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Relationship between Weight Loss and Visual Quality of Fruits and Vegetables

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Loss of water from harvested fruits and vegetables is a major cause of postharvest deterioration. Loss of substantial amounts of water may result in important quality and economic losses, and even when weight losses are subtle, the visual, compositional and eating quality of the produce may be impaired. Fourteen freshly harvested fruits and vegetables were stored at 20 °C and 85% to 95% relative humidity (RH), and weight loss and visual quality attributes (firmness, wilting, shriveling or browning) were evaluated every day or every other day until each individual fruit or vegetable was considered unacceptable for sale. A highly significant correlation was found between weight loss and visual quality attributes for each fruit and vegetable evaluated. As weight loss increased during storage, firmness decreased, and wilting, shriveling or browning increased. A maximum acceptable weight loss before each selected fruit and vegetable became unacceptable for sale is suggested.

Postharvest water loss has a great impact on fruit and vegetable quality and is a major cause of deterioration. Substantial water loss may result in a significant loss of fresh weight, resulting in economic loss if the commodity is sold by weight. Slight moisture loss can cause subtle quality changes in color and texture, and when the critical moisture loss threshold is reached, more obvious deleterious changes in turgidity, firmness, discoloration, flavor and nutritional value can occur. Accelerated senescence, increased pathogen invasion, and increased susceptibility to chilling injury have been reported to result from weight loss (Kays and Paull, 2004).

The rates of water loss vary widely among different fruits and vegetables, even when stored under the same environmental conditions (i.e., temperature and humidity). In general, tubers and bulbs tend to lose water at a slower rate than soft fruits, while leafy vegetables are extremely vulnerable (Kays and Paull, 2004). Nevertheless, the quality of most fruits and vegetables declines very fast with only small moisture losses, and in general, a loss of 3.0% to 10.0% may render a wide range of horticultural crops unacceptable for sale (Robinson et al., 1975).

Paull and Chen (1989) suggested that the major pathway for weight loss in papaya was mainly due to water lost through the stem scar, the stomata and the cuticle. Thus, the amount of water lost by a papaya fruit may differ depending on the cuticle thickness, which is in turn cultivar and maturity dependent. In fruits or vegetables, where a cuticle or natural waxy surface is absent (e.g., strawberry or mushroom) the difference in morphology may account to different rates of weight loss. Therefore, difference in weight loss between some fruits and vegetables, when stored under the same temperature and humidity conditions, may result not only from differences in physiological behavior, but also from differences in form and structure. For example, in mushroom the lack of a protective cuticle makes it more susceptible to water loss at a faster rate than tomato, which has a relatively thick waxed cuticle that protects the fruit from loosing water. On the other hand, compared with fruits where a waxed cuticle is absent, such as strawberry or raspberry, the rate of water loss in mushroom may be higher than in the latter. This may be explained by the fact that in mushroom the surface area exposed (i.e., cap, stalk and gills) is greater than in strawberry or raspberry. Cultivar variations as well as maturity at harvest, may also account for differences in the rate and amount of water loss within same fruit or vegetable category. For example, Sherman et al. (1987) showed that weight loss during storage under the same temperature and RH conditions depends on cultivar characteristics and that after 14 d at 5 °C weight loss of different summer squash cultivars varied from a maximum of 15.0% to a minimum of 3.0%, depending on the cultivar.

Although some studies describe water loss and quality changes in selected fruits and vegetables during storage, information is either inaccurate or incomplete regarding the environmental conditions during storage. Studies often compare only weight loss and shriveling rates, and disregard other quality changes. The objective of this work was to show the relationships between weight lost during controlled temperature and humidity storage, from fourteen freshly harvested fruits and vegetables, and the major visual symptoms of loss of quality associated with moisture loss, such as changes in general appearance, color, and texture.

Material and Methods

PLANT MATERIAL AND STORAGE CONDITIONS. Green asparagus cv. Guelph Milennium, green bell pepper cv. Bell Boy, lettuce cv. Boston, first flush white mushroom cv. Paris, three-quarter colored (i.e., light red) greenhouse-grown tomato cv. Trust, witloof chicory cv. Focus, high bush blueberry cv. Patriot, red raspberry cv. Killarney and three-quarter to full colored strawberry cv. Seascape were obtained from commercial operations in Quebec, Canada, during the 2000 and 2001 normal harvesting

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seasons. Snap beans 'Opus' and 'Leon', yellow summer squash 'Horn of Plenty' and 'Medallion', medium-ripe (i.e., more than 50% yellow or red) mango fruit 'Tommy Atkins' and 'Palmer' and "color break" (i.e., at the initiation of the change from green to yellow surface color) papaya fruit 'Exp.15' were obtained from commercial operations in Florida during the 2001 normal harvesting seasons. 'Dixieland' and 'Flame Prince' peach cultivars were harvested tree-ripe, that is, with maturity of about chip five (Meredith et al., 1989) and skin ground color L* = 66, a* = 8.4, and hue = 77.8, from a commercial field in Georgia during Summer 2001.

Commercially harvested fruits and vegetables were removed from the field with minimal delay after harvest and transported to the laboratory in Quebec City, Canada, or in Gainesville, FL, within ~1 to 6 h after harvest, depending on the distance from the field to the laboratory. A total of two harvests (experiments) were conducted for each fruit or vegetable. Upon arrival at the laboratory, fruits and vegetables were selected for uniformity of color and size, and freedom of defects, distributed by three subsamples and kept in either clamshells or larger plastic baskets for small or large commodities, respectively. A total of 45 asparagus spears and snap bean pods; 15 green bell peppers and lettuce heads; 30 mushrooms, raspberries, and strawberries; 16 tomatoes; and nine chicory heads, yellow summer squashes, mangoes, papayas, and peaches, were selected and stored under controlled temperature-humidity conditions for 3 to 18 d, depending on the commodity. Fruits and vegetables harvested in Canada were stored in a temperature-humidity controlled room at 20.5 °C ± 0.7°C and 90.0% ± 2.0% RH, and those harvested in the USA were stored at 20.0 °C ± 0.2°C and 90.0% ± 5.0% RH. Nondestructive quality evaluations were performed every day or every 2 d, always by the same trained individuals.

Weight loss. Pepper, lettuce, tomato, chicory, squash, mango, papaya, and peach were weighed individually, whereas each one of the three subsamples of 15 asparagus spears or snap bean pods were weighed individually. Similarly, each one of the three subsamples of 10 mushrooms, blueberry, raspberry, or strawberry was weighed individually. Weight of each subsample was measured using a precision scale with an accuracy of ±0.01 g (Acculab Model LT-3200, Acculab-Sartorius Company Group, Germany). Weight loss was then calculated from the weight of the fruit or vegetable measured at harvest and after every day or every 2 d of storage, depending on the commodity.

Color and firmness. Color was determined subjectively using a 1 to 5 visual rating scale (Table 1), and firmness was determined subjectively based on the whole fruit resistance to

Table 1. Visual rating scale for color.

