28

Immature Fruit Vegetables

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I. INTRODUCTION

The important examples of vegetables for which the edible part is botanically an immature fruit are mostly cucurbits and legumes, along with a solanaceous vegetable (eggplant, *Solanum melongena* L.), a member of the Malvaceae [okra, *Abelmoschus esculentus* (L.) Moench.], and a monocot (sweetcorn, *Zea mays* L. var. *rugosa* Bonaf.) (Table 1). Sweet or bell peppers (*Capsicum annuum* L. Grossum Group) may be harvested green, but have reached their maximum size and are mature when picked. (See Chapter 27.) The cucurbits and solanaceous fruits and okra are fleshy with relatively high water content and low calories (Table 2). The edible part of the legumes and sweetcorn are mainly or entirely seeds, and these vegetables thus have lower water contents, higher energy values, and higher protein levels in general. The immature fruit vegetables are moderately good sources of several important vitamins and minerals in the human diet.

The immature fruit vegetables are all warm season crops, with the exceptions of peas (*Pisum sativum* L.) and broad beans (*Vicia faba* L.), and with the exceptions of these two plus sweetcorn, they are all susceptible to chilling injury (CI). For a number of reasons, this group is among the most perishable of vegetables and is therefore rarely stored. Because these fruit vegetables are immature and are often undergoing rapid growth at the time of harvest, their metabolic rate is extremely high, and as a rule, they have not yet entered the developmental phase during which accumulation of storage compounds would occur. Their high rates of respiration, which are associated with their high metabolic rates, coupled with the lack of storage reserves, lead these vegetables to deteriorate rapidly. All

Table 1 Taxonomic Classification of Some Immature Fruit Vegetables

Common name	Genus and species
Dicots	
Cucurbitaceae	
Bitter gourd	*Momordica charantia* L.
Chayote	*Sechium edule* (Jacq.) Sw.
Cucumber	*Cucumis sativus* L.
Soft-rind or summer squash	*Cucurbita pepo* L.
Leguminosae	
Broad bean	*Vicia faba* L.
Green or snap bean	*Phaseolus vulgaris* L.
Lima bean	*Phaseolus lunatus* L.
Garden pea	*Pisum sativum* L.
Snow pea	*Pisum sativum* L. var. *macrocarpon* Ser.
Malvaceae	
Okra	*Abelmoschus esculentus* [L.] Moench.
Solanaceae	
Eggplant	*Solanum melongena* L.
Monocots	
Gramineae	
Sweetcorn	*Zea mays* L. var. *rugosa* Bonaf.

of the immature fruit vegetables behave as nonclimacteric fruit when harvested and handled as immature fruit. There is some controversy as to whether or not bitter gourds (*Momordica charantia*, L.) behave as climacteric fruit if allowed to ripen (Kays and Hayes, 1978; Zong et al., 1993).

For those vegetables in this group that are susceptible to CI, the lowest safe storage temperature may be as high as 12 or 13°C (Table 3), thus temperature control and refrigeration cannot be fully utilized to slow their rate of metabolism. Also, many of these vegeta-

Table 2 Composition of Immature Fruit Vegetables (Amount per 100-g Edible Portion Raw Product)

							Vitamins	
Vegetable	Water (%)	Calories	Protein (g)	Fat (g)	Ca (mg)	K (mg)	A (IU)	C (mg)
Broad bean	81.00	72	5.60	0.60	22	250	350	33.0
Chayote	93.00	24	0.90	0.30	19	150	56	11.0
Cucumber	96.05	13	0.54	0.13	14	149	45	4.7
Eggplant	91.93	26	1.10	0.10	36	219	70	1.6
Garden pea	78.86	81	5.41	0.40	25	244	640	40.0
Green or snap bean	90.27	31	1.82	0.12	37	209	668	16.3
Lima bean	70.24	113	6.84	0.86	34	467	303	23.4
Okra	89.58	38	2.00	0.10	81	303	660	21.1
Snow pea	88.89	42	2.80	0.20	43	200	145	60.0
Summer squash	93.68	20	1.18	0.21	20	195	196	14.8
Sweetcorn	75.96	86	3.22	1.18	2	270	281	6.8

Source: Haytowitz and Matthews, 1984.

Table 3 Chilling Threshold Temperatures and Visual Symptoms of Chilling Injury for Some Immature Fruit Vegetables

Vegetable	Chilling threshold (°C)	Symptoms
Cucumber	10–12	Shallow surfaces pits of various sizes, water-soaked spots, and increased decay
Eggplant	8–12	Pitting: brown surface areas that become sunken with time; calyx discoloration, and flesh browning
Green bean	4–7	Surface pitting, russetting (diagonal brown streaks), dullness of normal surface color, discoloration of seeds, increased susceptibility to decay
Lima bean	3–5	Rusty brown specks, spots or areas (followed by decay)
Okra	7–10	Discoloration, water-soaked areas, pitting, and increased calyx discoloration
Summer squash	5–10	Surface pitting and rapid decay

bles are more susceptible to water loss than the mature fruit vegetables because of their relatively thin cuticle and epidermal layer. This is also related to greater susceptibility to mechanical damage—and disruption of the cuticle allows accelerated water loss to occur.

Maturity at harvest may very well be the most important contributing factor to the overall potential postharvest quality of immature fruit vegetables. Size is the primary harvest index for most of these vegetables because of market expectations, but the decision to harvest must involve an awareness of the relationship between fruit size and the developmental stage of the fruit, which is different for each crop and may even differ among varieties within a specie. Kanellis et al. (1986) reported that the storage life of commercially immature (too small) cucumbers harvested 9 days after anthesis was 40% longer than that of larger, commercially mature 12-day-old fruit, while 15-day-old cucumbers, which were not substantially different in size from 12-day-old fruit, had a 40% shorter storage life. Because of the rapid morphological (e.g., seed coat development) and compositional changes (e.g., sugar-to-starch conversion in peas and sweetcorn) occurring, the harvest window for immature fruit vegetables can be extremely narrow—only 1 to 2 days for many of these crops. Overmaturity leads to negative quality changes in these crops, such as yellowing, toughening, fibrousness, and bitter flavor. Care in avoiding injuries during harvest is critical in order to minimize the negative effects of such damage, including acceleration of respiration and water loss, oxidative browning reactions, and increased potential for decay.

