AN INTEGRATED APPROACH TO REDUCE PEEL BREAKDOWN IN CITRUS

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
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To my family and friends who do not have anything to do with this but I just love them

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ABSTRACT OF THESIS PRESENTED TO THE GRADUATE SCHOOL
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Florida is the largest producer of citrus in the U.S.A., especially oranges for the juice market and grapefruit for the fresh market. Peel breakdown of fresh fruit usually manifests itself after packing and shipping and can result in major economic losses. Unusually severe peel breakdown problems were reported during the 2006-07 and 2007-08 fresh citrus seasons. Plots were established from 2007 to 2010 in commercial groves using standard fresh fruit growing practices to evaluate the effects of foliar nutritional sprays and water stress on peel breakdown of fresh citrus. Mono-potassium phosphate (MKP) was applied at 10.65 Kg MKP per acre (0-52-34; 3.62 Kg K_2O per acre) with 1.81 Kg per acre low-biuret urea (46-0-0), magnesium (Mg) was applied at 6% (4.53 Kg Epsom salts / 75.70 liters), MKP + Mg was applied separately as two tank mixtures, or an antitranspirant (Vapor Gard®) was applied at concentrations of 1% and 2% as whole tree foliar sprays at a rate of 473.17 liters per acre. In addition, whole-tree water stress was induced by withholding water for up to two months before harvest. Fruit samples were harvested at weekly or biweekly intervals and held at ~ 22.7^{o}C and 50-60% RH for three days before washing, coating with carnauba wax and then storing the fruit under ambient conditions. Evaluation of decay and the development of peel disorders and other physiological disorders occurred weekly or biweekly. Tree water

stress was measured using a pressure bomb. Incidence of peel breakdown significantly increased after blocking irrigation and rainfall for 49 days before harvest. Foliar applications of K, Mg, K + Mg, or Vapor Gard® reduced peel breakdown by about an average of 35.63%, 35.22%, 29.94%, and 45.03% respectively compared to the control fruit during the 2008-09 season. This trend continued the following season with reductions from Vapor Gard® being more pronounced whereas results from foliar K and Mg were not always significant.

For postharvest treatments, fruit were held for 3 days at 21^{o}C with 30%, 60%, or 95% RH. Afterwards, fruit were washed, and either left unwaxed, waxed, or coated with wax containing a fungicide (thiabendazole or Imazalil). Significant difference in total peel breakdown of different relative humidity treatments was observed among treatments with some consistent trends. Waxed fruits, which were kept at 30% RH in prestorage showed approximately eight times and five times more peel breakdown than fruits kept at 60% RH in prestorage after 25 and 45 days of storage respectively. This trend was observed over repeated experiments. Interestingly, in some experiments, adding 2,000 ppm of fungicide Imazalil reduced postharvest peel breakdown.

CHAPTER 1
INTRODUCTION

Taxonomy, Origin and History

The genus Citrus belongs to the Rutaceae family, sub-family Aurantioideae. Sweet oranges probably arose in India, the trifoliate orange and mandarin in China and acid citrus types in Malaysia.

Citrus was probably introduced in Florida by explorer Ponce de Leon’s when he brought citrus seeds to Florida in 1493(Michael, 2000). Citrus culture proliferated in Florida in the late 1700's, when the first commercial shipments were made. By the 1999-2000 season, Florida’s citrus industry was one of the largest sources of income and employment in Florida with an overall economic impact of $9 billion, $4 billion in value added, and employed 89,700 people (Hodges et al., 2001). Fresh Florida citrus had an overall economic impact of $1 billion and employed 17,471 in 1999-2000 season. Thus, research that improves the quality of fresh citrus is economically important to the state of Florida.

Florida’s citrus industry had an economic impact of $9 billion in industry output, $4 billion in value added, and 89,700 jobs in 1999-2000 season (Hodges et al., 2001). Fresh Florida citrus accounted for $1 billion in industry output with 17,471 jobs added in 1999-2000 season. Thus, research that improves the quality of fresh citrus is relevant to the state of Florida.

Production

Florida’s citrus industry is the largest producer of citrus in the United States of America. Seventy one percent of total U.S. citrus production in the 2008-09 season was from Florida with orange and grapefruit production at 162 million boxes and 21.7 million boxes respectively. There is a total of 530,900 acres of bearing citrus acres, which is down from the maximum of 941,471 acres in 1970 (Citrus summary, 2002 and 2009). Major citrus growing regions are in South Florida with Polk, Hendry, Highlands and Desoto counties being the top four producers representing 50% of the state's total citrus production.(Table 1-2 and Figure 1-1) (Citrus summary, 2009). The four counties combined accounted for over 55% of the State's total orange production. Indian River and St. Lucie counties produced almost 2/3 of the State's grapefruit crop (Citrus summary, 2009). Four percent of Florida oranges go to the fresh market while 43% of Florida grapefruit goes to fresh market. The Indian River Research and Education Center in Fort Pierce is located in the heart of this fresh grapefruit growing region and is strategically located in close contact with citrus growers and packers.

All citrus are small, spreading, evergreen trees or tall shrubs. Plantings are usually in rectangular arrangements which eventually become tall hedgerows. Spacings are typically 20 x 25m for grapefruit and vigorous trees, 15 x 20m for oranges and tangerines, and 12-15m x 18-20m for limes and smaller cultivars. Tree densities are about 100-110 trees/acre for grapefruit, and 130-140 for sweet orange. Very little training is needed for citrus but the trees are pruned at regular intervals. Citrus trees are generally budded onto various rootstocks, which are chosen based on rootstock's horticultural traits like yield, resistance to pests and diseases or tolerance to soil type. Drip irrigation is primarily used to supply water and fertilizer (Tucker, 1978). Over 97% of Florida citrus is irrigated. Micro-irrigation methods are used on over 67% of irrigated citrus groves (Marella, 1995).

Quality of Florida Citrus

Florida citrus is known all over the world for its quality. Florida citrus has different quality factors for the fresh and processing markets. For juice, the most important quality factors include fruit juice content, fruit size, color, soluble solids and acid concentrations and soluble solids-acid ratio. In addition to internal quality, fruit size, shape, color and maturity date are important for fresh fruit. ‘Ruby Red’, ‘Flame’ and ‘Marsh’ are important grapefruit varieties, ‘Hamlin’ and ‘Navel’ are important orange varieties, and ‘Sunburst’, ‘Honey’ and ‘Fallglo’ are important varieties of mandarin. Grapefruit, navel oranges, tangerines, and mandarin hybrids fetch relatively high economic returns as fresh fruit, but low returns when they are diverted for the juice market because of poor external quality (i.e., peel blemishes) (Stelinski et al., 2009).

Florida citrus is known all over the world for its quality. It is used both for fresh market as well as for extracting juice. Juice is particularly of high quality. The most important quality factors include fruit juice content, fruit size, color, soluble solids and acid concentrations and soluble solids-acid ratio. Florida citrus growers have different quality factors for the fresh and processing markets. Fruit size, shape, color and maturity date are most important for fresh fruit but high juice content and soluble solids are important for fruits used in processing. ‘Ruby Red’, ‘Flame’ and ‘Marsh’ are important varieties of grapefruit. ‘Hamlin’ and ‘Navel’ are important varieties of orange. ‘Sunburst’, ‘Honey’ and ‘Fallglo’ are important varieties of mandarin. Grapefruit, navel oranges, tangerines, and mandarin hybrids fetch higher value in fresh market and relatively lower value in processing market (Stelinski et al., 2009).

Harvest Operations

All citrus are non-climacteric fruit; they mature gradually over weeks or months and are slow to abscise from the tree. Hence, they store best on the tree for most of the season. External color changes during maturation, but it is a poor indicator of maturity. The best indices of citrus maturity are internal: total soluble solids, acid content, and the total soluble solids/acid ratio (Kader, 1999). For example, a high quality fresh-market grapefruit will be elliptical and firm, relatively blemish-free with a turgid, smooth peel (Soule and Grierson, 1986). The fruit will have an appropriate balance of soluble solids: titratable acidity with minimum bitterness.

The harvesting season for Florida citrus is usually from September – June. Grapefruit availability is throughout the season whereas different varieties of orange span the season. Specialty fruits like temples, k-early Citrus, tangelos and tangerines are available for shorter periods during the season. Citrus is harvested both mechanically and manually in Florida. However, all fresh citrus is harvested by hand using ladders, bags, bins, conventional fruit loading trucks or “goats” and flat-bed trucks.

Postharvest Operations

Citrus fruits are transported to packinghouses, where they are handled differently depending on their intended use. Standard packing line operations include dumping onto the packing line, culling, pre-sizing, washing, drying, grading, waxing, drying, final grade, sizing, and packing into approved containers.

Maintaining Postharvest Quality

Cultivar, environmental conditions, and postharvest handling practices are important factors in determining postharvest quality. Cultivar selection is important in addressing postharvest quality issues such as firmness, because most of these are genetically controlled (Prange and DeEll, 1997). Environmental conditions can influence postharvest quality in citrus and other commodities (Kader, 2002; Prange and DeEll, 1997). Fruit size is an important factor of quality for fresh citrus consumption (Agusti, 1999). Optimum storage temperature of citrus ranges from 0 to 15^{o}C depending on citrus variety and time of year (Table 1-1). Kumquats and mandarins are the most cold tolerant whereas Limes and citrons are the least (Ladaniya, 2008). Early season, un-waxed grapefruit should be shipped at 15°C to avoid chilling injury (Ritenour et al., 2003). Later in the season, temperature can be reduced to 12°C and then to 10°C. Late season grapefruit should be handled at 15 °C as it may become susceptible to chilling injury and decay. Depending on the gas diffusion of a particular wax formulation, waxed citrus can be held at lower temperatures without developing chilling injury compared to non-waxed fruit. Postharvest handling also influences the quality of a commodity. For optimum quality and quality retention during postharvest handling, fresh citrus must also be harvested at the correct maturity stage. For example, postharvest physiological disorders are more likely in fruits picked too early or too late in their season than in fruits picked at their optimum maturity (Kader, 1999).

Table 1-1. Optimum holding temperatures for maximum quality and shelf life of fresh Florida citrus fruit

Citrus type	Optimum holding temperature (^{0} C)
Oranges	0-1
Mandarin-type fruits	4
Lemon, Limes	10
Grapefruit	10-15

Citrus Quality Problems in Florida

Citrus quality in Florida can be negatively affected by many disorders, making it unacceptable for the fresh market. When the fruit is not suitable for the fresh market, it is consigned for juice purposes, which leads to less profit to the grower. It is a much worse situation if the disorder develops during shipment, which results in rejection at the destination. This leads to higher losses as the cost of shipping is also incurred. In addition, when the buyer receives such fruit, they are less inclined to purchase fruit from that shipper again. Among the diseases and disorders that render citrus fruit unsuitable for the fresh market are 1) physical injuries such as cuts and punctures, 2) infestation with pests such as the Caribbean fruit fly, 3) pathological disorders resulting in decay or peel blemishes (i.e., from melanose, canker, etc.), and 4) physiological disorders such as stem-end rind breakdown or chilling injury.

Citrus Peel and Peel Breakdown

The citrus rind consists of the flavedo and albedo. The flavedo comprises the outermost part of the rind and includes the cuticle, epidermal cells, sub epidermal cells and oil glands (Schneider, 1968). The albedo comprises the internal spongy white part of the peel and primarily contains parenchyma cells interspread with vascular bundles. Peel disorders severely degrades the fruit appearance, but usually do not affect the edible or nutritive quality of the fruit (Petracek et al., 2006). In addition, peel disorders predispose the fruit to invasion by decay organisms, thus reducing postharvest shelf life (Hopkins and McCornack, 1960; McCornack, 1973; Smoot, 1977; Schiffmann-Nadel et al., 1975). Peel disorders are difficult to study for several reasons: they can appear and disappear unpredictably and a single disorder can have multiple symptoms while multiple disorders may have similar symptoms, even in the same fruit. Unlike diseases, which can be positively identified by isolating the causal pathogenic organisms, there are typically no single factors that critically define a disorder (Petracek et al., 2006). Hence, it is often difficult to diagnose physiological disorders. Most peel disorders such as chilling injury, postharvest pitting, oleocellosis, and zebra skin start in the flavedo but some such as creasing originate in the albedo. Peel disorders can be classified as preharvest, harvest or postharvest disorders based on their time of appearance.

