the harvest period. In: Weichmann J, (ed.). Postharvest Physiology of Vegetables. New York: Marcel Dekker, 1987, p. 9–22.

Picton S, Barton SL, Bouzayen M, Hamilton AJ, Grierson D. Altered fruit ripening and leaf senescence in tomatoes expressing an antisense ethylene-forming enzyme transgene. Plant J 3:469–481, 1993.

Pratt HK. Melons. In: Hulme AC, (ed.). The Biochemistry of Fruits and Their Products. vol. 2. New York: Academic, 1971, p. 207–232.

Pratt HK, Goechel JD, Martin FW. Fruit growth and development, ripening, and the role of ethylene in the 'Honey Dew' muskmelon. J Amer Soc Hort Sci 102:203–210, 1977.

Rick CM. The tomato. Sci Amer 239:76–89, 1978.

Robinson RW, Decker-Walters DS. Cucurbits. New York: CAB International, 1997.

Rubatzky VE, Yamaguchi M. World Vegetables: Principles, Production, and Nutritive Values. New York: Chapman and Hall, 1997.

Ryall AL, Lipton WJ. Handling, Transportation and Storage of Fruits and Vegetables. vol. 2. Vegetables and Melons. 2nd ed. Westport, CT: AVI, 1979.

Saltveit ME. Carbon dioxide, ethylene, and color development in ripening mature green bell peppers. J Amer Soc Hort Sci 102:523–525, 1977.

Saltveit ME. Internal carbon dioxide and ethylene levels in ripening tomato fruit attached to or detached from the plant. Physiol Plant 89:204–210, 1993.

Saltveit ME. A summary of CA and MA requirements and recommendations for harvested vegetables. In: Seventh International Controlled Atmosphere Research Conference. vol. 4: Vegetables and Ornamentals. Davis, CA: University of California, Postharvest Horticulture Series 18:98–117, 1997.

Saltveit ME, Mencarelli F. Inhibition of ethylene synthesis and action in ripening tomato fruit by ethanol vapors. J Amer Soc Hort Sci 113:572–576, 1988.

Saltveit ME, Morris LL. Overview of chilling injury of horticultural crops. In: Wang CY, (ed.). Chilling Injury of Horticultural Crops. Boca Raton, FL: CRC, 1990, p. 3–15.

Saltveit ME, Sharaf AR. Ethanol inhibits ripening of tomato fruit harvested at various degrees of ripeness without affecting subsequent quality. J Amer Soc Hort Sci 117:793–798, 1992.

Schales FD, Isenberg FM. The effect of curing and storage on chemical composition and taste acceptability of winter squash. Proc Amer Soc Hort Sci 83:667–674, 1963.

Shellie KC, Saltveit ME. The lack of a respiratory rise in muskmelon fruit ripening on the plant challenges the definition of climacteric behavior. J Exp Bot 44:1403–1406, 1993.

Watt BK. Composition of Foods: Raw, Processed, Prepared. Washington, DC: U.S.D.A., Agr. Res. Service, Agr. Handbook 8, 1963.

Wu MT, Jadhav SJ, Salunkhe DK. Effects of sub-atmospheric pressure storage on ripening of tomato fruit. J Food Sci 37:952–956, 1972.

Yang SF. The role of ethylene and ethylene synthesis in fruit ripening. In: Thomson WW, Nothnagel EA, Huffaker RC, eds. Plant Senescence: Its Biochemistry and Physiology. Rockville, MD: Amer. Soc. Plant Physiol., 1987, p. 156–166.