Postharvest Biology and Technology 15 (1999) 233–247

Preharvest factors affecting appearance

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Received 30 June 1998; accepted 11 November 1998

Abstract

The appearance of fresh fruits and vegetables is a primary criterion in making purchasing decisions. Product appearance is characterized by size, shape, form, color, condition and absence of defects. A wide range of preharvest factors can modulate the appearance of the harvested product. These include: (1) biological factors (pathological, entomological, animal); (2) physiological factors (physiological disorders, nutritional imbalances, maturity); (3) environmental/cultural factors (e.g. climate, weather, soils, water relations, light intensity); (4) mechanical damage; (5) extraneous matter (growing medium, vegetable matter, chemical residues); and (6) genetic variation and aberrations. Creating and/or maintaining production conditions that minimize undesirable product appearance is essential. While field grading during harvest is utilized to eliminate a significant portion of product with substandard appearance, minimizing the occurrence of inferior product can significantly increase net profit. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Climate; Fruit; Genetic variation; Herbivores; Light intensity; Mechanical damage; Soils; Vegetable; Water relations

1. Introduction

The appearance of fresh fruits and vegetables is a primary criterion in making purchasing decisions (Kays, 1991). Product appearance is characterized by size, shape, form, color, condition and absence of defects. Appearance is utilized throughout the production–storage–marketing–utilization chain as the primary means of judging the quality of individual units of product. What is considered a desirable appearance changes for some products, depending upon where in the chain the product is assessed and who is making the assessment. Banana fruit color (*Musa × paradisiaca* L. var. *paradisiaca*)[1] is an excellent example of this. In the field and with arrival at the wholesale distribution center for ripening, fruit

[1] The scientific name for each crop is given when first cited in the text. Latin binomials for vegetable crops are taken from Kays and Silva Dias (1996) and for fruit crops from Terrell et al. (1986).

PII: S0925-5214(98)00088-X

with a uniform green coloration are desired. At the retail store, fruit that are starting to turn yellow are desired. Consumers, in contrast, display a broad range in the color (degree of ripeness) preferred, from partially green to when the peel is starting to develop brown senescence spots. Thus, while some appearance traits are not consistent across the production–distribution chain, others, such as the color of red apples (*Malus domestica* Borkh.), remain relatively constant.

2. Appearance traits

2.1. Size

Size of individual units of a product can significantly affect consumer appeal, handling practices, storage potential, market selection and final use. With many fruits and vegetables, consumers discriminate based upon size and their criteria for discrimination are not always constant. For example, when cantaloupes (*Cucumis melo* L. Cantaloupensis group) are sold by weight, somewhat smaller fruit are generally desired. However, when sold at a fixed price per fruit, larger tend to be preferred. Typically when product is sold by weight (size), exceedingly small and/or large individual units are discriminated against. Small Chinese water chestnuts (*Eleocharis dulcis* (Burm.f.) Trin. ex) are less desirable due to the greater losses incurred during peeling and the additional labor required. In contrast, large peas (*Pisum sativum* L. ssp. *sativum*) are generally considered lower in quality than small or petit pois. Seldom are large apples selected for long-term storage in that they are much more susceptible than small fruit to postharvest physiological disorders such as internal breakdown. Size may also determine what markets are available to the producer for the sale of the product. Early-season peaches (*Prunus persica* (L.) Batsch) grown in Georgia must be at least 4.1 cm in diameter to be shipped out of the state. Likewise, large sweetpotatoes (*Ipomoea batatas* (L) Lam.) are used for processing or animal feed rather than for fresh market sales.

Size may be determined by one of three general means: (1) dimension (length, width, diameter, or circumference); (2) weight; or (3) volume. In some instances, multiple measurements of size on a single product are utilized. During the preharvest period or during harvest, size discrimination decisions are largely made visually. Field crews will make a decision on each product unit when hand harvesting. For example, is an individual squash (*Cucurbita pepo* L.) fruit too small or too large. The larger fruit are generally picked and immediately discarded with very small fruit being left unpicked for later harvest.

2.2. Shape

Shape is the general outline of the product and can be determined precisely using specific measurements and/or their mathematical relationships. More often than not, however, shape is determined subjectively. Shape is an important factor in distinguishing between individual cultivars [e.g. carrots (*Daucus carota* L. subsp. *sativus*), pears (*Pyrus communis* L.), apples, pecans (*Carya illinoensis* (Wangenh.) K. Koch)]. Small irregularities in shape (e.g. in the shape of 'Delicious' apple fruit grown under different climatic conditions) are generally not a critical factor in the eventual consumer selection decision. More extreme variations in shape that may influence purchasing decisions, are typically discarded during hand harvest or in the packinghouse.