Pre-harvest Peel Disorders

Preharvest peel disorders can be classified as nutritional, spray damage, weather, or maturity related depending on the cause of the disorder.

Nutritional or spray damage disorders

- Aging and stem end rind breakdown: Detailed information on this disorder is given in the postharvest section of this chapter.

- Boron deficiency: As the name suggests, this disorder is caused by boron deficiency. Symptoms include raised bumps on the fruit surface and gummy pockets in the albedo that are visible when the fruit is cut open (Bryan 1950; Browning et al., 1995).

- Pineapple pitting: Pineapple oranges are more susceptible to this disorder than other citrus varieties. Low potassium levels in adjacent leaves is the main cause (Grierson, 1965).Symptoms include the collapse of small areas of the flavedo around the shoulder and cheek of the orange peel. Darkening and coalesce of pitted areas may be seen (Browning et al., 1995; Smoot et al., 1971).

- Spray damage: The main causes of this disorder are incompatible tank mix chemical combinations, incorrect application rates or timings or a phytotoxic active ingredient in the mixture (Albrigo and Grosser, 1996). Main symptoms are streaks of damaged or non degreened cells running longitudinally down the fruit surface or by rings at fruit to fruit or leaf to fruit contact points.

- Ammoniation: Ammoniation is observed when nitrogen is used in excess on copper deficient soil (Browning et al., 1995; Smoot et al., 1971). Main symptoms are black or brown raised lesions on fruit.

Weather related disorders

- Aging and stem end rind breakdown: Detailed information on this disorder is given in the postharvest section of this chapter.

- Freeze injury: Exposure to low enough temperatures in the field that results in ice formation within the fruit is the cause for this injury. Symptoms of freezing injury are internal drying and free juice in the core of fruit. Externally, a pinkish pitting may develop. Even lighter frost injury in the grove may predispose grapefruit to alternaria stem-end rot during storage (Schiffmann-Nadel et al., 1975).

- Sunburn: Temperature of 44.4^{o} C and 20% relative humidity has been shown to cause sunburn to ‘Valencia’ (Ketchie and Ballard, 1968). The typical symptoms are flat, pale, leathery areas on the exposed side of fruit (Smoot et al., 1971).

- Water spot: Water soaking and swelling of the rind around the stylar end is observed in this disorder. It is a typical problem of Navel oranges produced under low humidity conditions that are then subjected to a cool, wet period (Scott and baker, 1947; Klotz, 1975; Riehl and Carman, 1953; Smoot et al., 1971).

- Wind scarring: It is a problem in areas where high wind velocity coincides with post bloom period. Small (less than 1 cm in diameter) citrus fruits are so susceptible to abrasion injury that just rubbing against a leaf can cause lesions that expand to large silvery or tan blemishes as the fruit enlarges (Figure 1-4) (Elmer et al., 1973; Freeman, 1976; Smoot et al., 1971).

Maturity related disorders

- Creasing: The exact cause is unknown. Potassium nutrition, rootstock and water relations are considered to be probable factors (Bar-Akiva, 1975; Embleton et al., 1971; Grierson, 1965). Main symptoms are grooves or furrows which are irregularly distributed on the fruit surface (Browning et al., 1995; Smoot et al., 1971).

- Puffiness: It is the separation of peel from the pulp. Advancing fruit maturity, tree vigor and weather (particularly irregular water supply) are the main factors involved in this disorder (Grossenbacher, 1941; Kuraoka, 1962).

- Rind staining of navel oranges: It occurs when the peel is so physiologically over mature that epidermal wax softens and handling causes reddish brown blemishes (Eaks, 1964). Brownish discoloration of the rind surface is the characteristic symptom. The susceptibility is increased by ethylene exposure, use of certain rootstocks such as Rubidox sour and rough lemon, and in trees having high nitrogen fertilization (Eaks, 1969).

Harvest Related Disorders

- Blossom end clearing of grapefruit: Rough handling of late season fruit during warm temperatures is the primary cause of this disorder. It is characterized by the translucent, water soaked appearance of the fruit peel (most commonly at the blossom end) caused by internal bruising and juice leakage from juice vesicles (McCornack, 1966).

- Oleocellosis: It is breaking of oil cells, causing the oil to extrude which damages the surrounding tissues. Symptoms include discrete spots on the peel, large scalded areas, and concentric rings of small lesions (Figure 1-5) (Turrell et al., 1964). The main cause of this disorder is rough handling of very turgid fruit (Eaks, 1969; Smoot et al., 1971; Nel et al., 1974; Wardowski et al., 1976).

- Red colored lesions: These develop when superficial wounds, no deeper than the flavedo, develop a reddish color in the lesions and surrounding peel. It is attributed to a reaction in peel tissue that forms compounds that impart resistance to infection by *Pennicillium digitatum* (Kavanagh and Wood, 1967).

Postharvest Related Disorders

- Aging and stem end rind breakdown (SERB): Symptoms involve the collapse and subsequent darkening of epidermal tissues, particularly around the stem end of citrus fruit. A narrow 2 to 5 mm ring of undamaged tissue immediately around the calyx is a characteristic symptom of SERB (Figure 1-3). Aging of oranges and grapefruit which can occur after long term storage is almost indistinguishable from SERB, except that the characteristic narrow ring of healthy cells does not tend to persist around the calyx (Smoot et al., 1971).SERB is most severe on oranges and Temples, but it may also occur on tangelos and grapefruit. Small and well-colored fruit are most susceptible to this disorder. The humid environment of Florida makes the thinner-skinned fruit more prone to SERB than thicker-skinned fruit from drier, Mediterranean environments. Fruits affected with this disorder are more prone to decay during postharvest handling and marketing. The exact cause of SERB is uncertain. It is primarily associated with drying conditions. These drying conditions are due to factors such as delays in packing, holding fruit under low humidity and high temperatures, and excessive air movement around the fruit (McCornack and Grierson, 1965). Nutritional imbalances involving nitrogen and potassium can also be a cause (Chapman, 1958).

- Chilling injury (CI): It is a common disorder characterized by the collapse of discrete areas of peel that form sunken lesions which tend to coalesce. It is induced by low temperature i.e. below 10^{o} C storage (Chace et al., 1966). At very low temperatures, superficial scalding may occur instead of pitting. It is typically reddish or tan colored. Browning of the albedo and of carpellary membranes is peculiar to lemons. In grapefruit and tangelos, oil glands may darken (Smoot et al., 1971). In Florida, grapefruit are most susceptible to CI early (October-December) and late (March-May) in the season. The fruit usually become more resistant to CI during mid-season (December-March). Postharvest temperature treatments have been used to prevent CI. Intermittent warming throughout the storage period, stepwise lowering of temperature, and pre-storage heat treatments can mitigate CI (Davis and Hoffman, 1973). Delayed storage and storage at high relative humidity can lower the incidence of CI (Pantastacio et al., 1966). Very high initial concentrations of CO_2 can mitigate CI (Brooks et al., 1936; Vakis et al., 1970; Hatton et al.,1975). Methyl jasmonate (Meir et al., 1996) and squalene treatment (Nordby and McDonald, 1990) have shown some protection from CI.

- Drench phytotoxicity: Long term, unmonitored use of drench solution can lead to the accumulation of chemicals including salts, pre-harvest agro chemicals washed from the fruit, and even motor oil from truck drenches. If these chemicals reach phytotoxic concentrations, peel damage will occur. Symptoms include discolored circular and streaking patterns. The disorder may be called Green Ring due to characteristic green circles at fruit contact points with other fruit and bin surfaces that are evident after degreening (Ritenour and Dou, 2000).

- Postharvest pitting: It is characterized by clusters of collapsed oil glands scattered over the fruit surface (Figure 1-2) (Petracek and Davis, 2000). Application of waxes with low gas transmission rates exacerbates the disorder (Petracek et al., 1998). Symptoms of postharvest pitting may also arise after exposure to low (i.e., 30%) relative humidity environments after harvest, but it is unclear these disorders share a common fundamental mechanism (Alferez and Zacarias, 2001).

- Rind staining of navelina oranges: It is characterized by collapse and drying of flavedo and eventually by darkening of affected area over time (Laufente and

Sala, 2002). It is observed mainly in navel oranges. It is both a pre- and postharvest disorder. Rind staining occurs at the stage when the peel is physiologically over mature and epidermal wax softens. Hence, handling causes reddish-brown blemishes (Eaks, 1964). Ethylene treatment, high rates of nitrogen fertilization and root stocks that promote vigorous growth make fruit susceptible to this disorder.

Peel breakdown problems were severe during the 2006–07 and 2007–08 seasons in Florida. According to industry estimates, these two seasons has cost the fresh citrus industry as much as $1 million in claims both years. These breakdown problems were not associated with chilling injury (Petracek et al., 1995). The common disorders observed in this study were general peel breakdown and SERB. Symptoms included areas of peel pitting and necrosis that appeared during the winter months, especially after cool and/or windy weather, and progressed into the spring as stem-end rind breakdown (Ritenour and Dou, 2003) when trees were flushing/flowering and temperatures were warming. The occurrence of peel breakdown of ‘Fortune’ mandarin under cool and low relative humidity (RH) conditions was also reported (Agusti et al., 1997; Vercher et al., 1994), but these reports suggested the temperature was cold enough to cause CI. As previously stated, CI was not likely the cause of the Florida peel disorder. Recent studies in Florida have shown that sudden changes in relative humidity (RH; e.g., from 30% to 90%) after harvest can cause peel pitting of Florida citrus that is not related to CI (Alferez and Burns, 2004; Alferez et al., 2005).Of the preharvest factors, plant nutrition imbalance concerning potassium and nitrogen and water stress have been suggested as potential factors influencing the susceptibility of citrus fruit to postharvest peel breakdown (Alferez et al., 2005; Grierson, 1965). For example, SERB has been reported by some to be more severe when fruit are harvested from water-stressed trees compared to non-stressed trees, whereas others have found no significant relationship (Grierson, 1965). In addition, researchers in other countries found that nutritional imbalances involving high N and low K may predispose fruit to SERB (Chapman, 1958; Grierson, 1965). No conclusive relationship between plant water stress, low K, high N, and SERB development under Florida conditions has been demonstrated. Recent research showed reduced peel breakdown after a preharvest magnesium (Mg) application on ‘Nules Clementine’ mandarin in South Africa (Cronje et al., 2008). Improved plant water status was observed from the emulsions of wax, latex and plastic that dries on the foliage and forms thin films (Gu et al., 1996; Hummel, 1990; Nitzsche et al., 1991; Plaut et al., 2004). Foliar application of this emulsion minimized plant water loss by , decreasing stomatal conductance (gs), and reducing transpirational losses,. Better appearance and excellent weathering resistance was observed after the application of polyterpene antitranspirant, pinolene on the orange surface (Albrigo, 1970). SERB, oleocelosis and creasing can be reduced by using preharvest antitranspirants spray (Albrigo, 1970).

The current studies were initiated to evaluate various pre- and postharvest treatments to better understand the factors related to the development and prevention of postharvest peel breakdown on fresh citrus. Based on the above information related to the disorder, experiments were designed to test the hypothesis that postharvest peel breakdown can be reduced by improving plant nutrition through foliar K, Mg, or K + Mg sprays before harvest, reducing preharvest water stress of the trees, or by preventing postharvest exposure to low RH conditions.

