PEEL MORPHOLOGY AND FRUIT BLEMISHES

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Introduction

The canon that "consumers buy with their eyes" often dictates how fresh fruit are produced and handled. With respect to fresh citrus, consumers demand that the fruit have few blemishes, good color, and high gloss. Marketing of citrus thus depends on the peel quality.

The peel is a natural package. It protects the flesh from insect and microbial invasion and limits water loss and gas exchange. However, for the peel to become marketable, it must form and develop with few defects and be resilient enough to maintain its integrity on the tree and during postharvest storage. This section discusses peel morphology and selected peel blemishes and disorders.

Morphology and Composition of Citrus Peel

Citrus peels are comprised of two regions: the flavedo and the albedo (Figure 1). The flavedo consists of characteristic peel oils and pigments while the albedo is the white pithy region. Although the albedo is by far the thicker of the two layers, the critical positioning of the flavedo between the fruit and environment makes it more susceptible to damage and thus more likely to be affected by peel disorders.

Flavedo. The outer most constituent of the flavedo is the cuticle. The cuticle is a thin (< 3 µm for citrus fruit), continuous polymer that plays a pivotal role in the growth and storage of citrus fruit. Before postharvest wax application, the cuticle serves as the primary barrier between the fruit and its environment. Consequently, the cuticle determines gas exchange rates of water vapor, respiration metabolites like oxygen and carbon dioxide, ethylene, and flavor volatiles like alcohols and aldehydes. The cuticle also acts a barrier to insects and microbes that would readily consume an unprotected fruit.

The cuticle is comprised of a matrix and associated waxes. The matrix is essentially a polyester that is polymerized from hydroxylated fatty acids such as 10, 16-dihydroxyhexadecanoic acid (Figure 2). Waxes are embedded within or are deposited on this matrix. For most species, the primary wax constituents are long chain alkanes and alcohols (Figure 3). Other constituents include long chain aldehydes and fatty acids. In citrus cuticles, triterpenoids such as squalene and friedelin sometimes account for a high percentage of the total wax. The chemical composition of the cuticle is primarily dependent on the species, but time of season and growing conditions also influence composition. For citrus, waxes may transform from primarily soft waxes (soluble in petroleum vapors

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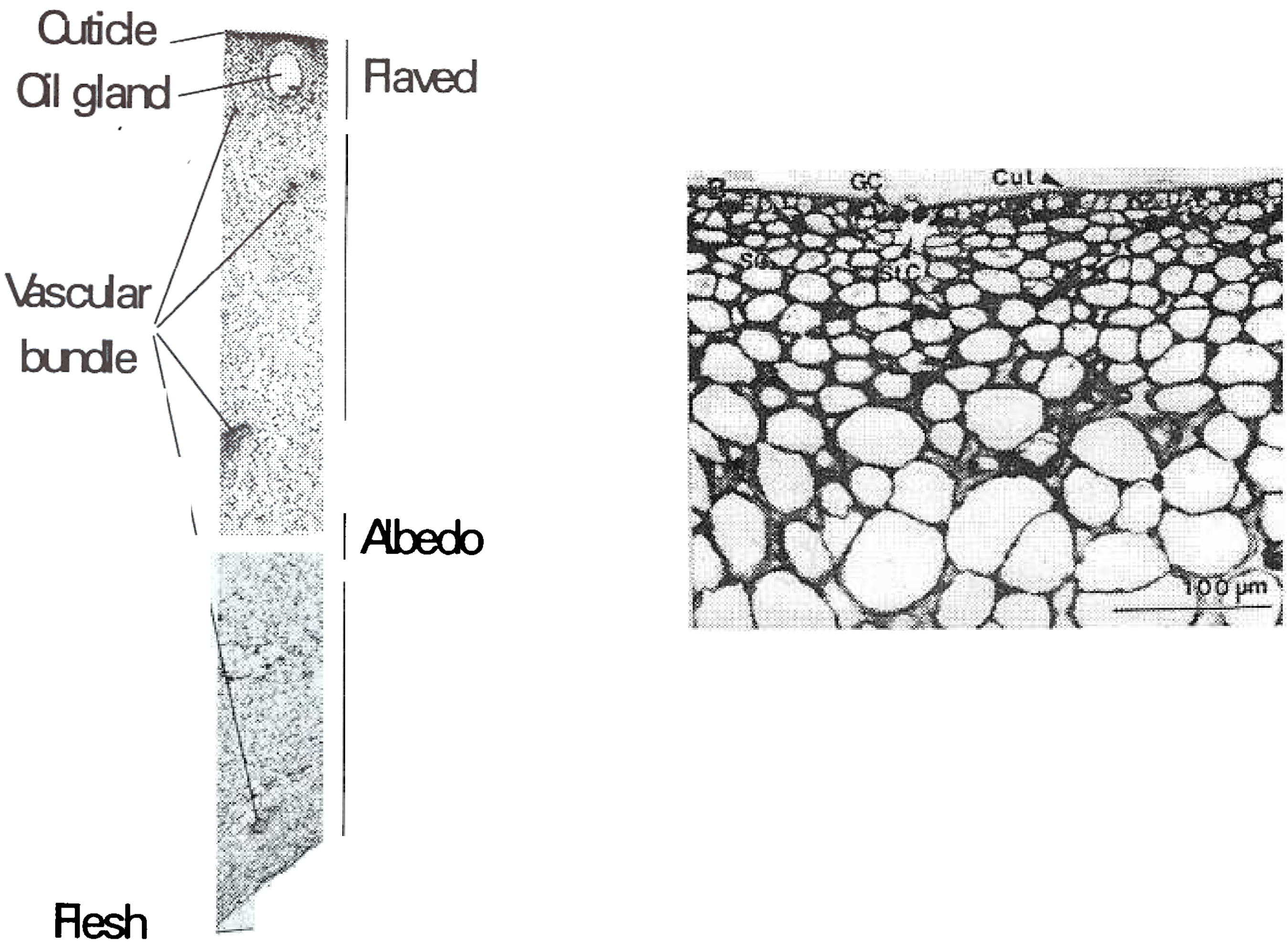

