QUALITY OF CARAMBOLA FRUIT (*Averrhoa carambola* L.) AS AFFECTED BY HARVEST MATURITY, POSTHARVEST WAX COATING, ETHYLENE, AND 1-METHYLCYCLOPROPENE

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

UNIVERSITY OF FLORIDA

2009

To Valerie.

ACKNOWLEDGMENTS

I would like to express my sincere gratitude to Dr. Steven Sargent as the supervisory chair of my committee for his continuous guidance, support, and encouragement. I would also like to thank the members of my committee; Dr. Donald Huber, Dr. Jeffrey Brecht, and Dr. Allen Wysocki for their guidance and suggestions.

I wish to thank Mr. Kevin Bryan of Brooks Tropicals for his support in organizing and coordinating specific harvests of carambola. I also wish to thank Brooks Tropicals (Homestead, FL) for their generosity in supplying all of the fruit used in these experiments.

I owe my sincere thanks to Adrian Berry, our senior biological scientist, for her helpful assistance with lab methods and statistical analysis. Also, I would like to thank senior biological scientist Kim Cordasco for her help setting up my gassing experiments. I would like to especially like to thank my fellow graduate students for their assistance and friendship.

I must thank Dr. Elizabeth Baldwin, Dr. Anne Plotto, and Tim Tillman of the USDA for their assistance in running and analyzing my volatile samples, and for their suggestions for presenting the data.

I would like to thank my mother and grandmother for providing me with a solid education and also guiding and inspiring me to attend graduate school.

Finally, my deepest gratitude and love to Valerie for her patience, time, assistance with laboratory analysis, and constant encouragement during my entire college career.

TABLE OF CONTENTS

page

LIST OF TABLES

LIST OF FIGURES

<u>Figure</u> <u>page</u>

LIST OF ABBREVIATIONS

^{o}C	Degrees Celcius
1-MCP	1-methylcyclopropene
C_2H_4	Ethylene
CO_2	Carbon dioxide
cv.	Cultivated variety, cultivar
d	Day
h	Hour
MAP	Modified atmosphere packaging
min	Minute
N	Newtons
NaCl	Sodium chloride
n.d.	Not detected
RH	Relative humidity
RI	Kovats retention index
SSC	Soluble solids content
TSS	Total soluble sguars
TTA	Total titratable acidity

Abstract of Thesis Presented to the Graduate School
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May 2009

Chair: Steven A. Sargent
Major: Horticultural Science

Carambola (*Averrhoa carambola* L.) fruits, also known as star fruit, are known for their unique shape. 'Arkin' is the major variety of carambola grown in Florida; it is popular because of its compact shape, which is favorable for shipping, and its natural sweetness. However, one problem at retail level is the poor appearance of the fruit. Another is the fruit is generally not as sweet as its potential. Currently carambolas are harvested at early ripeness (when color breaks or reaches 1/4 yellow) because fruit are firmer and less susceptible to mechanical injury during harvesting and shipping. But fruit harvested at the 1/2 yellow stage are known to be sweeter and have a significantly higher sugar-to-acid ratio than fruit harvested 1/4 yellow.

This study was initiated to examine the potential for harvesting 'Arkin' carambola at more advanced ripeness stages using the following postharvest treatments:three color stages (1/4, 1/2, and 3/4 yellow), application of carnauba wax, ethylene, aqueous 1-methylcyclopropene (1-MCP) ethylene-action inhibitor, 1-MCP followed by ethylene, and storage at several temperatures. A price sensitivity analysis was also performed to determine the costs of adding a 1-MCP treatment to fruit produced in Florida.

Storage at 5 ^{o}C for 14 d did not induce chilling injury symptoms and slowed weight loss, color development, maintained firmness, suppressed total volatile formation, and extended shelf life up to 3 d. Waxing with a carnauba-based coating gave the fruit a more glossy appearance but slowed color development in the fins. Fruit harvested at the 1/4 yellow stage, waxed and held at 5 ^{o}C for 14 d developed internal flesh browning; fruit harvested at the 1/2 and 3/4 yellow stage did not show these symptoms.

Prestorage, exogenous ethylene treatment (100 ppm, 48 h, 20 ^{o}C) slightly accelerated degreening of the fruit, while either 25 or 50 ppm treatment had no noticeable effect. However, after 14 d storage at 5 ^{o}C the 100 ppm ethylene-treated fruit had ehigher incidence of fin-margin browning, and surface pitting/browning than the 25 and 50 ppm treated fruit.

Fruit immersed in 50, 100 and 200 ug*L^{-1} aqueous 1-MCP for 1 min,delayed color development, notably in the fins of fruit harvested 1/4 yellow, and suppressed total volatile formation, especially norisoprenoid compounds that are associated with carotene degradation and over-ripe flavors. Fruit treated with 200 ug*L^{-1} were firmer and shelf life was extended for fruit harvested 1/4 or 1/2 yellow. This allows for a harvest at the 1/2 yellow (sweeter) stage. 1-MCP treatment followed by 14 d storage at 5 ^{o}C then 100 ppm ethylene treatment for 24 or 48 h at 20 ^{o}C was not beneficial in degreening the fins.

The additional costs to packers for 1-MCP treatment were estimated from $0.25 to $3.50 per shipping carton and found to be feasible. The increased retail price per fruit was less than $0.40 in most scenarios and could be passed on to the consumer.

CHAPTER 1
INTRODUCTION

The carambola (*Averrhoa carambola* L.) has been cultivated in tropical and subtropical regions for hundreds of years. The fruits are berries that originate from the ovary of the flower and usually have 4-6 fins (5 being the most common). The fruits are very fragile and are susceptible to wind scarring while growing on the tree. The size of a fruit ranges from 7.5 to 12.5 cm and is has a yellow to orange appearance some varieties have a whitish appearance.

Production in the U.S. is limited to Hawaii and Florida. In Florida, the major cultivar is 'Arkin'. 'Arkin' is popular because of its sweet flavor and compact fin shape. The 'Arkin' cultivar constitutes 95% of the Florida crop, other varieties grown are 'B10', 'Kary', and 'Golden Star' (Crane, 1994). Currently there are approximately 200 acres of commercial production in Florida, down from a high of 650 acres in 1992 (Kahout, 2004; J.H. Crane, Personal communication, 2007).

The Florida tropical fruit industry has approximate combined annual value of $75 million. Carambola constitutes ~13 % of this value with revenue of $9.5 million a year (Kahout, 2004; and Crane recent estimates). The cv. 'Arkin' makes up 95 % of the Florida crop. 'Arkin' is popular because of its natural sweetness and compact fin shape. Astringent varieties are undesirable, and varieties with long and thin fins are too fragile to withstand harvesting and packing.

The physical appearance of carambola fruit at the retail level is a major postharvest problem. Currently, carambolas are harvested at the one-quarter yellow stage, while the fruit are still firm, to avoid mechanical damage from harvesting and handling. When fruits are harvested early in their maturity their appearance is more susceptible to symptoms of chilling injury and they take longer to reach their peak ripeness. All of the mechanical and physiological injuries that the fruit have sustained cause the appearance to deteriorate and provide sites for pathogens to enter. Improper storage conditions also contribute to the appearance problems of carambola (Kader, 2002).

There are techniques that can be used to extend the shelf-life of fruit harvested at later maturity stages, as well as maintain the quality of the fruit postharvest. Edible wax coatings are commonly used on fruit to retain water and limit respiration. Water loss is a problem because it leads to a loss in saleable weight, also known as shrinkage. Storing carambola in high relative humidity conditions helps to slow water loss and maintain firmness (Ali et al., 2004). High humidity storage is impractical in most commercial settings; therefore, creating a modified atmosphere by waxing the fruit might prove advantageous.

Ethylene has been used commercially to hasten ripening and promote a uniform appearance of fruit (Reid, 2002). Ethylene is associated with two systems within plant physiology. System 1 is initiated by stress or injury and results in an increase in respiration and chlorophyllase activity. An increase in chlorophyllase activity in fruits leads to degreening (Amir-Shapira et al., 1987). Chlorophyll continues to degrade after an ethylene exposure (Purvis and Barmore, 1981).A postharvest ethylene treatment can start a degreening process that continues until the fruit are in a retail setting. The effectiveness of ethylene as a degreening treatment for green carambola has been investigated and the results were promising (Miller and McDonald, 1997; Sargent and Brecht, 1990).

1-methylcyclopropene (1-MCP) has been used commercially to delay ripening and senescence in many fruits and vegetables. Studies on the effects of 1-MCP on carambola are limited to gaseous application and the variety ‘Fwang Tung’. 1-MCP has not been used commercially on carambola in the U.S. 1-MCP works by binding to ethylene receptor sites and preventing ethylene from binding with the site (Sisler et al., 1996).

This study investigates the potential to extend shelf-life and maintain postharvest quality of commercially grown ‘Arkin’ carambola. Experiments were performed to evaluate the effects of harvest maturity, storage temperature, edible wax coating, postharvest ethylene, and 1-MCP treatments.

CHAPTER 2
REVIEW OF LITERATURE
Carambola

The carambola (*Averrhoa carambola* L.) originated in Southeast Asia, and has been cultivated in tropical and subtropical regions for hundreds of years. Carambola is also known as star fruit in the US. There are other names including: five corners, five fingers, and numerous non-English names. One of the most interesting non-English names comes from the Philippines where it is called ‘balembing’ or ‘belimbing’, which is an idiom also used to describe politicians who seem to have having multiple faces.

Carambola is a member of the Oxalidaceae family. The fruit is a berry that originates from the ovary and usually has 4-6 fins (5 being the most common). Other members of the family include bilimbi (*Averrhoa bilimbi* L.), also known as the tree cucumber, and wood sorrels (Oxalis sp.). Bilimbi fruit are similar to carambola but their shape is rounded like a cucumber. Sorrels are herbaceous annuals that can become a nuisance weed in greenhouses because the seed pods are explosively dehiscent. When the seed pod is mature, the slightest agitation will send seeds flying into adjacent pots.

The evergreen trees of carambola grow in tropical and subtropical regions. In the US, it is often sliced and used as a garnish for salads, tropical fruit drinks and sometimes made into wine. The fruit is also salted and pickled, cooked in puddings, mixed into curries, stewed with sugar and cloves, made into preserves and jams, cooked with fish (China), boiled with shrimp (Thailand), or sliced and dried. The juice of the fruit has a light refreshing flavor and is popular in Malaysia. There is potential for the fruit to be lightly processed and used in the fresh-cut industry as it has an attractive star shape when sliced transversely but preventing oxidative browning is imperative (Weller et al., 2006).

Significant production of carambola occurs in Taiwan, Malaysia, China, India, Philippines, Australia, India, Israel, Brazil, Peru, Guyana, and The United States (Florida and Hawaii). Carambolas are usually consumed in the country they are produced, except for high quality carambolas grown in Malaysia that are exported to Europe. The carambola was introduced to Florida in 1887 and at that time all of the available varieties were tart. In Florida, carambola is grown in home landscapes as well as commercially in Miami-Dade, Lee, Broward, and Palm Beach counties (Crane, 1994). Currently in Florida, approximately 81 hectares (200 acres) are in commercial production, down from approximately 650 acres in 1992 (Kahout, 2004; J.H.Crane, Personal communication, July 13, 2007). Carambolas are very susceptible to mechanical damage. Movement from wind results in considerable scarring and damage. Slight scratching of the fruit while on the tree leads to unattractive fruit at the retail level as scars get darker and more pronounced with storage. Production in Florida requires windbreaks and wind screens which prevent wind from disturbing fruit while on the trees. Fruit that swing while on the tree rub against other fruit and branches which causes mechanical damage. Windbreaks usually consist of mature Australian pine (*Casuarina equisetifolia*). The windscreens are made of wooden poles or more commonly aluminum poles with cables that support shade cloth.

Tropical fruit production in Florida has an annual value near $75 million. Carambola production is approximately 4.5 million pounds per year. This constitutes 13% of the total annual revenues for Florida’s tropical fruit industry, with a value approaching $9.5 million (Kahout, 2004, and Crane recent estimates). While in its native tropical habitat carambola trees bear fruit all year long, in Florida, the crop has two major harvesting seasons, August to September and December to February. The trees can be manipulated to fruit in the off season by pruning branches and thinning the young fruit set. This practice could add significant value to the crop by extending the season since there is no Florida-grown carambola from March to July. Nunez-Elisa and Crane (2000) found that pruning in July and September increased panicles of flowers by 14 and 20 % respectively, and that pruning in other months also proved successful.