The physiological disorders associated with immature fruit vegetables are primarily related to temperature stress (freezing, chilling, heat injury) and exposure to ethylene (Table 4). Freezing is related to water content and is thus more of a concern with the fleshy, immature fruits than with the immature seed crops. Solar injury (sunscald) is most likely to occur in eggplants because their shape (low surface to volume ratio) and relatively well-developed cuticle limit evaporative cooling. For the same reasons, calcium movement into eggplants may be limited, leading to calcium deficiency and blossom-end rot (Johnson, 1984).

A number of bacteria and fungi may cause postharvest rots of immature fruit vegetables (Table 5). These vegetables are usually not particularly susceptible to postharvest

Table 4 Physiological Disorders of Immature Fruit Vegetables

Freezing injury (preharvest and postharvest)
Chilling injury of all these crops except broad beans, peas, and sweetcorn
Solar injury (sunscald)
Blossom-end rot of eggplant (calcium deficiency)
Yellowing of green tissues—enhanced by C_2H_4

Table 5 Common Diseases of Immature Fruit Vegetables

Disease	Vegetables
Alternaria rot	Eggplants affected by chilling injury
Anthracnose (*Colletotrichum* spp.)	Snap beans, cucumber
Bacterial soft rot	Cucumber, eggplant, summer squash
Cottony leak (*Pythium* spp.)	Snap beans, cucumber, summer squash
Fusarium rot	Cucurbits
Gray mold rot (*Botrytis cinerea*)	Peas, bell pepper
Rhizopus rot	Cucumber
Watery soft rot (*Sclerotinia* spp.)	Snap beans, peas

Table 6 Generalized Postharvest Handling Procedure for Immature Fruit Vegetables

Step	Function
1.	Harvesting mostly by hand into buckets or trays; some harvesting aids are in use. a. Sweetcorn, snap beans, and peas are also harvested mechanically. b. Field-packed vegetables are usually not washed, but may be wiped with a moist cloth or spray-washed on a mobile packing line.
2.	For packinghouse operations, stacking buckets or trays on trailers or transferring to shallow pallet bins.
3.	Transporting harvested vegetables to packinghouse.
4.	Unloading by dry or wet dump.
5.	Washing or rinsing.
6.	Sorting to eliminate defects.
7.	Waxing cucumbers and peppers.
8.	Sizing.
9.	Packing in shipping containers by weight or count.
10.	Palletizing shipping containers.
11.	Cooling methods. a. Hydrocooling: beans, peas, sweetcorn. b. Forced-air cooling: chayote, cucumbers, eggplants, okra, summer squash. c. Slush-ice cooling and vacuum cooling: sweetcorn.
12.	Storaging temporarily.
13.	Transporting, destination handling, retail handling.

decays at their optimum storage temperature unless an injury causes a break in the cuticle, which may then serve as an entry point for wound-invading decay organisms such as *Erwinia carotovora* subsp. *carotovora* or *Rhizopus stolonifer*. More commonly, postharvest decays result from preharvest infections, usually on the underside of a fruit where it was in contact with the soil, especially in conjunction with wet conditions. Only a few decay organisms, such as *Fusarium* and *Cladosporium* spp., appear to be able to directly penetrate healthy tissue, but again usually only in conjunction with free moisture.

Immature fruit vegetables intended for fresh consumption are almost entirely hand harvested (Table 6). Those intended for processing are more likely to be machine harvested. Sweetcorn, green beans, and peas may be machine harvested for fresh market. Field packing is a viable option for most immature fruit vegetables. As long as the fruit are not likely to have come in contact with the soil during production, washing is not critical; most of these vegetables are not treated with postharvest fungicides and do not require extensive sorting, sizing, and grading. Only cucumbers commonly undergo application of coatings (waxing). All of the immature fruit vegetables may be hydrocooled.

II. POSTHARVEST PHYSIOLOGY AND HANDLING OF SELECTED IMMATURE FRUIT VEGETABLES

A. Green or Snap Bean (*Phaseolus vulgaris* L.)

The green, or snap, beans (also known as French beans or string beans) grown for vegetable consumption are immature, fleshy pods containing about four to 12 greenish or white, succulent seeds. The pods are typically 8 to 20 cm long and 1 to 1.5 cm wide. The best quality green beans are those harvested when the pods are about one-half to three-quarters of the maximum length (Yamaguchi, 1983). At this stage, the pods are tender and the seeds have not yet become starchy. Shewfelt et al. (1986) found that the percentage of seeds is a good index of snap bean maturity. The marketability of green beans is determined primarily by tenderness, crispness, green color, and freedom from blemishes. Tenderness is mainly affected by the fiber and pectin content of the pod tissue (Gonzalez et al., 1989). While Guyer et al. (1950) found no change in the proportion of fiber or seed in bush snap bean pods stored at 2, 10, or 21°C, however, Freeman and Sistrunk (1978) reported that shear values for snap bean pods increased with storage time and temperature. Lack of crispness, especially for immature pods, is due to wilting (Smith et al., 1982).

Chilling injury can occur at temperatures between 0°C and the chilling threshold temperature of 4–7°C (Table 3), the latter depending on the cultivar (Gorini et al., 1974; Kapitsimadi, 1989; Watada and Morris, 1966b). Development of russetting in response to CI is aggravated by free moisture and is especially noticeable in the center of shipping cartons where condensed water remains (Hardenburg et al., 1986). Above the chilling threshold temperature, storage life declines rapidly with increased temperature; for example, from 11 days at 5°C to only 2 days at 25°C (Watada and Morris, 1966a). The storage life of green beans is usually limited by fiber development (toughening), yellowing, and water loss (Costa et al., 1994; Littmann, 1967; Trail et al., 1992; Watada and Morris, 1966b).