	Scores and description				
	1	2	3	4	5
Asparagus[z]	Field-fresh, dark green, stalk is glossy	Dark green stalk, less glossy	Moderate browning of stem bracts	Slight browning of spear, and objectionable browning of the bracts	Browning of stem bracts, and of almost all the spear
Lettuce[y]	Fresh cut appearance, bright light green	Slight leaf discoloration, light green	Moderate leaf discoloration, green w/some yellow areas	Severe leaf discoloration, brownish-yellow	Extreme leaf discoloration, very dark brownish-green or yellowish-green
Mushroom	White and smooth glossy cap surface, stipe and gills, no signs of browning	White cap surface, stipe and gills, but less glossy, slight browning	Light brownish-creamy surface, and moderate browning	Light brownish surface, brownish stipe and gills	Completely dark brownish
Pepper, green bell[x]	Completely dark bright green	Dark green, less bright	Green, showing some loss of glossiness	Slight discoloration	25% red, yellow or other coloration
Snap bean[w]	Extremely bright green	Less bright green	Green	Dull green, yellowing	Extremely dull green, or completely yellow
Tomato	Light red color with traces of green (75% red)	Light red color, no trace of green	Red color	Dark red color	Very dark red color, overripe
Witloof chicory[v]	Fresh cut appearance, white color w/cream-yellow leaf edges, no trace of green or reddish discoloration	Slight discoloration, less white, and darker yellow leaf edges	Moderate discoloration, white color w/traces of some greenish-yellow color, or slight reddish discoloration	Severe discoloration, yellowish-green or brownish-green, marginal leaf browning	Extreme discoloration, green and/or brownish leaves, leaf surface is green, reddish discoloration objectionable
Blueberry[u]	Bright blue color, abundant waxy bloom	More deep blue	Dark blue, less waxy bloom	Very dark blue	Purple brownish-blue or black, no waxy bloom, overripe
Mango[t]	Half green half yellow-orange/red	More yellow-orange /red blush than green	Mostly yellow-orange/red with just a hint of green	Predominantly yellow-orange/red	Fully yellow/red
Papaya[s]	More green than yellow (color break to quarter-ripe)	Half green and half yellow (half ripe)	More yellow than green (three-quarter ripe)	Fully yellow	Fully yellow and overripe
Raspberry[r]	Very bright red color, reddish-orange	Bright red color	Red	Dark red	Dark dull brownish-red (overripe)
Strawberry[q]	Three-quarter to full red	Fully light red	Fully dark red	Very dark red (overripe)	Extremely overripe, brownish-red/purple

[z](King et al., 1988); [y](Kader et al., 1973); [x](Lownds et al., 1994); [w](Martinez et al., 1995); [v](Rubatzky and Salveit, 2004; Ryder, 1979); [u](Jackson et al., 1999; Sapers et al., 1984); [t](Jacobi et al., 1998); [s](Lam, 1990; Maharaj and Sankat, 1990); [r](Perkins-Veazie and Nonnecke, 1992; [q](Miszczak et al., 1995).

slightly applied finger pressure and recorded using a 1 to 5 tactile rating (Table 2). For most fruits and vegetables, a color rating of 3 was considered to be the limit of acceptability for sale, except for tomato, mango, and papaya, which can still be acceptable when color attains rating of 4. A firmness rating of 3 was considered to be the limit of acceptability for sale for all fruits and vegetables evaluated.

Shriveling. Shriveling, wilting, or dryness was determined subjectively using a 1 to 5 visual rating scale where: 1 = field-fresh, no signs of shriveling, wilting or dryness; 2 = minor signs of shriveling, wilting, or dryness; 3 = shriveling, wilting, or dryness evident but not serious; 4 = moderate shriveling, wilting, or dryness; 5 = extremely wilted and dry (Kader et al., 1973; King et al., 1988; Krarup, 1990; Quintana and Paull, 1993; Sherman et al., 1987). A shriveling rating of 3 was considered to be the limit of acceptability for sale.

Opening of the cap. Opening of the cap in mushroom was assessed using a visual rating scale modified from Roy et al. (1995) where: 1 = veil completely intact (tight), cap very close, gills not exposed; 2 = veil slightly broken but not opened; 3 = veil slightly broken, gills start to be slightly exposed; 4 = cap open, gills well exposed; 5 = cap open, gills surface flat. A total rupture of the veil exposing the dark gills underneath is considered as the complete cap opening, as against partial opening when the rupture of the veil does not show the gills (Gautam et al., 1998).

Statistical analysis. Data from two different harvests were combined and analyzed simultaneously using the Statistical Analysis System Computer Package (SAS Institute, Inc., 1982). Linear correlation analysis using Pearson's correlation coefficient was used to relate commodity weight loss to visual quality changes during storage.

Results and Discussion

Weight loss. Weight loss occurred during storage regardless the type of fruit or vegetable evaluated (Figs. 1–2). However, the rate of water loss was dependent on the type of crop evaluated, and was greatly related to the physiological and morphological characteristics of each individual fruit or vegetable, and with the expected shelf life under the environmental conditions used in this study.

In green asparagus 'Guelph Millennium', firmness to the touch decreased during storage (Fig. 3), but the tip of the spear was the first to show symptoms of loss of firmness, probably because of its greater fragility compared to the body of the spear. Besides, some of the asparagus tips became very soft and slimy after storage. When weight loss reached a maximum of 5.0%, 'Guelph Millennium' asparagus spears became less turgid and less straight, and bent easily. After 5 d, when weight loss attained 8.0%, browning of the bracts, feathering, dryness of the tips, and shriveling of the

Table 2. Tactile rating scale for firmness.[z]

	Scores and description				
	1	2	3	4	5
Asparagus[y]	Extremely soft, stem may collapse	Soft, bends easily, feathering of the spears	Moderately tender and firm	Tender and firm	Extremely tender and firm, closed compact tips, stalk is straight
Lettuce[x]	Extremely soft, leaves are completely limp and bendy	Evident loss of turgidity, leaves are limp, bendy and very soft	Firm, but some leaves may start to lose turgidity and become limp	Firm, leaves are still turgid and crunchy	Soft, but very firm and turgid, easily compressed, leaves are very firm, turgid and brittle
Pepper, green bell[w]	Flaccid, no resistance to finger pressure	Slightly firm, slightly resistant	Moderately firm, moderate yield	Firm, slight yield	Very firm, no yield
Snap bean[v]	Extremely soft, does not snap	Soft, bend easily	Moderately tender and firm	Tender and firm	Extremely tender and firm
Squash, summer	Very soft on touch	Soft on touch, particularly in the neck	Minor signs of softness on the neck	Less firm	Very firm and turgid
Tomato[u]	Completely soft, cedes easily to finger pressure	75% of the fruit is soft	50% of the fruit is soft	25% of the fruit is soft	Very hard and turgid
Witloof chicory	Very soft leaves and core, leaves are opened or torn	Major signs of softness, particularly in the external leaves (lose leaves)	Still firm, but not brittle, loss of turgidity, with some signs of softness	Fairly brittle, slight signs of head softness	Very brittle, firm and turgid, leaves are tightly attached to each other and snap easily; head is very compact
Blueberry[t]	Berry rupture on touch, very soft	Berry surface very depressed on touch, but no rupture	Berry surface depressed on touch	Slightly depression on touch	Berry firm, not yielding to touch
Mango, papaya, peach[s]	Very soft to the touch, does not offer any resistance to finger pressure	Soft to the touch, slight resistance to finger pressure	Moderate signs of softness, moderate resistance to finger pressure	Firm to the touch, substantial resistance to finger pressure	Very firm to the touch, very hard fruit with no esistance to finger pressure
Raspberry, strawberry	Very soft, leaky and deteriorated	Soft and leaky	Moderately firm	Firm	Very firm and turgid

[z]Firmness rating of 3 was considered to be the limit of acceptability for sale.
[y](King et al., 1988); [x](Kader et al., 1973); [w](Miller et al., 1986); [v](Martinez et al., 1995); [u](Artés et al. 1999); [t](Miller and Smittle, 1987; Miller et al., 1984; Sanford et al., 1991); [s](Hofman et al., 1997; Jacobi et al., 1998; Robson et al., 1989).