‘Arkin’, a sweet variety of carambola was selected in the 1970’s by Morris Arkin, an amateur propagator, of Coral Gables who grew plants from seeds and plant material that were collected in Thailand and Malaysia. Currently, approximately 95% of the Florida carambola crop is the cultivar ‘Arkin’, while the remaining plantings are ‘B-10’ and ‘Kary’ (J.H. Crane Personal communication, 2007). ‘B10’ carambolas are sweet with good flavor but the trees require cross pollination for proper fruit set. ‘Kary’ carambolas are also sweet but better adapted to growing conditions in Hawaii. ‘Arkin’ carambolas typically have 80% less oxalic acid than ‘Golden Star’, which is a tart variety of carambola (Campbell and Koch, 1988). ‘Arkin’ carambola trees can reach 7 m in height with a canopy diameter of 5 m (Knight, 2002). The lower height of the trees fits under windscreens very well.

Cost of Carambola Production in Florida

The cost of production for an acre of carambola estimated by IFAS (State of Florida, 2008) was $15,838. Pick, haul, and pack was the single highest line item on the income statement at $3522 / hectare ($8700/ acre). The estimated breakeven price per pound of a 20 hectare (50 acre) orchard in south Florida is $0.36. The average price per pound at seven terminal markets in the U.S. on August 30, 2008 was $2.65 (USDA, 2008). Costs will vary based on the size of each individual operation. The rule of economics of scale dictates that larger operations will have an advantage when purchasing supplies and therefore have a lower per unit cost. Also, keeping seasonal labor available will be easier for larger firms that have other crops throughout the year. Providing a permanent source of employment for workers will reduce the need to hire supplemental workers.

Carambola Orchard Recovery Post Hurricane Andrew

Tropical storms and hurricanes threaten the tropical fruit industry in Florida. When hurricane Andrew hit south Florida on August 24th, 1992, tropical fruit crops were devastated. The storm produced sustained winds up to 145 mph (230 kph) with gusts up to 175 mph (282 kph) and 2 to 4 inches (5.08 to 10.16 cm) of rain (Hebert et al., 1992). Because the storm passed directly over Miami-Dade County, tropical fruit trees were subjected to the leading and tailing edges of the storm, producing winds in multiple directions. Ten to 15 months after the storm, tree survival rate was recorded by tropical fruit researchers. The findings revealed that 93% of carambola trees survived the storm. Thirteen percent of the trees were toppled, leaving 76% of the trees still standing, the toppled trees were stood up soon after the storm. Only grafted lime trees had a better tree survival rate. Mango, longan, and lychee had significantly higher tree destruction. The flexible limb structure of carambola trees attributed to their high survival rate. In many cases the windbreaks, consisting of Australian pine plantings (*Casuarina equisetifolia*), fell onto the trees they were intended to protect. The windscreens, which were anchored with wooden or aluminum poles and wires holding shade cloth, lost all of their screens and some of the structures (Crane et al., 1993 and 1994). Despite the high rate of survival for carambola trees, acreage began to decline as prices declined. Growers started replacing carambola with lychee, longan, and some avocado. An estimated 10% of carambola acreage was lost to development (J.H.Crane, Personal communication, July 13, 2007). Before the 1992 storm there were 650 acres of carambola in production in south Florida, yielding almost 40,000 lbs per acre; by 1994 there were 532 acres. By December 1994 production for all tropical fruits was 35% below pre-hurricane Andrew production (Degner et al., 1997).

Consumers and Retailers

For produce buyers quality is the top concern, especially the appearance of the fruit. The primary complaint that buyers have about carambola is bruising of the ribs (buyers are also concerned about consumer's knowledge of tropical fruits) however, carambolas are more recognized by consumers than most tropical fruits produced in Florida. Only mangos, avocados, and papaya are more familiar to consumers than carambola. Despite being better recognized than other tropical fruits, growers and retailers feel that an increased marketing effort could increase consumer's awareness of the fruit. Of the retail stores surveyed by Degner (1997), 97% carried carambola while it was in season. Only mangos and papayas had higher rates of distribution, at 100%. Of the retailers who carried carambola, 47.3% indicated excellent sales, 35.6% indicated fair sales, and 17.1% indicated poor sales suggesting that most retailers believe that carambola have good sales when compared to other tropical fruits. These retailers also noted that short seasonal availability and tart fruit are problems (Degner, 1997). Tart varieties are not commonly produced commercially; instead the tart fruit probably comes from picking sweet varieties too early. The harvest seasons of carambola could be extended by manipulation of fruit set and selective pruning but this is not commonly practiced commercially.

Physiology, Harvesting and Storage

The physical appearance of the fruit at the retail level is a major postharvest problem. Mechanical injuries that occur during the growth, picking, or packing of the fruit cause the appearance to deteriorate and provide sites for pathogens to enter. Mechanical injuries can be caused by cuts, scrapes, impacts or vibration. The fruit can develop fin browning, wrinkled stem ends, surface browning (bruising caused by membrane disruption) and pitting, and water loss due to mechanical damage and low humidity storage (Kader, 2002).

Fruit accumulate sugar only while on the tree, getting progressively sweeter as the color changes from green to yellow and then orange. The brix/titratable acidity ratio is significantly higher at each color stage only while on the tree (Narain, 2001). The fruit in the yellow and orange stages are susceptible to damage and too fragile to pack and ship (Oslund and Davenport, 1983). Fruit also decreases in firmness postharvest. The yellow color stage is associated with changes in cell wall constituents. Cellulose accumulates while hemicellulosic materials and pectins decrease gradually beginning at the one-quarter yellow stage (Mitcham and McDonald, 1991: Chin et al., 1999).

Once harvested sugar concentrations remained fairly constant in low temperature storage and slightly decreased in fruit stored at 10 ^{o}C. Five degrees Celsius is the low temperature threshold for carambola. Acidity (oxalic and malic acids) slightly decreased in fruit stored at 10 ^{o}C but did not change in fruit stored at 5 ^{o}C. Fruit stored at 10 ^{o}C more likely had a higher metabolic rate (Campbell et al., 1987: Siller-Cepeda et al., 2004). Likewise, weight loss and color development were slowed when stored at 5 ^{o}C as apposed to storage at 10 ^{o}C and 28 ^{o}C. Ali et al., found that color development of carambola (cv. B-10) was closely linked to the storage temperature than to a modified atmosphere packaging (MAP) treatment (2004).

Chilling injury is a disorder that effects tropical and subtropical fruits when they are stored above freezing temperature but below their threshold for cold storage. While chilling injury is not common in carambola stored at 10 ^{o}C, Ali et al. reported chilling injury in fruit held at 10 ^{o}C for 40 days in MAP (2004). The symptoms of chilling injury are tissue browning, pitting, uneven ripening, failure to ripen, water soaking, off-flavor development, and an increase of pathogens leading to decay. These symptoms generally do not appear until the fruit is removed from the low temperature and transferred to a higher temperature. The more physiologically mature a fruit is when placed into chilling temperatures the less apparent the injury. This is partly because the major changes in the fruit have already taken place and cannot be disrupted by colder temperatures (Kader, 2002).

Florida carambola is currently harvested early in maturity, while the fruit is still firm, to reduce mechanical injury. The fruit is harvested by hand into plastic boxes and transported to the packinghouse. Fifty-three percent of the fruit harvested is sold to a packer/shipper from the orchard, while 44% of the fruit is packed and shipped by the grower (Degner, 1997). At the packinghouse the fruit is hand sorted and placed into cardboard boxes with a cardboard grid to separate each fruit, usually stem end down onto a foam liner. To slow desiccation, the fruit are sometimes wrapped in wax coated paper and then packed into the box.

Flavor and Volatiles

Carambolas have a unique aroma volatile profile contributing to a sweet floral flavor. Using a capillary gas chromatograph/mass spectrometer combination (GC/MS), 41 aroma volatiles were identified in carambola (Wilson et al., 1985). In one previous report 178 components were detected and identified by GC and GC-MS methods in ‘B.10’ variety grown in Malaysia and exported to Europe. The main volatile components of the Malaysian fruit were esters. Interestingly, carambolas were verified to share lactone constituents also found in peaches, apricots, and plums (MacLeod and Ames, 1990). More recently 53 volatile compounds were found to contribute to the unique flavor of carambola fruit using headspace solid phase micro extraction (SPME) and solvent extraction, (GC/MS), and gas chromatography-olfactometry (GC-O). Methyl benzoate (musty minty floral sweet) and ethyl benzoate (tropical sulfur-like floral) are two of the major compounds in concentration and aroma activity (Mahattanatawee et al., 2005). There are also some compounds that contribute to an overripe or unpleasant sulfur taste such as: 1-pentanol (apricot/banana), benzothiazole (sulfur/rubber), and quinoline (putrid/fishy) (Mahattanatawee et al., 2005; Wilson et al., 1985). Other major constituents were esters, aldehydes, alcohols, ketones, and some norisoprenoid compounds (Mahattanatawee et al., 2005; Herderich et al., 1997).

There are several explanations for the discrepancies in the number of volatile constituents reported in carambola. Testing methods most likely cause the major differences in the number and types of volatiles identified, and some research focuses only on the volatiles that are in high enough quantity for humans to perceive. Varietal type is another possible reason for the differences in the volatiles reported. Also, carambolas have probably been studied at different color stages. As indicated by Herderich et al., C_{13}-Norisoprenoid flavor precursors were identified in carambola. These compounds are by-products of carotenoid degradation (1992). Carotenoids in carambola are produced in high amounts while the fruit are mature and in 'Arkin', they are produced while nearing the overripe stage (Herderich et al., 1997). One more reason for the difference in the reported volatile constituents in carambolas is the difference in storage and commercial treatments the fruit have been subjected to. Some of the volatile and flavor research has been done on fruit obtained from market places and some has been directly acquired from research stations and farms. Ethylene, a common commercial treatment for many fruits, and a constituent of motor exhaust has been shown to reduce significant numbers (6 of 15) of key volatiles in tomato fruit. High temperature water treatments and low-temperature storage can have similar effects (McDonald, 1996). Low-temperature storage has caused tomato fruits to be perceived as being more tart in sensory analysis experiments. It has also caused the volatiles that contribute to a flavor to be suppressed (Maul et al., 2000). Since tomatoes and carambolas are fruits that have unique aroma profiles it can be assumed that the profiles are affected by the same factors.

Antioxidants and Health Effects

Evaluations of 14 tropical fruits produced in Florida showed that carambola have high antioxidant activity. High antioxidant activity has health benefits such as protection against cell damage (Mahattanatawee et al., 2006). The majority of the antioxidants (70%) in carambola are present in tissues and not the juice, despite the juice constituting approximately 95% of the fresh weight of the fruit. These antioxidants exist as polyphenolic compounds (Shui and Leong, 2004).

Despite the aforementioned health benefits; carambola should not be consumed by people diagnosed with kidney disease. The fruit contain oxalic acid, which has been associated with a loss in renal function. Various neurological problems can occur; even death has been reported (Moyses-Neto et al, 1998). Carambolas produced in the Guangzhou region of China have been found to contain heavy metals. These fruit are distributed to various parts of China and Hong Kong. Fruit produced in Guangzhou have been found to have unacceptably high levels of zinc, nickel, and cadmium. The source of cadmium is contaminated orchard soils (Li et al., 2005; Li et al., 2007).

Waxes and Edible Coatings

Carambola respiration is fairly constant, less than 20 mL CO_2 kg^{-1} h^{-1} at 20^oC while at breaker (1/4 yellow) stage with a slight increase while turning from yellow to orange, likely due to senescence of the fruit. Appropriate storage conditions can slow certain biological processes such as water loss and respiration. Water loss is a problem because it leads to a loss in saleable weight, also known as shrinkage. The surface to volume ratio of carambola is high due to its unique shape; this makes storage at high relative humidity necessary. Storing carambola at 5 ^oC and high relative humidity (85-95%) is an effective way to maintain fruit firmness (Ali et al., 2004). Waxes can be an effective way to prevent moisture loss. Two and 6% carnauba wax has shown promising results in preventing water loss. These wax treatments had no significant effect on total soluble solids, acidity, pH, color, flavor, or sensory texture (Miller and McDonald, 1993). Waxing is also a possible treatment for slowing respiration. Applying an edible wax coat to fruit has also been shown to limit CO_2 passage from the fruit to the surrounding atmosphere. In an experiment using citrus the internal concentration of CO_2 increased in waxed fruit and weight loss was reduced (Hagenmaier and Baker, 1993).

Ethylene

Ethylene is a natural plant hormone in the form of a gas. It is associated with ripening and senescence. Cultures around the world have used the properties of ethylene to enhance fruit for centuries. The bible mentions the practice of farmers who cut the top of sycamore figs in order to speed growth and ripening. The wound would initiate an ethylene response (Amos 7:14), The Romans stored ripe apples in the same room as quince in order to hasten the ripening, and the Chinese would burn incense in storage rooms filled with pears to accelerate ripening (Reid, 2002).