The objectives of this study were to evaluate the potential effect of preharvest plant water stress and foliar K, Mg and antitranspirant applications on postharvest peel breakdown of fresh Florida citrus (especially grapefruit). In addition, the effects of holding fruit under different RH conditions after harvest and the effects of different packingline treatments on peel breakdown were also evaluated. The goal was to better predict what conditions promote and retard peel breakdown, and to develop production and postharvest practices to reduce or eliminate the occurrence of this disorder.

Table 1-2. Florida Citrus: Production by counties and types, 2008-2009

County	All Citrus	Oranges Early-mid-Navel-Temple	Late (Valencia)	All	Grapefruit White	Colored	All
	1,000 boxes						
Brevard	806	381	303	684	25	56	81
Charlotte	3,503	907	1,973	2,880	12	409	421
Collier	10,069	4,290	5,214	9,504	29	383	412
DeSoto	20,639	9,068	11,198	20,266	26	193	219
Glades	3,057	1,598	1,330	2,928	9	34	43
Hardee	15,366	10,463	4,341	14,804	68	197	265
Hendry	21,796	8,274	12,201	20,475	250	723	973
Hernando	294	270	6	276	-	6	6
Highlands	23,219	9,670	12,417	22,087	382	358	740
Hillsborough	4,110	2,964	899	3,863	18	33	51
Indian River	11,434	2,320	1,684	4,004	2,751	4,519	7,270
Lake	4,737	2,636	947	3,583	59	476	535
Lee	3,226	1,070	1,786	2,856	19	264	283
Manatee	7,293	4,301	2,724	7,025	64	124	188
Marion	381	266	60	326	3	14	17
Martin	5,309	1,653	3,419	5,072	70	116	186
Okeechobee	2,137	950	787	1,737	110	220	330
Orange	1,359	783	465	1,248	8	36	44
Osceola	3,581	2,113	940	3,053	257	191	448
Palm Beach	237	12	-	12	-	50	50
Pasco	2,945	2,249	577	2,826	9	37	46
Polk	30,253	16,007	11,145	27,152	705	1,057	1,762
St. Lucie	12,329	1,873	3,175	5,048	1,686	5,386	7,072
Sarasota	439	96	138	234	22	152	174
Seminole	156	100	21	121	-	13	13
Volusia	292	192	40	232	16	36	52
Total	189,100	84,600	77,800	162,400	6,600	15,100	21,700

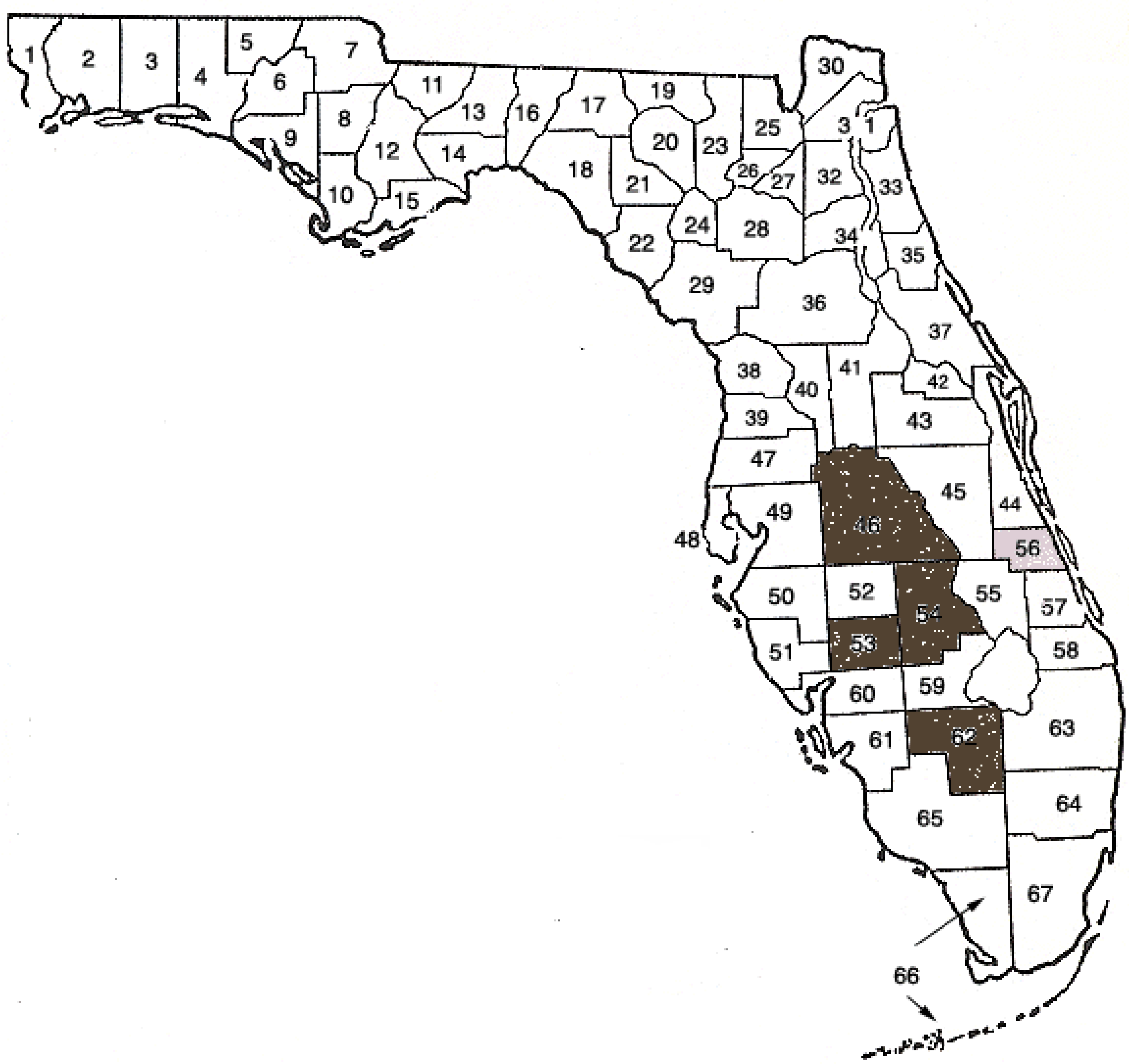

Figure 1-1.Major Citrus producing counties in Florida. Adapted from USDA, NASS Citrus summary 2008-09.County no. 46- Polk, County no. 54- Highlands, County no. 53- Desoto, County no. 62- Hendry and County no. 56- Indian River County.

Figure 1-2. Postharvest pitting in grapefruit.

Figure 1-3. Stem end rind breakdown in grapefruit.

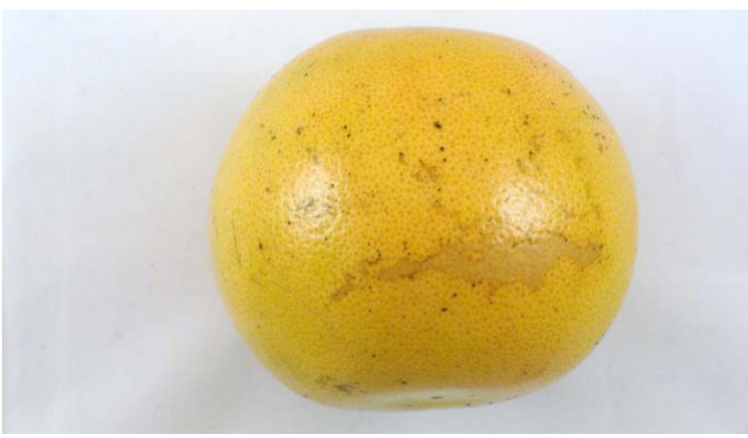

Figure 1-4. Wind scarring of grapefruit

Figure 1-5. Oleocellosis on grapefruit.

CHAPTER 2
PREHARVEST FACTORS AFFECTING PEEL BREAKDOWN OF CITRUS

Introduction

Plant nutrition and water stress have been suggested as potential preharvest factors influencing the susceptibility of citrus fruit to postharvest peel breakdown (Alferez et al., 2005; Grierson, 1965). However, results have not been conclusive. For example, some authors have reported SERB to be more severe when fruit are harvested from water-stressed trees compared to non-stressed trees, whereas others have found no significant relationship with water stress (Grierson, 1965). It has also been found that nutritional imbalances involving high nitrogen (N) and low potassium (K) may predispose fruit to SERB (Chapman, 1958; Grierson, 1965). While no conclusive relationship between plant water stress, low K, high N, and SERB development under Florida conditions has been demonstrated, trends in data taken in 2007-08 season supported further study and the potential use of alternate application methods.

Potassium nutrition is emerging as potentially a key factor in influencing peel health of citrus, especially it's interaction with different nutrients or climatic factors (Bar-Akiva, 1975; Embleton et al., 1971; Grierson, 1965). Fruit-rind K-deficiency was observed as superficial rind pitting (SRP) in 'Shamouti' oranges (Tamim *et al*., 2000), while K-deficiency increased creasing in many mandarin varieties and Valencia orange (Raber *et al*., 1997). Foliar-applied potassium has also been found to increase citrus fruit size, specific fruit components and increased yields in recent studies (Achilea , 2000; Erner *et al.,* 1993).

Low plant K levels have also been associated with other citrus peel disorders such as creasing and 'Pineapple' orange peel pitting (Petracek et al., 1995). Increased K fertilization has been reported to increase fruit size, weight, vitamin C content, and fruit storage potential (Embelton et al., 1975). Though high levels of K fertilization may have some negative effects, such as decrease sugar to acid ratio and color development, foliar K applications have been reported to increase size without decreasing sugar to acid ratios, total soluble solids (TSS), acid or juice contents and with no increase in peel thickness (Boman, 1997; Boman and Hebb, 1998). Imbalances between N and K have also been reported to affect peel breakdown in citrus (Petracek et al., 1995).Magnesium (Mg) nutrition was recently reported to reduce peel breakdown of ‘Nules Clementine’ mandarin in South Africa (Cronje et al., 2008).

Vapor Gard® forms a film on plant tissues and reduces transpiration by 25% to 80% depending on the plant tissue (Davenport et al., 1976, EI-Sharkawy et al., 1976). Studies showed that antitranspirant application can increase leaf water potential in bell pepper (Berkowitz and Rabin, 1988; Nitzsche et al., 1991). The emulsions of wax, latex and plastic that dried on the foliage and formed thin films improved plant water status. It minimizes transpiration and plant water loss by decreasing stomatal conductance (gs) (Gu et al., 1996; Hummel, 1990; Nitzsche et al., 1991; Plaut et al., 2004). Better appearance of fruit and excellent weathering resistance was observed after the application of a polyterpene antitranspirant, Pinolene on the orange surface topography (Albrigo et al., 1970). SERB and creasing can be reduced by using preharvest antitranspirant spray and was, therefore, included in this study.

The objective of the current research was to evaluate the potential effect of plant water stress and preharvest foliar K, Mg and antitranspirant application on postharvest peel breakdown of fresh Florida citrus (especially grapefruit).

Materials and Methods

Fruit

'Valencia' oranges, 'Marsh' white grapefruit, 'Sugar Belle' mandarin hybrid and 'Ruby' red grapefruit were used for the different experiments. Trees were located in commercial citrus blocks and received standard cultural practices used for fresh fruit. The grove location, citrus type, rootstock used, soil type and age of grove of the fields where treatment was initiated is followed below (Table 2-1).

Table 2-1. Grove location, citrus type, rootstock used, soil type and age of grove of the fields where treatments were initiated.

Grove location	Citrus type	Rootstock used	Predominant soil type	Age of grove
Vero Beach	'Valencia' orange	Sour orange	Winder fine sand	25
Fort Pierce	'Marsh' white grapefruit	Sour orange	Pineda fine sand	21
Fort Pierce	'Marsh' white grapefruit	Cleoparta	Wabasso fine sand	21
Vero Beach	'Ruby' red grapefruit	Sour orange	Riviera fine sand	30
Vero Beach	'Sugar Belle' mandarin hybrid	Unknown	Riviera fine sand	Unknown

For each experiment, whole trees were exposed to different combinations of the following treatments:

- Control (unsprayed trees with normal irrigation).
- Foliar applied K (10.6 Kg MKP/acre [0-52-34]; 3.6 Kg K_2O/acre) with 1.8 Kg per acre low-biuret urea (46-0-0).
- Foliar applied Mg (6% [4.53 Kg Epsom salts /75.7 liters])

- Foliar applied K plus Mg. Applied separately as two tank mixtures with the same concentrations used above.