Green beans are quite prone to oxidative discoloration when the epidermis of the pod is damaged. So-called "broken-end discoloration" (BED) resulting from enzymatic oxidation of phenolic compounds that are synthesized in the pod tissue in response to wounding (Buescher and Doherty, 1978; Buescher et al., 1974; Henderson and Buescher, 1977; Henderson et al., 1977b) varies with temperature (Reitmeier and Buescher, 1975) and cultivar (Henderson et al., 1977a; 1977b). This is a serious problem for mechanically harvested snap beans, which are often injured during the harvest operation. Both low temperature (i.e., rapid cooling) and elevated (10–20%) CO_2 atmospheres inhibit the development of BED (Reitmeier and Buescher, 1975). Hydrocooling is the most effective method for reducing snap bean temperatures and also improves pod texture by helping to maintain the pods in a more turgid state and more effectively reduces decay and BED than forced-air cooling or room cooling (Brecht et al., 1990a). The latter effect was found to be due to the presences of chlorine in the hydrocooler water rather than to leaching of phenolics or the faster cooling rate. Forced-air cooling is reasonably effective but requires careful management to avoid undesirable water loss (Risse and Craig, 1988). Controlled atmosphere (CA) storage has some potential for snap beans if used during long-distance (e.g., export) shipping because besides inhibiting browning, low O_2 and high CO_2 also reduce respiration, inhibit decay, inhibit yellowing, and reduce susceptibility to CI (Costa et al., 1994).

B. Bitter Gourd (*Momordica charantia*, L.)

Bitter gourd, also known as bitter melon, African cucumber, Karela, carille, art pumpkin, balsam pear, maiden apple, or koe, has great potential as a food source in both developing and developed countries and is rich in iron, phosphorous, and ascorbic acid (Kalra et al., 1988). The young fruit are normally cooked and eaten as a vegetable. To a lesser extent they are also canned in the form of pickles, and the seed is used as a condiment (Mohammed and Wickham, 1993). The fruit of bitter gourd has about 10 irregular, longitudinally rounded ridges and between them, smooth pebbled protrusions on the surface, which gives it a warty appearance. The fruit may be pear-shaped or oblong, in all varieties tapering toward the tip. Fruit size can vary from 4 to 30 cm in length and 1.5 to 6 cm in width (Yamaguchi, 1983). Fruit that are free of blemishes with bright, uniform green color, firm texture, and tender flesh, and that have immature seeds are considered to be of high quality. Being a fast bearing fruit, if bitter gourds are left on the vine for even 3 to 4 days beyond the marketable stage the fruit loses its luster and the seed coat becomes hard, making the fruit unfit for consumption (Abusaleha and Dutta, 1994). Fruit are therefore harvested when a desirable size is attained and while still tender. Tender fruit are usually white to green in color (Zong et al., 1993) and may be harvested between 50 to 70 days from sowing (Tindall, 1983).

The bitter gourd has high moisture content, large surface area/volume ratio, and relatively thin cuticle, which make it very susceptible to moisture loss and physical injury. Senescence of the fruit is rapid under tropical ambient conditions and is indicated by yellowing. This is followed by changes normally associated with ripening of the fruit: excessive softening, development of a bright yellow color, and intense red pigmentation of the arils (Mohammed and Wickham, 1993). Freshly harvested bitter gourd fruit are very turgid, and therefore must be handled with extreme care during packing operations. Prior to packing, all fruit that show signs of overmaturity (yellowing of the skin), decay, soft spots, cracks, sunken areas, bruises, or transit rub or that are badly misshapen or very immature should be discarded. Bitter gourds placed in full or half telescopic two-piece fiberboard cartons to net weights of 4.5 to 9 kg (9 to 20 lb) should be separated in single layers with a sheet of tissue paper. This will prevent damage caused by abrasions and compressions. The likelihood of such physical damage is related to the rough warty surface and thin skin of the fruit. Over- or underpacking of fruit that are not uniform in size could result in breakage of individual warts and lead to rapid senescence.

Since bitter gourd fruit are grown on trellises and are therefore not in direct contact with the soil, they may appear clean. Dust, pesticide residue, and unsanitized field containers make it imperative to wash the fruit after harvest, however. A postharvest dip treatment consisting of water at 8–10°C and 500 ppm sodium hypochlorite is administered for 45 min to remove the field heat and to eliminate surface pathogens (Mohammed and Wickham, 1993). Air drying of fruit to remove all water droplets is accomplished by spreading fruit in a single layer on absorbent paper for 42 to 45 min with an oscillating fan prior to packing to minimize fruit decay. Following this, fruit are individually wrapped and sealed in low-density polyethylene (LDPE) 1.2 μm thick and stored in ventilated fiberboard cartons.

Film-wrapped bitter gourd fruit in ventilated cartons should be cooled to 5–7°C immediately after harvest. Relative humidity (RH) in the storage room should be 85–95%. Storage under these conditions resulted in a storage life of 21 days, which was at least 15 days more than those stored at 20–22°C or 28–30°C (Mohammed and Wickham, 1993). At the two higher temperatures, storage life was shortened due to rampant development of stem scar and surface decay. Refrigerated storage (5–7°C) of individually wrapped bitter gourds can confer additional benefits by delaying ripening and senescence when compared with unwrapped fruit. While unwrapped fruit at 5–7°C maintained a green color and resisted decay, marketable quality ratings declined rapidly after 18 days because of extensive shriveling, reduction in firmness, and the appearance of visible symptoms of CI (i.e., pitting on ribbed regions that coalesced longitudinally) (Mohammed and Wickham, 1993). Film-wrapped fruit stored at 5–7°C remained marketable for up to 21 days with less fresh weight losses, less softening, less CI, reduced incidence of postharvest rots, and minimal changes in vitamin C content and pH compared with unwrapped fruit. Fruit stored at higher temperatures (20–22°C or 28–30°C) appeared desiccated and ripe within 10 days, producing a distinct color change from green to orange-yellow accompanied by marked splitting of fruit and a color change of the arillated seeds from creamy white to an intense red (Mohammed and Wickham, 1993). Zong et al. (1993) stored bitter gourds without any packaging treatments and concluded that a marketing period of 1 to 2 weeks is feasible at 10–12.5°C.

When bitter gourd fruit reach maturity, ripening is initiated within a week and the color changes from light green to yellow to orange. Ripening can be induced prematurely, however, by physical, insect, or pathogenic damage to the fruit at ambient temperatures. The development of orange pigmentation directly precedes rupture of the fruit wall and decomposition (Kays and Hayes, 1978). When ripe, the fruit has intensely red seeds that contrast strikingly with the orange pericarp. When fully ripe, the fruit pericarp splits into several valves, revealing the red seeds (Rodriguez et al., 1976). Bitter gourd fruit synthesize a large number of carotenoids during the ripening process, with cryptoxanthin being responsible for the orange color of the ripe fruit (Rodriguez et al., 1976).