Ethylene is associated with two systems within plant physiology. System 1 is a constant basal rate of ethylene production where ethylene is produced in low amounts. Ethylene is also initiated by stress or injury. Exogenous ethylene applied to non-climacteric fruit or vegetative tissue down-regulates (auto-inhibits) ethylene production but up-regulates respiration. System 2 is associated with the ripening of climacteric fruits. Ethylene is produced and an autocatalytic rise in ethylene production occurs. Exogenous application of ethylene to climacteric fruit auto-stimulates the climacteric rise in ethylene. During a typical climacteric fruit ripening the rise in respiration is followed by or is in unison with a rise in ethylene production (Burg and Burg, 1965). Ethylene binds to the receptor site and initiates chemical changes within the fruit including: conversion of starches to sugars, pigment production, and volatile production. For non-climacteric fruits ethylene is commonly used commercially to enhance the external color of fruit postharvest. For example: ethylene is applied to citrus postharvest to de-green the fruit by degrading chlorophyll. When ethylene is applied to citrus an increase in chlorophyllase activity can be observed. Chlorophyllase is an enzyme involved in the process of degrading chlorophyll. Also, an increase in chlorophyllide A activity was observed by Amir-Shapira when ethylene was applied (1987). Ethylene treatments lead to a decrease in chlorophyll A and B (Amir-Shapira et al., 1987). Certain cultivars of tangerines (calamondins and Robinson tangerines) will not degreen unless ethylene is applied. Fruit treated with ethylene and then placed in air storage chlorophyll degradation continued for 24 h then ceased (Purvis and Barmore, 1981).

Carambola exhibit non-climacteric ripening behavior. Fruit stored at 25 ^{o}C produced very low amounts of ethylene. Once the fruit were considered fully ripe they were producing more ethylene and their respiration rate was also increased but this was attributed to microbial activity and senescence of the fruit (Oslund and Davenport, 1983). Lam and Wan (1987) found that respiration was slightly suppressed by storage at lower temperatures and ethylene production was undetectable at 5 ^{o}C. They also reported that green fruit had higher respiration rates than riper fruit; this was attributed to higher physiological activity in less mature fruit. The fruit in Lam and Wan’s experiment displayed higher respiration and ethylene production toward the end of their storage time, which was also attributed to senescence (1987). Ethylene has been applied to mature green carambola to initiate color change and has been proven as an effective ripening agent. Color was enhanced by 2 day storage at 20 ^{o}C and 100 ppm ethylene. When the fruit were gassed for 1 day the “ripening” was incomplete, when gassed for 3 days the incidence of decay was significantly increased. There was no noticeable trend in soluble solids content or titratable acidity due to ethylene treatments (Sargent and Brecht, 1990). Miller and McDonald found that exogenous ethylene increased carambola peel scald, stem end breakdown, fin browning, and enhanced mold growth (1997). There was a noticeable difference in titratable acidity and total soluble solids between mature green fruit and slightly yellow fruit. The mature green fruit had higher titratable acidity, lower pH, and lower soluble solids content. The concentration of ethylene used in Miller and McDonald's work was 0.1 mL L^{-1}; this concentration might have been too high.

1-Methylcyclopropene (1-MCP)

A common goal of postharvest scientists is to maintain the quality of harvested fruits and delay senescence. One method of attaining this goal is to limit exposure to ethylene gas. Cyclopropenes have been proven as effective ethylene antagonists; particularly cyclopropene, 1-methylcyclopropene, and 3,3-dimethylcyclopropene (Sisler et al., 1996a). Of these compounds 1-methylcyclopropene (1-MCP, commercial name *SmartFresh*™), is the most stable of the cyclopropenes and active at 1000 times lower concentration in high temperature applications. 1-MCP is an effective treatment for increasing the shelf life of many commodities because of its approved commercial use and ease of application. Since 1-MCP is an ethylene antagonist the benefits of application to climacteric fruits are obvious. 1-MCP has proven to be effective in delaying the ripening and senescence of climacteric and non-climacteric fruits. A good example can be found in plums, because there are both climacteric and non-climacteric varieties. Both types of plums treated with 1-MCP at 0.25, 0.50, and 0.75 µL L^{-1} showed positive effects including delayed physical, chemical, and biochemical changes; firmer fruit with lower percentage weight loss and lower brix to acid ratio which indicates suppressed ripening (Martinez-Romero et al., 2003). Some common benefits of 1-MCP application include: maintenance of firmness and color, reduction in respiration rate and ethylene production, and limiting weight loss (Sisler et al., 1996b). 1-MCP works by binding to a metal in the ethylene receptor and out-competes ethylene for the receptor site. 1-MCP treatment at a concentration of

0.5 nL L^{-1} has been shown to lengthen shelf life of bananas by 12 days held at 24 ^{o}C. The fruit ripened normally after this period. Mature green tomatoes benefitted by delaying the rise in respiration by 8 days and the rise in ethylene by 12 days, lengthening shelf life by 8 days (Sisler et al., 1996a; Sisler and Serek, 1999; Jiang et al., 2004). The effectiveness of 1-MCP in maintaining firmness of fruit held at various temperatures has been demonstrated in bananas, nectarines, and plums (Jiang et al., 2004; Bregoli et al., 2005; Martines-Romero, 2003).

The carambola cv. 'Fwang Tung' was harvested at 1/2 yellow color and gassed in a hermetically sealed container for 24 h at 25 ^{o}C with 1-MCP concentrations of 500 nL L^{-1} or 1 µL L^{-1}. Fruit respiration was lowered significantly and the fruit had better fruit color maintenance with 1-MCP treatments at 0.5 and 1 µL L^{-1}. The fruit that were treated did not have a significant delay in ripening (Teixeira and Durigan, 2006).

All of the above treatments used 1-MCP as a gas, which requires airtight chambers and 1 h to 1 d applications with concentrations ranging from 10 to 1000 nL L^{-1}. Technology exists for 1-MCP to be applied in aqueous solutions. This technology was originally developed for preharvest applications to be made in the field. The benefits of an aqueous application are: no airtight chambers required and shorter application times (this would allow large quantities of a commodity to be treated over a shorter time, such as on a packing line). A 1 minute aqueous application 625 ug L^{-1} had the same effectiveness as a 9 h gaseous application of 500 nL L^{-1} (Choi and Huber, 2008). Aqueous application of 1-MCP on tomatoes delayed softening, suppressed ethylene and respiration climacteric peaks, and delayed the production of lycopene. It also increased polygalacturonase activity (Choi and Huber, 2008; Choi et al., 2008).

If water loss cannot be limited by storing and transporting fruit under high humidity conditions then waxing the fruit can be beneficial. During long storage periods, especially periods that have been extended by the use of 1-MCP, waxing fruit has been shown to limit water loss. In an experiment with avocado, Jeong et al., (2003) showed that waxing limited weight loss during storage. The wax and 1-MCP treated fruit had delayed peaks in respiration and ethylene production (Jeong et al., 2003).

1-MCP maintains the turgidity and green color of leafy vegetables such as choy sum, and bok choy (Thomson et al., 2003). Leafy vegetables are especially prone to wilting because of their high surface to volume ratio. If the cold chain is disrupted, 1-MCP-treated vegetables maintain a better appearance than non-treated vegetables. 1-MCP has also been shown to reduce leaf abscission in spearmint cuttings produced as fresh herbs (Thomson et al., 2003).

Research Objectives

The objectives of this research project were to determine the effect of harvest maturity on the edible quality of carambola as determined by firmness, compositional parameters, and aroma profile. The second objective was to determine the effects of storage temperature, postharvest waxing, ethylene, and 1-methylcyclopropene (1-MCP) treatments on quality and delaying ripening of carambola. The last objective was to conduct a price sensitivity analysis of the costs of proposed treatments versus current handling methods.

CHAPTER 3
POSTHARVEST QUALITY AS AFFECTED BY HARVEST MATURITY, STORAGE TEMPERATURE, AND WAX COATING

Introduction

Carambola grows well in tropical and subtropical areas and is a good fruit for fresh consumption. When sliced it makes an attractive garnish because of its unique transverse shape. Usually the fruits are harvested early, while in the green or one-quarter yellow stage and still firm, to limit mechanical injury. Fruit accumulate sugar only while on the tree, getting progressively sweeter as the color changes from green to yellow and then orange. The soluble solids content to total titratable acidity ratio is significantly higher at each color stage only while on the tree (Oslund and Davenport, 1983; Narain, 2001). Once harvested, sugar concentrations remain fairly constant but titratable acidity slightly decreas in certain storage temperatures (Campbell et al., 1987; Siller-Cepeda et al., 2004). Carambola cv. ‘Arkin’ is popular because it is sweeter and less astringent that other varieties of carambola. ‘Arkin’ also has a desirable size and shape for transportation (Crane, 2007).

The surface-to-volume ratio of carambola is high because of the shape of the fins. The high surface-to-volume ratio of some fruits leads to increased transpirational water loss. Waxing carambola significantly lessened weight loss, and fin browning, but also led to surface pitting (Miller and McDonald, 1993). Applying an edible wax coat to citrus fruit was shown to reduce CO_2 transmissivity from the fruit to the surrounding atmosphere, slowing respiration as the internal CO_2 concentration increased (Hagenmaier and Baker, 1993).

The objective of this experiment was to establish the optimum harvest maturity for carambola based on flavor attributes (sugar and acid composition) and to examine whether waxing would aid in extending the visual quality of the fruit during postharvest storage.

Material and Methods

Plant Material

Commercially grown ‘Arkin’ carambolas were hand-harvested into plastic containers (containers held approximately 30 fruit) at one-quarter yellow, half yellow and three-quarter yellow color stages in Pine Island, FL, on the morning of December 7, 2006. The fruits were placed into the containers on their sides and stacked up to three layers deep. The grower was Brooks Tropicals. Harvested fruits were transported in the containers to the Postharvest Horticulture Laboratory at the University of Florida, Gainesville (approximately 418 km from Pine Island) by car the same day. The fruit were stored in the plastic containers at 10 ^{o}C overnight.

Preparation and Treatments

The next morning the carambola fruit were rinsed in 200 ppm chlorine solution and allowed to air dry on paper towels at room temperature (approximately 22 ^{o}C) under fans for no longer than 30 minutes.

Fruit were sorted by color stage as follows; one-quarter yellow, up to 25 % yellow; half yellow, 25% to 50 % yellow; three-quarter yellow, 75 % or more yellow with fin margins (tips) remain green. Green, orange, and over-ripe color stages were not used in this experiment.

Fruit were dipped into a container containing a commercial food grade wax (FMC Food Tech Sta-Fresh® 819F, 50:50 v/v) solution with deionized water, and allowed to air dry on metal racks until the wax was no longer sticky, at room temperature (approximately 22 ^{o}C).

The fruit were placed on plastic trays lined with paper towels and stored in temperature controlled rooms with 80 – 95 % RH. Fruit were either stored constantly at 20 ^{o}C or at 5 ^{o}C for 14 d then transferred to 20 ^{o}C, to simulate commercial storage and retail conditions.

Determination of Respiration Rate and Ethylene Production

Carambola fruit (n=4) were weighed and placed individually in 1900 mL plastic container with lids left unsealed to maintain normal atmosphere and stored at 20 ^{o}C. Prior to daily headspace sampling the plastic lids were sealed on each of the containers for 1 h. Then two, 1.0-mm samples (one for CO_2 and one for ethylene C_2H_4) were withdrawn from the headspace using a syringe inserted through a rubber septum. This was repeated daily until the fruit showed signs of decay

Carbon dioxide concentration was measured using a gas chromatograph (series 580; GOW MAC, Bridgewater, N.J.) fitted with a thermal conductivity detector (TCD) and a 1219 x 3.18 mm, 80/100 mesh Porapak Q column. The carrier gas (helium) flow rate was 30 ml min^{-1}. The detector and injector were operated under ambient conditions (26 to 27 C) and the oven was at 40 C.

Ethylene production rate was measured using a gas chromatograph (Tracor, series 540, Arlington, VA, USA) equipped with a photo ionization detector (PID). The column for the Tracor is stainless steel packed with alumina F1, 80/100 mesh and is 914 x 3.18 mm (length x dia.) made by Supelco. The carrier gas (helium) flow rate was 40 ml min-1. The detector and injector were operated at 100 ^{o}C and the oven was 50 ^{o}C.

Ripening and Marketability

Appearance was subjectively rated on individual fruit each 3rd d for each of the following disorders: fin-margin browning, stem-end shriveling, surface pitting / browning, and persistent green fins based on a 4 point scale (1 = No defect, 3= The limit of acceptability, 4 = Maximum damage) (Figure 3-1) (Table 3-1). Fruit were considered unmarketable when any of the subjective categories was rated a score of 4. Fruit were considered to be in the orange stage once the fruit were one-quarter orange; this is the peak ripeness (Figure 3-2). In this experiment, once fruit were considered to be at their peak ripeness (orange stage) or unmarketable the whole fruit was stored in plastic zip top bags at -20 ^{o}C until further analysis of soluble solids content, total titratable acidity, and pH. Mean (n=10) of fruit.