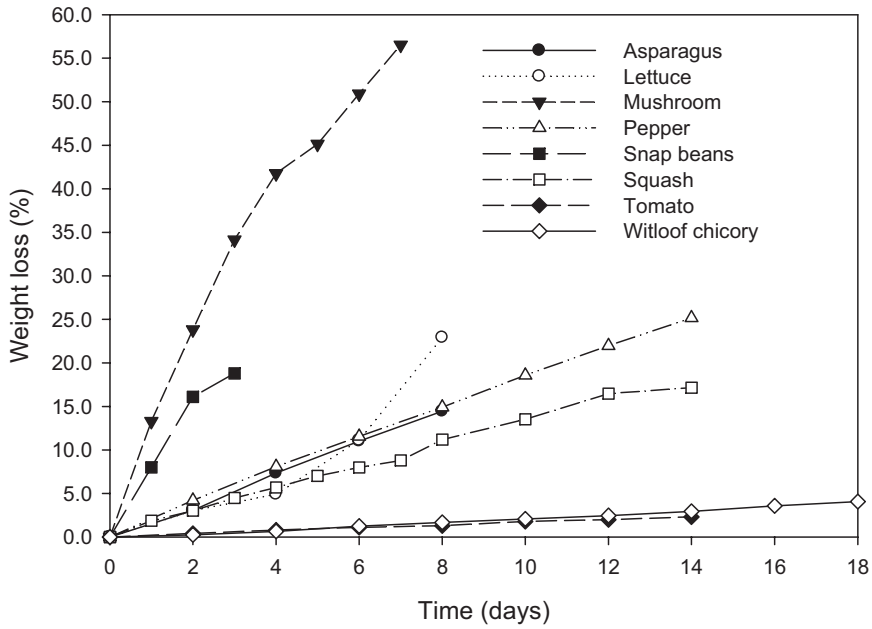

Fig. 1. Weight loss from various vegetables during storage at 20 °C and 85% to 95% relative humidity.

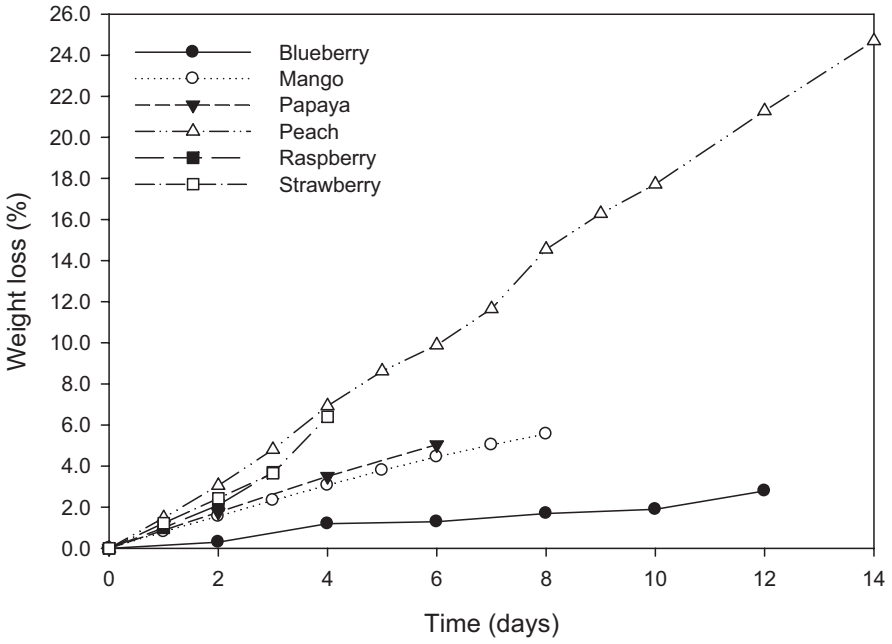

Fig. 2. Weight loss from various fruits during storage at 20 °C and 85% to 95% relative humidity.

stem became objectionable (Fig. 3, Table 3). Other studies have also shown that asparagus spears can lose significant amounts of water, becoming less turgid, softer, and with increased fibrousness when stored under adverse ambient conditions. For example, asparagus spears lost ~2.0% of their initial weight in 24 h if held at temperatures between 20 and 22 °C, and 65.0% to 70.0% RH (Fehér, 1994). Compared to storage at 4 °C, asparagus stored at 20 °C for 1 d showed a rapid increase in cell wall thickness and, consequently, increased toughness (Zurera et al., 2000). Likewise, storage for 3 d at 21 °C significantly increased asparagus strength mainly in the last portion of the stem (Rodriguez-Arcos et al., 2002). Textural changes during postharvest life of asparagus are also markedly affected by the tissue water status. Cell expansion was shown to continue even without any water supply, particularly in the first 24 h at 20 °C, due to internal reallocation of water from other parts of the spear (Heyes et al., 1998). In asparagus stored at 20 °C, the bracts lost their turgidity within 48 h while auxiliary buds and central meristem retained turgidity for over 96 h (Heyes et al., 1998).

Development of wilting is largely associated with moisture loss, which is generally faster in leaf lettuce when compared to other types of head lettuce. For example, in 'Boston' lettuce initial symptoms related to moisture loss, such as wilting and loss of leaf turgidity, became apparent when weight loss reached ~2.7% (Fig. 3), while 'Iceberg' lettuce stored for 2 weeks at 2 °C showed objectionable wilting levels when weight loss attained