2.3. Form

Form is the general arrangement of the individual parts of a product and, like shape and size, can also affect acceptability. For many fruits and vegetables, form is not a critical factor in that most are individual units (e.g. an apple or pear) rather than being made up of a number of individual subunits. In leafy vegetables that comprise individual leaves, the arrangement of the leaves on the stalk generally does not vary sufficiently to warrant concern. With a few crops such as gemmiferous mustard (*Brassica juncea* (L.) Czernj. & Coss. var. *gemmifera* Lee & Lin), ginger (*Zingiber officinale* Roscoe), grapes (*Vitis* spp.) and bignay (*Antidesma bunius* (L.) Sprengel), the arrangement of the individual parts can be such that an undesirable form occurs. In general, form is a minor consideration for the majority of fruits and vegetables. In direct contrast, the form of ornamental crops such as potted flowers is critical, where the number and position of the individual flowers on the plant can vary considerably.

2.4. Color

Color of fruits and vegetables probably contributes more to the assessment of quality than any other single factor. Consumers have developed distinct correlations between color and the overall quality of specific products. Tomatoes (*Lycopersicon esculentum* Miller) should be red; bananas yellow. Reverse the order and it would be difficult to give the produce away, even if their quality were superior. Hence, upon the first visual assessment of product quality, color is critical.

Color is a function of the light striking the product, the differential reflection of certain wavelengths, and the visual perception of those wavelengths. The colors perceived are due to the presence of pigments within the product. When we see a red apple, the red color is due to the absorption by the pigments of all of the other wavelengths in the visible spectrum, except the red region, which is reflected from the product. Plant pigments can be separated into four primary classes based on their chemistry: chlorophylls, carotenoids, flavonoids, and betalains. There are additional pigments (e.g. quinones, phenalones, phyrones) which are generally of minor importance. In addition to the normal complement of pigments in fruits and vegetables, pigments are formed during discoloration reactions. Phenolic compounds appear to be important in a wide range of reactions that result from injury and a loss of organizational resistance between substrates and enzymes within the cell. Common examples are bruising of fruits or broken-end discoloration of snapbeans. When browning occurs, constituent phenols are oxidized to produce a quinone or quinone-like compound that polymerizes, forming brown pigments. These unsaturated brown polymers are generally referred to as melanins or melaninodins. Among the compounds believed to be important as substrates are chlorogenic acid, neochlorogenic acid, catechol, tyrosine, caffeic acid, phenylalanine, protocatechin, and dopamine (Kays, 1991). For a critique of the general chemistry involved in tissue browning, see Amiot et al. (1997).

While color is used as a primary criterion to assess the general quality of many products, quality and color do not necessarily correlate closely with each other. In some cases, the association between what is perceived as optimum color and optimum quality is not at all valid. For example, a number of orange (*Citrus* spp.) cultivars have fruit that are quite green when at their peak of quality (especially so in tropical regions). Since most consumers believe that oranges should be orange, the marketability of green fruit is much diminished. The color of many products changes markedly during development and a number of preharvest factors can affect color development. Thus, understanding the factors that modulate product color in a desirable or conversely in an unfavorable way, is essential.

2.5. Condition

Condition is a somewhat nebulous quality consideration that appears to encompass a wide range of the properties of the product in question. Assessment of condition may include general visible quality parameters such as color, shape, and freedom from defects. It may also include considerations less easy to define such as freshness, cleanliness, and maturity. Freshness often includes the general physical condition of the product, for example, wilting of lettuce (*Lactuca sativa* L. var. *longifolia* Lam.) or shriveling of fruits. Other characteristics of freshness, such as odor, may be more elusive.

2.6. Absence of defects

Absence of defects is another important quality consideration for fruits and vegetables. Variation is an inherent factor in the production of agricultural products. Due to variation, some portion of the total of each commodity to be harvested will deviate from what is considered optimum for one or more quality components. Products in this category display quality defects, the presence of a fault that is undesirable, which prevents them from being optimal in quality. While we tend to think of defects as distinctly atypical, externally imposed alterations, such as insect or hail damage, substandard product within each of the previous appearance categories (size, shape, form, color and condition) is also defective.

3. Product defects

Product defects can be categorized, based upon the cause of the condition, into the following classes: (1) biological factors; (2) physiological factors; (3) environmental factors; (4) mechanical damage; (5) extraneous matter; and (6) genetic variation and aberrations. Each of these classes can be further subdivided into more specific causes of defects. The following is a critique of the causes of preharvest defects with an example to illustrate each. Some defects have been studied closely and there is a wealth of published information. However, with more obscure defects or causes thereof, the literature can be extremely limited. While a complete review of the literature on preharvest factors causing appearance defects is not within the scope of this report, the following section summarizes the primary causes, giving representative examples; for additional information on preharvest factors affecting quality, see Beverly et al. (1993), Crisosto et al. (1997), Prange and DeEll (1997), Salunkhe et al. (1991) and Weston and Barth (1997).