Compositional Analyses

In this experiment, fruit was stored at -20 ^{o}C until processed. The stem end and blossom ends of the fruit were discarded leaving the edible portion, approximately 80%, of the fruit which was diced while still frozen and blended in a commercial blender (Model 908, Hamilton Beach/Proctor-Silex, Washington, N.C., USA), centrifuged (Model J2-21, Beckman, Palo Alto, California, USA) at 15,000 rpm for 20 minutes at 5 ^{o}C, then the supernatant was filtered through 8 layers of cheesecloth.

Soluble Solids Content (SSC), Total Titratable Acidity (TTA) and pH

To determine the soluble solids content, one to two drops of the supernatant was placed on the prism of a digital refractometer (Model 10480, Reichert-Jung, Mark Abbe II Refractometer, Depew, NY) and SSC was reported as ^{o}Brix. To determine total titratable acidity and pH, 6 g of filtered supernatant was added to 50 mL of deionized H_2O, and then initial pH and titratable acidity were measured using an automated titrimiter (Model 719S Titrino, Metrohm, Herisau, Switzerland), standardized with pH 4.00 and 7.00 buffers. The endpoint was set to pH 8.2 and the base solution was 0.1 N NaOH. The total titratable acidity was calculated using the malic acid equivalent. The pH was determined from the same supernatant with a pH meter standardized with pH 4.0 and 7.0 buffers.

Statistical Analysis

The experiment was conducted using a randomized block design. Temperature was the blocking treatment. Statistical analysis was performed using the PC-SAS software package

(SAS-Institute, 2007). All data were subjected to analysis of variance and treatment means were compared using Duncan's Multiple Range Test ($P<0.05$).

Results

Respiration

The control fruit had similar respiration rates to the waxed treatment. Respiration rates of the unwaxed control carambola were approximately 20.4 mL $CO_2{}^{*}kg^{-1*}h^{-1}$ at 20 °C and the waxed carambola were about 18.7 mL $CO_2{}^{*}kg^{-1*}h^{-1}$. Since the rates were not statistically different, the rates were combined (Fig. 3-3). The fruit in both treatments required approximately 21 d to turn orange and then the fruit started to display signs of senescence and decay.

Ethylene Production

Ethylene production during carambola ripening at 20 °C became evident 14 d after harvest at the one-quarter yellow stage (Fig 3-4). Ethylene production was detectable once the fruit began to progress from the three-quarter yellow stage to the orange stage. Ethylene production became most apparent while the fruit were progressing into the over-ripe stage. The maximum recorded ethylene produced was 0.8 ul / $kg^{-1*}h^{-1}$. The amount of ethylene produced by waxed fruit was similar to the control. The amount of ethylene produced by waxed fruit did not always cross the detection threshold of the GC, therefore there were missing values for some replicates and a low standard error for the treatment.

Weight Loss

No interaction of harvest maturity, waxing, and temperature existed; therefore, the data were combined to determine the treatment effect of waxing on weight loss during storage at the two temperatures. Waxed fruit lost less weight than the unwaxed fruit at each storage temperature. Weight loss for waxed carambola was 2.4 and 3.7% for fruit stored at 5 and 20 °C respectively, for unwaxed fruit weight loss was 6.0 and 5.9% for fruit stored at 5 and 20 °C respectively (Table 3-2). The mean initial weight for all fruit used in this experiment was 182.7 g.

Appearance

Fruit harvested at the one-quarter yellow stage, waxed, and stored at 5 ^{o}C for 2 wk never reached the orange stage (Table 3-3). Instead, those fruit turned brown and had an unmarketable appearance (Figure 3-5). Fruit harvested at the one-quarter yellow stage, unwaxed and stored at 5 ^{o}C had a rating of 3 in each of the following categories: fin margin browning, surface scald/ pitting, and stem end shriveling once the fruit were in the orange stage. The persistent green fins were rated 1. Since these fruit took the longest to turn orange and their appearance was poor due to stem-end shriveling and fin-margin browning.

The ground color (color of the skin at the crux of two fins) of the waxed one-quarter yellow fruit, held at constantly at 20 ^{o}C, turned orange, the outer fins and stem end were persistently green until signs of senescence and decay were apparent, having a rating of 4.

Compositional Analyses

The pH of the fruit was lowest at the one-quarter yellow stage (4.09), higher in the half yellow fruit (4.19), and highest in the three-quarter yellow fruit (4.33) (Table 3-4). The sugar-to-acid ratio increased significantly with each harvest maturity. There were no differences between waxed and unwaxed fruit and there were no differences between fruit stored at 5 and 20 ^{o}C. Fruit harvested at the three-quarter yellow color stage had the highest soluble solids content (7.41 ^{o}Brix); half yellow fruit was slightly lower (7.04 ^{o}Brix). Fruit harvested at the one-quarter yellow stage, waxed, and stored at 5 ^{o}C never reached the orange stage, instead the fruit turned brown. Informal taste tests indicated that the waxed fruit were in an anaerobic state, which led to the formation of off flavors and fermented aromas.

Discussion

Respiration and Ethylene Production

The respiration rate of carambola was steady only showing a slight rise as the fruit turned from orange to over-ripe (Figure 3-3). These rates are typical of non-climacteric respiratory fruit, which is similar to the pattern reported by Lam and Wan (1987). Some of the fruit showed signs of decay in the over-ripe stage. Non-climacteric fruit increase their respiration rate when attacked by decay organisms or when exposed to exogenous ethylene. Biale and Shepherd (1941) showed that lemons increased their respiration rate immediately after being exposed to the 'vapors' (presumably aroma volatiles and ethylene) produced by the *Penicillium digitarum* fungus and increased their respiration rate 3 d after being inoculated with the fungus. This increase in respiration after inoculation was part of the stress response caused by a pathogen.

The ethylene production became most apparent when the fruit were progressing to the over-ripe stage, probably due to senescence and decay (Figure 3-4). Oslund and Davenport (1987) reported that microbial activity was responsible for the increase in ethylene production in the later stages. Decay organisms cause a stress response in fruit which leads to stress induced ethylene production which is associated with a rise in respiration rate and defense against the pathogen.

Weight Loss

Carambolas have a high surface to volume ratio because of their unique shape. The high surface to volume ratio leads to water loss through transpiration. Water can also be lost through the stem scar, and also through any places where the integrity of the epidermis has been compromised. High relative humidity in storage areas can limit this water loss to a degree (Ali et al., 2004). Edible waxes can create a physical barrier to retain water within the fruit. This barrier also limits respiration. Miller and McDonald (1993) found that 2 and 6 % carnauba based wax applied to carambola limits water loss without affecting total soluble solids, titratable acidity, pH, color, flavor, or sensory texture. Toxicity was not reported. Hagenmaier and Baker (1993) also showed that waxing prevents weight loss in citrus. In this experiment the waxing treatment limited weight loss significantly (Table 3-2).

Color and Flavor

Color and flavor (informal taste test) were affected by the waxing treatment in this experiment, but there were no effects on total soluble solids, titratable acidity, and pH (Table 3-4). Hagenmaier and Baker (1993) showed that carnauba and other types of wax coatings limited the passage of carbon dioxide out of the fruit and increased the internal carbon dioxide concentration. The waxing treatment in this experiment was likely too limiting and prevented gas exchange so much that the internal atmospheric composition of the fruit was anaerobic and led to the formation of off flavors (informal taste test) and a brownish appearance of internal tissue for some treated fruit. The brown internal color indicates dead tissue. The wax also limited gas diffusion in the fruit that was harvested at the 3/4 color stage so much that it slowed metabolic activity and prevented the fins from turning yellow. This parallels Hagenmaier (2001) who stated that mandarins treated with thick wax coatings had a less “fresh” and more “fermented” taste than fruit treated with thinner or more permeable wax.

Appearance

The appearance of the fruit was affected by wax treatment (Table 3-3). The fruit harvested at the one-quarter yellow stage, waxed, and stored at 5 ^{o}C had an unmarketable appearance after storage. Their internal tissue turned brown, likely due to the lack of oxygen to the inner tissues of the fruit (Figure 3-5). Fruit waxed and held at 20 ^{o}C had a limited metabolism due to the treatment; this prevented the outer margin of the fin from turning yellow and led to the persistent green problem. In some commercial cases an appropriate waxing treatment might be beneficial, particularly the treatment described by Miller and McDonald (1993), because the fruit could potentially be subjected to lower relative humidity storage. Lower relative humidity storage conditions for carambola led to stem-end shriveling and surface pitting.

Conclusions

The waxing treatment in this experiment was too limiting for necessary gas diffusion. It limited respiration so much that off-flavors formed, normal ripening was inhibited, and internal tissue died. Fruit harvested at the 1/4 yellow stage, treated with wax, and stored at 5 ^{o}C showed signs of chilling injury likely because the waxing treatment prevented the fruit from ripening normally. There may be potential for some waxes on carambola, especially since weight loss was significantly reduced; however, this treatment did not aid in maintaining the overall postharvest quality.

Figure 3-1. Appearance defects of ‘Arkin’ carambola. Upper left: fin margin browning; Upper right: stem-end shriveling; Lower left; surface pitting/ browning; Lower right; persistent green fins.

Green (Immature) One-quarter Yellow One-half Yellow

Three-quarter Yellow One-quarter Orange Over-ripe

Figure 3-2. Carambola maturity stages.

Table 3-1. List of carambola appearance categories and subjective rating definition (3 = the limit of acceptability, 4 = unacceptable).

Appearance Categories	Rating Definition 1	2	3	4
Fin-Margin Browning	No browning	Some browning visible on fins, less than 25%	Browning visible on fins, 25% to 50%	Browning on majority of fins, more than 50%
Stem-End Shriveling	No shriveling	Some shriveling on stem end, less than 25%	Shriveling present over most of the stem end, 25% to 50 %	Shriveling present over most of the stem end, more than 50%, also brown spots visible
Surface Pitting/Browning	No pitting/browning	Some pitting or browning visible, less than 5%, all spots smaller than 1 cm	Pitting or browning present, 5% to 20%, all spots smaller than 1 cm	Pitting/browning present on more than 20%, or spots larger than 1 cm
Persistent Green Fins	No green on fin margins	Very slight green on fin margins, less than 0.5 cm	Slight green on fin margins, From 0.5 to 1 cm	Green on fin margins prominent on more than 1 cm, or at stem and blossom ends

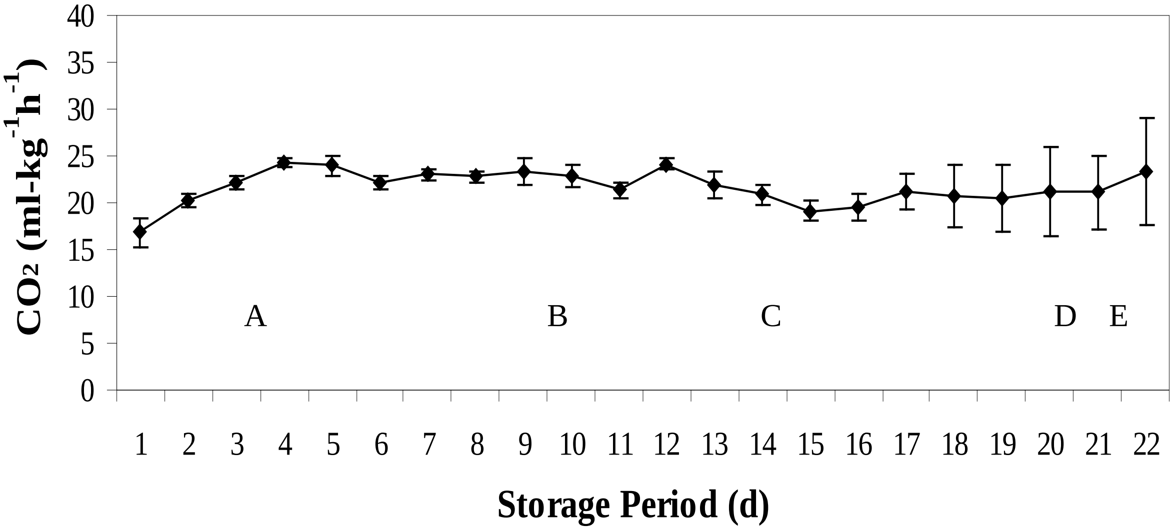

Figure 3-3. Combined respiration rates of unwaxed and waxed 'Arkin' carambola during ripening at 20 °C, harvested at 1/4 yellow stage (n=8). A, 1/4 yellow stage; B, 1/2 stage; C, 3/4 Yellow stage; D, 1/4 orange stage; E, over-ripe stage (senescence and decay present).