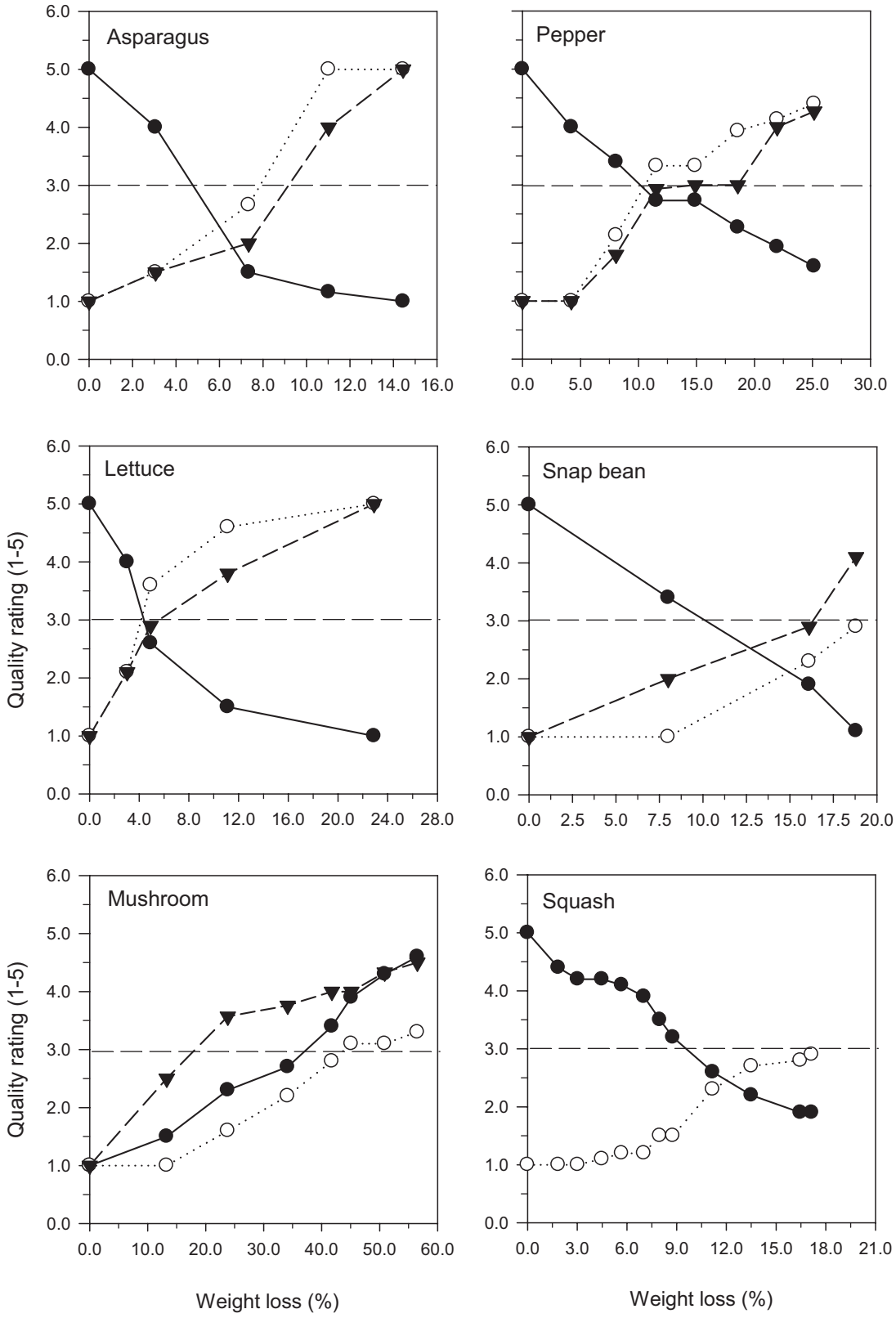

Fig. 3. Relationship between weight loss and visual quality of various vegetables stored at 20 °C and 85% to 95% relative humidity (the dotted line corresponds to the limit of acceptability before the quality of the fruit became unacceptable). (●) Firmness; (○) shriveling, wilting, drying; (▼) color changes. In mushroom, ●) dryness of the cap and stalk; (○) cap opening and stipe elongation; (▼) color changes.

Table 3. Maximum acceptable weight losses from various vegetables stored at 20 °C and 85% to 95% relative humidity (RH) before the commodity becomes unacceptable for sale.

	Maximum acceptable loss (%)[z]	Holding period (days)	Symptoms
Asparagus	5.0 to 8.0[y]	3 to 5[x]	Softening of the tips, darkening of the color, browning of the bracts, feathering, dryness of the tip, shriveling of the stem
Lettuce	4.0 to 5.0	3 to 4	Wilting, loss of turgidity, yellowing of the leaves
Mushroom	15.0 to 45.0[w]	1.5 to 5	Browning, dryness of the cap and stipe, cap opening
Pepper, green bell	10.0 to 11.0	4 to 6	Softening of the tissues, skin shriveling, browning of the stem, development of coloration
Snap bean	10.0 to 19.0	2 to 3	Softening, browning, shriveling of the pod edges
Squash, yellow summer	10.0 to 17.0	7 to 14	Softening, skin shriveling and dryness of the internal tissues of the neck
Tomato	1.0 to 2.0	5 to 11	Softening, darkening of the color, over ripeness, shriveling of the skin is not a problem if at 90% RH
Witloof chicory	2.5 to 3.5	12 to 15	Softening of the head, wilting of the outer leaves, browning of the leaf edges, greenish color development

[z]Percentage of original fresh weight.
[y]Lower weight loss values corresponds to first signs of water loss (i.e., softening); higher weight loss values correspond to objectionable visual quality (i.e., softening, changes in color and shriveling).
[x]Shorter holding periods correspond to first signs of water loss; longer holding periods correspond to objectionable weight loss.
[w]Objectionable browning developed at 15.0% weight loss; dryness of the cap and stalk were evident at 35.0% weight loss, cap opening and stipe elongation occurred at 45.0% weight loss.

~6% (Artés and Martínez, 1996). After ~4 d at 20 °C, 'Boston' lettuce leaves had 5.0% weight loss, were limp and flaccid, and greenish-yellow (Figs. 1 and 3, Table 3). In another study, after ~2 d, lettuce stored at 20 °C attained a 3.0% to 5.0% weight loss, depending on the cultivar, and were considered unacceptable for sale (Robinson et al., 1975). Differences in holding periods until maximum acceptable weight loss is attained may be related to differences in RH during storage under same temperature conditions. That is, when held at the same temperature but different humidity levels, lettuce exposed to low RH will tend to lose water faster that lettuce exposed to higher RH.

Hughes (1959) found that black stems (i.e., stipes) and open veils in mushrooms were correlated with the rate of water loss. Thus, as weight loss increased, mushroom caps and stems developed a brownish dark color while the cap opening increased, exposing the gills. Weight loss from mushrooms stored at 18 °C and 90% to 95% RH was ~10% per day, and after 5 d mushroom initial weight was reduced by 50.0% to 60.0% (Smith et al., 1993). Narvaiz (1994) considered a weight loss of 14% still acceptable in mushrooms stored for 12 d at 12 °C. However, results from the present study show that the maximum weight loss before mushrooms were judged unacceptable varied greatly, depending on the quality attribute evaluated (i.e., cap opening, dryness, or browning of the cap). Thus, a weight loss between 15.0% and 17.0% would correspond to a maximum acceptable discoloration (i.e., browning), or before the mushrooms were considered unacceptable for sale, while a weight loss of 24.0% to 46.0% would correspond to a maximum acceptable cap opening. Moreover, a weight loss of 22.0% to 42.0% would correspond to a maximum acceptable dryness (Fig. 3). Since discoloration (i.e., browning) was the quality characteristic that primarily limited the postharvest life of the mushrooms, it should be considered the quality factor best related to the maximum acceptable weight loss before mushrooms became unacceptable for sale. Therefore, a weight loss of ~15.0% may be considered to be the maximum acceptable before mushroom quality become objectionable (Fig. 3, Table 3).

Development of flaccidity in green bell pepper appears to be directly associated with water loss (Lownds et al., 1994). In the present study, 'Bell boy' green peppers developed objectionable softening and flaccidity, shriveling of the skin, and development of yellow coloration after 6 d at 20 °C, when weight loss attained 11.0% (Fig. 3, Table 3). In another study, Hruschka (1977) also reported that deterioration in commercial appearance of green bell peppers accompanied moderate shriveling symptoms, and was noted when weight loss averaged 12.0% (Hruschka, 1977). According to Robinson et al. (1975), a weight loss of ~7.0% should be considered the maximum acceptable before green pepper becomes unacceptable for sale. Lownds et al. (1994) reported that New Mexican type of peppers became flaccid in 3 to 5 d at 20 °C, which corresponded to a weight loss of 7.0% to 10.0%. González and Tiznado (1993) also observed that when green peppers lost 5.0% of their original weight, initial signs of shriveling took place. Therefore, according to the results from the present study, and from other published studies, maximum acceptable weight loss for pepper should be considered between 5.0% and 12%, depending on the type of cultivar.

