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).

Kays and Paull (1989) suggested that the major pathway for weight loss in papaya was mainly due to water loss 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 waxy cuticle that protects the fruit from losing 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 loss 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 Millennium, 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
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 \(L^* \approx 66, a^* \approx 8.4, \) 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.

**Table 1.** Visual rating scale for color.

<table>
<thead>
<tr>
<th>Asparagus*</th>
<th>Lettuce*</th>
<th>Mushroom</th>
<th>Pepper, green bell*</th>
<th>Snap bean*</th>
<th>Tomato</th>
<th>Witloof chicory*</th>
<th>Blueberry*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field-fresh, dark green, stalk is glossy</td>
<td>Fresh cut appearance, bright light green</td>
<td>White and smooth glossy cap surface, stipe and gills, no signs of browning</td>
<td>Completely dark bright green</td>
<td>Extremely bright green</td>
<td>Light red color with traces of green (75% red)</td>
<td>Fresh cut appearance, white color w/cream-yellow leaf edges, no trace of green or reddish discoloration</td>
<td>Bright blue color, abundant waxy bloom</td>
</tr>
<tr>
<td>Dark green stalk, less glossy</td>
<td>Slight leaf discoloration, light green</td>
<td>White cap surface, stipe and gills, but less glossy, slight browning</td>
<td>Dark green, less bright</td>
<td>Less bright green</td>
<td>Light red color, no trace of green</td>
<td>Slight discoloration, less white, and darker yellow leaf edges</td>
<td>More deep blue</td>
</tr>
<tr>
<td>Moderate browning of stem bracts</td>
<td>Moderate leaf discoloration, green w/some yellow areas</td>
<td>Light brownish-creamy surface, and moderate browning</td>
<td>Green, showing some loss of glossiness</td>
<td>Green</td>
<td>Red color</td>
<td>Moderate discoloration, white color w/traces of some greenish-yellow color, or slight reddish discoloration</td>
<td>Dark blue, less waxy bloom</td>
</tr>
<tr>
<td>Slight browning of spear, and objectionable browning of the bracts</td>
<td>Severe leaf discoloration, brownish-yellow</td>
<td>Light brownish surface, brownish stipe and gills</td>
<td>Slight discoloration</td>
<td>Dull green, yellowing</td>
<td>Dark red color</td>
<td>Severe discoloration, yellowish-green or brownish-green, marginal leaf browning</td>
<td>Very dark blue</td>
</tr>
<tr>
<td>Browning of stem bracts, and of almost all the spear</td>
<td>Extreme leaf discoloration, very dark brownish-green or yellowish-green</td>
<td>Completely dark brownish</td>
<td>25% red, yellow or other coloration</td>
<td>Extremely dull green, or completely yellow</td>
<td>Very dark red color, overripe</td>
<td>Extreme discoloration, green and/or brownish leaves, leaf surface is green, reddish discoloration objectionable</td>
<td>Purple brownish-blue or black, no waxy bloom, overripe</td>
</tr>
</tbody>
</table>
| *King et al., 1988; *(Kader et al., 1973); *(Lownds et al., 1994); *(Martinez et al., 1995); *(Rubatzky and Salveit, 2004; Ryder, 1979); *(Jackson et al., 1999; Sapers et al., 1984); *(Jacobi et al., 1998); *(Lam, 1990; Maharaj and Sankat, 1990); *(Perkins-Veazie and Nonnecke, 1992; *(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).

### Table 2. Tactile rating scale for firmness.

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

*Firmness rating of 3 was considered to be the limit of acceptability for sale.

*King et al., 1988; †Kader et al., 1973; ‡Miller et al., 1986; §Martinez et al., 1995; ¶Artés et al. 1999; ‡Miller and Smittle, 1987; Miller et al., 1984; Sanford et al., 1991; 🇨🇦Hofman et al., 1997; Jacobi et al., 1998; Robson et al., 1989.*

**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...
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.
~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 than lettuce exposed to higher RH.

Hughes (1959) found that black stems (i.e., stipes) and open veins 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, 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

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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.

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

1Percentage of original fresh weight.
2Lower weight loss values correspond 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).
3Shorter holding periods correspond to first signs of water loss; longer holding periods correspond to objectionable weight loss.
4Objective 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.

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).

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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-salable 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 rabbiteye) 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.](image-url)
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.
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 before the appearance of peaches was compromised. 'Killarney' raspberries had lost ~3.8% of their initial weight, and the fruit quality was considered unacceptable before the appearance of peaches was compromised (Hruschka, 1977).

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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**