- Foliar applied Vapor Gard® (1% = 473.1 liters per acre).

- Irrigation deficit (1 month before harvest - plugged irrigation jets and Tveyk was laid around the base of the trees to prevent rain from replenishing soil moisture).

- Vapor Gard® (2%).

Unless otherwise stated, field plots were established in a randomized complete block design with 4 replicates of 5 trees each. Foliar treatments were sprayed to all sides of the tree uniformly at a rate of approximately 473.1 liters/acre. Fruits were evaluated from middle 3 trees. Fruit were harvested 7, 14, 21, 28 and/or 35 days after spraying. Fifty fruits were harvested per replicate and brought to Indian River Research and Education Center at Fort Pierce, Florida on the same day. Fruit were placed on the postharvest lab floor (~23 ^{0}C, 50-60% RH) for 3 or 4 days before washing and waxing. Ten extra fruits were harvested for internal quality assessment in the 3rd week after spraying. Fruits were washed and rinsed (without SOPP, chlorine or any other fungicides) and waxed (carnauba, FMC Corporation). Fruits were then kept under ambient conditions on the postharvest facility floor (~ 23 ^{0}C), conditions thought to promote peel breakdown. Decay and peel breakdown was visually evaluated on each fruit and the percentage of fruit showing any decay or peel breakdown was calculated. Decayed fruits were discarded from the replicate after each week of evaluation.

Experiment 1

Treatments were initiated on 27 May, 2009 in a Vero Beach block of ‘Valencia’ oranges. Spraying started at 12 pm and was completed at 2 pm. Wind velocity was less than 2 meter per second and the air temperature was 34^{o} C. Field treatments included foliar applications of K, Mg, K plus Mg and 1% Vapor Gard®.

Experiment 2

Treatments were initiated on 20 November, 2009 with ‘Marsh’ white grapefruit in Fort Pierce, Florida. Spraying started at 10 a.m. Air temperature was 21^{o}C and wind velocity was less than 2 meter per second. Irrigation jets were plugged to stop irrigation in the respective treatment on the same day. Field treatments included foliar applications of K, Mg, 1% & 2% Vapor Gard® and withholding irrigation rain. Fruit were harvested 14, 21 and 35 days after treatment. Fruit from the irrigation deficit treatment were harvested 35 days after treatment initiation. Forty fruits were harvested per replicate from the experimental site.

Experiment 3

Treatments were initiated on 26 January, 2010 with ‘Marsh’ white grapefruit in Fort Pierce, Florida. Spraying was done in the afternoon. Wind velocity was 4 meter per second. Temperature was 20^{o} C. Field treatments included foliar applications of K, Mg, 1% & 2% Vapor Gard®, Foliar K, Mg, & 1 % Vapor guard (applied separately, in that order), Miller cocktail (Calexin; Millerplex; Greenstim; 1% Vapor Guard) and withholding irrigation/rain. Field Treatments were done in RCB design with 4 replicates of 3 trees each. Fruits were evaluated from middle tree. Fruit were harvested after 1, 3, 5 and 7 weeks after treatment. Irrigation deficit treatment fruit were harvested 5 weeks after treatment. Forty Fruits were harvested per replicate.

Experiment 4

Treatments were initiated on 23 February, 2010 with ‘Ruby’ red grapefruit in Vero Beach, Florida. Spraying was done in the afternoon. Wind velocity was approximately 2 miles per hr. Temperature was 25^{o} C. Field treatments included foliar applications of K, Mg, 1% & 2% Vapor Gard®, Foliar K, Mg, & 1 % Vapor guard (applied separately, in that order) and Miller cocktail (Calexin; Millerplex; Greenstim; 1% Vapor Guard).Field treatments were done in RCB design with 4 replicates of 3 trees each. Fruits were evaluated from middle tree. Fruit were harvested after 1 and 3 weeks after treatment. Forty fruits were harvested per replicate.

Experiment 5

Treatments were initiated on 14 December, 2009 with ‘Sugar Bells’, a mandarin hybrid in Vero Beach, Florida. Spraying was done in the afternoon at 3 p.m. Temperature was 25^{o}C and wind speed was 2 meter per second from east to west. Single tree replicates were used. Field treatments included foliar applications of K and Mg.- Four reps of 1 tree each were used for treatments. Fruit were harvested after 1, 7 and 21 days after treatment. Sixty Fruits were harvested per replicate.

Fruit Quality Parameters

Peel color

Peel color was measured using a Minolta Chroma Meter (CR-300 series, Minolta Co. Ltd., Japan) at three equidistant locations on each fruit along the equator of the fruit and expressed as L*, a* and b* values. The hue and chroma values were calculated from a* and b* values using the following formulas:

$$\text{Hue} = \text{arc tangent } (b^{*} \cdot a^{*-1})$$

$$\text{Chroma} = (a^{*2} + b^{*2})^{1/2}$$

Peel puncture resistance

Peel puncture resistance was measured at two equidistant spots along the equator of each fruit using a texture analyzer (Model TAXT2i, Stable Micro Systems, Godalming, England) with a 2 mm diameter, flat-tipped, cylindrical probe. The analyzer was set so the probe traveled at a speed of 2 $mm \cdot s^{-1}$ and the maximum force exerted to puncture the peel recorded. Peel puncture resistance was expressed in Newtons.

Soluble solids content and titratable acidity

Fruit were cut into halves along the equator and juice was extracted using a test juice extractor (Model 2700, Brown Citrus Systems Inc., Winter Haven, Fla.). Juice total soluble solids (TSS) was measured using a temperature-compensated refractometer (Abbe-3L, Spectronic Instruments Inc., Rochester, N.Y.) and the juice titrable acidity (% citric acid) was measured by titrating 40 mL of juice samples to pH 8.3 with 0.3125 N NaOH using an automatic titrimeter (DL 12, Mettler-Toledo Inc., Columbus, Ohio).

Percent juice

Percent juice was calculated from the total weight of fruit and total weight of juice.

Percent juice = Juice weight (g) · 100/ Fruit weight (g)

Statistical analysis

Percentage data (peel breakdown, decay) was transformed to arcsine values and all data were analyzed by analysis of variance using SAS (PROC GLM) for PC (SAS Institute Inc, Cary, N.C.). When differences were significant ($P < 0.05$), individual treatment means were separated using Duncan’s multiple range tests ($P = 0.05$).

Results and Discussion

Experiment 1

There was no significant difference among the treatments for peel color, total soluble solids and titratable acidity, peel puncture resistance and juice percent (data not shown here).Foliar applications of K, Mg, K + Mg, and Vapor Gard® reduced peel breakdown by about an average of 35%, 35%, 29%, and 45% respectively compared to the control fruit. Peel breakdown and fruit decay increased as storage duration increased. Peel breakdown was much lower in fruit harvested 1 week after field treatments were administered compared to the other harvests (Table 2-2 and 2-3).This trend was also observed in other experiments(data not shown here). This coincides with the previous study done (Ritenour et al., 2008). In the table 2-2, decay and peel breakdown of 'Valencia' orange is shown. Total peel breakdown is the aggregate of all types of peel breakdown observed in the fruit. In this experiment, the total peel breakdown was due to general breakdown and not due to stem end rind breakdown or other peel disorders. Foliar application of potassium and 1% Vapor Gard® reduced peel breakdown by 50% as compared to control fruit.

In the table 2-3, peel breakdown and decay of 'Valencia' orange is observed after 44 days of storage. These fruits were harvested 3 weeks after treatment application. Total decay and peel breakdown has increased irrespective of treatment applied in this week as compared to 2 week after treatment application(table 2-2). Treatment of 1% Vapor Gard® reduced peel breakdown by more than 50% as compared to control fruit.

Table 2-2. Peel breakdown and decay of ‘Valencia’ oranges after 44 days of storage under ambient conditions. The fruit were harvested on 10th June, 2009, 2 weeks after treatment application.

				Peel breakdown			
Treatment	Sound	Total decay		General		Total	
Control	47	28	ab	34	a	34	a
1% Vapor Gard®	65	27	bc	15	c	15	c
K	60	38	a	14	c	14	c
Mg	65	17	c	22	bc	22	bc
Foliar K + Mg	56	27	bc	27	ab	28	ab
p value	0.0578	.0069		0.0065		0.0075	

Values within each column followed by different letters are significantly different by Duncan’s multiple range test at P ≤ 0.05.
Significant at P ≤ 0.05.

Table 2-3. Peel breakdown and decay of ‘Valencia’ oranges after 44 days of storage under ambient conditions. The fruit were harvested on 17th June, 2009, 3 weeks after treatment application.

Treatment	Sound		Total decay	Total breakdown	
Control	50	bc	26	37	a
Foliar K	47	c	31	36	a
Foliar Mg	59	ab	15	31	ab
Foliar K + Mg	54	bc	28	29	ab
1% Vapor Gard®	66	a	24	16	b
p value	0.0143		0.2384	0.028	

Values within each column followed by different letters are significantly different by Duncan’s multiple range test at P ≤ 0.05.
Significant at P ≤ 0.05.

Experiment 2

In the first harvest on 04th December,2009 after 2 weeks of treatment showed no peel breakdown at all even after 46 days of treatment (Data not shown here). Interestingly, there was not much decay as well after long durations of storage of this fruit. This trend was also observed in other fruits harvested at week 3, week 4 and week 6 harvests in this block (Data not shown here). This could be due to the season of harvest. These fruits were harvested early in the season. The weather around the month of harvest can also be a factor in negligible peel breakdown and decay in this experiment.

Experiment 3

In this experiment, the treatments vapor guard 2% and Foliar K + Mg + Vapor guard 1% showed the highest reductions in peel breakdown compared to untreated fruit. In the 3rd week after harvest, an interesting trend was observed with most of the peel breakdown being manifested on the fruit after approximately 25 days of storage and even when the fruits were stored till 63 days, the total peel breakdown percentage did not increase more than 2% in all the treatments (table 2-4 and 2-5). The decay percentage of fruits increased in the meantime. This trend continued in other harvests as well (data not shown here).

In the table 2-4, peel breakdown and decay of ‘Marsh’ white grapefruit after 25 days of storage is observed. Foliar K + Mg + 1% Vapor Gard® showed no peel breakdown at all. Vapor Gard® 2% showed 8 times less peel breakdown than control fruit. Hence, Vapor Gard® has consistently shown its effectiveness to reduce peel breakdown and can be recommended to growers for reducing peel breakdown. In the table 2-5, Peel breakdown and decay of ‘Marsh’ white grapefruit after 63 days of storage under ambient conditions is observed. The fruit were harvested 3 weeks after treatment application. Foliar K + Mg + 1% Vapor Gard® and Vapor Gard® 2% showed 9 times less peel breakdown than control fruit. Also, even after 63 days of storage, peel breakdown in fruits irrespective of treatment did not increase by more than 2% as compared to 25 days of storage. It can be possible that peel breakdown incidence is manifested till a certain period of time after harvest.

Table 2-4. Peel breakdown and decay of 'Marsh' white grapefruit after 25 days of storage under ambient conditions. The fruit were harvested on 19th Feb, 2010, 3 weeks after treatment application.

Treatment	Sound	Total Decay		Total breakdown
Mg	80	5	bdc	13
Vapor Gard®1%	87	3	dc	9
K application	85	1	d	12
Control	79	3	bdc	16
Foliar K + Mg	83	7	bac	8
Vapor Gard®2%	90	7	bac	2
Foliar K + Mg+ 1% Vapor Gard®	89	10	a	0
Miller cocktail	86	8	ba	5
p value	0.8347	0.015		0.223

Values within each column followed by different letters are significantly different by Duncan's multiple range test at P ≤ 0.05.
Significant at P ≤ 0.05.