Softening of 'Opus' and 'Leon' snap beans developed after 2 d of storage at 20 °C when weight loss attained 10.0% (Fig. 3), while browning and shriveling of the pod edges developed when weight loss attained ~16.0% and 19.0%, respectively (Fig. 3, Table 3). Thus, overall quality of snap bean became objectionable when weight loss attained 19.0% of the initial weight (Fig. 3, Table 3). Loss of turgidity and crispness of snap bean pods was attributed to loss of water and also to increased soluble pectin (Sistrunk et al., 1989). According to Robinson et al. (1975), snap beans were considered unacceptable for sale after a loss of weight greater than 5.0%, while Hruschka (1977) reported that deterioration in commercial appearance when weight loss attained ~41.0% of bean initial weight. The large divergence between weight losses

might be explained by differences in cultivar morphology (i.e., thickness of the epidermal and hypodermal layers) and maturity at harvest (Reeve and Brown, 1968).

'Horn of Plenty' and 'Medallion' yellow summer squash lost 17.0% of their initial weight after 14 d at 20 °C. At this weight loss, softening of the whole fruit became objectionable, and shriveling of the skin, dryness of the internal tissues, particularly in the neck area, rendered the fruit unacceptable for sale (Fig. 3, Table 3). According to data found in the literature, first signs of shriveling in yellow crookneck squash are noted when weight loss reaches 10.0 to 58.0%. Deterioration in commercial appearance accompanies moderate shriveling symptoms, which are noted when percent weight loss reaches about 24% (Hruschka, 1977). Again, differences between weight loss and development of first visual symptoms of deterioration may be related to cultivar variation, maturity and quality criteria used to evaluate loss of visual quality.

Greenhouse-grown 'Trust' tomato used in the present study, showed objectionable softening and overripe appearance after 11 d of storage, when weight loss attained 2.0%. Although the fruit were completely soft and unacceptable for sale after 14 d of storage at 20 °C, shriveling was not yet visible (Fig. 4, Table 3). Therefore, shriveling of the tomato skin was not considered an important quality limiting factor compared to fruit softening. Quality deterioration of 'Trust' tomato occurred at lower weight loss when compared to weight loss reported in the literature. For example, Robinson et al. (1975) and Hruschka (1977) reported a maximum acceptable weight loss before tomato become non saleable which varied between 6% and 7.0%. In another study, appearance of mature-green tomato started to deteriorate due to development of wrinkles, shrinkage of the skin, and loss of brightness after 3 weeks at 12 °C and 85% RH, and after 4 weeks tomato had lost about 9.8% of its initial weight (Bhowmik and Pan, 1992). Differences in weight loss before visual deterioration of tomato occurs are most likely related to cultivar variations, such as for example size of the fruit, thickness of the cuticle, and may also be related to the size of stem scar. Besides, in the literature, the maximum acceptable weight loss is established based mostly on shriveled appearance of the fruit, which in the case of 'Trust' tomato never develop during the evaluation period considered in the present study. However, even though the skin of the fruit maintained acceptable visual integrity, the tomatoes were extremely soft, ceding easily to slight finger pressure.

Weight loss of witloof chicory attained a maximum level of ~4.0% after 18 d at 20 °C (Fig. 1). Softening of the chicory heads and wilting of the leaves, some of the signs that the moisture loss from the chicory leaves started to be objectionable, became unacceptable after ~12 d when weight loss attained 2.5%. Browning on the outer leaf edges and leaf green coloration developed during subsequent storage, becoming objectionable after 15 d, when weight loss attained about 3.5% (Fig. 4, Table 3). Witloof chicory leaves should be pure white with creamy-yellow points and not have any torn, greenish leaves or reddish discoloration. Witloof chicory cultivars vary in flavor and bitterness, and when exposed to light and high temperatures chicon rapidly turn green and increase in bitterness (Ryder, 1979; Rubatzky and Salveit, 2004).

After 10 d at 20 °C weight loss of highbush 'Patriot' blueberry attained 2.0%, the fruit appeared shriveled, darker in color, slightly soft and unacceptable for sale (Figs. 2 and 5, Table 4). On the other hand, maximum weight loss before lowbush blueberry becomes non-salable, was reported to be about 5.0 to 8.0% (Sanford et al. 1991). Differences is weight loss before the berries of low and highbush cultivars become unacceptable for sale may be explained by the size of the fruit, and also by the amount of waxy bloom. The waxy bloom or simply bloom is the grayish waxy deposit on the skin of the berries, which is a natural protective coating. The amount of bloom depends on the variety of the berry but also on the degree of freshness (Jackson et al., 1999; Sapers et al., 1984). Furthermore, 'Patriot' blueberry, and highbush cultivars in general, are larger, and have a higher surface area than the fruit of lowbush cultivars, which makes them more susceptible to develop symptoms related to water loss (Makus and Morris, 1993). Cultivar variations within the same type of blueberry (i.e., low, highbush or rabiteye) may also influence the rate of water loss during storage. For example, during simulated marketing condition (21 d at 5 °C) weight loss of rabbiteye blueberry varied between 4.5 and 6.7%, for 'Climax' and Woodward' blueberries, respectively (Smittle and Miller, 1988). Firmness of 'Patriot' blueberry decreased during storage, but it never reached unacceptable levels even after 12 d at 20 °C (Fig. 5). Blueberries of the cultivar Patriot are bigger and firmer

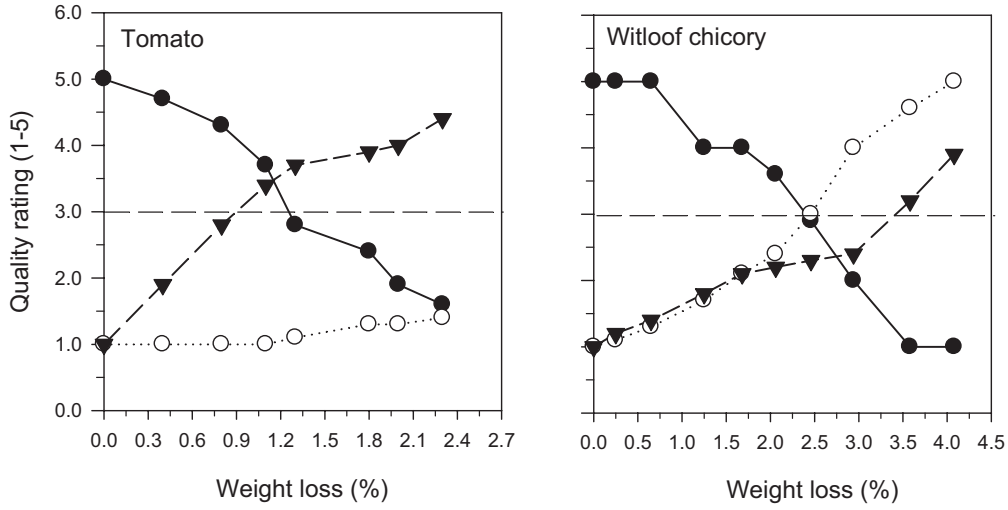

Fig. 4. Relationship between weight loss and visual quality of tomato and witloof chicory stored at 20 °C and 85% to 95% relative humidity (the dotted line corresponds to the limit of acceptability before the quality of the fruit became unacceptable). (●) Firmness; (○) shriveling, wilting, drying; (▼) color changes.