Reports on the chemical composition of bitter gourd fruit are quite variable, and this may be related to cultivar differences, growth conditions, and preharvest cultural practices. Mathur (1954) reported the total carbohydrate content to be 4.2%. Kalra et al. (1983a) measured reported sugars to be 3.0–3.8% and total sugars to be 3.5–4.4%. Kalra (1983a) reported 6.2–6.9% for crude fiber, while Mathur (1954) reported levels of 0.8–1.70%. The protein content of bitter gourd was reported by Kalra et al. (1983a) to be related to fruit size, with larger fruit having a higher protein content than smaller fruit.

The same authors reported the occurrence of aspartic acid, serine, glutamic acid, threonine, alanine, γ-aminobutyric acid, citrulline, and pipeonic acid in bitter gourd fruit. Bitter gourd fruit are a good source of ascorbic acid. Kalra et al. (1983a) analyzed several cultivars and reported ascorbic acid ranging from 96.3 to 144.1 mg 100 g^{-1}. It was also claimed that ascorbic acid content decreased with maturity; while the smaller fruit contained 175.5 mg 100 g^{-1}, the larger fruit contained 92 mg 100 g^{-1}.

Bitter gourd fruit contain the enzyme peroxidase. The catechol activity, which causes enzymic browning, is reported to be low in bitter gourds (Kalra et al., 1988). The activity of catalase and peroxidase is highest in the outer scales and seeds (Kumar et al., 1991). The bitterness of the fruit is due to the presence of the akaloids charatin and momordicin (Kalra et al., 1983a).

Respiration of bitter gourd fruit can be classified as moderate. Zong et al. (1993) reported rates at 0°C as 4 ml CO_2 kg^{-1} h^{-1}, increasing two-fold at 5°C and up to 15, 27, and 34 ml CO_2 kg^{-1} h^{-1} at 10, 15, and 20°C, respectively. Bitter gourd fruit are sensitive to ethylene (Kalra et al., 1988; Kays and Hayes, 1978, Zong et al., 1993). As such, fruit must be isolated from all sources of ethylene, including ripening fruits, decaying commodities, and smoke. Kays and Hayes (1978) claimed that the evolution of CO_2 by bitter gourd fruit coincided with an increase in ethylene production following harvest. Bitter gourd may be a climacteric fruit since ethylene production increased sharply prior to visible changes in coloration and fruit ripening. Further tests to conclude its climacteric nature are warranted, however, even though Kays and Hayes (1978) also found that treatment of the fruit with exogenous ethylene resulted in a pronounced increase in the rate of ripening. Zong et al. (1993) also found that exposure of fruit to ethylene at 20°C greatly accelerated ripening and decay.

Kalra et al. (1983a; 1988) and Kumar et al. (1991) reported that bitter gourd fruit have a moisture content of 79.5–82.2% when freshly harvested. Mohammed and Wickham (1993) reported fresh weight losses of bitter gourds as high as 12.69% after 6 days at 20–22°C, and 29.95% after the same time at 28–30°C. When fruit were individually film-wrapped, however, the losses in fresh weight were 1.21% and 17.7%, respectively, for the same durations and temperatures.

Bitter gourd fruit can be classified as moderately sensitive to CI (Mohammed and Wickham, 1993). Fruit stored in air at 5–7°C developed visible symptoms of pitting after 12 days of storage. These symptoms were not apparent when the fruit were film-wrapped, however, suggesting that the water-saturated microenvironment created by sealing the fruit alleviated chilling stress. Transfer of fruit after 21 days to ambient conditions resulted in a progressive increase in the severity of CI, which was evidenced by high electrolyte leakage and low bioelectrical resistance as the duration of exposure to the warmer temperatures progressed. The symptoms of severe CI are extensive large pits in the ribbed regions, surface discoloration from green to dark brown, secondary infections, russetting, and internal breakdown (Mohammed and Wickham, 1993).

Mohammed and Wickham (1993) reported on the major causal organisms associated with fruit decay in bitter gourds that were secondary to the inception of severe CI damage. These included *Fusarium sp.*, *Gloesporium sp.*, *Chaetomella sp.*, *Erwinia sp.*, and *Curvularia sp.*

C. Cucumber (*Cucumis sativus* L.)

Cucumbers are immature, fleshy berries with a smooth, slightly ribbed, or warty surface and a thin but relatively strong peel. The fruit are harvested before they have fully elongated and while the seeds are still succulent (Yamaguchi, 1983). The proper harvest maturity and size varies by cultivar and intended usage. Slicing cucumbers typically are about 20 to 45 cm in length and 5 to 8 cm in diameter, while pickling cucumbers are less than 20 cm long. High quality cucumbers are dark green, firm, and turgid. Yellowing during storage is an indication of senescence and is promoted by ethylene exposure. As little as 1 $\mu l\ L^{-1}$ ethylene may cause noticeable yellowing within 1 day at 15°C (Apeland, 1961). While green color is an important quality factor in storage, it is poorly correlated with physiological age of cucumber fruit on the plant and thus is a poor maturity index (Schouten et al., 1999).

Cucumbers are very sensitive to CI in storage, but the degree of sensitivity varies among cultivars (Cabrera et al., 1992; Hakim et al., 1999; Kapitsimadi et al., 1991) and is greater in less mature fruit (Hirose, 1971, cited in Ryall and Lipton, 1979). Surface pitting is usually the first visible symptom of CI, followed by water soaking, tissue collapse, and shriveling. These symptoms are often not apparent at the chilling temperature, developing only upon transfer to ambient conditions, at which time rapid decay development also occurs. Other symptoms of CI include weight loss, increased respiration, ethylene production, electrolyte leakage, watery exudate, and changes in chlorophyll fluorescence (Cabrera et al., 1992; Hakim et al., 1999). Differences in chilling sensitivity among cucumber varieties depend on the CI symptom, with the greatest differences occurring in the onset and extent of pitting and decay (Hakim et al., 1999). Storage at high RH (Morris and Platenius, 1938) and application of hydrophobic coatings (Purvis, 1994) inhibit pitting development in chilled cucumbers by inhibiting the water loss that accompanies cell collapse in the pit areas, an observation that is often cited with regard to the distinction between injury per se in CI and the development of CI symptoms.