Table 2-5. Peel breakdown and decay of 'Marsh' white grapefruit after 63 days of storage under ambient conditions. The fruit were harvested on 19th Feb, 2010, 3 weeks after treatment application.

Treatment	Sound	Total Decay	Total breakdown	
Mg	51	37	16	a
Vapor Gard®1%	59	34	12	ba
K application	56	37	13	ba
Control	48	46	18	a
Foliar K + Mg	46	50	12	ba
Vapor Gard®2%	65	33	2	b
Foliar K + Mg+ 1% Vapor Gard®	56	42	2	b
Miller cocktail	50	40	13	ba
p value	0.0801	0.1594	0.0056	

Values within each column followed by different letters are significantly different by Duncan's multiple range test at P ≤ 0.05.
Significant at P ≤ 0.05.

Experiment 4

In this experiment, similar trend was followed with most of the peel breakdown being manifested in the first 30 days of storage in 'Ruby' red grapefruit and not much change in the percentage of peel breakdown even after prolonged durations of storage (table 2-6 and 2-7).

The treatment Vapor Gard® 2% showed the maximum reduction in peel breakdown. The average reduction in peel breakdown was 86% followed by foliar K + Mg + Vapor Gard®1%, which had an average reduction 69%. In the table 2-6, peel breakdown and decay of 'Ruby' red grapefruit after 31 days of storage was observed in 1 week after treatment application with 2% Vapor Gard® showing 6 times less reduction than control fruit. In the table 2-7, peel breakdown and decay of 'Ruby' red grapefruit after 59 days of storage was observed in 1 week after treatment application with 2% Vapor Gard® showing 5 times less reduction than control fruit. Diplodia was the main reason for decay in the experiment.

Table 2-6. Peel breakdown and decay of 'Ruby' red grapefruit after 31 days of storage under ambient conditions. The fruit were harvested on 05th March, 2010, 1 week after treatment application.

Treatment	Sound	Total Decay	Total breakdown	
Mg	62	12	29	ba
Vapor Gard®1%	79	21	21	ba
K application	62	21	16	bac
Control	56	16	31	a
Foliar K + Mg	51	27	24	ba
Vapor Gard®2%	79	14	5	c
Foliar K + Mg+ 1% Vapor Gard®	62	27	13	bc
Miller cocktail	60	22	22	ba
p value	0.1174	0.0906	0.0185	

Values within each column followed by different letters are significantly different by Duncan's multiple range test at P ≤ 0.05.
Significant at P ≤ 0.05.

Table 2-7. Peel breakdown and decay of 'Ruby' red grapefruit after 59 days of storage under ambient conditions. The fruit were harvested on 05th March, 2010, 1 week after treatment application.

Treatment	Sound		Total Decay		Total breakdown	
Mg	41	ba	46	d	29	ba
Vapor Gard®1%	37	bac	52	bdac	21	ba
K application	33	bc	61	ba	16	bac
Control	35	bc	48	a	31	a
Foliar K + Mg	24	c	61	a	24	ba
Vapor Gard®2%	48	a	49	bdac	6	c
Foliar K + Mg+ 1% Vapor Gard®	34	bc	60	bac	13	bc
Miller cocktail	39	ba	54	bdac	23	ba
p value	0.0189		0.041		0.0271	

Values within each column followed by different letters are significantly different by Duncan's multiple range test at $P \leq 0.05$.
Significant at $P \leq 0.05$.

Experiment 5

In this experiment, there was 96% average reduction in peel breakdown in 'Sugarbelle' mandarin hybrid from the treatment foliar K + Mg but the data was not significant (data not shown here).

CHAPTER 3
POSTHARVEST FACTORS AFFECTING PEEL BREAKDOWN OF WHITE GRAPEFRUIT

Introduction

Postharvest factors including humidity, storage time, and storage temperature are critical to achieve maximum quality of a fresh horticultural commodity. Other researchers have shown that peel breakdown of fresh citrus may be reduced by maintaining high relative humidity during storage and shipping (Ben-Yehoshua et al., 2001; Porat et al., 2004)., Citrus fruit can develop peel pitting even after relatively brief (3 hours) exposure to low (30%) relative humidity (RH) followed by high (90%) RH after harvest (Alferez and Burns, 2004).

During the 2006-07 and 2007-08 seasons, peel breakdown was relatively severe on fresh Florida citrus fruit. The disorder did not appear to be caused by chilling injury (CI) or postharvest pitting (Petracek et al., 1995), two of the most common causes of peel breakdown in citrus. In the winter months, especially after cool and/or windy weather, symptoms of peel pitting and areas of peel necrosis were observed that progressed into stem-end rind breakdown as the season progressed into spring with warmer temperatures and when trees were flushing/flowering.

Peel breakdown of ‘Fortune’ mandarin under cool and low RH conditions was previously reported (Agusti et al., 1997; Vercher et al 1994), but these reports suggested the temperature was cold enough to cause CI. As previously stated, CI was likely not the cause of the Florida peel disorder. Hence, the need to investigate the possible cause(s) and best preventative measure(s) for the Florida disorder. Anecdotal reports suggested that inclusion of thiabendazole (TBZ) or Imazalil may reduce postharvest peel breakdown of citrus. While fungicides would not be expected to affect a physiological disorder, the current experiments included treatments containing TBZ or Imazalil to evaluate any possible effects. Increased peel breakdown has also been observed after incomplete rinsing of detergent from the fruit (Petracek et al., 2006). Thus, the objective of these experiments was to evaluate the effect of exposing fruit to low (30%) and medium (60%) RH environments and different packingline handling treatments (i.e., not rinsing detergent from the fruit or inclusion of a fungicide in with the wax coating) on the development of postharvest peel breakdown of fresh citrus fruit.

Materials and Methods

Fruit

Two separate harvests of ‘Marsh’ white grapefruit were performed in Vero Beach, Florida on 26 January and 16 February 2009. Healthy white grapefruit were randomly harvested from every part of the tree at the height of 1 to 2 meters above ground level. The trees were healthy and the grove received standard commercial care. These fruits were transported to Indian River Research and Education Center in Fort Pierce, Florida on the day of harvest for postharvest treatment.

Humidity Treatments

After harvesting, fruits were kept in plastic crates at different humidity conditions i.e. 30% RH, 60% RH and 95% RH for 3 days at ambient temperature of approximately 73 F. Then different packingline treatments were administered before storing the fruit under ambient conditions of approximately 23^{o}C and evaluating weekly for decay and the development of peel and other physiological disorders. Unless otherwise stated, all fruit were washed with a detergent, briefly dried, and then coated with carnauba wax (JBT FoodTech, Lakeland, fla.) before final drying. The standard packingline procedures were altered depending on the treatment. Treatments are listed below (table 3-1). A dehumidifier was used to maintain 30% RH, whereas the laboratory environment maintains approximately 60% RH. Wet rags were placed on fruit crate tops in the 95% RH environment to maintain high RH levels. Dataloggers were used to measure air temperatures and RH. A completely randomized design was used. Each treatment had four replicates of fifty fruits.

Table 3-1. Different humidity and packingline treatment given to 'Marsh' white grapefruit were performed in Vero Beach, Florida on 26th January and 16 February 2009.

Treatment no.	Initial storage RH (%)	Changes to packingline handling
1	30	None
2	60	None
3	90	None
4	95	2000 ppm TBZ
5	95	2000 ppm Imazlil
6	95	Wash but no wax
7	95	No rinse or wax

Decay and Peel Breakdown

Decay and peel breakdown was visually evaluated on each fruit weekly and the percentage of fruit showing any decay or peel breakdown was calculated. Decayed fruits were discarded after each evaluation and evaluations were discontinued after about 50% of the fruits had decayed.

Weight Loss

To measure weight loss, ten fruits were weighed from each replicate at harvest, after going over packing line, and after 7, 14 and 21 days of storage. Values are expressed as percent weight lost per day.

Statistical Analysis

Percentage data was transformed to arcsine values and all data were analyzed by analysis of variance using SAS (PROC GLM) for PC (SAS Institute Inc, Cary, N.C.). When differences were significant ($P < 0.05$), individual treatment means were separated using Duncan's multiple range tests ($P = 0.05$).

Results and Discussion

Holding fruit for 3 days at different RH significantly affected subsequent peel breakdown during storage for 25 (Figure 3-1) or 45 (Fig. 3-2) days. Unwaxed fruits that were kept at 95% RH in prestorage developed approximately twice the peel breakdown of non-rinsed, unwaxed fruits after 25 days of storage. Fruits, kept at 30% RH in prestorage showed approximately eight times and five times more peel breakdown than fruits kept at 60% RH in prestorage after 25 and 45 days of storage respectively (Figure 3.1 and 3.2). Alferez et al., (2005) reported that Florida citrus can have peel pitting disorder due to sudden changes in relative humidity after harvest. Fruits kept at 30% RH received such sudden change in relative humidity. No significant difference was observed between waxed fruits prestored at 60% RH, prestored at 95% RH and prestored at 95% RH (with 2000 ppm TBZ + wax) (Figure 3.1 and 3.2). Fruits treated with wax and 2000 ppm Imazalil, which were kept at 95% RH in prestorage showed approximately seven times and four times less peel breakdown than fruits kept at 95% RH in prestorage after 25 and 45 days of storage respectively (Figure 3-1 and 3-2). Ben-Yehoshua et al. (2001) had reported that peel breakdown incidence may be reduced by maintaining high relative humidity during storage but in our study, keeping fruits at high humidity did not reduce peel breakdown significantly compared to holding at 60% RH. Interestingly, in this first experiment, inclusion of Imazalil in the wax significantly reduced postharvest peel breakdown, whereas inclusion of a different fungicide (TBZ) did not.

For the fruits harvested on 26th January, significant difference in total peel breakdown was again observed among treatments after 24 and 52 days of storage (Figure 3-3 and 3-4). Fruits kept at 30% RH during prestorage showed about four times and three times more peel breakdown than fruits kept at 60% RH prestorage after 24 and 52 days of storage, respectively (Figure 3-3 and 3-4). In this experiment, neither fruits treated with 2000 ppm Imazalil nor TBZ showed any significant reduction in peel breakdown (Figure 3-3 and 3-4). Hence, Imazlil and TBZ are not effective in reducing peel breakdown consistently.

The fruit lost water gradually during storage, with fruit pre-stored at 30% RH loosing significantly more water that fruit pre-stored at 60%, which in tern lost water significantly faster that fruit stored at 95% RH (Table 3-2). These differences became insignificant as storage time progressed and the initial water loss became a smaller fraction of total water loss. The fact that water loss was slowest after pre-storage at 95% RH concurs with previous research showing that RH should be maintained as high as possible to keep citrus fruit fresh and turgid (Ritenour et al., 2003).

There was significant effect of different treatments on decay caused in fruits harvested on 26th January by diplodia and penicillium (Table 3-3 and 3-4). Unwaxed fruits, which were kept at 95% RH in prestorage showed approximately three times and 1.5 times more decay than non-rinsed, unwaxed fruits kept at 95% RH in prestorage after 24 and 52 days of storage respectively (Table 3-3 and 3-4). Waxed fruits, which were kept at 30% RH in prestorage showed approximately three times more decay than fruits kept at 60% RH in prestorage after 24 and 52 days of storage (Table 3-3 and 3-4). Fruits prestored at 95% RH showed four times less decay than fruits kept at 60% RH in prestorage after 24 days of storage but no significant difference after 52 days of storage. Fruits treated with wax and 2000 ppm Imazalil showed three times more decay than fruits treated with 2000 ppm TBZ after 52 days.