3.1. Biological factors causing defects

3.1.1. Pathological

Plant pathogens cause substantial losses of fruits and vegetables during production. Typically pathological damage is apparent in the field and the affected object is discarded at harvest or during subsequent grading. In some cases, such as with quiescent infections, inoculation occurs prior to or during harvest. Subsequent development of the organism and degradation in appearance does not occur until the postharvest period. The stress imposed by plant pathogens invariably leads to distinct alterations in the appearance of the affected tissue. These range from undesirable alterations in pigmentation, shape, and condition to premature ripening (e.g. powdery mildew (*Sphaerotheca fuliginea*) on pumpkin (*Cucurbita* spp.); Hill, 1995). Specific examples of pathogens resulting in undesirable alterations in appearance include: (1) bacterial—bacterial spot on tomato fruit (*Xanthomonas campestris* pv. *vesicatoria* (Doidge) Dye) (Jones et al., 1991); (2) fungal—white mold (*Sclerotinia sclerotiorum* (Lib.) de Bary) which produces white mycelium generally on the blossom end of cucurbits (Mordue and Holliday, 1976); (3) virus—zucchini yellow mosaic virus of squash (*Cucurbita pepo* L.) which results in small, distorted fruit (Schrijnwerkers et al., 1991) and tomato mosaic virus which causes discoloration of the mature fruit (Broadbent, 1976); and (4) nematodes—northern root-knot nematode (*Meloidogyne hapla* Chitwood) which causes distorted carrot roots (Bélair, 1987). For a detailed critique of vegetable crop pathogens see Howard et al. (1994).

3.1.2. Entomological

Feeding by a diverse array of insects generally results in distinctly undesirable alterations in product appearance. Substandard appearance may be due to changes in shape, color, size, and general condition of the product. Examples of leaf feeding insects on products in which the leaf is the article of commerce are flea beetles (*Phyllotreta* spp.) and cutworms (Rings, 1977). Likewise, cabbage loopers (*Trichoplusia ni* Hüber) create holes in the foliage and an undesirable appearance. Tomato horn worms (*Manduca* spp.) will feed directly on the fruit causing extensive damage. Feeding by western flower thrips (*Frankliniella occidentalis* Pergande) on cucumber (*Cucumis sativus* L.) results in a distinctive scarring of the fruit surface.

Insect damage is not necessarily limited to the exterior of the product. With some insects, alterations in the external appearance are minimal and the primary damage is done by the developing larva that tunnels throughout the interior of the product (e.g. the sweetpotato weevil, *Cylas formicarius elegantulus*; Nottingham et al., 1989; Thai et al., 1997). In many instances, these insects continue their destructive activity during the postharvest period.

Another form of insect damage is via the lack of or incomplete pollination resulting in misshapen fruit. Cucurbits exhibit small, distorted fruit that are generally shed before reaching harvestable maturity when pollination is inadequate. Likewise, apple (Tromp, 1990) and strawberry (*Fragaria* × *ananassa* Duchesne) (Gilbert and Breen, 1987) fruit are distorted in shape upon reaching maturity due to inadequate pollination.

3.1.3. Animals

A wide range of wild and domestic animals damage the edible portion of a diverse cross-section of fruits and vegetables. These include dog, coyote, deer, fox, goat, mice, possum, raccoon, rat, squirrel, vole and a number of species of birds. Birds represent a major problem for certain fruit crops. For example, great-tailed grackles (*Quiscalus mericanus*) can do substantial damage to grapefruit (*Citrus* × *paradisi* Macfad.) and oranges (Johnson et al., 1989). In addition to losses in product volume, damage to the appearance of individual product units renders them unmarketable.

3.2. Physiological factors causing defects

3.2.1. Physiological disorders

A wide range of physiological disorders occur that unfavorably alter the appearance of horticultural products during the preharvest period. Many of these are nutritional and/or water status related and are found most frequently in fruit. Examples are: (1) tomato blossom-end rot (a calcium deficiency related problem; Shear, 1975); (2) apple bitter pit (calcium deficiency; Shear, 1975); (3) apple cork spot (calcium deficiency; Shear, 1975); (4) pear black end (calcium deficiency; Woodbridge, 1971); (5) black heart of celery (*Apium graveolens* L. var. *dulce* (Mill.) Pers.) (calcium deficiency; Shear, 1975)]; (6) apple and pear drought spot (B deficiency); and 7) tomato and cherry (*Prunus avium* (L.) L.) fruit cracking (nutrition/water relation problem).