Cucumbers lose water easily after harvest and water loss is indicated by wrinkled or ''pinched'' stem ends and overall flaccidity. Cucumbers are usually waxed and held in high humidity (95% RH) storage to protect against water loss. Greenhouse types are often shrink-wrapped in plastic film for the same reason. The problem with water loss by cucumbers is exacerbated by their sensitivity to CI—the chilling threshold temperature of cucumbers is relatively high (Table 3), and they wilt and yellow rapidly at higher temperatures. This leaves only a narrow temperature range of 10–12°C within which cucumbers can be successfully stored for more than about 2 weeks. The characteristic flavor of cucumber is credited to the aroma volatiles trans-2, cis-6-nanadienal, and trans-2-hexanal, with a stronger flavor imparted by 2-nonenal (Forss et al., 1962). It is unclear how chilling temperatures may affect cucumber aroma and flavor; CI can cause inhibition of aroma volatile synthesis in other commodities, however (Maul et al., 2000). Since cucumbers are most commonly eaten in cold salads, it is questionable how important the characteristic aroma is to culinary quality. It has been recommended (Ryall and Lipton, 1979) that cucumbers can be stored briefly at temperatures of 5°C or less if they are to be consumed immediately because CI symptoms develop rapidly only at higher temperatures.

Cucumbers may be commercially cooled by several different methods, including room cooling, forced-air cooling, and hydrocooling. Room cooling is recommended only for cucumbers harvested in mild weather conditions that do not require substantial cooling to reach the optimum storage temperature. Hydrocooling is the most ideal cooling method for cucumbers because of their susceptibility to water loss. Attention must be given to sanitation of the hydrocooler water in order to prevent the hydrocooler from becoming a source of pathogen inoculation. DeEll et al. (2000) demonstrated that cucumbers can be hydrocooled using water temperatures below the chilling threshold without any detrimental affect on quality, presumably because of the very short exposure time. This technique can greatly reduce the required cooling time. Cucumbers are often packed in waxed shipping cartons whatever the cooling method in order to minimize water loss that occurs due to absorption of moisture by dry, uncoated fiberboard.

There is some disagreement over the potential benefits of CA storage for cucumbers. Ryall and Lipton (1979) indicated that proper CA conditions (i.e., 5% O_2 plus 5% CO_2) can be expected to add only about 4 to 6 days to the storage life of cucumbers and that care must be taken to avoid chilling temperatures because high CO_2 and low O_2 aggravate CI. Wang and Qi (1997), however, more recently reported that a CA of 1% O_2 plus 3% CO_2 was beneficial in reducing CI and maintaining cucumber quality, allowing the fruit to be stored at 5°C. The CA would also be expected to minimize the negative effects of ethylene.

D. Eggplant (*Solanum melongena* L.)

Eggplant, also known as melongene, baigan, or brinjal, is one of the staple vegetables of India, China, the southern United States, and the Caribbean. Eggplant is a warm season vegetable that requires a relatively long growing season to produce economic yields. Eggplant is a nonclimacteric fruit (Kader, 1992). The rate of respiration is classified as low to moderate, while C_2H_4 production rate is low (Kader, 1992). Eggplants are more sensitive to low temperature than either tomatoes (*Lycopersicon esculentum* Mill.) or sweet peppers.

The purple eggplant is most prevalent in the market; other types vary from egg-shaped to elongate. The fruit of eggplant should be dark purple, firm, and glossy, with a dark green calyx and stem. Dull and shriveled skin and browning of the calyx are indicative of excessive water loss and aging (Medlicott, 1990). Quality eggplants should also have relatively tender skin, flesh that is firm instead of soft or spongy, and succulent seeds (Maynard, 1987). White eggplant, considered a specialty item, usually is 15 to 20 cm long and has a green calyx and edible skin. In addition, there are miniature eggplants, also grown as specialties (Maynard, 1987).

The stage at which eggplant should be harvested can be difficult to identify without experience. Eggplants are initially very dark purple when immature, and when fully ripe very pale in color. In between these two stages is the correct time for harvesting (Mohammed and Sealy, 1986). Eggplant fruit begin to lighten from the tip, and this paling of color gradually extends back toward the calyx. Harvesting of eggplants is best when this color change is first seen, although the fruit can be left on the plant for up to a week after this without loss of quality (Mohammed and Sealy, 1986; 1988). Eggplants left beyond this time become pale and unattractive. Immature eggplants wrinkle and soften quickly after harvest and have a much-reduced shelf life. Maynard (1987) indicated that a suitable guideline to maximize both quality and yield would be to harvest fruit when they reach about 80% full size. Esteban et al. (1992) reported that sugar, ascorbic acid, and polyphenol contents increase during eggplant fruit development to reach maxima at about this stage. As the fruit mature, the flesh softens and becomes spongy. Eggplants are immature if an indentation remains after pressing the tissue with the thumb. Bitterness in eggplants is generally associated with overmaturity or production during periods of high temperatures (Maynard, 1987).

Fruit of marketable size should be cut or clipped from the plant, leaving the calyx attached to the fruit. The fruit stems are heavy and tough, and if not cut, excessive breaking of the branches or damage to the fruit will occur. Overmature fruit should be removed from the plant and discarded in the field to stimulate further flowering and fruit set. Other fruit showing signs of overmaturity, decay, soft spots, sunscald, insect damage, excessive scars, cracks, sunken areas, bruises, or other physical damage, are to be rejected in the field or prior to packaging. Care must be taken to ensure that the spines on the calyx do not damage the surface of adjacent eggplants in picking containers.

Harvested eggplants should be carefully placed in a suitable container for transport from the field. Careful handling is necessary, because even slight bruising will disfigure the skin. Harvested fruit, especially the purple types, should be protected from the direct rays of the sun because they are highly susceptible to sunscald. Under conditions of high solar radiation, an exposure period of 1 h is sufficient to render fruit unmarketable. For this reason, field containers should be of a light color to reflect as much solar radiation as possible.

Eggplants should be cooled promptly and rapidly after harvest. Mohammed and Sealy (1988) reported that hydrocooled eggplants had superior marketable quality ratings compared to air (dried) fruit after 8 days at 28–30°C. They also indicated that hydrocooling delayed the appearance of CI symptoms when fruit were stored at 5°C in comparison to air-cooled fruit. Hydrocooler water should be managed to maintain 100 ppm sodium hypochlorite.