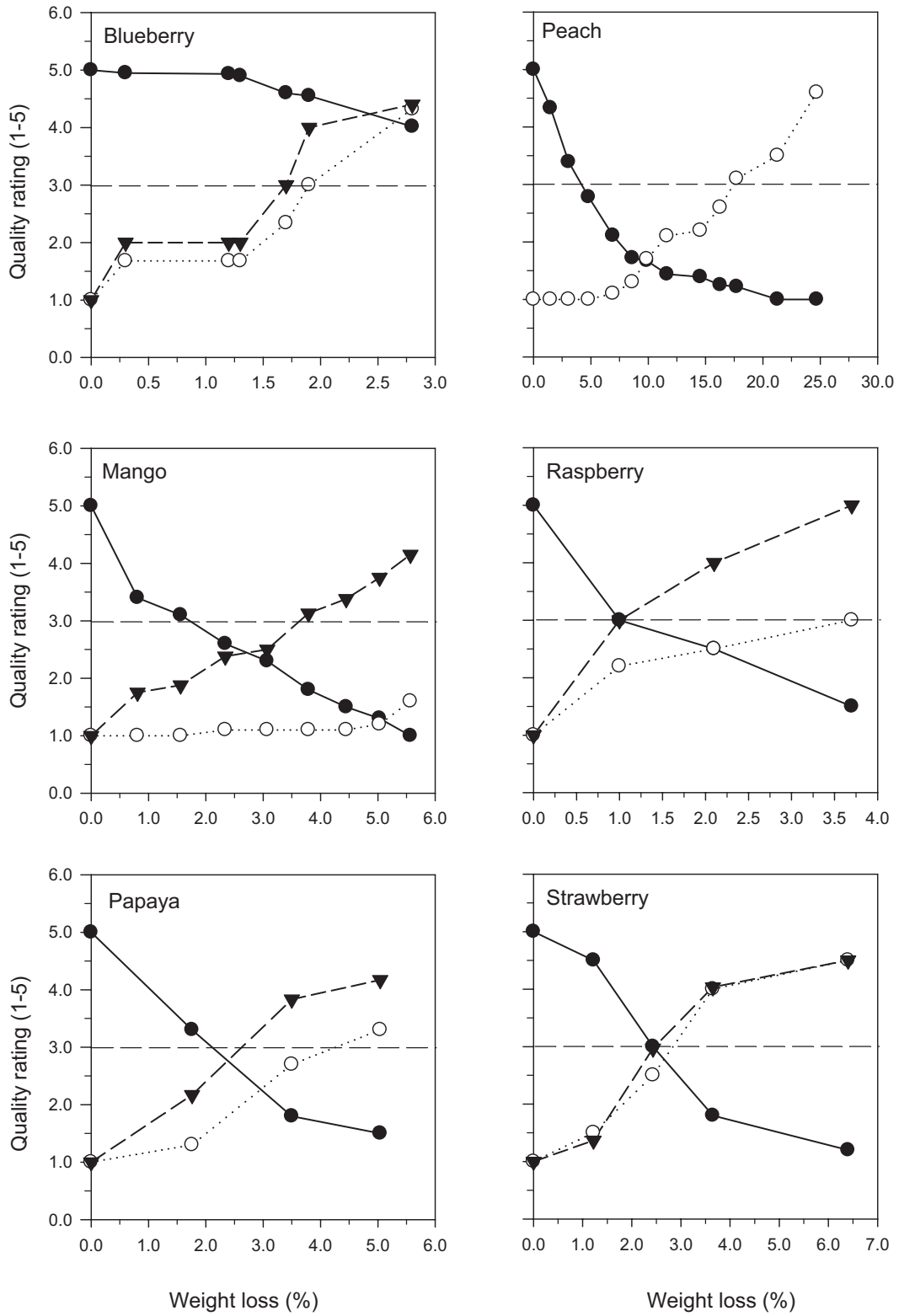

Fig. 5. Relationship between weight loss and visual quality of various fruits stored at 20 °C and 85% to 95% relative humidity (the dotted line corresponds to the limit of acceptability before the quality of the fruit became unacceptable). (●) Firmness; (❍) shriveling, wilting, drying; (▼) color changes.

Table 4. Maximum acceptable weight losses from various fruits stored at 20 °C and 85% to 95% relative humidity (RH) before the commodity becomes unacceptable for sale.

	Maximum acceptable loss (%)[z]	Holding period (days)	Symptoms
Blueberry	1.5 to 2.0[y]	7 to 10[x]	Shriveling of the skin, darkening of the color, loss of waxy bloom
Mango	1.5 to 4.0	2 to 5	Softening of the flesh, over ripeness and increased peel coloration, shriveling of the skin is not a problem if at 85% RH
Papaya	2.0 to 4.5	2 to 6	Softening of the flesh, over ripeness and increased peel coloration, shriveling of the peel
Peach	4.0 to 17.5	3 to 9	Softening of the flesh, shriveling of the peel, overripeness
Raspberry	1.0 to 3.8	1 to 3	Softening of the flesh, darkening of the color, over ripeness, shriveling
Strawberry	2.5 to 3.0	2.5 to 3	Softening of the flesh, darkening of the color, over ripeness, shriveling and dryness of the calyx and skin

[z]Percentage of original fresh weight.
[y]Lower weight loss values corresponds to first signs of water loss (i.e., softening); higher weight loss values correspond to objectionable visual quality (i.e., softening, changes in color and shriveling).
[x]Shorter holding periods correspond to first signs of water loss; longer holding periods correspond to objectionable weight loss.

Table 5. Coefficients of linear correlation (r) for weight loss with visual quality (textural changes, shriveling, wilting or dryness, color changes, cap opening and stipe elongation in mushroom during storage of various fruits and vegetables[z]

	Visual quality			
	Firmness	Shriveling, wilting, dryness	Color changes	Cap opening and stipe elongation
Asparagus	–0.940*	0.966**	–0.972**	
Lettuce	–0.885*	0.864NS	0.953*	
Mushroom		0.989***	0.948***	0.972***
Pepper, green bell	–0.977***	0.963***	0.969***	
Snap bean	–0.998**	0.917ns	0.967*	
Squash, yellow summer	–0.985***	0.955***		
Tomato	–0.984***	0.909**	0.959***	
Witloof chicory	–0.978***	0.983***	0.974***	
Blueberry	–0.900**	0.919**	0.918**	
Mango	–0.967***	0.750*	0.992***	
Papaya	–0.972*	0.971*	0.980*	
Peach	–0.871***	0.959***		
Raspberry	–0.943NS	0.930NS	0.960*	
Strawberry	–0.933*	0.942*	0.940*	

NS, *, **, ***Nonsignificant or significant at $P < 0.05$, 0.01, and 0.001, respectively, using Pearson's correlation coefficient.

than many other highbush blueberry cultivars, and that might explain the little softening of the fruits even when stored at high temperatures (Nunes et al., 2003).

After 2 d, weight loss of 'Tommy Atkins' and 'Palmer' mangoes attained about 1.5% of the fruit initial weight and at this time softening was already evident. After 5 d, the fruit appeared overripe and weight loss had attained about 4.0% of the fruit initial weight (Fig. 3, Table 3). Reddy and Raju (1988) reported an average 3.96% weight loss in 'Alphonso' mango stored at ambient temperature for 5 d, which was similar to the weight loss observed for 'Tommy Atkins' and 'Palmer' mangoes used in the present study stored at 20 °C for 5 d (Fig. 2).