3.2.2. Nutritional imbalances

Macro- and micronutrient deficiencies and toxicities result in a wide assortment of undesirable alterations in the appearance of horticultural products. In general, these alterations are in the coloration, shape, and size of the product.

Examples of color alterations categorized by specific nutrients are: (1) nitrogen deficiency in leafy vegetables, blotching in pear (Raese et al., 1979), scab in lemon (*Citrus limon* (L.) Burman f.) (Koo et al., 1973), high nitrogen resulting in poor coloration in apple, cranberry (*Vaccinium macrocarpon* Aiton), peach (Francis and Atwood, 1965; Reeves and Cummings, 1970; Fallahi et al., 1985) and nectarine (Daane et al., 1995); (2) potassium deficiency resulting in poor peach coloration (Reeves and Cummings, 1970) and increased blotchy ripening of tomato (Picha and Hall, 1981); (3) phosphorus excess results in poor cranberry color development (Francis and Atwood, 1965); (4) magnesium deficiency results in poor coloration in leafy vegetables; (5) manganese excess causes apple discoloration (Ferree et al., 1984) and browning and necrotic lesions on the cotyledons of pea (Anderson and Corstens 1974); (6) sulfur deficiency results in poor coloration in leafy crops; (7) zinc deficiency in peach and cherry decreases fruit coloration (Claypool, 1975); (8) copper deficiency reduces citrus fruit color (Jones and Smith, 1964); (9) iron deficiency reduces peach fruit coloration (Rogers et al., 1974 Rogers, 1975); and (10) boron deficiency causes external corking of apple (Cain and Shear, 1964).

Examples of mineral nutrition mediated size alterations include: (1) nitrogen occurring as a high percentage in the ammoniacal form results in smaller orange fruit (Bar-Akiva et al., 1968) and nitrogen deficiency reduces stone fruit size (Daane et al., 1995); (2) potassium deficiency causes small citrus and tomato fruit (Embleton et al., 1975); (3) phosphorus deficiency results in large Valencia oranges (Embleton et al., 1971, 1975); (4) zinc deficiency decreases citrus fruit size (Jones and Smith, 1964); (5) iron deficiency reduces citrus (Jones and Smith, 1964) and peach fruit size (Rogers et al., 1974 Rogers, 1975); (6) boron deficiency reduces strawberry fruit size (Neilson and Eaton, 1983).

Imbalances in certain nutrients can also have a pronounced effect on shape. Examples are: (1)

nitrogen in excess increases tip burn in cabbage (*Brassica oleracea* L. var. *capitata* L.) (Peck et al., 1983); (2) phosphorus content is related to fruit shape (height) in orange (van Beusichem, 1993); (3) zinc deficiency alters the shape of peach and cherry fruit (Claypool, 1975); (4) copper deficiency affects citrus fruit shape (Jones and Smith, 1964) and walnut (*Juglans regia* L.) kernel shape and fill (Cain and Shear, 1964); (5) iron deficiency alters citrus shape (Jones and Smith, 1964); (6) boron deficiency affects strawberry fruit shape (Neilson and Eaton, 1983) and in citrus causes misshapen fruit (Jones and Smith, 1964); and (7) molybdenum deficiency alters the shape of cauliflower (*Brassica oleracea* L. var. *botrytis* L.) (Purvis and Carolus, 1964).

3.2.3. Maturity

Maturity, whether viewed as physiological maturity or harvestable maturity, can have a pronounced influence on the appearance of fruits and vegetables. The type of maturity will depend upon the product in question. For example in apple and pear, the fruit becomes physiologically mature. In contrast most vegetable crops never reach physiological maturity. For these crops, harvestable maturity is a more appropriate term in that they are harvested early in their developmental cycle (e.g. mung bean sprouts (*Vigna radiata* (L.) Wilcz.)). During development, the individual units of a product exhibit a progressive increase in size, and in many instances the size at harvest is a critical factor (e.g. gerkins (*Cucumis sativus* L.)). Exceeding a required size class can greatly reduce the value and marketability of certain products. In other instances, size is less critical and a relatively wide range of sizes are acceptable (e.g. the giant taro, *Alocasia macrorrhiza* (L.) G. Don.).

With some products, there are distinct alterations in color during maturation. For example bramble fruits (e.g. raspberry (*Rubus idaeus* L.); Robbins and Fellman, 1993) undergo marked changes in color and these changes in color are largely dependent upon attachment to the parent plant. When harvested at an immature stage, the normal complement of pigments is not synthesized and the product's appearance is substandard.

A very limited number of fruits and vegetables undergo significant alterations in surface topography during maturation which are of importance in achieving the final desired appearance of the product. Examples are the surface netting of cantaloupe, surface spines of the African horned cucumber (*Cucumis metuliferus* E. Meyer ex Naudin), and changes in the surface topography of passion fruit (*Passiflora mollissima* (Kunth) L.H. Bailey) during the latter stages of maturation.