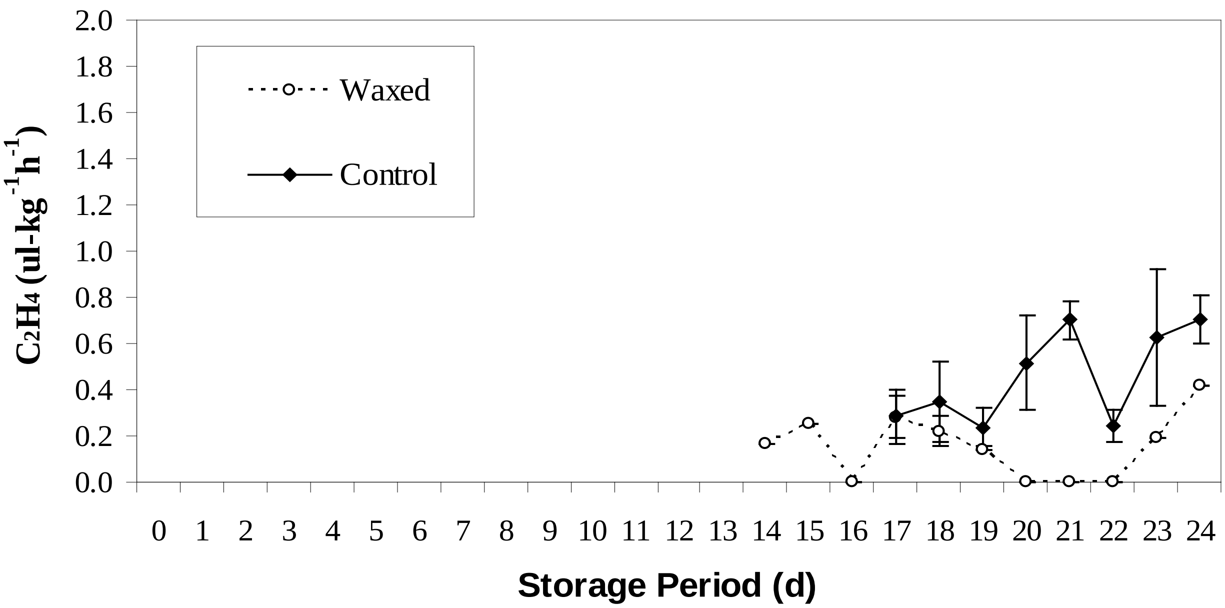

Figure 3-4. Ethylene production rates of waxed and control 'Arkin' carambola harvested at 1/4 yellow during ripening at 20 °C (n = 4)

Table 3-2. Weight loss for 'Akin' carambola after storage.

Weight Loss[z]	Treatment	Weight Loss (%)
5°C	Unwaxed	6.04 a
	Waxed	2.43 b
20°C	Unwaxed	5.87 a
	Waxed	3.65 b

[z]Within each treatment (n = 12 fruit/treatment) values followed by different letters between ripeness stages are significantly different at the P<0.05, according to Duncan's Multiple Range Test.

Figure 3-5. Internal browning of 'Arkin' carambola harvested at one-quarter yellow, waxed, and stored at 5 °C for 14 d. Left: cross section of a fruit with circles added to indicate areas of internal tissue browning, Right: cross section of a normally developed fruit with no internal tissue browning.

Table 3-3. Subjective appearance ratings for ‘Arkin’ carambola at the orange stage harvested at different maturities and stored at different temperatures (n= 4)

			Appearance Category			
Storage Temperature (^{o}C)	Treatment	Harvest Maturity	Fin-Margin Browning	Stem-End Shriveling	Surface Pitting/ Browning	Persistent Green Fins
5	Unwaxed	1/4 Yellow	3[Z]	3	3	1
		1/2 Yellow	3	3	2	1
		3/4 Yellow	3	3	2	1
	Waxed	1/4 Yellow	[Y]	[Y]	[Y]	[Y]
		1/2 Yellow	[Y]	[Y]	[Y]	[Y]
		3/4 Yellow	2	2	3	3
20	Unwaxed	1/4 Yellow	2	2	1	1
		1/2 Yellow	2	2	1	1
		3/4 Yellow	2	2	1	1
	Waxed	1/4 Yellow	2	2	3	4
		1/2 Yellow	2	1	1	3
		3/4 Yellow	2	1	1	3

[Z]Based on Table 3-1. 1=little or none, 2=slight, 3=moderate, 4=severe
[Y] Fruit never reached the orange stage, instead the turned brown or showed signs of decay.

Table 3-4. Selected compositional quality parameters for ‘Arkin’ carambola harvested at three ripeness stages, analyzed at full-ripe stage.

Compositional Parameter[X]	(1/4 yellow)	1/2 Yellow	3/4 Yellow
SSC (^{o}Brix)[Y]	6.06 b	7.04 ab	7.41 a
TTA (%)	0.28 a	0.28 a	0.25 a
pH	4.09 c	4.19 b	4.33 a
SSC/TTA ratio	22.1 c	25.9 b	29.9 a

[X]Within each treatment row (n = 4 fruit/treatment) values followed by different letters between ripeness stages are significantly different at the $P<0.05$, according to Duncan’s Multiple Range Test.
[Y]SSC = Soluble Solids Content; TTA = Total Titratable Acidity (malic acid equivalent).

CHAPTER 4
EFFECTS OF HARVEST MATURITY ON THE EDIBLE QUALITY AND AROMA PROFILE OF 'ARKIN' CARAMBOLA

Introduction

Carambola accumulate sugar only while on the tree, getting progressively sweeter as the color changes from green to yellow and then orange. The sugar/ acid ratio is significantly higher at each color stage only while on the tree (Narain, 2001). The fruits in the yellow and orange stages are particularly susceptible to damage and are considered too fragile to pack and ship (Oslund and Davenport, 1983). Carambola fruit also soften postharvest. The color stage is associated with changes in cell wall constituents. Cellulose accumulates in the intercellular space while hemicellulosic materials and pectins decrease gradually beginning at the 1/4 yellow stage (Mitcham and McDonald, 1991: Chin et al., 1999).

Carambolas have a unique aroma volatile profile contributing to a sweet floral flavor. Using a capillary gas chromatograph/mass spectrometer combination (GC/MS), 41 aroma volatiles were identified in carambola (Wilson et al., 1985). For 'B10' carambola grown in Malaysia and exported to Europe 178 components were detected and identified by GC and GC-MS methods. The main volatile components of the Malaysian fruit were esters. More recently 53 volatile compounds were found to contribute to the unique flavor of carambola fruit using headspace solid phase micro extraction (SPME) and solvent extraction, (GC/MS), and gas chromatography-olfactometry (GC-O). Methyl benzoate (musty, minty, floral, and sweet) and ethyl benzoate (tropical sulfur-like floral) are two of the major compounds in concentration and aroma activity (Mahattanatawee et al., 2005). There are also some compounds that contribute to an overripe or unpleasant sulfur taste such as: 1-pentanol (over-ripe apricot/banana), benzothiazole (sulfur/rubber), and quinoline (putrid/fishy) (Mahattanatawee et al., 2005; Wilson et al., 1985). Other major constituents were esters, aldehydes, alcohols, ketones, and some norisoprenoid compounds (Mahattanatawee et al., 2005; Herderich et al., 1997).

There are a few possible explanations for the discrepancies in the number of volatile constituents reported in carambola. Testing methods most likely cause the major differences in the number and types of volatiles identified, and some research focuses on only the volatiles that are in high enough quantity for humans to perceive. Varietal type is another possible reason for the differences in the volatiles reported. More importantly, the carambolas have probably been studied while in different ripeness stages. As indicated by Herderich et al., C_{13}-Norisoprenoid flavor precursors were identified in carambola. These compounds are by-products of carotenoid degradation. Carotenoids in carambola are produced throughout ripening, but in large amounts while nearing the over-ripe stage (Herderich et al., 1997).

The objective of this experiment was to investigate the compositional parameters and volatile profile of 'Arkin' carambola when harvested at five different harvest maturities, ranging from 1/4 yellow to over-ripe.

Material and Methods

Plant Material

'Arkin' Carambola were hand-harvested into plastic containers at 1/4 yellow, 1/2 yellow, 3/4 yellow, orange, and over-ripe stages in Pine Island, FL. The fruit were placed on their side in the container up to three layers deep. The commercial grower was Brooks Tropicals. Harvested fruit were transported in plastic containers to the Postharvest Horticulture Laboratory at the University of Florida, Gainesville by car the same day. The fruit were stored in their plastic containers at 10 ^{o}C overnight.

The following day fruit were prepared for compositional analysis.

Preparation for Compositional Analyses

Compositional analysis for SSC, TTA, pH, and all statistical analysis were done on frozen tissue (n = 4). Fruits were prepared by cutting the stem and blossom end off and the edible portion of the fruit was stored in zip top plastic freezer bags at -20 ^{o}C until preparation for soluble solids content, total titratable acidity, pH, total sugars, and volatile analysis.

Firmness

A 10-mm thick slice of fruit was taken from the equator of the fruit with a sharp, stainless steel knife, and the slice was immediately placed on a stationary steel plate. Internal firmness of the fruit was evaluated using an Instron Universal Testing Instrument (Model 4411, Canton, MA, USA) equipped with a convex-tip probe (8.0 mm diameter) and 5-kg load cell using a crosshead speed of 50 mm*mm^{1}. Maximum force through 7 mm deformation of a 10-mm cross-section slice of fruit was recorded in Newtons (N) and there were two measurements per fruit slice, at the midpoint of the locule, avoiding seeds or points with an abundance of vascular tissue.

Total Sugars Content assay

Total soluble sugars were measured in tissue that was stored at -20 ^{o}C using the phenol-sulfuric method described by Dubois el al (1956). In this experiment, the stem end and blossom end of the fruit were discarded leaving the middle 80% of the fruit, which was diced and blended in a commercial blender (Model 908, Hamilton Beach/Proctor-Silex, Washington, N.C., USA), centrifuged (Model J2-21, Beckman, Palo Alto, California, USA) at 15,000 rpm for 20 minutes at 5 ^{o}C, then the supernatant was filtered through eight layers of cheesecloth. Fifteen uL of the supernatant was diluted into 10 mL of cold 80% ethanol and stored at 5^{o}C overnight to precipitate ethanol-insoluble materials.

To prepare samples for measurement of total soluble sugars, in a test tube: 0.5 mL of 5% phenol (w/w) was added to 0.5 mL of the sampled mentioned above, the mixture was vortexed

(Model 128101, Mini Vortexer, Fisher Scientific, Pittsburgh, PA, USA), then 2.5 mL concentrated sulfuric acid was added and the mixture vortexed again. The test tubes were let to stand for 15 min until the mixture was at or near room temperature. 100 uL of each mixture was pipetted into a well on a 96-well plate. The total soluble sugars were measured by reading the absorbance at 490 nm using a universal microplate reader (Model EL 800, Bio-Tek Instruments Inc., Winooski, VT, USA) the absorbance values were compared to a standard curve of glucose solutions at concentrations of: 40, 80, 120, 160, and 200 ug*L^{-1}. The absorbance of the standards was graphed in Excel (Microsoft Corporation, 2003) and a linear trend line was drawn. The absorbance values for the samples were put into the equation for the trend line and a value was given.

Volatiles

Frozen fruit was diced and then blended in a commercial blender (Model 908, Hamilton Beach/Proctor-Silex, Washington, N.C., USA). An equal weight of blended fruit and saturated NaCl solution (30% NaCl w/w) were homogenized using a polytron (Model FGLH, PowerGen 700, Fisher Scientific, Pittsburgh, PA, USA) on the highest setting. A 5-g aliquot of the homogenate was placed into a 10 mL glass vile, which was capped with a silicone septa cap, frozen and stored at -80 ^{o}C. The samples were transported on dry ice to the U.S.D.A. Citrus and Subtropical Products Laboratory in Winter Haven, FL. Ten uL of 3-hexanone was added to the sample to total 100 ppm as an internal standard, as well as an injection of d6-phenol to total 1 ppm. The samples were stored at -80 ^{o}C for later analysis.