Figure 1. Anatomy of the peel of white grapefruit. Light micrographs of cross section of the entire peel (left, bar equals 0.5 mm) and close up of flavedo (right). EC - epidermal cells, SC - subepidermal cells, GC - guard cell, StC - stomatal chamber, and Cut - cuticle

such as alkanes and alcohols) to hard waxes (insoluble in petroleum vapors such as oleanic acid) as the fruit matures on the tree.

The process of cuticular formation is still not well understood. The chemicals that form the cutin matrix and cuticular waxes are probably synthesized in the underlying epidermal cells. The chemical constituents of the cutin matrix may be exuded onto the surface of the epidermal cells and be polymerized. Waxes may also be exuded from the epidermal cells and transported through the cutin matrix by natural solvent or perhaps diffuse through channels. The cuticle itself may be the site of post-deposition polymerization and modification of wax structure.

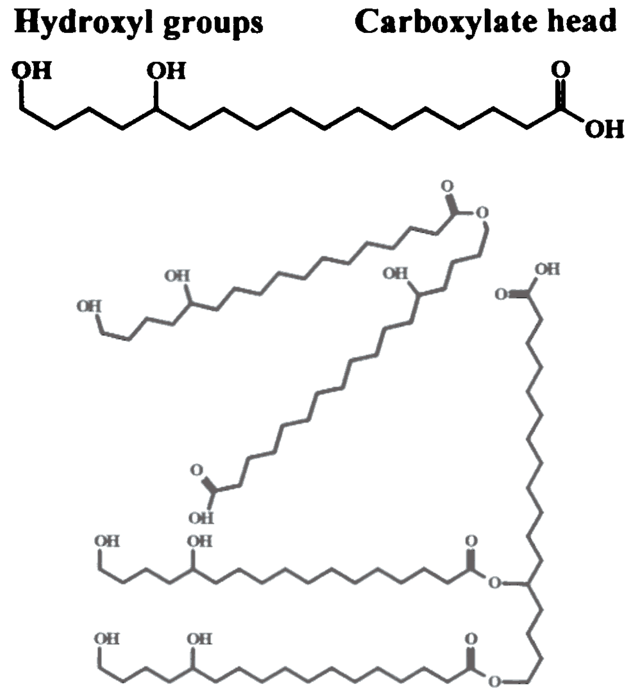

Figure 2. Primary constituent of the cutin matrix. Chemical structure of monomeric (top) and polymeric (bottom) forms of 10, 16-dihydroxyhexadecanoic acid