3.3. Environmental/cultural factors causing defects

3.3.1. Climate

Apples grown in a climate with warm, clear days and cool nights were more conic–elongate than those grown in hot days and warm nights (Westwood and Burkhart, 1968). Likewise, differing climatic conditions between two geographical sites had a significant effect on banana fruit size and shape (Cano et al., 1997). Production temperature affects cucumber fruit length with very high and low temperatures repressing development (Kanahama, 1989). Likewise, cucumber fruit curvature is increased with increasing temperature (Kanahama, 1989). Seasonal changes in the production environment resulted in a shift in the factors responsible for rejection of chayote fruit (*Sechium edule* (Jacq.) Swartz.). On the average, 19.5% of the fruit reaching the packinghouse were substandard (Saenz and Valverde, 1986).

3.3.2. Weather

3.3.2.1. Chilling injury. A number of fruits and vegetables are impaired by exposure to non-freezing temperatures in the 0–13°C range. While chilling injury is often associated with the postharvest period, exposure and injury can occur prior to harvest. The threshold for injury of banana is in the 12–13°C range and for cucumber 7–10°C. Unlike freezing injury, chilling injury generally requires an extended exposure and the symptoms often do not appear until after the product is returned to non-chilling temperatures. In sweetpotato, chilling injury increases rotting and the formation of 'hardcore', a condition where a woody core forms in the storage root (Buescher et al., 1976). When young cucumber fruit are exposed to chilling temperatures, the surface of the fruit is scarred and an undesirable curvature develops (Howard et al., 1994).

3.3.2.2. Freezing/frost damage. While the terms freezing injury and frost injury are widely used in the literature, the distinction between the two is not always clear. Both actually represent freezing injury. By definition, freezing is a phase change between a liquid and a solid, while frost is an external covering of ice on an object. Frost occurs through the sublimation of water vapor on objects that are below 0°C. Frost injury is frequently used when referring to a mild form of freeze damage that occurs with the formation of frost on the product surface. Frost, however, can also occur under quite severe freezing temperatures if the conditions are right. The terms radiative and advective freezing represent a more precise distinction (see review by Reiger, 1989), the difference centering on the direction of the flow of thermal energy. A radiative freeze typically occurs under clear skies, with calm or light wind, and a relatively high subfreezing temperature or dewpoint (similar to the conditions that often cause frost). Advective freezing, in contrast, occurs when subfreezing temperatures result from an influx of very cold air together with high winds; cloud cover may also be present. Under radiative freezing, thermal energy moves from the air to the vegetation, soil, and other objects (i.e. the air is cooled by the vegetation), while with advective freezing the flow of thermal energy is in the opposite direction (i.e. the air cools the vegetation) (Reiger, 1989).

For most fruits and vegetables, freezing occurs one to several degrees below the freezing point of water due to the presence of solutes within the aqueous medium of the cells. For example, the highest freezing point for the following products is: apple −1.1°C; date (*Phoenix dactylifera* L.) −15.7; persimmon (*Diospyros kaki* L. f.) −2.2; asparagus (*Asparagus officinalis* L.) −0.6; carrot −1.4; tomato −0.5; and pecan −6.7 (Whiteman, 1957). For most products, freezing has disastrous consequences for quality. The extent of damage is a function minimum temperature, the rate of drop in temperature, the duration of exposure, and the susceptibility of the product. Changes in external appearance vary with the product in question. After thawing, freeze injured tissue is typically darker and exhibits a flaccid, water soaked appearance. For leafy crops, freezing results in a limp, wilted, and unmarketable product. Some crops display discoloration of the exterior (e.g. banana) while for others, internal symptoms are more pronounced (e.g., immature pecan kernels blacken). In citrus for processing, losses can be reduced with immediate harvest and processing (Bartholomew et al., 1950).

Some crops can withstand radiative freezing with little or no damage (e.g. Brussels sprouts (*Brassica oleracea* L. var. *gemmifera* Zenk.)), while others are seriously damaged or completely destroyed (e.g. leaf lettuce). Radiative freeze damage of strawberry often results in smaller fruit (Meesters, 1995) and depending upon the developmental stage when damage occurs, misshapen fruit (Goulart and Demchak, 1994). Other examples of degradation in appearance include: discoloration of kiwifruit (*Actinidia chinensis* Planchon) (Testolin et al., 1994); frost rings on apple; and frost circles on peach.