The samples were analyzed following the methods of Mahattanatawee et al., 2005. The vial was placed in a water bath of 40 ^{o}C for 15 min, then a SPME fiber (50/30 um DVB/Carboxen/PDMS on a 2-cm StableFlex fiber, (Supelco, Bellefonte, Pa.)) was inserted into the headspace of the sample vial and exposed for 45 min. The fiber was then thermally desorbed in the GC injector port for 5 min at 250 ^{o}C. Separation and identification of aroma volatiles was accomplished using an Agilent 6890 GC equipped with a 30 m x 0.25mm x 0.25 um HP-5 column, and coupled with a 5973N MS detector (Agilent, Palo Alto, Calif.). The column oven was programmed to maintain 50 ^{o}C for 5 min, and then increased 4 ^{o}C/min until reaching 250 ^{o}C and then holding for 15 min. Helium was the carrier at a flow rate of 2 mL*min^{-1}. Injector and ionizing source were maintained at 250 ^{o}C and 280 ^{o}C respectively. The split ratio was 1:1 with a 0.2 uL sample injection. The splitless mode was used when samples were introduced by SPME. Data were collected using the ChemStation G1701 AA data system (Hewlett-Packard, Palo Alto, Calif., USA). The peak areas were matched within treatments using the retention times, then averaged and reported as tentative identifications based on the Kovats index, which was calculated from GC/MS runs devoted to Kovats runs. The relative area for each volatile was calculated by dividing the absolute value of the peak area of the volatile sample by the area of the D6-phenol internal standard within the sample. The relative area percentage was used to calculate the concentration of the volatile within the headspace of the vial. This percentage was converted to concentration by multiplying the percentage by 1 ppm to give the value in ppb. Total volatiles were calculated by adding the relative concentrations of volatiles reported, minus the concentrations of 3-pentanone and D6-phenol.

This experiment revealed 27 volatiles. Mahattanatawee et al., (2005) showed 53 volatiles, and there were 41 and 178 volatiles found in Wilson et al. (1985) and MacLeod and Ames (1990), respectively. The difference in the number of volatiles was likely due to the method of quantifying the volatiles for this experiment. If all four samples in a particular harvest maturity did not show the presence of a certain volatile then that volatile was not placed on the list.

Results

Firmness

The firmness of carambola decreased with each ripeness stage (Fig. 4-1). The firmness of carambola fruit ranged from 30.5 N at the 1/4 yellow stage to 14.0 N at the over-ripe stage. Fruit at the 1/2 yellow stage was 16.0 N, which was 14.8 % lower than firmness at the 1/4 yellow stage. The firmness of the fruit in the 3/4 yellow stage was 20.1 N, which was 34.1 % lower than fruit at the 1/4 yellow stage. Fruit firmness also decreased significantly in the orange stage (15.8 N).

Compositional Parameters

To test whether harvest maturity affects the flavor of ‘Arkin’ carambola, the values of soluble solids content (SSC), total titratable acidity (TTA) and pH were measured in fruit harvested at five stages of maturity (Table 4-1).

SSC of fruit in the 1/2 yellow stage was significantly higher than fruit at the 1/4 yellow stage (1/4 yellow). SSC of ‘Arkin’ carambola ranged from 5.8 to 7.2 ^{o}Brix. Fruit in the orange stage was significantly higher than fruit in the 1/2 yellow stage.

Total titratable acidity (TTA) of ‘Arkin’ carambola ranged from 0.174 to 0.365. Fruit had different TTA depending on the maturity at harvesting. Fruit harvested in the 1/4 yellow stage had the highest TTA (0.365) and fruit harvested at the over-ripe stage had the lowest TTA (0.174).

The pH of ‘Arkin’ carambola ranged from 3.8 (1/4 yellow) to 4.2 (over-ripe). The fruit had a different pH depending on the harvest maturity. Sugar-to-acid ratio is an important indicator of sweetness. This ratio was influenced by the harvest maturity. The ratio ranged from 15.9 to 41.4. The fruit with the lowest ratio was the 1/4 yellow, while the over-ripe fruit had the highest ratio but flavor was poor due to off aromas.

Total Sugars

The total sugars in ‘Arkin’ carambola ranged from 3.33 (1/4 yellow) to 4.50 (over-ripe) (Table 4-2). Total sugars significantly increased by each ripeness stage, except between 1/4 orange and over-ripe.

Volatiles

Twenty-seven volatiles were present in most of the samples analyzed. Two internal standards were added for quantification purposes (Table 4-3). There were many more volatiles identified in some of the fruit sampled, but these were not included because they were not found in the majority of the fruit. All of the values represent the averages of four replicates; each replicate was tissue from one individual fruit.

Acetic acid was the only volatile acid commonly found in the fruit samples. It was found in all of the fruit harvested in the over-ripe stage. The descriptors for acetic acid are pungent stinging and sour.

Ethanol was the only alcohol to be found exclusively in the over-ripe fruit, which indicates anaerobic respiration and confirms that fruits that are completely orange are over-ripe. 1-pentanol was detected only in fruit harvested at the 1/2 yellow color stage. Mahattanatawee et al. (2005) reported that 1-pentanol has an unpleasant sulfur aroma. 1-octanol and 1-nonanol were found in all samples of each of the harvest maturities. The descriptors for 1-octanol are: soapy, chemical, metal and burnt. The descriptors for 1-nonanol are oily, floral, and powerful.

There were several aldehydes that were present in greater abundance in the earlier harvested fruit. Pentanal had a concentration of 401 ppb in fruit from the 1/4 yellow stage, but the concentration drops to 99 ppb in the 1/2 yellow fruit, then 71 ppb (3/4 yellow), 54 ppb (1/4 orange), and not detected in the over-ripe stage. Hexanal and 2-hexenal follow a similar trend. Furfural is only identified in the 1/4 yellow and 1/2 yellow fruit. Nonanal is the only aldehyde that does not follow the trend of the others; it has a concentration at least 16 times higher in the over-ripe stage than any other stage.

Aromatic benzene derivatives were also not mentioned in the literature as being important aroma contributors to carambola. Benzenecarboxylic acid, which falls into the two classes of acids and aromatic benzene derivatives, follows the same trend as acetic acid. Benzenecarboxylic acid only appeared in the fruit harvested in the over-ripe stage.

Ethyl butyrate was only found in the over-ripe fruit. Ethyl ether was found in fruit harvested at all maturities. Ether analogs with sulfur are very strong compounds that give the aroma of: sulfur, mold, cabbage, and gasoline (Rouseff, 2008; Acree, 2008). Dimethyl sulfide, an ether analog with sulfur, was found in all stages except the 1/4 yellow and over-ripe.

Generally the ketones were less abundant in the fruit harvested at the later color stages. Megastigma-4,6(E)(8) Z-triene was only present in the orange and over-ripe stages. Beta ionone was not present in the 1/4 yellow stage or the 3/4 yellow stages.

Discussion

Firmness

The firmness of the fruit decreased significantly with ripening except for the change from 1/4 orange to over-ripe (Figure 4-1). Informal tasting indicated that the texture of the fruits becomes less ‘crisp’ and more watery with every progression. The data from this experiment confirms results of Mitcham and McDonald (1991) that showed a decrease firmness of carambola fruit in progressing maturities. They also reported that firmness decreased postharvest as the fruit were ripening. The decrease in firmness is reportedly due to changes in the cell wall composition. As cellulose increases, hemicellulose and pectins decrease (Chin et al., 1999). Oslund and Davenport (1983) reported that the fruit in the yellow stage are too fragile to withstand the stresses of harvest, packing, and shipping. Fruits are handled and moved several times; first they are harvested into containers in the field, and then they are transported to a packinghouse where they are sorted and hand packed into cardboard boxes for shipping.

Compositional Analysis

Carambola fruits increase sugar only while they are on the tree. The total soluble solids of the fruit increased during ripening on the tree (Table 4-1). The fruits in the 1/2 yellow stage had significantly higher total soluble solids content than the fruit in the 1/4 yellow stage. This parallels the statement made by Narain (2001) that sugar-to-acid ratio increases with each color stage (^{o}brix to titratable acidity ratio ranged from 6.13 to 30.05). The pH increased slightly and the TTA decreased significantly with ripening. The total titratable acidity decreased significantly while pH slightly increased in fruit that were harvested at the earlier stages and stored (Campbell et al., 1987: Siller-Cepeda et al., 2004). It may be possible that as the fruit accumulate sugar on the tree they also accumulate water, which in turn dilutes the acid. The sugar-to-acid ratio is significantly higher at each stage, indicating that the fruit have a sweeter flavor when left on the tree past the 1/4 yellow stage.

Total Sugars

The total sugars assay is a more accurate measurement of the sugars within the fruit tissue than soluble solids content. By diluting in cold ethanol, the larger pectins are removed from solution leaving sugars and some smaller pectins. The sugar value reported by the U.S.D.A. is 3.98 g of sugar per 100 g of carambola (U.S.D.A., 2008). The data from this experiment suggests that the fruit material used by the U.S.D.A was harvested in the 1/4 orange to over-ripe stage, or fruit from another cultivar was used. In a commercial setting it would be impracticable to harvest fruit from the 1/4 orange or over-ripe stages.

These data, as well as the data from the compositional analysis, indicates that carambola are more pleasant to eat when harvested in the 1/2 yellow color stage than the 1/4 yellow color stage (Table 4-2) because of the higher sugar-to-acid ratio. Harvesting at a later color stage may pose some problems such as: reduced yield due to fewer harvests, a decrease in the visual quality due to increased time on the tree and susceptibility to wind scarring, and a shorter shelf-life because the fruit are closer to the 1/4 orange stage when they are harvested.

Volatiles

Alkanes were not mentioned as being an important aroma class in carambola; however, they do follow a similar trend to the aldehydes by decreasing in concentration as the maturity stage progresses. Even though the alkanes are not reported as an important class of contributing compounds to the aroma volatile profile of carambola they may indicate the by-products of certain physiological processes and be indicators of flavor (Table 4-3).

Esters are an important aroma class contributing to the unique profile of carambola (Mahattanatawee et al., 2005). The two esters that were found in the samples slightly increased in concentration as the fruit progressed from the first maturity to the last. Ketones are an important class of volatiles contributing to the profile of carambola (Mahattanatawee et al., 2005; Herderich et al., 1997). The ketones generally decreased in concentration from the first maturity to the last.

Norisoprenoids are associated with carotene break down. Their presence indicated that the fruit were beginning to senesce (Herderich et al., 1997). Even though the norisoprenoids do not have unpleasant aromas themselves, their presence indicated the formation of off aromas.

Conclusions

'Arkin' carambola had a higher sugar-to-acid ratio when harvested in the 1/2 yellow color stage than when harvested in the 1/4 yellow stage. 'Arkin' carambola is popular because of its sweetness and should be harvested later than the 1/4 yellow stage to exploit its natural sweetness. The firmness data showed a decrease from the 1/4 yellow stage to the 1/2 yellow stage, but there may be postharvest treatments that will maintain firmness. The fruit that were harvested when completely orange were attractive; however, these fruit had high amounts of ethanol and other volatiles that indicate an over-ripe flavor. Therefore, fruit should be consumed once they start to show some orange color and before they reach the completely orange stage.

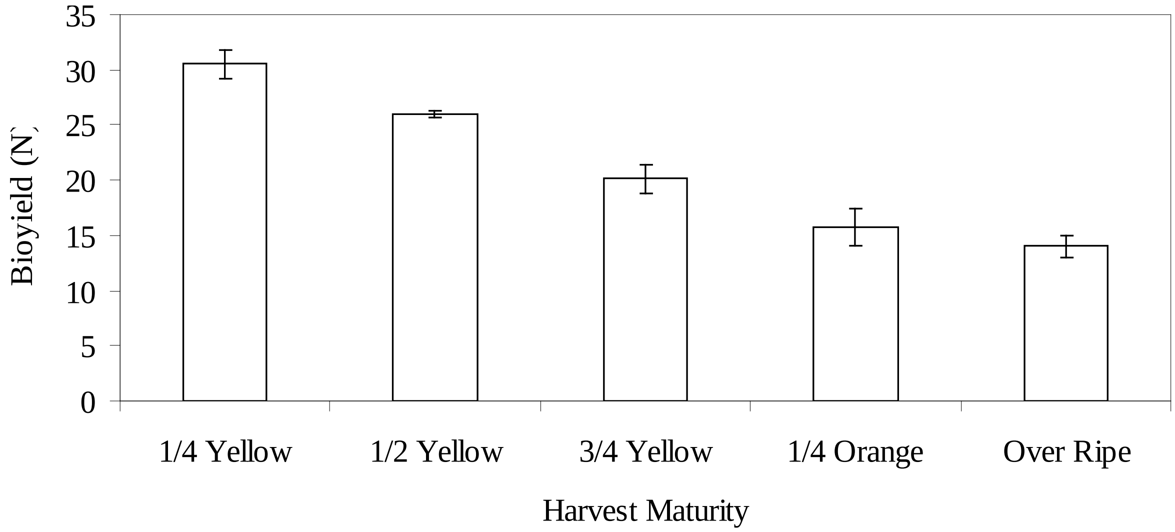

Figure 4-1. Firmness (maximum force through 7 mm of 10 mm fruit cross-section) of ‘Arkin’ carambola harvested at five maturities (n = 6).

Table 4-1. Initial compositional parameters of ‘Arkin’ carambola harvested at five maturities.