'Exp 15' papaya used in the present study developed objectionable softening of the flesh, overripe appearance and severe shriveling when weight loss attained 4.5% (Fig. 5, Table 4), whereas according to Paull and Chen (1989) the loss of ~8% of the initial weight from 'Sunset' and 'Sunrise' mature-green papayas results in "rubbery" texture, low-gloss, slight to moderate skin shrivel, and nonsalable fruit. As mentioned previously, the major pathway for weight loss in papaya was mainly due to water lost through the stem scar, the stomata and the cuticle (Paull and Chen (1989). Thus, the amount of water lost by a papaya fruit may differ depending on the cuticle thickness, which is in turn cultivar and maturity dependent.

Appearance of 'Dixieland' and 'Flame Prince' peaches stored for 9 d at 20 °C deteriorated due to softening of the flesh, severe shriveling and overripe appearance when weight loss attained about 17.5% (Fig. 5, Table 4). Similar results were reported previously for peaches, where the percent weight loss associated with zero, trace, slight, moderate, severe, and extremely severe shriveling were less than 9.0%, 11.0%, 14.0%, 16.0%, 18.0%, and 20.0%, respectively. Thus, more than 16% weight loss (moderate shriveling) must be attained before the appearance of peaches was compromised (Hruschka, 1977).

After 3 d at 20 °C, 'Killarney' raspberries had lost ~3.8% of their initial weight, and the fruit quality was considered unacceptable due to extreme softening, darkening of the color, overripe appearance and shriveling (Fig. 2, Table 3). In another study however the maximum acceptable weight loss before raspberries became unacceptable for sale was considered to be 6% (Robinson et al., 1975). Differences in weight loss and visual quality deterioration in raspberries may be related not only with cultivar variations, but

also with the quality criteria used to evaluate visual deterioration. For example, in the present study, softening of the fruit became objectionable (at 1.0% weight loss) before any visual changes had occurred (at 3.8% weight loss).

According to the literature, the maximum acceptable weight loss before strawberries become nonsalable is 6.0% (Robinson et al., 1975). After ~3 d at 20 °C, 'Seascape' strawberries had lost less than ~3.0% of their initial weight (Fig. 2), a value that was well below the maximum previously considered acceptable for strawberry. Nevertheless, softening in strawberries stored at 20 °C attained a moderate to severe rate after ~2.5 d, which corresponded to a weight loss of 2.5%, while shriveling of the fruit and dryness of the calyx became evident when weight loss attained 3.0% (Fig. 5, Table 4).

Quality. Fruit and vegetable general quality deteriorated during storage as weight loss increased (Figs. 3–5). Firmness decreased during storage, regardless the fruit or vegetable, and was the most important limiting quality factor for most fruits and vegetables evaluated. Therefore, first symptoms of water loss were perceived as loss of lettuce and witloof chicory turgidity, softening of the entire fruit or partial softening of asparagus tips or snap beans ends, which became rubbery with increased water loss. Changes in color usually followed changes in tissue firmness. Fruits developed a dark coloration and overripe appearance, lettuce leaves became yellow and less bright green, asparagus tips developed browning of the bracts, and mushroom caps developed a whitish-brown coloration (Tables 3–4). Shriveled, wilted or dry appearance developed only when textural and color changes were already noticeable, at the same time as weight loss attained a maximum threshold, which was dependent on the fruit or vegetable evaluated (Figs. 3–5). A significant linear correlation was found between weight loss and visual quality attributes evaluated, and the higher the weight loss, the softer, more colored or brownish, and more shriveled the fruit or vegetable (Table 5). Increased weight loss resulted in moderate to severe browning in mushroom, asparagus, snap beans and witloof chicory, yellowing of the leaves in lettuce and accelerated coloration (i.e., overripe appearance) in most fruits. In peach, the percent extractable juice declined by 12.0% to 20.0% after moisture loss, during storage at 5 °C (Perkins-Veazie et al., 1999).

In summary, maximum postharvest life (i.e., when the fruit or vegetable became unacceptable for sale due to impaired visual quality) under the environmental conditions used in this study was ~3 d for raspberry, strawberry, and snap beans; 4 d for lettuce; 5 d for mushroom, asparagus, and mango; 6 d for papaya and green bell pepper; 9 d for peach; 10 d for blueberry; 11 d for tomato; 14 d for yellow summer squash; and 15 d for witloof chicory (Tables 3–4). Depending on the maximum postharvest life, weight loss was greatest (45.0%) in mushroom and least (2.0%) in tomato, stored under the same temperature and humidity conditions. Tomato, witloof chicory, blueberry, raspberry, mango, papaya, and strawberry lost less than 5.0% of their initial weight; asparagus lost 8.0% of its initial weight; yellow summer squash, snap beans, peach, and green bell pepper lost between 11.0% and 25.0% of their initial weight; and mushroom lost more than 40.0% of the initial weight after storage (Figs. 1–2). At these levels of weight loss, visual quality of the fruits and vegetables evaluated was already considered objectionable. When weight loss increased slightly above such levels, visual quality deteriorated at a faster rate and the fruit or vegetable appeared unacceptable for sale, due to severe softening, color deterioration, shriveling, wilting or dry appearance. Deterioration of fruit and vegetables visual quality may not be exclusively attributed to water loss, but rather to a summation of many appearance defects, some of which may result from excessive loss of water.

Literature Cited

Artés, F., M.A. Conesa, S. Hernández, and M.I. Gil. 1999. Keeping quality of fresh-cut tomato. Postharvest Biol. Technol. 17:153–162.

Bhowmik, S.R. and J.C. Pan. 1992. Shelf life of mature-green tomatoes stored in controlled atmosphere and high humidity. J. Food Sci. 57:948–953.

Fehér, E. 1994. Storage losses in fresh asparagus (*Asparagus officinalis* L.). Acta Hort. 368:190–194.

Gautam, S., A. Sharma, and P. Thomas. 1998. Gamma radiation effect on shelf-life, texture, polyphenol oxidase and microflora of mushrooms (*Agaricus bisporus*). Intl. J. Food Sci. Nutr. 49:5–10.

González, G. and M. Tiznado. 1993. Postharvest physiology of bell peppers stored in low density polyethylene bags. Lebes. Wisse. Technol. 26:450–455.

González, M., A. Centurión, E. Sauri, and L. Latournerie. 2005. Influence of refrigerated stotage on the quality and shelf life of 'Habanero' chili peppers (*Capsicum chinense* Jacq.). Acta Hort. 682:1297–1302.

Heyes, J.A., V.M. Burton, and L.A. de Vré. 1998. Cellular physiology of textural change in harvested asparagus. Acta Hort. 464:455–460.

Hofman, P.J., L.G. Smith, D.C. Joyce, G.I. Johson, and G.F. Meiburg. 1997. Bagging of mango (*Mangifer indica* cv. 'Keitt') fruit influences fruit quality and mineral composition. Postharvest Biol. Technol.12:83–91.

Hruschka, H.W. 1977. Postharvest weight loss and shrivel in five fruits and vegetables. Agr. Res. Serv., U.S. Dept. Agr. Mktg. Res. Rpt. No. 1059.

Hughes, D.H. 1959. Mushroom discoloration research at the University of Delaware, p. 447–449. In: A.I. Odense (ed.). Mushroom Science IV, Proc. Intl. Conf. on Scientific Aspects of Mushroom Growing. Copenhagen.

Jackson, E.D., K.A. Sanford, R.A. Lawrence, K.B. McRae and R. Stark. 1999. Lowbush blueberry quality changes is response to prepacking delays and holding temperatures. Postharvest Biol. Technol. 15:117–126.