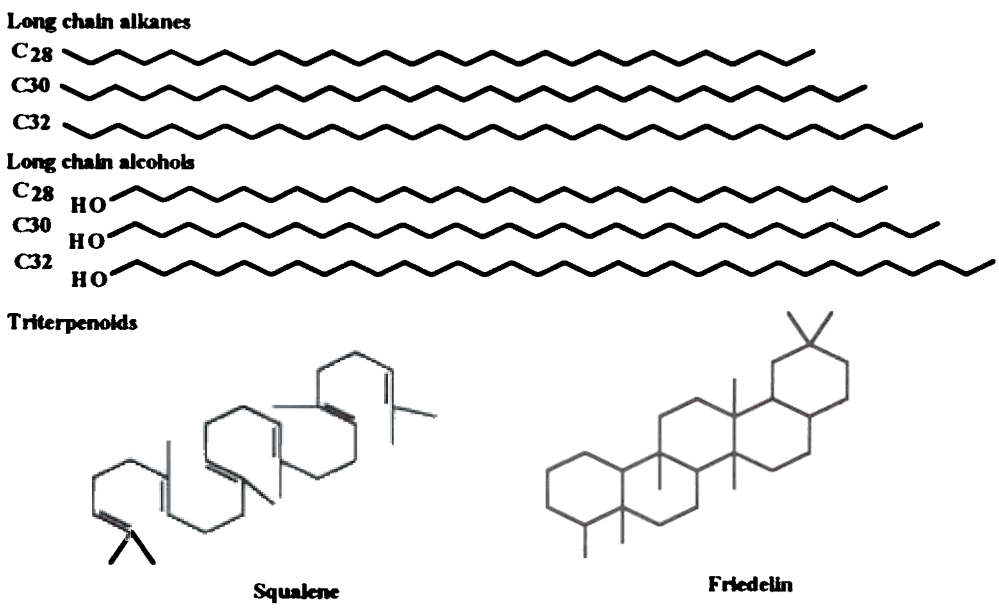

Figure 3. Constituents of epicuticular and (intra)cuticular waxes. Chemical structures of some primary constituents of the wax cuticle.

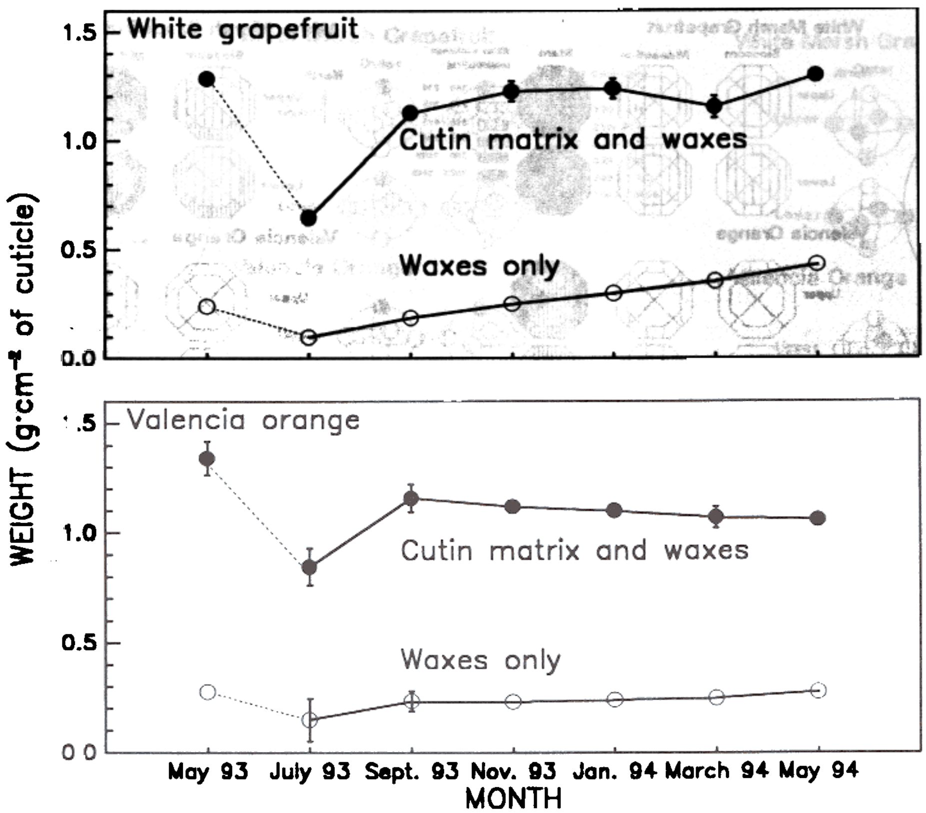

Figure 4. Effect of time of season on cuticular weight of Marsh white (top) and Valencia orange (bottom). Pesticide-free fruits were harvested in May 1993 and then every two months during the 1993-94 season. Cuticular disks (4.15 cm^2) were enzymatically isolated, weighed, and solvent extracted (n = 10 cuticles ± SE).