Fungi cause the most serious decay in citrus in Florida and warm, humid climate of Florida exacerbates the incidence. The most common postharvest fungus diseases of Florida citrus are Diplodia stem-end rot (Lasiodiplodia theobromae), green mold (Penicillium digitatum), sour rot (Galactomyces citri-aurantii) and anthracnose (Colletotrichum gloeosporioides) (Ritenour et al., 2003). Alternaria stem-end rot (black rot) (Alternaria citri) and brown rot (Phytophthora palmivora and P. nicotianae) are less frequent in the state of Florida, but may cause substantial losses in some seasons.

Citrus fruit stored at low relative humidity after harvest are more likely to decay. Low RH causes stress that promotes peel breakdown and increased peel breakdown can lead to increased decay (which has been described in detail in the earlier chapter). Application of a wax coating and fruit storage and rapid handling at high humidity retards desiccation and maintains fruit turgidity and freshness compared to washed but not-waxed fruit, but not necessarily un-washed fruit. Hence, it helps in reducing susceptibility to green mold and stem-end rind breakdown, thereby, making the fruit less susceptible to decay. Relative humidity should be 90 to 98% for fruits held in wooden/plastic containers and 85-90% in fiberboard cartons to prevent the deterioration of carton (Ritenour et al., 2003).

Thiabendazole (TBZ) is a benzimidazole fungicide and is effective against Lasiodiplodia theobromae and Penicillium digitatum. It is applied with bin drenchers and on the packinghouse line. TBZ should be applied at a concentration of 1,000 ppm (0.1%) as a water suspension or at 2,000 ppm (0.2%) in a water-based wax (Ritenour et al., 2003).

Imazalil is very effective against Penicillium digitatum but not much for control of Lasiodiplodia theobromae and it is ineffective against Phytophthora palmivora and Galactomyces citri-aurantii. Imazalil should be applied at 1,000 ppm (0.1%) as a water suspension or at 2,000 ppm (0.2%) in a water base wax (Ritenour et al., 2003).

Significant effect of different treatments on decay was observed in fruits harvested on 16th February by diplodia and penicillium (Table 3-5 and 3-6). Unwaxed fruits, which were kept at 95% RH in prestorage showed approximately two times less decay than non-rinsed, unwaxed fruits kept at 95%

RH in prestorage after 24 days of storage (Table 3-5). This result is different from the trend observed in the previous harvest. Waxed fruits, which were kept at 30% RH in prestorage showed approximately three times and 1.5 times more decay than fruits kept at 60% RH in prestorage after 24 and 52 days of storage respectively (Table 3-5 and 3-6). Fruits prestored at 95% RH showed 2.5 times and 1.5 times more decay than fruits kept at 60% RH in prestorage after 24 and 52 days of storage respectively. This result is different from the trend observed in the previous harvest. Fruits treated with wax and 2000 ppm Imazalil showed 1.5 times less decay than fruits treated with 2000 ppm TBZ after 52 days (Table 3-5 and 3-6).

The results showed TBZ and Imazlil reduced green mould significantly which concurs with the previous study done by Ritenour et al., (2003).

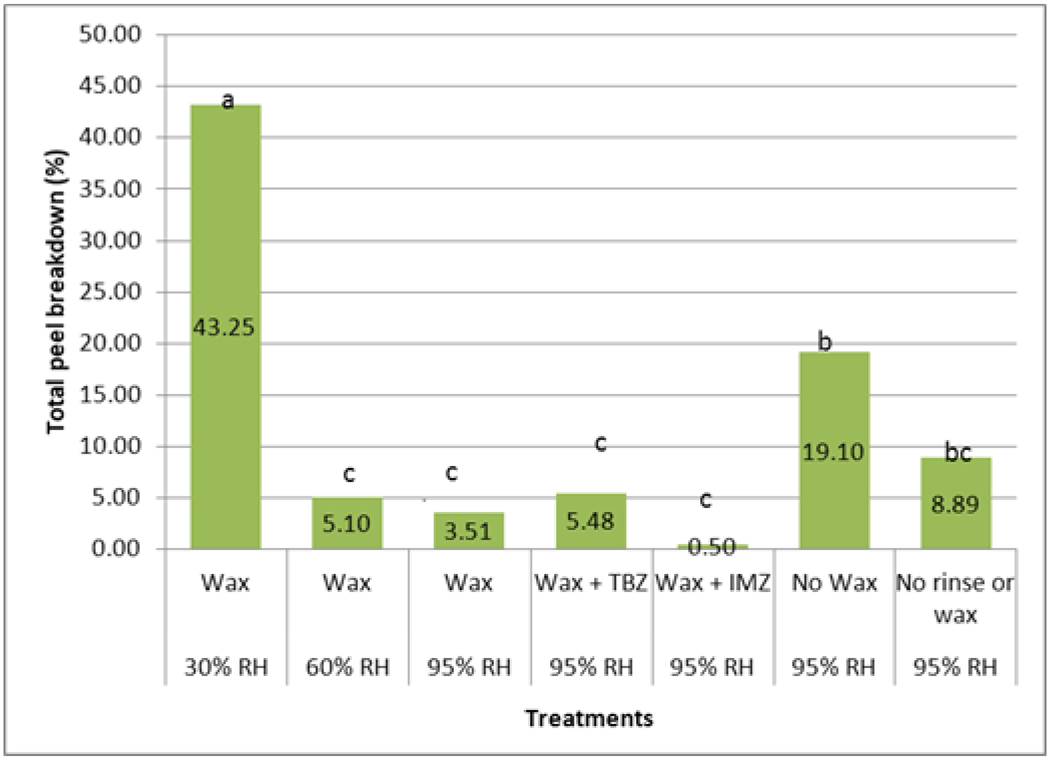

Figure 3-1. Total peel breakdown (%) of white grapefruit harvested on 16February after 25 days of storage. Bars with different letters are significantly different by Duncan's multiple range test at P ≤ 0.05.

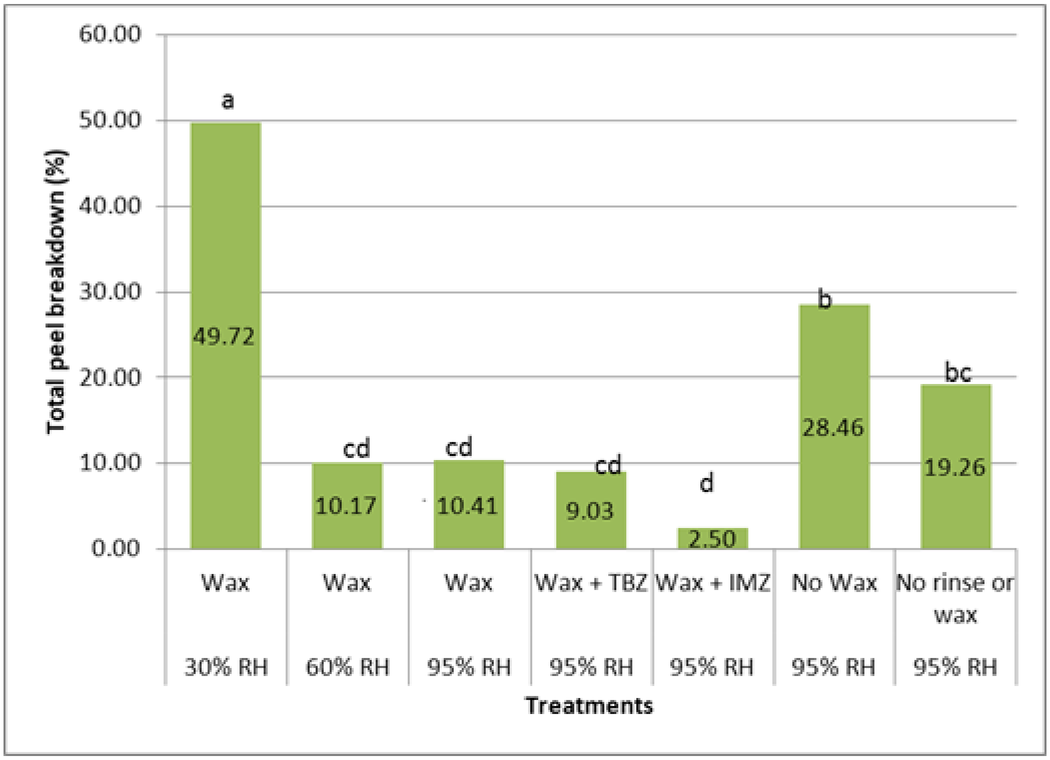

Figure 3-2. Total peel breakdown (%) of white grapefruit harvested on 16 February after 45 days of storage. Bars with different letters are significantly different by Duncan's multiple range test at P ≤ 0.05.

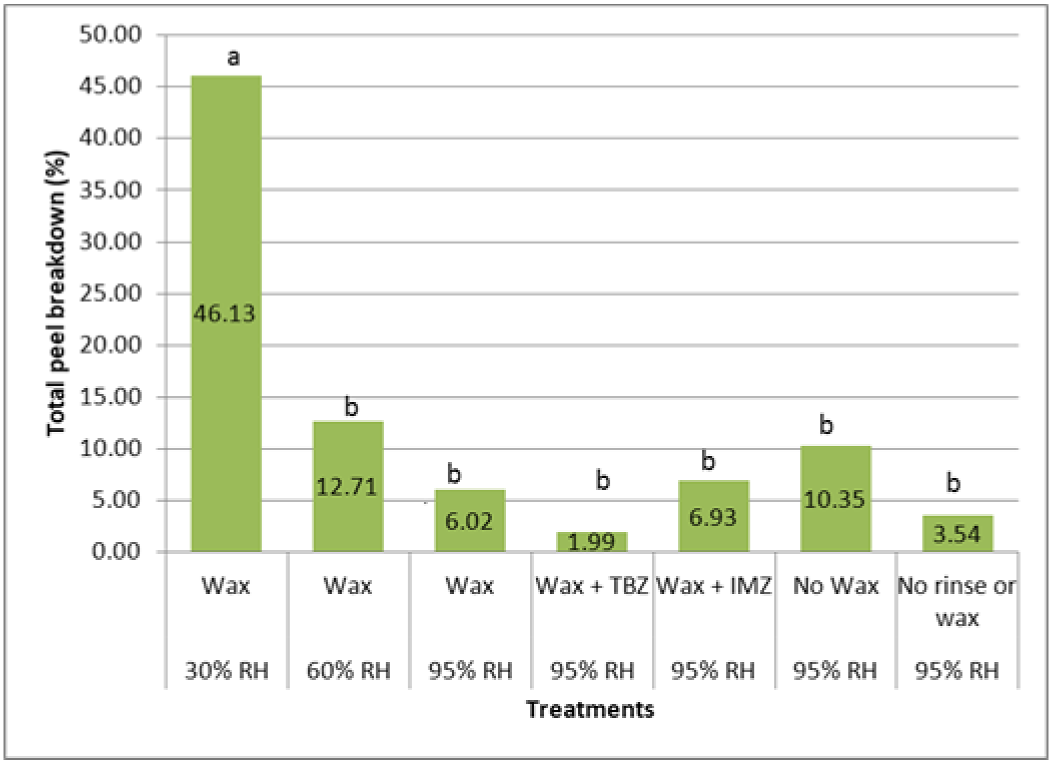

Figure 3-3. Total peel breakdown (%) of white grapefruit harvested on 26 January after 24 days of storage. Bars with different letters are significantly different by Duncan's multiple range test at P ≤ 0.05.