Jacobi, K.K., E.A. MacRae, and S.E. Hetherington. 1998. Early detection of abnormal skin ripening characteristics of 'Kensington' mango (*Mangifera indica* Linn). Scientia Hort. 72:215–225.

Kader, A.A., W.J. Lipton, and L.L. Morris. 1973. Systems for scoring quality of harvested lettuce. HortScience 8:408–409.

Kays, S.J. and R.E. Paull. 2004. Stess in harvested products, p. 355–414. In: S.J. Kays and R.E. Paull (eds.). Postharvest biology. Exon Press, Athens, GA.

King, G.A., K.G. Henderson and R. Lill. 1988. Shelf-life of stored asparagus is strongly related to postharvest accumulated heat units. Ann. Appl. Biol. 112:329–335.

Krarup, C. 1990. Initial weight loss, packaging and conservation of asparagus. Acta Hort. 271:477–482.

Krüger, E., E. Schöpplein, S. Rasim, G. Cocca, and H. Fisher. 2003. Effects of ripening stage and storage time on quality parameters of red raspberry fruit. Europ. J. Hort. Sci. 68:176–182.

Lam, P.F. 1990. Respiration rate, ethylene production and skin colour change of papaya at different temperatures. Acta Hort. 269:257–266.

Lownds, N.K., M. Banaras, and P.W. Bosland. 1994. Postharvest water loss and storage quality of nine pepper (*Capsicum*) cultivars. HortScience 29:191–193.

Maharaj, R. and C.K. Sankat. 1990. Storability of papayas under refrigerated and controlled atmospheres. Acta Hort. 269:375–385.

Makus, D.J. and J.R. Morris. 1993. A comparison of fruit of highbush and rabbiteye blueberry cultivars. J. Food Quality 16:417–428.

Martinéz, C., G, .M.J. Ros, G. Periago, J.O. López, and F. Ricón. 1995. Physico-chemical and sensory quality criteria of green beans (*Phaseolus vulgaris* L.) Lebens. Wiss. Technol. 28:515–520.

Meredith, F.I., J.A. Robertson, and R.J. Horvat. 1989. Changes in physical and chemical parameters associated with quality and postharvest ripening of harvester peaches. J. Agr. Food Chem. 37:1210–1214.
Miller, W.R. and D.A. Smittle. 1987. Storage quality of hand- and machine-harvested rabbiteye blueberries. J. Amer. Soc. Hort. Sci. 112:487–490.
Miller, W.R., L.A. Risse, and R.E. McDonald. 1986. Deterioration of individually wrapped and non-wrapped bell peppers during long term storage. Trop. Sci. 26:1–8.
Miller, W.R., R.E. MacDonald, C.F. Melvin, and K.A. Munroe. 1984. Effect of package type and storage time-temperature on weight loss, firmness and spoilage of rabbiteye blueberries. HortScience 19:638–640.
Miszczak, A., C.F. Forney, and R.K. Prange. 1995. Development of aroma volatiles and color during postharvest ripening of 'Kent' strawberries. J. Amer. Soc. Hort. Sci. 120:650–655.
Narvaiz, P. 1994. Some physicochemical measurements on mushrooms (*Agaricus campestris*) irradiated to extend shelf-life. Food Sci. Technol. 27:7–10.
Nunes, M.C.N., J.P. Emond, and J.K. Brecht. 2004. Quality curves for highbush blueberries as a function of the storage temperature. Small Fruits Rev. 3:423–438.
Paull, R.E. and N.J. Chen. 1989. Waxing and plastic wraps influence water loss from papaya during storage and ripening. J. Amer. Soc. Hort. Sci. 114:937–942.
Perkins-Veazie, P. and G. Nonnecke. 1992. Physiological changes during ripening of raspberry fruit. HortScience 27:331–333.
Perkins-Veazie, P., N. Roe, J. Lasswell and M.J. McFarland. 1999. Temperature manipulation improves postharvest quality of mid-season peach. J. Food Quality 22:75–84.
Quintana, M.E.G. and R.E. Paul. 1993. Mechanical injury during postharvest handling of 'Solo' papaya fruit. J. Amer. Soc. Hort. Sci. 118:618–622.
Reddy, L.S. and K.R.T. Raju. 1988. Effects of prepackaging and post-harvest treatments on the storage behaviour of mango fruits cv. Alphonso. Acta Hort. 231:670–674.
Reeve, R.M. and M.S. Brown. 1968. Histological development of green been pod as related to culinary texture. 2. Structure and composition at edible maturity. J. Food Sci. 33:326–331.
Robinson, J.E., K.M. Browne, and W.G. Burton. 1975. Storage characteristics of some vegetables and soft fruits. Ann. Appl. Biol. 81:399–408.
Robson, M.G., J.A. Hopfinger and P. Eck. 1989. Postharvest sensory evaluation of calcium treated peach fruit. Acta Hort. 254:173–177.
Rodriguez-Arcos, R., A.C. Smith, and K.W. Waldron. 2002. Mechanical properties of green asparagus. J. Sci. Food Agr. 82:293–300.
Roy, S., R.C. Anantheswaran, and R.B. Beelman. 1995. Fresh mushroom quality as affected by modified atmosphere packaging. J. Food Sci. 60:334–340.
Rubatzky, V. and M. Salveit. 2004. Chicory. In: K.C. Gross, C.Y. Wang, and M. Saltveit (eds.). The commercial storage of fruits, vegetables, and florist and nursery crops. Agr. Hdbk. 66. U.S. Dept. Agr., Agr. Res. Serv., Beltsville, MD. 19 May 2007. <http://www.ba.ars.usda.gov/hb66/index.html>.
Ryder, E.J. 1979. Endive and chicory, p. 171–194. In: E.J. Ryder (ed.). Leafy salad vegetables. AVI Publ., Westport, CT.
Sanford, K.A., P.D. Lidter, K.B. McRae, E.D. Jackson, R.A. Lawrence, R. Strak, and R.K. Prange. 1991. Lowbush blueberry quality changes in response to mechanical damage and storage temperature. J. Amer. Soc. Hort. Sci. 116:47–51.
Sapers, G.M., A.M. Burgher, J.G. Phillips, S.B. Jones, and E.G. Stone. 1984. Color and composition of highbush blueberry cultivars. J. Amer. Soc. Hort. Sci. 109:105–111.
Sherman, M., H.S. Paris, and J.J. Allen. 1987. Storability of summer squash as affected by gene B and genetic background. HortScience 22:920–922.
Sistrunk, W.A., A.R. Gonzalez, and K.J. Moore. 1989. Green beans, p. 185–215. In: N.A. Eskin (ed.). Quality and preservation of vegetables. CRC Press, Boca Raton, FL.
Smith, J.F., M.E. Love and K.S. Burton. 1993. Comparative studies of the quality of fresh and stored mushroom of *Agaricus bisporus* with two tropical *Agaricus bisporus* strains. Ann. App. Biol. 122:593–603.
Smittle, D.R. and W.R. Miller. 1988. Rabbiteye blueberry storage life and fruit quality in controlled atmospheres and air storage. J. Amer. Soc. Hort. Sci. 113:723–728.
Vaserveld, G.W. and D.G. Richardson. 1980. Evaluation of storage and processing quality of mechanically and hand-harvested *Rubus* spp. fruit. Acta Hort. 112:265–272.
Zurera, G., M. Muñoz, R. Moreno, J.A. Gonzalez, and M.A. Amaro. 2000. Cytological and compositional evaluation of white asparagus spears as a function of variety, thickness, portion and storage conditions. J. Sci. Food Agr. 80:335–340.