The mechanisms by which external factors influence cuticular development also are not well understood. In some species, environmental conditions such as humidity, temperature, sun exposure, and acid rain influence wax content. In citrus, early maturing varieties (e.g. mandarins) have lower wax levels than later maturing varieties. Low humidities and higher temperatures tend to stimulate wax production. Fungicides such as benomyl also may increase wax production. Also, sun exposure of outer canopy fruit alters triterpenoid levels in white grapefruit.

In order to examine seasonal changes of cuticle weights, we enzymatically isolated cuticles from the same trees throughout the growing season. The cuticles were exhaustively extracted with

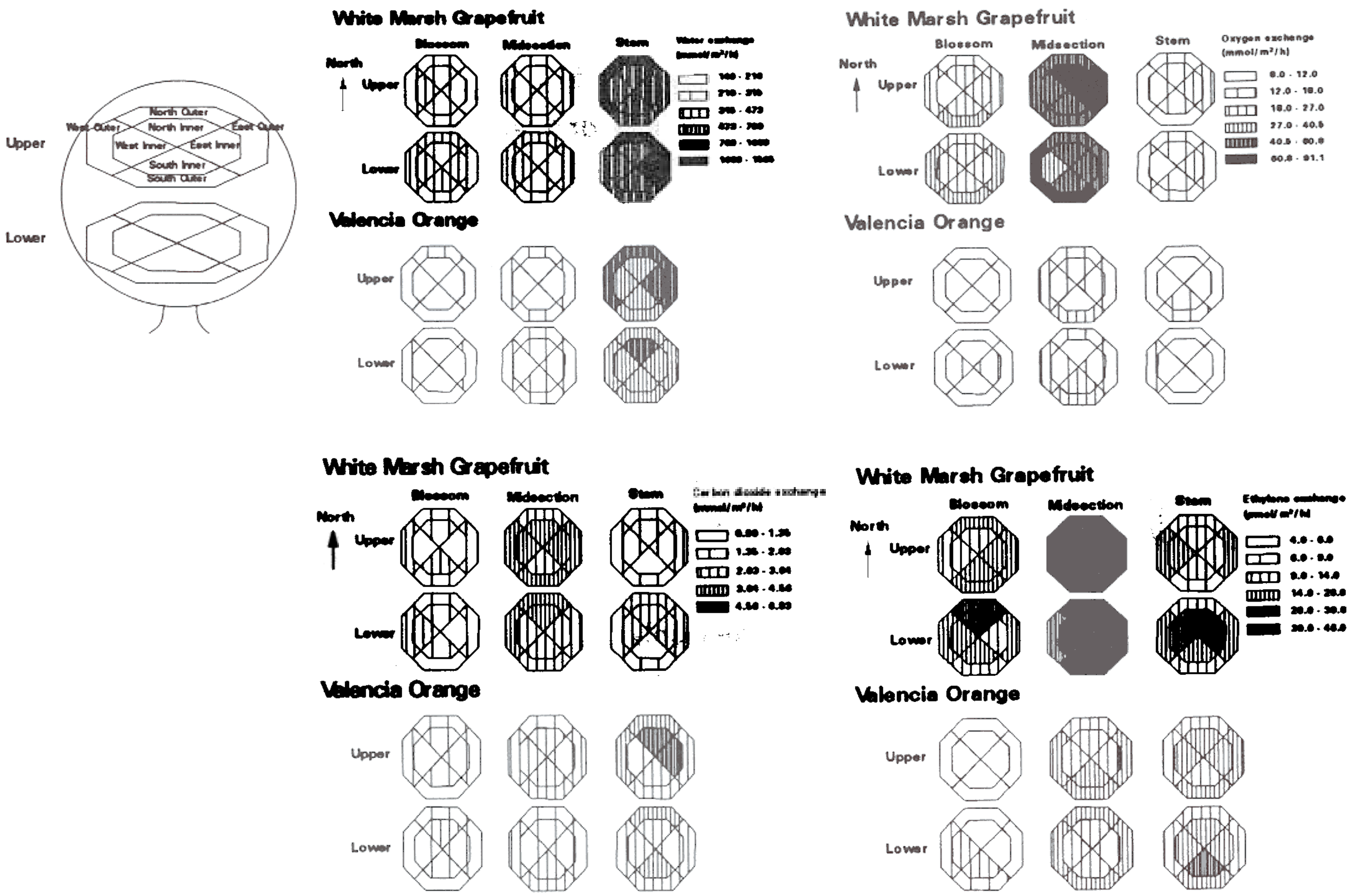

Figure 5. Effect of canopy position on gas exchange of mature white grapefruit and oranges. Water, oxygen, and carbon dioxide exchange rates were measured by flow through cells (23 mm diam.) attached to the surface of the fruit. Ethylene exchange was measured by collection cells (23 mm diam.) attached to the surface of the fruit after exposure to 24 h to 10 $\mu L \cdot L^{-1}$ ethylene.

solvent to determine the weight of wax. In these studies, we found that cuticles from early season (May and June) fruit could not be isolated because they readily fragmented. Those fragments that could be recovered were small (< 1 cm^2) and thin. The framenting suggests that the cutin matrix during the early stages of development are probably insufficiently cross-linked. This lack of integrity may explain the susceptibility of the fruit to wind scar, insect damage, and chemical burns. Cutin weights of white grapefruit and Valencia oranges increased between July and Sept. but remained nearly constant between Sept. and May (Figure 4). Wax levels also increased sharply between July and Sept. for grapefruit and oranges and changed little in mature oranges. However, wax levels of