3.3.2.3. High temperature stress. A wide range of appearance disorders are caused by preharvest high temperatures. The injury sustained is temperature and time dependent and varies with species, cultivar, stage of development, condition, plant part in question, and other factors. Products most likely to incur high temperature injury are generally those in direct sunlight and damage is exacerbated by conditions that impede transpiration such as water deficit stress. Direct effects of high temperature stress include damage to cellular membranes, proteins, and nucleic acids. Indirect effects to appearance include inhibited pigment synthesis (Vogele, 1937) and thermal degradation of existing pigments giving a wide range of sun scald or sun burn symptoms (also see the section on light intensity). In addition, high temperature can inhibit ripening (Yoshioka et al., 1980), cause premature ripening (e.g. pumpkin; Hill, 1995), alter the translucency of pineapple tissue (Paull and Reyes, 1996), and increase desiccation through accelerated water loss leading to a cross-section of unfavorable appearance alterations.

3.3.2.4. Wind damage. Wind damage can be separated into two general categories based upon the severity and frequency: damage caused by relatively infrequent severe storms (typhoon/hurricane); and that caused by much more frequent winds of intermediate strength. High intensity winds result in leaf damage and defoliation which in leafy vegetables has a disastrous effect on product appearance and marketability. With fruit crops, defoliation routinely leads to smaller fruit (Eckstein et al., 1996), may result in poor fruit color (e.g. citrus; Ogata et al., 1995), and increased surface blemishes such as friction marks on kiwifruit (McAneney et al., 1984; Lizana and Stange, 1988), wind scab of French prune (*Prunus domestica* L.) (Michailides and Morgan, 1993), and wind rub of persimmon (George et al., 1997). Use of windbreaks has long been advocated in fruit and vegetable production areas that are subject to excessive wind (Holmes and Koekemoer, 1994).

3.3.2.5. Hail damage. Hail damage is sporadic but worldwide more extensive than is generally thought. For example, in one area of northern Italy during 1995, hail affected 1728 ha of fruit with damage ranging from 10 to 50% of a cross-section of fruit crops (Petermair, 1995). Hail stone size, crop growth stage (Duran et al., 1994) and the duration of exposure are critical factors affecting the degree of damage. Hail damage results in a direct effect on the physical quality of the product (e.g. increased deformed fruit (Hong et al., 1989) and anatomical alterations (Visai and Marro, 1986; Fogliani et al., 1985)), but also increases the incidence of disease (e.g. bacterial spot (*Xanthomonas campestris* pv. *vesicatoria* (Doidge) Dye) of pepper (*Capsicum annuum* L. Grossum group; Kousik et al., 1994). Where the incidence of hail is frequent, methods to minimize damage may be cost effective [e.g. use of bunch covers on bananas (Eckstein and Fraser, 1996) and the use of hail nets over apple, pear, and other orchard tree crops (Reid and Innes, 1996)].

3.3.3. Soils

The effect of soil on the appearance of fruits and vegetables is largely through its textural properties, drainage, soil reaction, and nutrient availability. Soil physical and chemical properties that most frequently alter the preharvest appearance of fruit and vegetable crops, affect size. Soil texture is especially important for many root and tuber crops in that soils with a high mechanical impedance can result in significant alterations in shape (e.g. sweetpotato). In carrot, physical impedance from stones or compaction result in root forking and stunting. Likewise, high density and/or poor drainage conditions can result in an oxygen deficiency stress (Chua and Kays, 1981) that alters the appearance of underground storage organs. Sandy soils in windy locations can result in abrasions to the surface of the product.

3.3.4. Moisture relations

Water stress is a universal problem in production agriculture and can have a significant impact upon product appearance. In addition to yield reduction, water stress conditions during development typically result in products of reduced size. Examples are: seed crops (Bradford, 1994); olive (Inglese et al., 1996); muskmelon (*Cucumis melo* L. Reticulatus group) (Lester et al., 1994); citrus (Bielorai, 1982); and peach (Veihmeyer and Hendrickson, 1949). Water stress can also alter other appearance characteristics of fruits and vegetables through its effect on discoloration and surface topography (e.g. tissue collapse as in lettuce leaves and sweet corn kernels (*Zea mays* L. subsp. *mays*)). A secondary effect of water deficit stress is that it renders the product more susceptible to thermal injury.

Changes in water status alter the general condition of the product with economic losses being due to both decreased quality and product weight. Generally, a loss of only 5–10% moisture is sufficient in most fruits and vegetables to render the product unsalable (Robinson et al., 1975).

3.3.5. Pollution

Injury to vegetation due to exposure to pollutants has increased markedly in the last three decades. Pollutants may interact with the plant as solids, liquids, or gases. Ions of heavy metals, for example, can cause serious injury and death of cultivated crops. The most toxic of these are Ag, Cd, Co, Mg, Mn, Ni and Zn which may be introduced to the plant through soil amendments, runoff, or contaminated irrigation water.