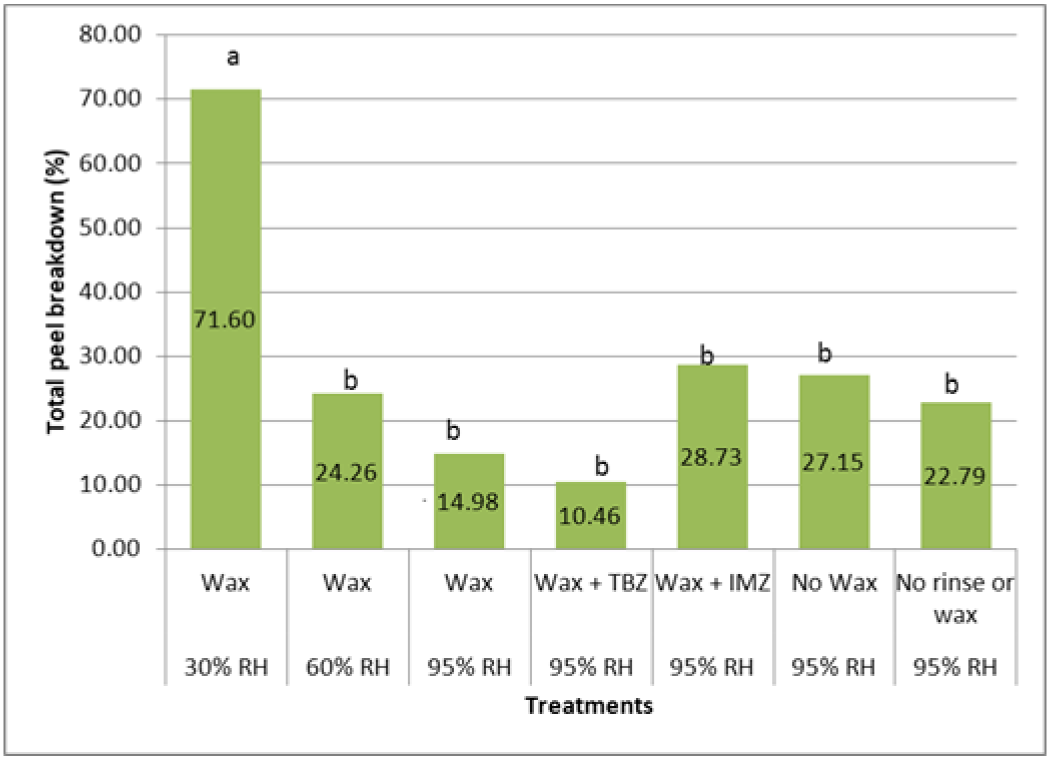

Figure 3-4. Total peel breakdown (%) of white grapefruit harvested on 26 January after 52 days of storage. Bars with different letters are significantly different by Duncan's multiple range test at P ≤ 0.05.

Table 3-2. Weight loss in white grapefruit harvested on 26 January after 2, 7, 14 and 21 days of storage at respective relative humidity Different letters are significantly different by Duncan's multiple range tests at P ≤ 0.05.

Pre Storage RH (%)	2 Days Wt. Loss %	7 Days Wt. Loss %	14 Days Wt. Loss %	21 Days Wt. Loss %
30	1.4 a	2.0 a	3.5 a	4.8 a
60	0.9 b	1.9 a	3.4 a	4.7 a
95	0.1 c	1.7a	3.0 b	4.3 b

Table 3-3. Decay (%) of white grapefruit harvested on 26 January after 24 days of storage Different letters are significantly different by Duncan's multiple range test at P ≤ 0.05.

Pre Storage RH(%)	Packingline Treatment	Healthy%	Total decay%	Total Breakdown (%)
30	Wax	50 b	6 a	46 a
60	Wax	85 a	2bc	12 b
95	Wax	93 a	0 c	6 b
95	2000 ppm TBZ + Wax	97 a	0 bc	1 b
95	2000 ppm IMZ + Wax	91 a	1 bc	6 b
95	No Wax	86 a	4 ab	10 b
95	No Rinse or Wax	94 a	1 bc	3 b
	P-Value	<.0001	0.0193	0.0002

Table 3-4. Decay (%) of white grapefruit harvested on 26 January after 52 days of storage Different letters are significantly different by Duncan's multiple range test at P ≤ 0.05.

Pre Storage RH(%)	Packingline Treatment	Healthy%	Total decay%	Total Breakdown (%)
30	Wax	27 c	24 a	71 a
60	Wax	67ab	9 bc	24 b
95	Wax	68ab	12 bc	14 b
95	2000 ppm TBZ + Wax	87 a	2 d	10 b
95	2000 ppm IMZ + Wax	64 b	7 cd	28 b
95	No Wax	59 b	14 b	27 b
95	No Rinse or Wax	68 ab	9 bc	22 b
	P-Value	0.0004	<.0001	0.0002

Table 3-5. Decay (%) of white grapefruit harvested on 16th February after 25 days of storage Different letters are significantly different by Duncan's multiple range test at P ≤ 0.05.

Pre Storage RH (%)	Packingline Treatment	Healthy%	Total decay%	Total Breakdown (%)
30	Wax	51 c	9 a	43 a
60	Wax	92 a	2 c	5 c
95	Wax	89 ab	6 b	3 c
95	2000 ppm TBZ + Wax	92 a	0 c	5 c
95	2000 ppm IMZ + Wax	99 a	1 c	0 c
95	No Wax	77 b	2 c	19 b
95	No Rinse or Wax	86 ab	5 b	8 bc
	P-Value	<.0001	<.0001	<.0001

Table 3-6.Decay (%) of white grapefruit harvested on 16th February after 45 days of storage. Different letters are significantly different by Duncan's multiple range test at P ≤ 0.05.

Pre Storage RH (%)	Packingline Treatment	Healthy%	Total decay%	Total Breakdown (%)
30	Wax	40 d	22a	49 a
60	Wax	78 ab	14bc	10 cd
95	Wax	69 bc	21 ab	10 cd
95	2000 ppm TBZ + Wax	76 abc	14 bc	9 cd
95	2000 ppm IMZ + Wax	89 a	8 c	2 d
95	No Wax	62 c	10 c	28 b
95	No Rinse or Wax	68 bc	13 bc	19 bc
	P-Value	<.0001	0.007	<.0001

CHAPTER 4
EFFECT OF DIFFERENT COATINGS ON REDUCING FREEZE INJURY OF WHITE GRAPEFRUIT

Introduction

While Florida is a subtropical environment with an excellent climate for growing high quality citrus, occasional cold fronts from the north can bring freezing temperatures in the winter season that may injure fruit and trees. The decade of the 1980s brought a set of severe freezes to Central Florida, killing many of the state's citrus trees and shifting the citrus growing region from north and central Florida to south Florida. Freezing temperatures affected a large portion of Florida's citrus growing areas in January 1981, January1982, December 1983, January 1985, February 1989 and December 1989 (Miller, 1991).The citrus producing region of Florida experienced 8 days of sub-freezing temperatures during January 5-13, 2010 (USDA Citrus Forecast March 2010). Symptoms of freezing injury are internal drying and free juice in the core. External symptoms of freeze damage on the fruit occur on the outer, sun exposed area which gets a pink pitting injury. Injury can begin with as little as 2 to 4 hours below –2.2^{o}C. Frost injury in the grove predisposes grapefruit to alternaria stem-end rot on fruit during storage (Schiffmann-Nadel et al., 1975). Citrus peel is less susceptible to freeze injury as compared to internal membranes and juice vesicles. Externally uninjured fruit can contain large areas of completely desiccated tissue, typically at the stem end of the fruit. As with most other blemishes, the extent of fruit damage permitted varies with local regulations (Grierson and Ting, 1978). Vapor Gard® (Miller Chemical and Fertilizer,Hanover, Pa.), an antitranspirant, is sold to retard transpiration and maintain healthy foliage. Antitranspirants are believed to act as barriers to external nucleators(Levitt, 1980). The antitranspirant film on the surface of the leaves should impede the frost that forms on the surface from providing a nucleator for water inside the plant.

Earlier published results of antitranspirants use for reducing freeze injury have been variable. Dieback of cold-stored sycamore (Platanusoccidentalis L.) seedlings was reduced after antitranspirant treatment whereas freeze damage to developing peach (PrunuspersicaBatsch) fruits (Matta et al., 1987; Rieger and Krewer, 1988) and young citrus trees (Burns, 1970, 1973) was not reduced by antitranspirant treatment. Carnauba wax (FMC Corporation, Lakeland, fla.) is a coating which is applied to citrus fruits for reducing weight loss from transpiration losses. We believed that its spray will impede frost by providing a protective layer over the fruit.

The objective of this study was to evaluate the two commercially available materials (Vapor Gard® and Carnauba wax) for frost and freeze protection of citrus trees under field conditions and their effect on peel breakdown of grapefruit.

Materials and Methods

Fruit

Experiments were conducted on January 6th, 2010 at two commercial Marsh White grapefruit groves; one located west of Fort Pierce and the other in Vero Beach, Florida. Temperature was 20^{o}C and wind speed was less than 5 meter per second from north to south on 6th January, 2010. Spraying operation was performed in the afternoon on 6th January, 2010.

In the Fort Pierce block, Grapefruit trees were sprayed with either 1% or 5% Vapor Gard® (Miller Chemical and Fertilizer,Hanover, Pa.) or 1:1 or 1:10 dilutions of carnauba wax(JBT Food techCorporation, Lakeland, fla.). Control trees were left unsprayed. The experiment was established in a randomized complete block design with each treatment having three replicates. Single tree replicates were used. Rows were oriented north and south. In the Vero block, grapefruit trees were sprayed by with either 1% or 5% carnauba wax or left unsprayed (control). In this block, each treatment had three replicates.

Harvest and Postharvest Operation:

Fifty fruits were harvested per replicate on January 12, 2010 from both the experimental sites and brought to Indian River Research and Education Center at Fort Pierce, Florida on the same day. Fruit were placed in the postharvest lab floor (~23 oC, 50-60% RH) for 3 days before washing and waxing with Carnauba wax. Fruits were cut in 1/12 in 1/4" slices for freeze injury detection according to the USDA procedure. Two fruits were cut open per replicate before washing and waxing and noted for any abnormalities. The remaining fruits from each replicate were washed and waxed and placed on the postharvest facility floor for evaluation.

A freezing injury scale ranging from 1 (no freezing symptoms) to 9 (severe freezing symptoms), depending on the severity of freeze injury was used to visually evaluate the trees for freeze injury (figures 4-3 to 4-9). For example, tree with maximum leaves having severe freeze injury symptoms were given a rank of 9 in the scale. Wilting, leaf curl, necrosis and brown spots were used as symptoms of freeze injury in these evaluations. These four symptoms were combined together to observe the freeze injury incidence.

Weight Loss

Weight of 10 fruits per replicate was taken after washing and waxing and then again 15 days later.

Statistical Analysis

Percentage data (peel breakdown, decay) was transformed to arcsine values and all data was analyzed by analysis of variance using SAS (PROC GLM) for PC (SAS Institute Inc, Cary, N.C.). When differences were significant ($P < 0.05$), individual treatment means were separated using Duncan's multiple range tests ($P = 0.05$).

Results and Discussion

After the freeze events, trees at the Vero block showed no signs of freeze injury (data not shown). However, freeze injury symptoms were observed at the Fort Pierce block where minimum field temperatures dropped lower than in the Vero block (Figure 4-1 and 4-2).

There was no significant difference between treatments with regard to freeze injury. Fruits were cut immediately after harvest with no visible internal or external injury. No freeze injury was found in fruit from the Vero block after 24 days storage (data not shown). Just a few fruit showed freeze damage from the Fort Pierce block after 24 days storage, but there were no significant difference between treatments (data not shown). Trees were evaluated for freeze scale and leaf wilting was less and the general condition of trees looked better than the first evaluation just after freeze (Table 4-1 and Table 4-2). The trees at Vero block showed no external freeze injury symptoms like wilted leaves (Data not shown here). External freeze injury symptoms were observed in Emerald block.

Table 4-1.Fruit drop and tree injury of the Fort Pierce block evaluated on 14January, 2010. Tree injury rating is from 1 (no damage) to 9 (severe damage).

Treatment	Fruit drop average	Standard error	Tree injury average	Standard error
Carnauba 1:1	7.3	2.4	2.3	0.3
Carnauba 1:10	7.0	0.5	4.0	0.0
Control	4.6	0.8	3.3	1.2
Vapor Gard®1%	4.6	0.3	3.6	0.3
Vapor Gard®5%	3.0	1.1	3.3	0.3

Table 4-2. Fruit drop and tree injury of the Fort Pierce block evaluated on 08February, 2010. Tree injury rating is from 1 (no damage) to 9 (severe damage).