	Harvest Maturity				
Compositional Parameter	1/4 Yellow	1/2 Yellow	3/4 Yellow	1/4 Orange	Over-ripe
SSC [Z]	5.8 c [Y]	6.2 b	6.5 ab	7.2 a	7.2 a
TTA	0.365 a	0.305 b	0.272 c	0.202 d	0.174 e
pH	3.8 b	3.9 ab	3.9 ab	3.9 ab	4.2 ab
SSC/TTA ratio	15.9 e	20.3 d	23.9 c	35.6 b	41.4 a

[Z] SSC = Soluble Solids Content; TTA = Total Titratable Acidity (malic acid equivalent).
[Y] Mean (n=4) rows with different letters are significantly different at P< 0.05, according to Duncan’s Multiple Range Test.

Table 4-2. Total sugars of ‘Arkin’ carambola harvested at three maturities.

	Harvest Maturity				
	1/4 Yellow	1/2 Yellow	3/4 Yellow	1/4 Orange	Over-ripe
Total Sugars (%)	3.33 d[Z]	3.57 c	3.81 b	4.36 a	4.50 a

[Z] Mean (n=4) rows with different letters are significantly different at P< 0.05, according to Duncan’s Multiple Range Test.

Table 4-3. Volatile profiles of 'Arkin' carambola harvested at five maturities.

Volatile[Z]	RI[Y]	Aroma Descriptors (Rouseff)	Aroma Descriptors (Acree)	Harvest Maturity ¼ Yellow	½ Yellow	¾ Yellow	¼ Orange	Over-ripe
Acids								
Acetic acid	595	pungent, stinging, sour	sour	n.d.[X]	n.d.	n.d.	n.d.	14.9
Alcohols								
Ethanol	491		sweet	n.d.	n.d.	n.d.	n.d.	6.6
1-Pentanol	763	green, grassy, powerful	fruit	n.d.	5.9	n.d.	n.d.	n.d.
1-Octanol	1071	soapy	chemical, metal, burnt	25.4	21.9	19.5	30.3	18.3
1-Nonanol	1167	oily, floral, powerful		27.5	34.4	26.3	31.3	29.1
Aldehydes								
Pentanal	687		almond, malt, pungent	40.1	9.9	7.1	5.4	n.d.
Hexanal	801	fatty, green, grassy, powerful	grass, tallow, fat	48.7	11.6	14.2	18.7	8.5
Nonanal	1108	piney, floral, citrus	fat, citrus, green	40.8	20.6	21.0	68.2	1108.2
2-Hexenal	860	green, banana-like	fat, rancid	398.9	111.4	192.0	207.9	41.0
Furfural	838	pungent, sweet, bread-like	bread, almond, sweet	83.3	6.8	n.d.	n.d.	n.d.
Alkanes								
Nonane	906		alkane	50.9	n.d.	n.d.	n.d.	n.d.
Decane	1006		alkane	n.d.	13.0	4.3	n.d.	n.d.
Undecane	1101		alkane	52.1	13.6	6.2	n.d.	n.d.
Dodecane	1196		alkane	34.5	12.0	7.5	4.6	5.8
Tridecane	1292		alkane	22.1	6.3	n.d.	n.d.	n.d.
Tetradecane	1393		alkane	16.8	4.6	n.d.	n.d.	n.d.
Aromatic Benzene Derivatives								
Benzenecarboxylic acid	1150			n.d.	n.d.	n.d.	n.d.	6.8
D6-Phenol[W]	978		phenol	100.0	100.0	100.0	100.0	100.0
Benzaldehyde	981	cherry, candy	almond, burnt sugar	11.5	6.5	n.d.	5.9	n.d.
Esters								
Ethyl butyrate	797		apple	n.d.	n.d.	n.d.	n.d.	48.0
Ethyl ether	516			7.1	12.5	14.6	9.1	19.9
Ether Analogs with Sulfur								
Dimethyl sulfide	529	sulful, moldy, cabbage-like	cabbage, sulfur, gasoline	n.d.	3.6	4.8	4.7	n.d.

Table 4-3. Continued

		Aroma Descriptors (Rouseff)	Aroma Descriptors (Acree)	Harvest Maturity				
				¼ Yellow	½ Yellow	¾ Yellow	¼ Orange	Over-ripe
Ketones								
Acetone	510	light, ethereal, nauseating		6.0	n.d.	2.7	n.d.	n.d.
3-Pentanone[W]	684		ether, fruit	40.1	22.4	22.5	17.3	14.9
2-Methyl-3-Pentanone	745			8.9	4.7	4.5	n.d.	n.d.
4-Hexen-3-one	837			83.3	6.8	n.d.	n.d.	n.d.
4-Heptanone	877			122.4	67.6	60.8	50.3	41.0
Norisoprenoids								
Megastigma-4,6(E)(8)Z-triene	1370			n.d.	n.d.	n.d.	20.7	31.1
Beta Ionone	1498	dried fruit, woody, violet-like	seaweed, violet, flower, raspberry	n.d.	40.9	n.d.	28.2	12.2
Total Acids				0.0	0.0	0.0	0.0	14.9
Total Alcohols				52.9	62.2	45.8	61.6	54.0
Total Aldehydes				611.8	160.3	234.3	300.2	1157.7
Total Alkanes				176.8	47.5	18.0	4.6	5.8
Total Aromatic Benzene Derivatives				11.5	6.5	0.0	5.9	6.8
Total Esters				7.1	12.5	14.6	9.1	67.9
Total Ether Analogs with Sulfur				0.0	3.6	4.8	4.7	0.0
Total Ketones				260.7	101.5	90.5	67.6	55.9
Total Norisoprenoids				0.0	40.9	0.0	48.9	43.3
Total Volatiles				1220.3	536.7	508.0	602.7	1506.4

[Z]Within each treatment (n = 1 fruit/rep, 3 reps averaged), value represents area of curve as a percentage of the area of the internal standard (D6-phenol).
[Y]Concentration (ppb) based on headspace of 10-ml vial containing 5 g of homogenate.
[X]Listed volatiles are significant contributors to the aroma profile of carambola found in initial samples. Volatiles have been tentatively identified using Kovats Retention Index (RI).
[W]Internal standard added to tentatively quantify peak areas. Only D6-phenol was used in calculating relative areas.
[V]n.d. = not detected in all replicates of the same treatment.

CHAPTER 5
EFFECT OF POSTHARVEST EXOGENOUES ETHYLENE ON THE EDIBLE QUALITIES AND AROMA PROFILE OF ‘ARKIN’ CARAMBOLA

Introduction

Carambola displays a respiration pattern and ethylene production rates of a typical non-climacteric fruit (Chapter 3). System 1 ethylene production is a basal rate of ethylene production. Ethylene production is also initiated by stress or injury. Ethylene is produced in low amounts (less than 1.0 $ul*kg^{-1}h^{-1}$). Exogenous ethylene applied to non-climacteric fruit or vegetative tissue down-regulates (auto-inhibits) ethylene production but up-regulates respiration (Burg and Burg, 1965). It also initiates chlorophyll degradation by chlorophyllase activity. Chlorophyllase is an enzyme involved in the process of degrading chlorophyll. Exogenous ethylene treatments lead to a decrease in chlorophyll a and b in non-climacteric fruit (Amir-Shapira et al., 1987). For citrus, a non-climacteric fruit, ethylene is used commercially to enhance the external color of fruit postharvest. Ethylene stimulates chlorophyll degradation and causes degreening. Sargent and Brecht (1990) showed that color of carambola was enhanced in light green fruits by 2 d storage at 20 ^{o}C and 100 ppm ethylene. When the fruit at light green stage was gassed for 1 d the degreening was incomplete, and when gassed for 3 d the incidence of decay was significantly increased. There was no noticeable effect on soluble solids content or titratable acidity due to ethylene treatments (1990). Miller and McDonald found that exogenous ethylene increased carambola peel scald, stem end breakdown, fin browning, and enhanced mold growth (1997).

The objective of this experiment was to evaluate the effect of three different concentrations of ethylene treatment on the postharvest quality of ‘Arkin’ carambola harvested at 1/4, 1/2, and 3/4 yellow stages.

Material and Methods

Plant Material

'Arkin' carambola were hand-harvested into plastic containers at 1/4 yellow, 1/2 yellow, and 3/4 yellow color stages in Pine Island, FL on the morning of August 6th, 2007. The fruit were placed on their side in the container up to three layers deep. The commercial grower was Brooks Tropicals. Harvested fruits were transported in their plastic containers to the Postharvest Horticulture Laboratory at the University of Florida, Gainesville by car the same day. The fruit were stored in their plastic containers at 10 ^{o}C overnight.

Washing, respiration, ethylene measurements, and compositional analysis for SSC, TTA, pH, and appearance, and all statistical analyses were done as described in Chapter 3. Volatile analysis was done according to the methods described in chapter 4.

Ethylene Treatment and Storage Regime

Carambola fruit were stored in 175-L sealed containers on plastic trays lined with paper towels with flow-through air containing 25, 50, or 100 ppm ethylene for 48 h at 20 ^{o}C, 90% RH (n=4). The mixed gasses were humidified by bubbling through a jar with water in it before entering the chamber. The fruit were treated at 20 ^{o}C for 2 d, then transferred to 5 ^{o}C for 14 d (the low temperature limit) and then transferred to 20 ^{o}C and held until each fruit reached the orange stage (peak ripeness).

Days to Orange

Ripening of carambola was determined objectively using a hand-held colorimeter (CR-400 Chroma Meter, Konica Minolta Sensing, Inc., Japan). One-quarter orange stage (peak ripeness) was determined by having a positive "a" value. The fruit were subjectively rated using Table 3-1 outlined in chapter 3.

Firmness

In this experiment, a 10 mm thick slice of fruit was taken from the equator of the fruit with a sharp, stainless steel knife, and immediately placed on a stationary steel plate. Internal firmness of the fruit was evaluated using an Instron Universal Testing Instrument (Model 4411, Canton, MA, USA) equipped with a convex-tip probe (3.3 mm diameter) and 5-kg load cell using a crosshead speed of 50 mm*mm^{1}. Maximum force at 7 mm deformation was recorded in Newtons (N) and there were 2 measurements per fruit slice, at the midpoint of the fin, avoiding seeds.

Volatiles

Volatiles were analyzed according to the methods described in Chapter 4.

Results

Days to Orange Stage

Time required for fruit to reach the orange stage ranged from an average of 10.9 days (3/4 yellow fruit) to 20.8 days (1/4 yellow fruit) (Table 5-1). The fruit harvested at 3/4 yellow required the least amount of time to reach the orange stage (12.5), regardless of ethylene concentration treatment. The fruit harvested at the 1/4 and 1/2 yellow stages took approximately the same amount of time to reach the orange stage (20.1).

Appearance

Fruit treated with 100 ppm ethylene generally had more ratings of damage than those of fruit treated with 50 or 25 ppm ethylene for stem end shriveling and fin margin browning, regardless of harvest stage (Table 5-2). The appearance of the fruit treated with 100 ppm ethylene for 48 h at 20 ^{o}C was poor; fin margin browning was exacerbated by the treatment. The 100 ppm treatment had a degreening effect but did not enhance the overall appearance. Surface pitting/ browning was not affected by ethylene concentration. The ethylene treatments in this experiment did not induce the appearance of fruit harvested at different maturities to develop more uniform color.

Weight Loss

Fruit harvested at the 1/4 yellow stage lost the most weight (average 3.7%), followed by fruit harvested at 1/2 yellow (average 2.6 %), and 3/4 yellow (average 1.0%) (Table 5-3). Weight loss was not affected by the concentration of ethylene.

Firmness

There were no clear trends in the firmness data that showed effects from harvest maturity, waxing, or storage temperature (data not shown). The probe and probing location were not suitable to accurately gauge the firmness of the fruit. The probe was a 3.3 mm convex tip and the testing location was between vascular areas, which led to all fruits giving readings of the same firmness. In the next chapter, a larger probe tip (8.0 mm) was used and the testing location moved to the middle of the cross section of the fin.

Compositional Analysis

The soluble solids content (SSC) of fruit at the 1/2 yellow stage was slightly higher than fruit in the 1/4 yellow stage (1/4 yellow) (Table 5-4). SSC of 'Arkin' carambola ranged from 6.2 to 8.0 ^{o}Brix. Fruit in the 3/4 yellow stage was significantly higher than fruit in the 1/4 yellow stage. SSC of the fruit was not affected by ethylene concentration.

Total titratable acidity (TTA) of 'Arkin' carambola ranged from 0.23 to 0.26. TTA of the fruit was not affected by ethylene or harvest maturity. The pH of 'Arkin' carambola ranged from 4.17 (quarter yellow) to 4.35 (3/4 yellow). The fruit had a slightly different pH depending on the harvest maturity. The sugar-to-acid ratio was influenced by the harvest maturity but not the ethylene treatment concentration. The ratio ranged from 24.3 to 34.0. The fruit with the lowest ratio was the quarter yellow; the 3/4 ripe fruit had the highest ratio.