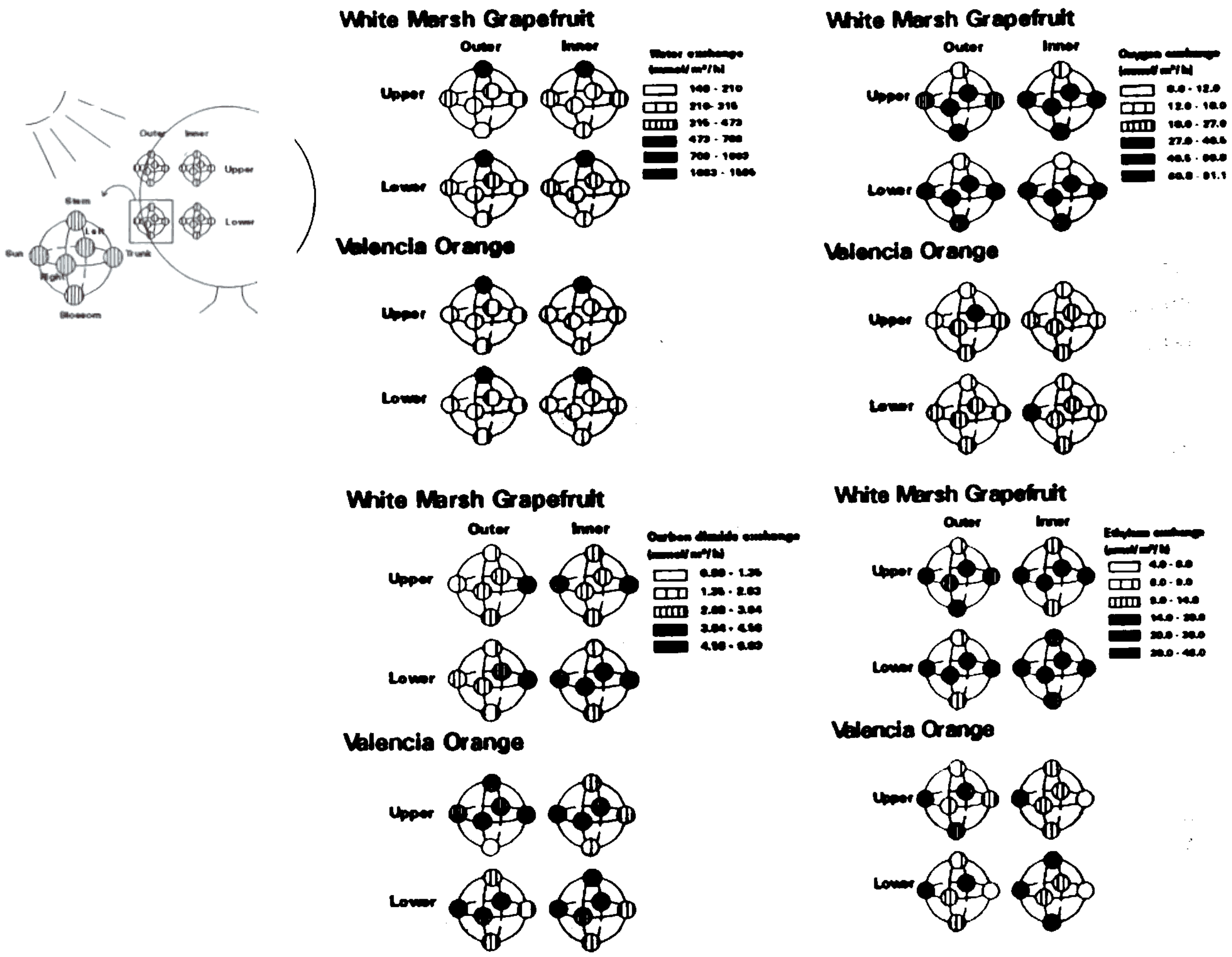

Figure 6. Effect of canopy position on gas exchange of mature white grapefruit and oranges harvested from a southern canopy. Water, oxygen, and carbon dioxide exchange rates were measured by flow through cells (23 mm diam.) attached to the surface of the fruit. Ethylene exchange was measured by collection cells (23 mm diam.) attached to the surface of the fruit after exposure to 24 h to 10 $\mu L \cdot L^{-1}$ ethylene.

white grapefruit increased steadily (about two-fold) between Sept. and May.

The cuticle is not unlike a sheet of polyester onto which candle wax has been poured. The wax effectively fills the matrix. Increasing the wax content tends to make the matrix more impregnable and thus tends to reduce water loss. The difference between the cuticle and a wax-filled piece of cloth, however, is that the cuticle is perforated with stomatal pores that are protected by guard cells (Figure 1). Since the fruit is respiring, the cuticle must allow oxygen to be taken up and carbon dioxide to be released. The stomates allow the fruit to exchange these gases and thus permit the oxygen and carbon dioxide levels within the fruit to remain close to ambient levels (18 - 20% and 1 - 3%, respectively).

During fruit maturation, waxes fill some stomatal pores and block gas exchange. Our studies on the effect of canopy position (Figures 5 and 6) and sun exposure (Figure 6) suggest that location of the fruit and orientation of the fruit to the sun generally played little role in influencing gas exchange. However, gas exchange decreased with increasing weights of either cutin matrix and waxes, and thus illustrated the importance of cuticular properties on fruit physiology.