Outgrading requirements based on the level of scarring and scabs (caused by aphids, mites, thrips, or windscar) vary between the varieties. 'Black Beauty'-type eggplants are unacceptable for the export market if scars and scabs are present with dimensions greater than 3 cm wide and a cumulative length of 4 cm. Green streaking from the stem is unacceptable in the 'Black Beauty' eggplant. The outgrading requirements for the 'Long Purple' type are slightly less stringent than for the 'Black Beauty' (Medlicott, 1990). Size grading into cartons is necessary with the 'Black Beauty' eggplant, resulting in small, medium, and large categories. All fruit should be of similar size in each carton. Some eggplants can be individually wrapped in paper and carefully packed into containers to prevent stems from puncturing the other fruit in the containers. Eggplant should be loose packed in full or half-telescopic two-piece fiberboard cartons to net weights of 4.9 to 9 kg. The larger net weight is suitable for the 'Long Purple,' while lower net weights are preferred for the 'Black Beauty.'

Eggplant fruit are chilling sensitive and deteriorate rapidly at warm temperatures, so they are not adapted to long storage (Hardenburg et al., 1986). Pitting, surface bronzing, and browning of seeds and pulp are symptoms of CI. Sensitivity of eggplant to CI differs with cultivar, maturity, size (i.e., maturity) of fruit, and season of harvest (Abe et al., 1976, 1980; Uncini et al., 1976). Ryall and Lipton (1979) indicated that pitting following breaks in the skin is induced during 4 days or even fewer at 0–1°C, and within 10 days at any temperature between 2–5°C. Pocking (scald), Alternaria rot, and death of the flesh are clearly evident at room temperature after prior exposure to 2–5°C for 6 days or to 4°C for 10 days. These symptoms are minimal after 10 days exposure to 10°C (Ryall and Lipton, 1979). Eggplants have a short shelf life, about 2 to 4 days under ambient conditions, after which visible changes in quality such as shriveling and softening become obvious. The shelf life of eggplants can be extended up to 15 days in refrigerated storage at 7 or 14°C (Mohammed and Sealy, 1988). The quality of eggplant is best at 7°C when compared to 14 or 30°C. Storage below 7°C, however, results in CI (Mohammed and Sealy, 1988). Sealing eggplants in LDPE or high-density polyethylene (HDPE) bags drastically reduced weight loss and consequently resulted in a superior quality for 15 days at 7°C (Mohammed and Sealy, 1988). The modified atmosphere as well as the saturated microenvironment created within the polyethylene bags are mainly responsible for the better quality mentioned above. If eggplants are packaged at 28–30°C, the result is faster rotting, particularly at the stem end. At this temperature, the RH in the enclosed package often becomes too high, making conditions favorable for growth of microorganisms and the development of decay.

Eggplants are very susceptible to water loss. Shriveling symptoms may become evident with as little as 3% weight loss (Gull, 1981). Precooling and storage in a high RH (90–95%) will minimize the weight loss. Wrapping eggplants with shrink film reduces weight loss and maintains firmness due to the high RH inside the wrap (Gull, 1981; Mohammed and Sealy, 1988). Eggplants can be waxed, but only a thin coating should be applied. Waxing provides some surface lubrication, which reduces chafing in transit. Water loss can also be minimized by packing eggplants into cartons having moisture-retentive liners or into perforated polyethylene bags (Gull, 1981; Mohammed and Sealy, 1988).

Exposure of eggplants to ethylene for 2 or more days hastens deterioration and results in fruit showing a lack of sheen. Decapping of stem and calyx also takes place, followed by rotting of the fruit.

The major postharvest diseases of eggplant are Alternaria rot, bacterial soft rot, Phomopsis rot, and Rhizopus rot. Alternaria rot (*Alternaria tenuis*) causes the development of numerous brown, sunken, circular spots. These spots, which can occur anywhere on the surface, including the calyx, have definite margins when small or after they coalesce to form irregularly shaped areas. Surface mold grows on old lesions and is dark gray, but may appear velvety and olive-green if covered with spores. The lesions may penetrate the flesh, where the affected tissue turns tan to grayish-tan and spongy (Ryall and Lipton, 1979). Alternaria rot develops in response to CI; thus the decay can be controlled by holding fruits at 10°C (Ryall and Lipton, 1979). The causal agent in bacterial soft rot is *Erwinia carotovora*. Eggplants infected with this disease produce lesions that are grayish-brown, with the skin being wrinkled with a watery underlying tissue. The bacteria enter through any puncture of the skin and grow very rapidly during warm, rainy weather. Very careful handling and rapid cooling to 10°C retard this decay. Phomopsis rot, caused by *Phomopsis vexans*, produces lesions that are circular with well-defined margins. Lesions are tan to light brown and are slightly sunken. The infection frequently originates under the calyx, but may occur anywhere on the surface of the fruit. Older lesions are darker brown at the center with a wide, lighter colored margin. Older lesions are pimpled with masses of fruiting bodies that lie just below the surface, but emerge when they break. Internally, much of the tissue may be affected, as shown by its light brown discoloration and spongy texture. This common and destructive disease of eggplants originates before harvest, particularly during warm, wet weather. The fungus grows best at about 26–30°C; thus prompt cooling to 10°C will substantially reduce this decay even if fruit with undetected infections are shipped (Ryall and Lipton, 1979).

E. Okra [*Abelmoschus esculentus* (L.) Moench.]

Okra is a member of the Malvaceace family. It is a perennial vegetable of the tropics but can be found growing in subtropical climates (Blennerhassett and El-Zeftawi, 1986). The fruit is a long pod that is generally ribbed, and it is harvested while still tender and immature. Fruit attain a length of 8 to 20 cm and a diameter of up to 3 cm or more. Primary pods are ready for harvest about 2 months after planting, but plants continue to bloom and set fruit if all pods are harvested at the proper early stage (Sackett, 1975).