Air pollutants also cause extensive damage to plants during the production phase. Of primary concern are ozone, sulfur dioxide, fluoride, and nitrogen compounds such as nitrogen oxides. When the concentration of an air pollutant is sufficiently high, discoloration and surface lesions occur. For example, fluoride results in discoloration of peach fruit; ozone causes surface blistering of spinach (*Spinacia oleracea* L.) leaves; nitrogen dioxide results in marginal and interveinal collapse of lettuce leaves; and ammonia causes discoloration of dandelion (*Taraxacum officinale* Wiggers) leaves. For additional details and a pictorial atlas, see Jacobson and Hill (1970).

3.3.6. Growth regulators

While there are innumerable instances in the literature of one or more plant growth regulators positively or negatively altering the appearance of fruits and vegetables, these chemicals are largely not used in production agriculture and, as a consequence, are of little importance. The following is a brief survey of the effect of several growth regulators on appearance. Ethephon alters apple (Bae et al., 1995) and orange fruit pigmentation (Gaona et al., 1994) and mung bean sprout shape (Ahmad and Abdullah, 1993). Gibberellic acid has been shown to alter grapefruit color (McDonald et al., 1997), to decrease the fruit size of pear (Honeyborne, 1996), and increase apricot fruit (*Prunus armeniaca* L.) weight (Southwick and Fritts, 1994). Gibberellic acid is used commercially to increase the size of certain grape cultivars. Dichloroprop applied to apple alters fruit coloration (Byun et al., 1995) and *N*-(2-chloro-4-pyridyl)-*N*-phenylurea application alters kiwifruit size (Lötter, 1992).

3.3.7. Light intensity

Alterations in product appearance due to light intensity can be due to insufficient or excess light striking the plant and/or product. Excess light results in sun scald that is a significant problem for a wide range of crops. Excess solar energy initially results in degradation of the pigmentation in the affected area and if the duration of exposure or intensity is sufficiently high, cellular death and collapse of the tissue follows. The effect of high light intensity stress is predominantly thermal in nature, though light bleaching of chlorophyll can occur. Examples of several crops in which sun scald is a significant problem are: persimmon (George et al., 1997); tomato (Dodds et al., 1997; Harender et al., 1995); mandarin (*Citrus reticulata* Blanco) (Myhob et al., 1996); brambles (Stiles, 1995); pomegranate (Panwar et al., 1994); blueberry (*Vaccinium corymbosum* L.) (Caruso, 1995); cranberry (Caruso, 1995); pineapple (*Ananas comosus* (L.) Merr. (Lutchmeah, 1992); apple (Sibbett et al., 1991); and banana (Wade et al., 1993).

Insufficient light typically results in smaller fruit (e.g. strawberry (Osman and Dodd, 1994); satsuma (*Citrus reticulata* Blanco) (Izumi et al., 1992); apple (Rom, 1990)). In strawberry low light decreases the surface glossiness of the fruit (Osman and Dodd, 1994). Low light intensity reduces the color development in red apple cultivars (Campbell and Marini, 1992), a common situation when fruit are located well within the tree canopy (Moran and Rom, 1991). Other examples of light deficiency stress on color development are: grape (*Vitis vinifera* L.) (Hummell and Ferree, 1997); peach (Corelli-Grappadelli and Coston, 1991; Marini et al., 1991); strawberry (Saks et al., 1996); kiwifruit (Antognozzi et al., 1995); persimmon (Hasegawa and Nakajima, 1990); sweet cherry (Patten and Proebsting, 1986); and cucumber and tomato (Janse, 1984). In tomato, low light results in an increased incidence of puffy fruit and blotchy ripening (Rylski et al., 1994), while in grape there is a higher percentage of 'shot' berries (Hummell and Ferree, 1997).

3.3.8. Pruning/thinning

Production operations such as pruning (Myers, 1993) and fruit thinning can significantly affect fruit size. For example, fruit thinning increases the size of peaches (Westwood and Balney, 1963) and apples (Batjer et al., 1957). The effect on size is based upon the fact that under good production conditions, many fruit crops set more fruit than desirable. Thinning increases the leaf to fruit ratio giving larger individual fruit; for a critique, see Westwood (1993).

3.3.9. Bagging

Enclosing individual fruit or fruit clusters within bags has been used to a limited extent to decrease insect and disease damage and in some instances to inhibit color development. For example, bagging decreases the incidence of anthracnose (*Colletotrichum*) and stem end rot (*Dothoriella* spp.) in mango (Hofman et al., 1997) and russett in pear (Hong et al., 1996). Bagging decreases insect damage in bitter gourd fruit (*Momordica charantia* L.) due to melon fly (*Dacus cucurbitae*) (Fang, 1989), in pomegranate (*Punica granatum* L.) due to the pomegranate fruit fly (*Virachola livia*) (Hussein et al., 1994), and in apples due to the codling moth (*Cydia pomonella*) (Bentley and Viveros, 1992).