Epidermal cells form the outer most cell layer in the peel (Figure 1). The next 3 to 8 layers of cells are the subepidermal or hypodermal cells. Epidermal and subepidermal cells are structurally similar and tend to be densely packed together. The parenchyma cells, which are found underneath the subepidermal cells and extend through the albedo to the flesh, create an airy network in which vascular bundles are interspersed.

Oil glands are found immediately directly under the hypodermal layer and amongst the parenchyma cells. The oil glands consist of large cells of which the cell walls are often thin or collapsed. The oil within these glands is primarily d-limonene, a powerful organic solvent that solubilizes most cells. Since the oil is toxic to many organism, it may play an important role in protecting the fruit from insect and microbes. However, the oil is toxic most of the cells in the peel and therefore must be contained. The cells that envelope these glands are apparently resistant to the effects of the oil and thus contained and prevent damage.

Albedo. The albedo is comprised mostly of airy parenchyma cells interspersed with vascular bundles. These cells are susceptible to enzymatic degradation by cellulases and pectinases that may become more active as the fruit ages. The cells of the albedo play an important physiological role in that the vascular bundles that network the albedo provide water an solutes for the peel and flesh. However, this vacuous network does little to inhibit gas movement in comparison with the cuticle.

Peel Blemishes and Disorders

The correct diagnosis of a peel blemish or disorder is essential to determining its control. Disorders can often be readily identified by visual observation. However, since a single peel disorder may have as many manifestations as Vishnu, diagnosis sometimes require a familiarity with several forms of the disorder. In many cases, production and handling information of the fruit is essential. Histological evaluation may also provide additional clues. This section discusses selected peel defects that arise during production and postharvest handling and storage.