High quality okra should be firm, fresh, and tender, with uniform pods that are relatively straight and green without indication of yellowing. Pods that are dull, flaccid, and yellowish are inferior, mainly because of their high fiber content. The size of okra pods seems to be related to maturity and quality. The crude fiber content of the biggest pods was found to be higher (7.78%) than that in smaller sized pods (2.27%) (Kalra et al., 1983b). The height of the ridges is not related to quality but is a genetic characteristic; however, the ridges should not be discolored (Gull, 1981). Because of the pod size requirements of marketers and the rapid rate of growth and development, okra have to be harvested every 1or 2 days to ensure that the pods are within the size specification range. Okra should not be harvested in the rain or when excessively wet. Pods should be handled with care; rubber gloves should be used during harvesting and handling, secateurs for harvesting, harvesting bags for collection, and ventilated field crates for transport prior to packaging (Medlicott, 1990). On harvesting, approximately 1 cm of the stem should remain attached to the pod. Oversized and damaged pods are to be removed from the plant, but outgraded in the field. Removal of pods that show discoloration, bruising (blackening of the ridges), chemical residue, or insect damage is required during grading procedures. All pods meeting the same size specifications can be loose packed into cartons. Okras are graded by hand on moving conveyors or standard grading tables.

Okra can be sprayed, washed, or placed in water dump tanks. Water for cleaning pods should be chlorinated at a concentration of 75 to 100 ppm of free chlorine. Following washing, excess water can be removed by sponge rollers or air blowers. Free water should be removed from the pods to prevent bleaching or discoloration. Prolonged contact of water on harvested okra causes spotting, therefore hydrocooling is not generally recommended. Okra has a very high rate of respiration and deterioration, therefore rapid precooling is desirable. Unless okra is cooled to below 15–16°C soon after being packed, the heat of respiration will cause the temperature of the product to rise rapidly and result in deterioration. A bleaching type of injury may develop when okra is held in containers for more than 24 h without refrigeration. Gull (1981) recommended cooling okra to 9–12°C before storage. Okra in good condition can be stored satisfactorily for 7 to 10 days at 7–10°C. At higher temperatures toughening, yellowing, and decay are rapid.

Okra has high rate of respiration. Pods stored at 25–27°C have a respiration rate of 328 to 362 mg CO_2 $kg^{-1}h^{-1}$. Low temperature storage drastically reduces the rate of respiration to 86 to 95 mg CO_2 $kg^{-1}h^{-1}$ at 10°C, and to 53 to 59 mg CO_2 $kg^{-1}h^{-1}$ at 4 to 5°C (Hardenburg et al., 1986). Okra is nonclimacteric in nature and is considered to be a low producer of ethylene. If okra pods are stored together with high ethylene producers such as passion fruit or banana or any other ethylene source, however, discoloration will be rapid, resulting in rapid senescence.

Okra is very susceptible to water loss. Wilting symptoms may become evident with as little as 3% weight loss. To avoid wilting, okra should be held in an atmosphere with about 90–95% RH. Containers with moisture barriers or prepackaging in perforated film would aid in maintaining freshness and also help avoid physical injury of the tender pods.

Okra is moderately susceptible to CI. Below 7°C, surface pitting, discoloration, and decay occur (Hardenburg et al., 1986; Ryall and Lipton, 1979). Holding okra for 3 days at 0°C may cause severe pitting (Hardenburg et al., 1986).

Postharvest decay organisms are obligate parasites and therefore do not normally enter the product through healthy exterior tissue. These organisms require mechanical damage or weakening of tissue before they can enter. Pathogens in contaminated water may enter through natural openings around the calyx, however. Alternaria rot is considered to be one of the major diseases in okra. The disease usually manifests itself by a general decay and brown exudation of viscous substances. Controlled atmosphere storage of pods had little direct effect on Alternaria rot (Baxter and Waters, 1990). Only an O_2 concentration of 0.5% was reported by Baxter and Waters (1990) to inhibit sporulation and mycelial growth of the pathogen.

F. Summer Squash (*Cucurbita pepo* L.)

Summer squash (or "vegetable marrow" in Great Britain) are immature fruit of *C. pepo*, the same specie as winter squash and pumpkin. Specific cultivars of summer squash are used for either immature or mature harvest, rarely both, while the vegetable marrow cultivars grown in Great Britain may be used at any stage of maturity. Dark green zucchini-type cultivars along with yellow crookneck and straightneck types and striped cocozelles and scallops are the most popular summer squashes (Paris, 1986; Robinson and Decker-Walters, 1997). There are also yellow versions of usually green summer squash that make use of the *B* allele (Sherman et al., 1987). Like cucumbers, summer squash are harvested when the seeds are still succulent, typically 3 to 7 days following anthesis (Yamaguchi, 1983). A good harvest maturity index is to pick summer squash soon after the blossom falls from the fruit because they are more tender and slightly sweet at this stage (Robinson and Decker-Walters, 1997). It is usually necessary to pick summer squash fruit every 1 or 2 days. Careful handling is critical to avoid damage to the epidermis, which can lead to increased water loss and decay.

The storage life of summer squash is quite short, about 1 to 2 weeks (Lorenz, 1951; Smittle et al., 1980). The fruit surface becomes dull, green summer squash begin to turn yellow, and the flesh softens. Susceptibility to CI varies among cultivars of summer squash, reportedly varying from 5–10°C (Ryall and Lipton, 1979; Sherman et al., 1987), although not enough work has been done to specify the exact threshold temperature for all of the different cultivars. In a comparison of several types of summer squash with and without the *B* allele, it was found that CI was least severe in the scallop type and most severe in the vegetable marrow type, with zucchini intermediate (Sherman et al., 1987). Weight loss and shriveling and loss of overall appearance quality 7 days after harvest were all most severe in the vegetable marrow type. Within summer squash types, the cultivars with the B allele were each worse than the normal cultivars for the same factors previously mentioned.

G. Sweetcorn (*Zea mays* L. var. *rugosa* Bonaf.)

Traditional sweetcorn varieties are *su1* (*sugary1*) mutants of wild-type corn that contain about twice the sugar (primarily sucrose) content of field corn as well as 8-to-10-fold higher water-soluble polysaccharide content. The latter imparts a creamy consistency to *su1* sweetcorn. Other mutants with increased sugar content have more recently been used, primarily *sh2* (*shrunken 2*), which has at least double again the sugar content of *su1*, but almost no water-soluble polysaccharides. Less commonly used is *su1/se* (*sugary-enhancer*); *se* modifies *su1* to also double the sugar content, but with no loss of water-soluble polysaccharide content (Wann et al., 1997). The *sh2* mutation inhibits starch biosynthesis, while *se* does not. These newer varieties are collectively referred to as "supersweet" sweetcorn. Supersweet varieties have become the dominant type in virtually all the major sweetcorn producing regions of the United States. The high initial sugar content coupled with inhibited starch synthesis in *sh2* varieties effectively doubles the potential postharvest life of sweetcorn. Supersweet varieties remain extremely perishable, however.