Depending upon the type of bag and the length of time it covers the fruit, its presence can have a significant effect upon pigment synthesis. In some instances this may be beneficial (e.g. the inhibitory effect on chlorophyll synthesis in bitter gourd results in fruit that are cream colored and preferred by consumers in some countries) while in many other species the effect on color may be undesirable (e.g. mango (*Mangifera indica* L.); van Straten et al., 1994; Hofman et al., 1997).

3.3.10. Herbicide injury

Occasionally product appearance is compromised by the inappropriate selection of a herbicide, the incorrect concentration, drift from adjacent crops, or residual material in the soil from a previous crop. Distorted, misshapen tomato fruit occur with herbicides that act as plant growth regulators (e.g. 2,4-D and dicamba) (Howard et al., 1994). Soil residues of sulphorylurea and imidazolinone herbicides can be particularly damaging to vegetable crops. Amitrole residue, for example, results in deformed potato tubers.

3.4. Mechanical damage

During growth, plants are subjected to mechanical stresses from a variety of sources (e.g., wind, rain, hail, herbivores, soil compaction) and these stresses can have a pronounced effect on the eventual appearance of the product. Mechanical stress can be separated into two general types, mechanical perturbment and physical wounding (Kays, 1991). The former, while not resulting in a direct wound to the product, can result in distinct alterations in the growth and development, altering the eventual size and shape of the product. Physical wounding is perhaps the more readily recognized form of mechanical damage in that it causes a physical injury (a mechanical failure) to the tissue. Types of mechanical stress include friction, impact and compression and these lead to one or more types of tissue failure (cleavage, slip, bruising, and buckling) which result in subtle to pronounced alterations in the appearance of the product. Examples of causes of mechanical damage during the preharvest stage of development are wind and hail (for additional details see the section covering weather), blowing sand damage to leafy and fruit crops, and compression of developing fruit due to adjacent fruit or limbs.

3.5. Extraneous matter

The presence of extraneous matter on or with the product can greatly reduce its attractiveness. The presence of growing medium, a common malady of mushrooms, is one example of extraneous matter. Likewise, the presence of vegetable matter such as damaged, diseased, wilted or dead leaves, especially in leafy vegetables, is undesirable. Foreign plant material such as weeds also reduces the attractiveness of the commodity. Other extraneous matter such as insect webbing, excreta, and dead bodies is also highly undesirable.

Minerals deposited via the evaporation of water from overhead irrigation and residual agricultural chemical sprays (e.g. $CaCO_3$ sprays on plum; Joubert and Kotze, 1989) can unfavorably alter the surface appearance of horticultural products. With products that can be washed during the postharvest period, surface residues can generally be removed. However, with crops that are easily damaged or can not be exposed to free water (e.g. bramble fruits, strawberry), residual surface chemicals are distinctly undesirable.

3.6. Genetic factors

Cultivar selection is of primary importance in achieving the desired product appearance. While cultivars range widely in shape, size, and color (e.g. white versus green asparagus; Sanchez, 1996), they also vary in their ability to achieve the desired phenotype under differing production conditions. In addition, some cultivars are sufficiently heterozygous that they continue to segregate during field production. This can result in a much wider range in appearance characteristics of the harvested product than in a more homozygous cultivar.

In addition to genetic variation among cultivars, a certain percentage of the product exhibits genetic aberrations, rendering them substandard or unacceptable in appearance. These may be due to mutations (e.g. color mutations are common in sweetpotato storage roots) or to stress conditions altering the developmental sequence. Occasionally, quite bizarre forms are produced (e.g. tomato, pepper, squash, potato (*Solanum tuberosum* L.)).

4. Removal of defective product

Elimination or segregation of product with appearance defects is normally via visual assessment of each individual product unit during hand harvest and/or in the packinghouse. Mechanically harvested products may be graded on the harvester or likewise, in the packinghouse. Grading for appearance defects after harvest utilizes visual means and depending upon the product, a variety of possible mechanical and/or electronic means. Product down graded due to appearance is not necessarily discarded, though it typically commands a lower market price. Some crops with appearance defects can be readily utilized in processing (e.g. jumbo sweetpotatoes are used for pureed products such as baby food or pie fillings). Likewise, a portion of the total volume of down graded product moves into secondary markets with different quality tolerances (Mukai, 1987).

5. Conclusion

It is evident that a diverse range of biotic and abiotic factors can alter the appearance of fruits and vegetables prior to harvest. Even under optimum production conditions, a portion of every crop is invariably down graded due to appearance defects. Although it is not possible to eliminate all preharvest losses due to appearance defects, the extent of these losses can be reduced through a better understanding of the nature of the problem and by being cognizant of potential solutions.

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