Treatment	Fruit drop average	Standard error	Tree injury average	Standard error
Carnauba 1:1	12.0	2.5	3.3	0.3
Carnauba 1:10	11.3	2.1	4.0	0.0
Control	4.3	1.4	3.6	0.3
Vapor Gard®1%	10.3	1.8	4.0	0.5
Vapor Gard®5%	5.3	1.8	5.0	0.5

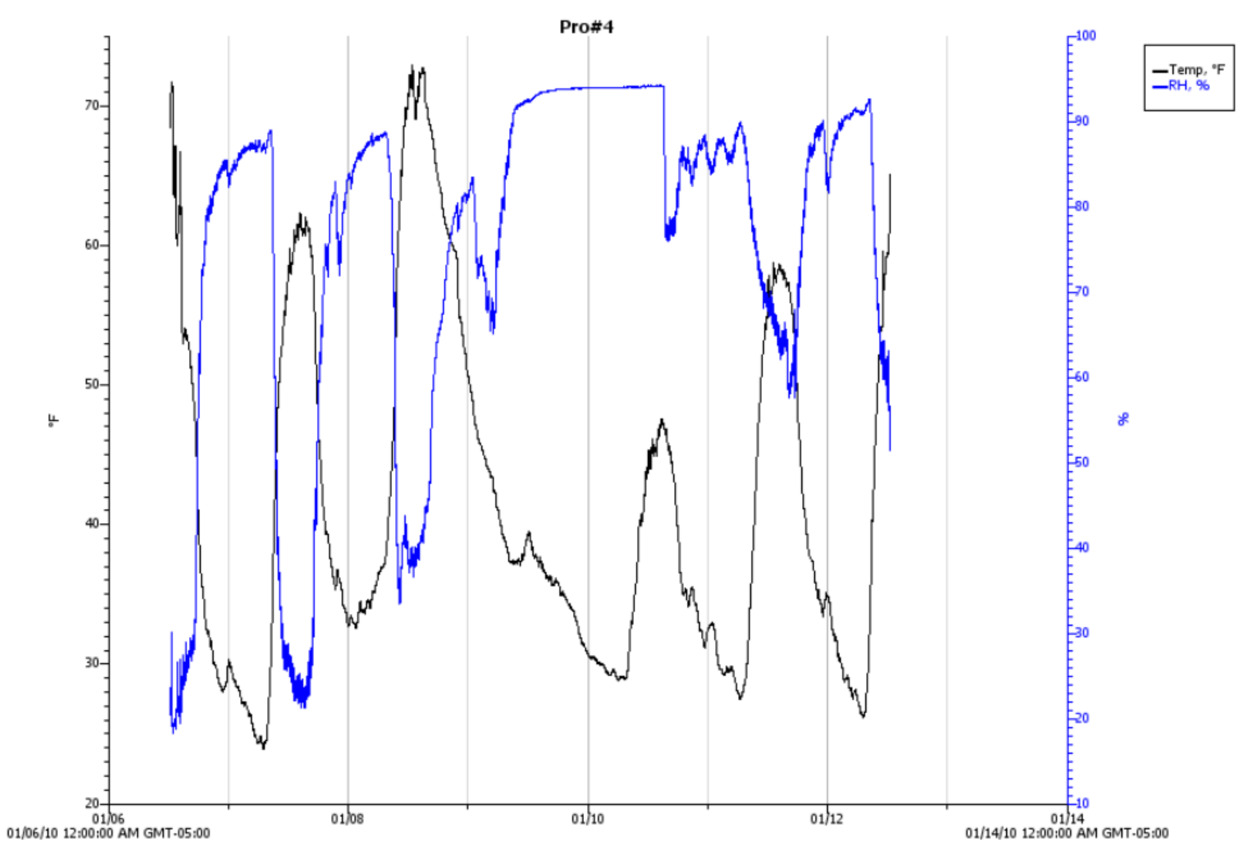

Figure 4-1.Temperature and RH data from the data logger at Fort Pierce block in the week of harvest from 01/06/10 to 01/14/10.

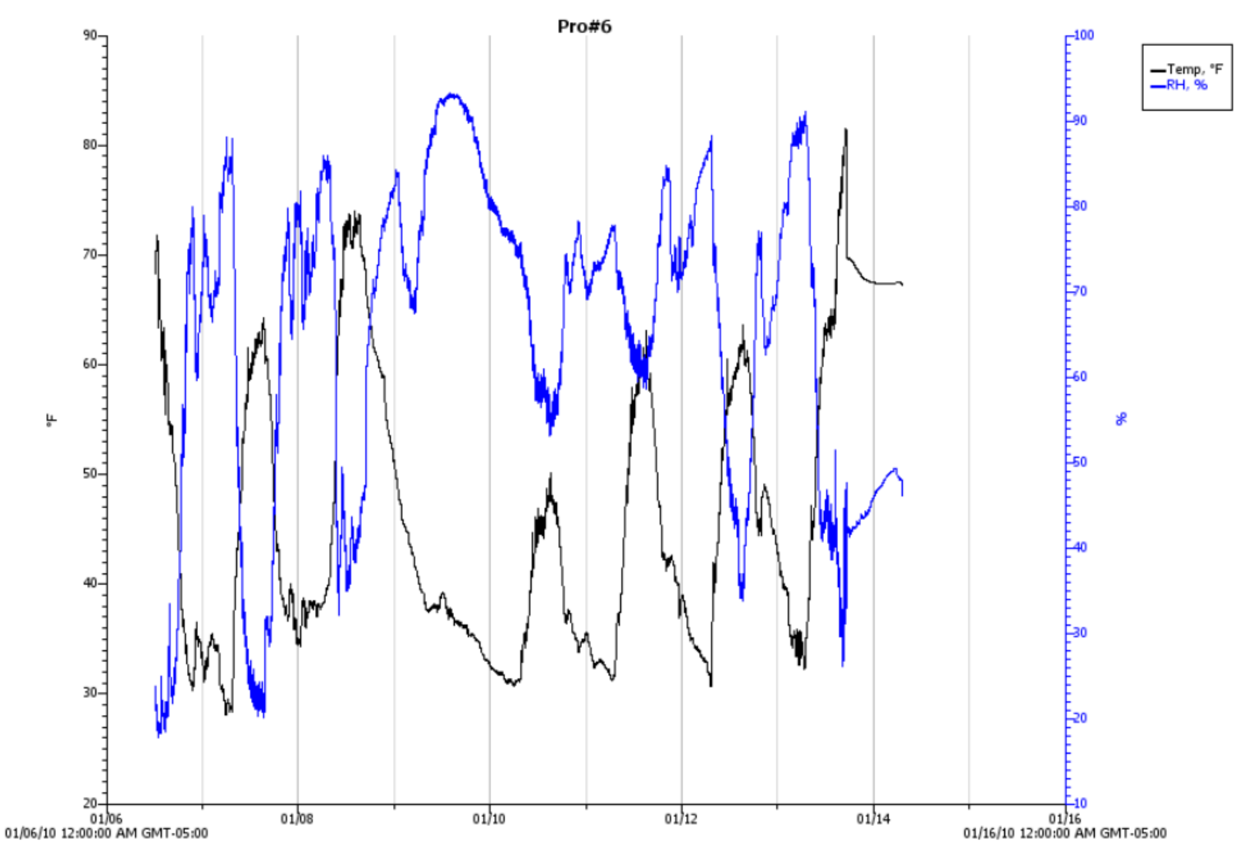

Figure 4-2. Temperature and RH data from the data logger at Vero block in the week of harvest from 01/06/10 to 01/14/10.

Figure 4-3.Freeze injury (Number 9 on the freezing scale).

Figure 4-4.Freeze injury (Number 8 on the freezing scale).

Figure 4-5. Freeze injury (Number 7 on the freezing scale).

Figure 4-6. Freeze injury (Number 5 on the freezing scale).

Figure 4-7. Freeze injury (Number 4 on the freezing scale).

Figure 4-8. Freeze injury (Number 3 on the freezing scale).

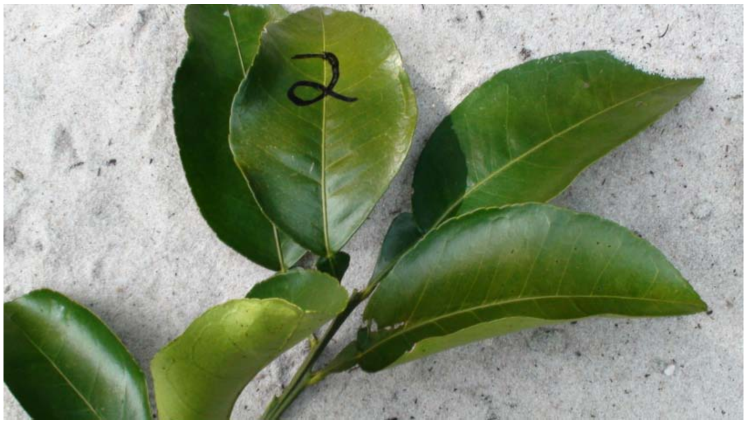

Figure 4-9. Least severe freeze injury (Number 2 on the freezing scale).

CHAPTER 5
CONCLUSION

The research reported in this thesis has shown the effects of preharvest foliar potassium (K), magnesium (Mg), or Vapor Gard® application, water deficit treatment, different postharvest humidity conditions and packingline treatments along with storage time in reducing peel breakdown of citrus. Two commercially available materials (Vapor Gard® and carnauba wax) were evaluated for frost and freeze protection of citrus trees under field conditions.As a result of these studies, it was found that there was no significant effect of Vapor Gard® or Carnauba wax in reducing freeze injury but there was very little freeze injury to the fruit.

Foliar applications of K, Mg, K + Mg and 1% Vapor Gard® reduced peel breakdown in ‘Valencia’ oranges compared to the control fruit in the month of May. 1% Vapor Gard® showed the best results and can be recommended to growers for reducing peel breakdown in summer. There was increase in total decay with the increasing days of storage. In the first week of harvest after treatment, the peel breakdown was very less compared to other harvests.

The white grapefruit harvested in December showed negligible peel breakdown even after long durations of storage. There was not much decay as well after long durations of storage of this fruit. This can be possibly due to the effect of seasonal changes. Early season fruit is less susceptible to peel breakdown as compared to late season fruit.

The effect of 2% Vapor Gard® and the treatment foliar K + Mg + 1% Vapor Gard® in reducing peel breakdown in white grapefruit was very important. In the 3rd week after harvest, an interesting trend was observed with most of the peel breakdown being manifested on the fruit after approximately 25 days of storage and even when the fruits were stored till 63 days, the total peel breakdown percentage did not increase more than 2% in all the treatments. Hence, there is a possibility that peel breakdown manifestation is dependent on particular time of storage.

In red grapefruit, similar trend was followed with most of the peel breakdown being manifested in the first 30 days of storage. The treatment 2% Vapor Gard® showed the maximum reduction in peel breakdown. Hence, the treatment 2% Vapor Gard® can be recommended to reduce peel breakdown in red grapefruit.

Significant differences in postharvest treatments with respect to total peel breakdown were observed after different durations of storage. After long duration of storage at ambient conditions, shelf life of fruit held for 2 to 3 days at 30% RH was reduced by developed about three to eight times more than fruit held at 60% RH.Hence, fruits kept at 30% RH received sudden change in relative humidity causing more peel breakdown.Fruits treated with wax and 2000 ppm Imazalil showed inconsistent results in reducing peel breakdown.

Water loss in the fruit showed gradual losses in every treatment after every evaluation. The relative differences in weight loss reduced among fruits prestored at 30%, 60% and 95% RH for 3 days over longer storage durations. The lowest looses in water were at 95% RH. The results showed TBZ and Imazalil reduced green mould significantly. Previous results have also shown their effectiveness in reducing postharvest decay. Hence, they can be recommended to packers.

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