Preharvest disorders. There are potentially dozens of blemishes and peel disorders that may develop on citrus fruit during production. The causes of these defects include damage from climatic conditions (e.g. hail damage, wind scar), nutritional deficiencies or toxicities, chemical spray burns (e.g. heribicides, insecticides, nutrients, and growth regulators), mites and insects, or microorganisms (e.g. scale spots, melanose, scab, greasy spot). Despite the wide range of defects, most have characteristic traits such as pattern of damage, color, and roughness that provide information regarding the cause of the damage. Symptomology may be classified by the type of damage. For example, wound periderms, scabs, or scars suggest that the cuticle has been compromised and that underlying cells have been affected. Discoloration suggests cell damage. Location of damage (e.g. stylar end vs. stem end, inner canopy vs. outer canopy, and oil gland vs. inter oil gland) also provides valuable evidence about the cause of the damage.

The most common peel blemishes that develop on the tree are caused by insects. These blemishes typically result from damage to the cuticle, epidermal, and subepidermal cells. Growers can reduce their losses by selecting blocks that have a history of producing high pack-outs. Proper fertilization, irrigation programs are important in producing high quality fruit. Perhaps most important is to develop good pest monitoring and spray schedules to minimize insect damage. Citrus rust mite damage can be controlled with proper monitoring and spray application.

Table 1. Potential relationships between preharvest condition and postharvest stress for citrus fruit peel disorders.

Disorder	Symptom	Preharvest condition	Postharvest stress
Blossom end clearing	Wet peel at stylar end	Turgid, over mature	Rough handling
Chilling injury	Collapse of peel	Outer canopy fruit	Long term cold storage (<10C)
Creasing	Grooves in albedo	Potassium deficiency?	?
Oleocellosis	Collapse of peel between oil glands	High water content of peel	Rough handling
Postharvest pitting	Collapse of the oil glands	Larger fruit sizes	High temperature storage of waxed fruit
Puffing	Separation of peel from flesh	Late maturity?	?
Stem end rind breakdown	Collapse of peel near stem end	Late maturity?	Excessive water loss
Zebra skin fruit	Striped peel of mandarin	High water content of fruit grown under drought	Degreening

Adapted from Pantastico 1975, Petracek, 1996, Smoot 1967, and Whiteside 1988.

Chemical burns result from spray application during production and during postharvest handling. Spray burns are characterized by peel collapse and discoloration. Sometimes no wound periderm forms since chemicals penetrate the cuticle with disrupting it. Spray problems may increase with the use of multi-component sprays. Combinations may produce incompatibilities that increase the likelihood of producing chemical burns.

Although most citrus peel blemishes and disorders are associated with the flavedo, several common peel disorders develop in the albedo. Puffing, creasing, and aging are most apparently the result of the breakdown of the albedo. The resulting deep collapse of these disorders may occur on the tree, but are most often observed after packing. Symptoms of nutrient-related disorders may also be expressed in the albedo. Boron deficiency symptoms, for example, include development of small brown patches that may become gelatinous in the advanced stages.

<u>Postharvest disorders.</u> Peel disorders are often considered to be either a preharvest or postharvest problem. Preharvest conditions affect fruit susceptibility to postharvest stress. The variability in fruit response to postharvest stress suggests that susceptibility is variable and perhaps be alterable. The determination of the cause and control of a postharvest disorder therefore may benefit from an examination of the events prior to packing. Studies of production and storage factors are complex, however, and thus require a considerable investment of time and resources. While the precise effects of preharvest conditions postharvest disorders is not well understood, several relationships have been discovered or postulated (Table 1).

Oleocellosis or oil spotting is a disorder commonly associated with rough handling of turgid fruit. When oil glands are physically ruptured, the oil may spread over the surface of the fruit. Oil transferred to the surface of other fruit will cause their peels to collapse. Microscopic evaluation of oleocellosis shows that peel oil causes epidermal, subepidermal, and parenchyma cells to collapse, but oil glands and cells enveloping the oil gland remain in tact. Consequently, oleocellosis results from the collapse of the flavedo of all regions except that of the oil gland.

Chemical burns sometimes result from postharvest handling. Excessive chemical levels in denching solutions may lead to characteristic necrotic rings in the peel. These anuluses form because drench solution is held between the fruit. As the drench solution evaporates, the chemical solutes condense at the contact points and create deposits with high chemical concentrations. The chemical diffuses through the peel and damages cells of the flavedo.