High quality sweetcorn has uniform size and color (yellow, white, or bicolor); sweet, plump, tender, and well-developed kernels; and fresh, tight, and green husks; and is free from insect injury, mechanical damage, and decay. Sweetness is the most important quality factor in consumer satisfaction with sweetcorn (Culpepper and Magoon, 1927; Evensen and Boyer, 1986; Showalter and Miller, 1962; Wann et al., 1971). All sweetcorn varieties lose sweetness and aroma during storage, but the taste of *su1* and *su1/se* varieties becomes starchy, while *sh2* varieties eventually taste watery and bland.

Sweetcorn harvest maturity is determined by a combination of ear fill, silk drying, kernel development, kernel sweetness, and kernel tenderness. The endosperm or juice appearance is a good indicator of maturity for *su1* and *se* varieties, where a milky (not watery or doughy) consistency represents proper maturity, but not for *sh2* varieties, which always have watery endosperm.

Sweetcorn is most commonly handled in wirebound wooden crates and, less commonly, in waxed fiberboard cartons or returnable plastic containers, all with a net weight of about 19 kg. Some sweetcorn is prepackaged in polyvinylchloride (PVC) film-overwrapped trays (Aharoni et al., 1996; Risse and McDonald, 1990), with the ends of the ears trimmed and the husks partially removed to expose some kernels. The PVC film is highly permeable to O_2 and CO_2 and acts primarily as a moisture barrier.

Rapid removal of field heat from sweetcorn, often at 30°C or higher, is especially critical to retard deterioration. Maximum quality retention can be obtained by precooling corn to near 0°C within 1 h after harvest and holding ears at 0°C during marketing. In practice cooling to this extent is rarely achieved. Cooling is the first step in a good temperature management program, however. Sweetcorn has a high respiration rate, which results in a high rate of heat evolution. Supersweet varieties have respiration rates equal to that of traditional sweetcorn varieties (Brecht et al., 1991) and lose sugars as rapidly (Brecht and Sargent, 1988; Evensen and Boyer, 1986; Olsen et al., 1991; Wann et al., 1971), so cooling is still critical. Sweetcorn should not be handled in bulk unless copiously iced, because it tends to heat throughout the pile.

Sweetcorn can be precooled adequately by vacuum cooling, but it must be wetted first (and top iced after vacuum cooling) to minimize water loss from husks and kernels (Showalter, 1957; Stewart and Barger, 1960). Crated sweetcorn can be vacuum cooled from about 30°C to 5°C in 30 min. Hydrocooling by spraying, showering, or immersion in water at 0–3°C is effective, although it takes longer than vacuum cooling for the same temperature reduction if the sweetcorn is packed before it is cooled. Bulk sweetcorn would take about 60 min to cool from 30°C to 5°C in a well-managed hydrocooler, while crated sweetcorn would take about 80 min (Talbot et al., 1989; 1991), and few, if any, operators leave it that long. It is important to check cob temperatures during hydrocooling to determine if temperatures are being lowered to at least 10°C. Hydrocooling nomographs for bulk and crated sweetcorn are available (Stewart and Couey, 1963). After hydrocooling, top icing is desirable during transport or holding to hasten continued cooling, remove the heat of respiration, and keep the husks fresh. When precooling facilities are not available, sweetcorn can be cooled with package ice and top ice. In a comparison of commercial cooling operations, ''slush ice'' cooling (injection of an ice-water slurry into sweetcorn cartons) was comparable to hydrocooling and better than vacuum cooling in maintaining sweetcorn quality (Talbot et al., 1989; 1991), probably due to residual ice in the cartons since the cooling rate was slower than for the other methods.

Traditional sweetcorn varieties are seldom stored because storage for more than a few days results in serious deterioration and loss of tenderness and sweetness. The sugar content, which largely determines quality in sweetcorn and which decreases rapidly at ordinary temperatures, decreases less rapidly if the corn is kept at about 0°C. The loss of sugar is about four times as rapid at 10°C as at 0°C (Appleman and Arthur, 1919). At 30°C, 60% of the sugars in *su1* sweetcorn may be converted to starch in a single day as compared with only 6% at 0°C. While *sh2* varieties lose sugars at the same rate as *su1* varieties, the higher initial sugar levels in *sh2* sweetcorn keep it sweet tasting longer. For *sh2* varieties, water loss and pericarp toughening supplant loss of sweetness in limiting postharvest life (Brecht et al., 1990b). The former is minimized by cooling promptly, trimming flag leaves and long shanks, and maintaining high RH, usually by icing. Water loss from husk leaves induces denting of the kernels by drawing moisture from them (Showalter, 1967). A loss of 2% moisture from sweetcorn may result in objectionable kernel denting. Pericarp toughening can also be minimized by prompt cooling and by maintaining sweetcorn at 0°C. Under optimum storage conditions, the potential postharvest life of *sh2* sweetcorn is more than 2 weeks.

Increased attention for CA and modified atmosphere packaging (MAP) for sweetcorn has been spurred by interest in using marine transport to export sweetcorn from the United States to Europe and the Far East, which can involve transit times on the order of 2 weeks or more. Research has shown that injurious atmospheres at 1.7°C contain less than 2% O_2 or more than 15% CO_2 (Spalding et al., 1978), resulting in fermentation and off-flavors and odors. Reduced O_2 and elevated CO_2 reduce respiration and maintain higher sucrose content, while elevated CO_2 also reduces decay and maintains husk chlorophyll levels (Aharoni et al., 1996; Schouten, 1993; Spalding et al., 1978).

Decay is not usually a serious problem with sweetcorn, typically occurring on the husk and silks when present. Trimming sweetcorn ears can induce decay development on the cut kernels and other damaged tissues mainly caused by *Alternaria alternata* (Fr.) Keissler, *Fusarium moniliforme* Sheldon, and *Mucor hiemalis* Wehmer (Aharoni et al., 1996; Barkai-Golan, 1981). Proper sanitation and temperature management are thus important to minimize decay in trimmed sweetcorn.

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