Postharvest handling of the fruit has a substantial effect on peel physiology. Perhaps the most significant is the application of the water based shellac wax (Figure 7). While washing slightly increases water loss, wax application greatly reduces weight loss and water vapor exchange and virtually stops exchange of oxygen, carbon dioxide, and ethylene. The applied coatings of commonly used water based shellac waxes form sheets that are 3 to 15 µm over the surface of the peel. These sheets may be cracked or have gaps (non-waxed regions), but often are contiguous. The result is that wax application adds a significant barrier to gas exchange.

Despite the substantial effects on gas exchange, little is known about the role of waxing in the development of peel disorders. However, several effects have been documented. First, waxing tends to reduce chilling injury. Chilling injury is a disorder that occurs primarily in the epidermal and subepidermal cells. The benefit of wax application is often attributed to the reduction of water loss since high humidity storage also tends to reduce chilling injury.

Second, reduction of water loss by wax application also reduces stem end rind breakdown. Stem end rind breakdown is a disorder characterized by the collapse of the peel mainly around the stem end. This disorder may be triggered by excessive localized loss of water resulting from high

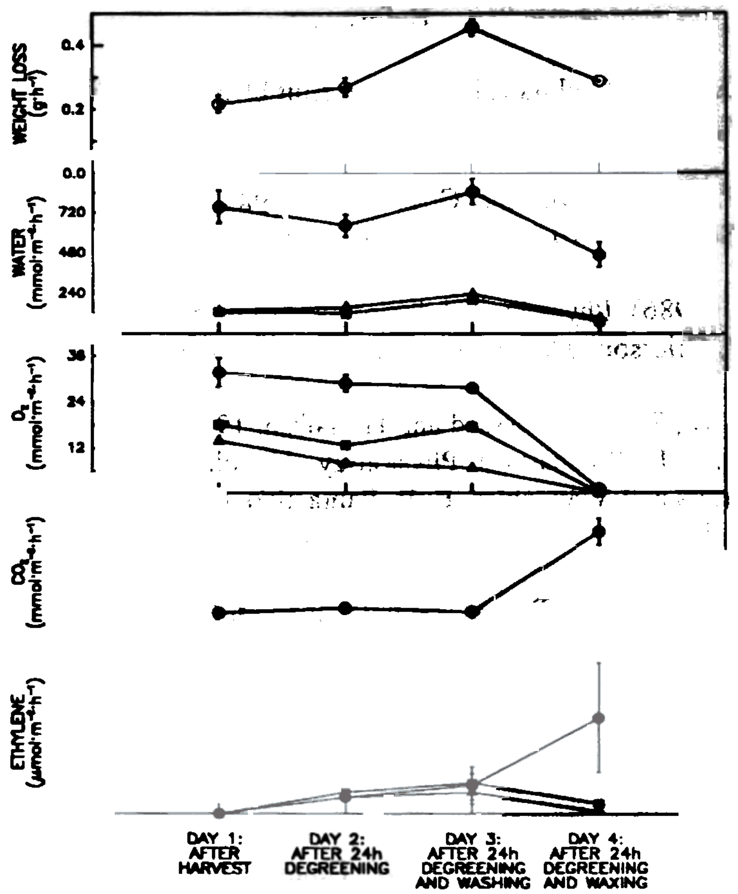

Figure 7. Effects of packinghouse treatment on whole fruit weight loss over a one hour period (o) and gas exchange of white grapefruit peel at stem end (•), mid-section (▪), and stylar end (▴). Fruit were treated and analyzed over four consecutive days. In sequence, fruit were harvested and analyzed (day 1), degreened 24h with 10 µL/L ethylene at 29.5C and 95% RH and analyzed (day 2), degreened 24h, washed, and analyzed (day 3), and degreened 24h, waxed, and analyzed (day 4). Sampling cells were 23 mm diam. Data represent the mean of five fruit (± SE).

percentages of stomatal pores that are not plugged with waxes at maturity. The application of wax effectively replaces the cuticular waxes and thus may reduce water loss and SERB.

Third, postharvest pitting, a disorder first characterized in early 1994, is caused by wax application and subsequent storage at high temperatures. Waxing decreases gas exchange, and high temperatures disproportionately increase respiration. Oxygen levels rapidly decrease and the fruit undergoes hypoxia or anaerobiosis. Other factors such as increased levels of ethanol resulting from anaerobic respiration and reduced gas exchange may also play a role.

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