Volatiles

Acetic acid was found only in fruit harvested at the quarter yellow stage (Table 5-5). The flavor descriptors for acetic acid are: pungent, stinging, and sour (Acree, 2008; Rouseff, 2008). Ethanol was mostly found in fruit harvested at the quarter yellow stage, but there was a small amount found in fruit harvested at 1/2 yellow and treated with 25 ppm ethylene.

Mahattanatawee et al. found that aldehydes are an important class of aroma volatiles for carambola (2005). Pentanal, hexanal, nonanal, and 2-hexenal were found in all of the samples in this experiment. Nonanal was found in great abundance in the all of the fruit, but higher in fruit treated with 100 ppm ethylene in both harvest maturities. The aroma descriptors for nonanal are: piney, floral, citrus, fat, and green (Acree, 2008; Rouseff, 2008).

The aromatic benzene derivative, benzaldehyde, was only found in fruit harvested at the quarter yellow stage treated with 50 or 100 ppm ethylene. The aroma descriptors for benzaldehyde are: cherry, candy, almond, and burnt sugar (Acree, 2008; Rouseff, 2008).

Esters were found to be an important class of volatiles that contribute to carambola flavor (Mahattanatawee et al., 2005; MacLeod and Ames, 1990). Ethyl butyrate was found in higher amounts in the fruit harvested at the quarter yellow stage. Ethyl butyrate has an aroma descriptor of apple (Rouseff, 2008).

Mahattanatawee found ketones to be an important contributing class of volatiles for carambola (2005). 3-Pentanone was used as an internal standard and co-eluted with peaks in the same class of volatiles naturally found in carambola. This masked the presence on the chromatogram of natural ketones that may have been present in the fruit; however, 4-heptanone was identified and found to be in higher concentrations in fruit harvested at the 1/2 yellow color stage.

Megastigma-4,6(E)(8)Z-triene was found in most of the samples but were higher in the fruit harvested at 1/2 yellow stage. The norisoprenoid compounds are important because they are associated with carotene degradation and are likely associated with off flavors and aromas. Beta ionone, another norisoprenoid, was only found in fruit harvested at the 1/2 yellow stage. Beta ionone is also associated with carotene degradation.

Discussion

Days to Orange

The 1/4 orange stage is the peak ripeness of 'Arkin' carambola, once the fruit is completely orange the flavor is affected by off-aromas. In this experiment, there was no treatment effect for days to orange; however, the fruit treated with the highest ethylene concentration degreened faster. The harvest maturity dictated the days required for the fruit to turn orange (Table 5-1). Even though the statistics indicated little difference between harvest maturities and days to orange, there is significance when considering the feasibility of shipping the fruit and displaying them in a retail situation. Even though the Duncan grouping assigned similar letters to many of the averages, there are other factors affected by the time required to reach the orange stage. More weight is lost in fruit that are stored for a longer period of time. Fruit treated with 100 ppm had a higher incidence of fin margin browning. The formation of off aromas also takes place during longer storage periods. For the next experiment days to orange will consider all of the replicate fruits within a treatment rather than each fruit.

Appearance

The degreening of the fruit treated with 100 ppm ethylene most likely was caused by an increase in chlorophyllase activity (Table 5-1). The ethylene treatments led to a decrease in chlorophyll a and b. When ethylene is applied to citrus, an increase in chlorophyllase activity is observed. Chlorophyllase is an enzyme involved in the process of degrading chlorophyll, which causes to degreening. Also, an increase in chlorophyllide a activity was observed by Amir-Shapira when ethylene was applied (1987).

Sargent and Brecht (1990) showed that color was enhanced by 2 d storage at 20 ^{o}C and 100 ppm ethylene for fruit harvested at light green. In this experiment, fruit appearance was negatively affected by the same treatment before storage; however, the 100 ppm ethylene treatment was the only concentration that had a degreening effect on the fruit. The appearance of the fruit was not homogeneous after being treated with ethylene. Fruit harvested at the 1/4 yellow stage was still greener than fruit harvested at the 1/2 and 3/4 yellow stages.

Weight Loss

The only factor affecting weight loss was harvest maturity (Table 5-2). This was likely due to the greener fruit taking longer to reach the orange stage. The greener the fruit at harvest, the longer it took to reach the 1/4 orange stage; therefore, fruit harvested at greener stages lost the most weight during the longer storage. This trend is similar to a previous report that showed weight loss of carambola was increased by long term storage at 5 and 10 ^{o}C (Campbell et al., 1989).

Compositional Analysis

The range of SSC of the fruit in this experiment (6.23 to 8.00 ^{o}Brix) (Table 5-3) is higher than the range reported in Chapter 3 (6.06 to 7.41 ^{o}Brix) (Table 4-1). This is likely because the fruit in this experiment were grown during summer months with longer days, which allowed the fruit to accumulate more soluble solids. In contrast, the fruit used in Chapter 3 were grown during the winter and were subjected to shorter days and a lower angle of the sun.

The titratable acidity of the fruit was not affected by the ethylene treatment or the harvest maturity. This was likely due to a similar storage time for all fruit. Campbell et al. (1987) and Siller-Cepeda et al. (2004) both reported that acidity decreased with storage time.

The fruit had a slightly different pH depending on the harvest maturity. Sugar-to-acid ratio is an important indicator of sweetness in carambola. This ratio was influenced by the harvest maturity but not the ethylene treatment concentration. The fruit with the lowest ratio was the quarter yellow; the three quarter ripe fruit had the highest ratio. This reflects the statement made by Narain (2001) that the sugar-to-acid ratio increases with each color stage.

Volatiles

Ethanol was mostly found in fruit harvested at the quarter yellow stage, but there was a small amount found in fruit harvested at 1/2 yellow and treated with 25 ppm ethylene. The formation of ethanol was likely due to a longer storage time.

Nonanal was likely a by-product of increased respiration due to the high ethylene concentration treatment. In the previous experiment (chapter 4), the samples that had an abundance of nonanal were in the over-ripe stage. Nonanal is associated with an over-ripe and off flavor.

Norisoprenoids indicate the physiological changes that occur when fruit reach their peak ripeness and increase in concentration while the fruit begin to become over-ripe. Norisoprenoid compounds were reported as important aroma contributors by Mahattanatawee et al. (2005) and Herderich et al.(1992).

Ethyl butyrate was found in higher amounts in the fruit harvested at the 1/4 yellow stage. Ethyl butyrate has an aroma descriptor of apple (Rouseff, 2008). The scent of the fruit in the green stage had a strong green apple aroma (Informal observation).

Conclusions

When exposed to 100 ppm ethylene for 48 h at 20 ^{o}C the epidermis of carambola was noticeably degreened but surface pitting/ browning of the fruit was increased. The ethylene treatment had no affect on the compositional parameters of the fruit. The ethylene treatments increased the total volatiles and more of them were associated with over-ripe and off flavors. The ethylene treatments did not enhance ripening enough to promote a uniform color for fruits harvested at different color stages.

Table 5-1. Average days required for fruit to turn orange after harvest at three maturities, treated with ethylene and stored at 20 ^{o}C.

Harvest Maturity	Ethylene Concentration (ppm)	Days to Orange [Z]
1/4 Yellow	25	20.8 ± 0.42 a
	50	20.8 ± 0.42 ab
	100	20.7 ± 0.48 ab
1/2 Yellow	25	19.7 ± 0.67 ab
	50	19.2 ± 0.92 abc
	100	19.3 ± 0.82 bc
3/4 Yellow	25	10.9 ± 4.43 d
	50	13.8 ± 4.87 cd
	100	12.7 ± 5.06 d

[Z] Mean (n = 10) followed by standard deviation. Different letters are significantly different at P<0.05, according to Duncan's Multiple Range Test.

Table 5-2. Appearance ratings for 'Arkin' carambola fruit treated with ethylene once reaching the orange stage.

Ethylene Concentration (ppm)	Harvest Maturity	Appearance Categories		
		Fin Margin Browning	Stem End Shriveling	Surface Pitting/ Browning
100	1/4 Yellow	4	2	2
100	1/2Yellow	4	3	3
100	3/4 Yellow	2	2	3
50	1/4 Yellow	2	2	2
50	1/2Yellow	3	3	3
50	3/4 Yellow	2	1	3
25	1/4 Yellow	3	1	1
25	1/2Yellow	3	3	2
25	3/4 Yellow	1	1	3

Based on Table 3-1. 1=little or none, 2=slight, 3=moderate, 4=severe

Table 5-3. Weight loss (expressed as % of original weight) for fruit upon reaching the orange stage.

	Ethylene Concentration		
Harvest Maturity	25 ppm	50 ppm	100 ppm
1/4 Yellow	4.0 a[Z]	3.5 a	3.7 a
1/2 Yellow	2.8 b	2.2 b	2.8 b
3/4 Yellow	0.7 c	1.0 c	1.4 c

[Z]Within each treatment (n = 10 fruit/treatment) values followed by different letters between ethylene concentrations are significantly different at the P<0.05, according to Duncan's Multiple Range Test.

Table 5-4. Selected compositional quality parameters for 'Arkin' carambola harvested at three color stages, treated with ethylene, and analyzed at full-ripe stage

Compositional Parameter[z]	1/4 Yellow	1/2 Yellow	3/4 Yellow
SSC (^{o}Brix)[y]	6.23 b	6.82 ab	8.00 a
TTA (%)	0.26 a	0.23 a	0.23 a
pH	4.17 b	4.18 b	4.35 a
SSC/TTA ratio	24.3 c	29.3 b	34.0 a

[Z]Within each row (n = 6 fruit/treatment) values followed by different letters between ripeness stages are significantly different at the P<0.05, according to Duncan's Multiple Range Test.

[y]SSC = Soluble Solids Content; TTA = Total Titratable Acidity (malic acid equivalent).

Table 5-5. Headspace aroma volatiles (relative areas) for 'Arkin' Carambola harvested at 1/4 and1/2 yellow, in relationship with ethylene treatment and harvest maturity, analyzed at full-ripe stage.

		1/4 yellow			1/2 Yellow		
		Ethylene Concentration (ppm)					
Volatile[ZY]	RI	25	50	100	25	50	100
Acids							
Acetic acid	595	68.2	48.2	50.8	n.d.[X]	n.d.	n.d.
Alcohols							
Ethanol	491	17.3	13.8	13.5	3.8	n.d.	n.d.
1-Octanol	1071	9.2	7.9	9.3	11.5	11.7	11.2
1-Nonanol	1167	8	n.d.	8.5	8.6	8	8.5
Aldehydes							
Pentanal	687	24.3	30	20.5	22.3	23.6	196.3
Hexanal	801	93	125.8	85.3	74.8	70.3	151.9
Nonanal	1108	1604.7	1337.5	2443.1	1058.9	1079.8	1243.9
2-Hexenal	860	15.6	15.2	21.2	35.3	21.6	21.4
Alkanes							
Nonane	906	7.3	14.4	10.6	n.d.	n.d.	n.d.
Decane	1006	8.4	n.d.	12	n.d.	n.d.	9.3
Dodecane	1196	n.d.	n.d.	n.d.	n.d.	n.d.	7.2
Tridecane	1292	n.d.	n.d.	n.d.	7.5	n.d.	n.d.
Tetradecane	1393	10	8.9	14.4	7.4	8.3	8.7
Aromatic Benzene Derivatives							
D6-Phenol [X]	978	100	100	100	100	100	100
Benzaldehyde	981	n.d.	14.1	18.2	n.d.	n.d.	n.d.
Toluene	771	12.6	n.d.	5.2	8.9	n.d.	13.2
Esters							
Ethyl butyrate	797	51.6	25.3	52.7	21.7	20.7	n.d.
2-Ethyl-2-Butenal	798	93	125.8	n.d.	n.d.	n.d.	n.d.
Ethyl ether	516	19.3	30.5	9.8	13.7	17.4	16.9
Ketones							
3-Pentanone	684	17.9	30	18.5	22.3	21.3	17.6
4-Heptanone	877	33.7	34.8	39	48.4	43.2	37.4
Norisoprenoids							
Megastigma-4,6(E)(8)Z-triene	1370	14.8	n.d.	8.7	20	12.2	17.7
Beta Ionone	1498	n.d.	n.d.	n.d.	9.4	11.6	9.9

Table 5-5 Continued

Total Acids	68.2	48.2	50.8	0.0	0.0	0.0
Total Alcohols	34.5	21.7	31.3	23.9	19.7	19.7
Total Aldehydes	1737.6	1508.5	2570.1	1191.3	1195.3	1613.5
Total Alkanes	25.7	23.3	37.0	14.9	8.3	25.2
Total Aromatic Benzene Derivatives	12.6	14.1	23.4	8.9	0.0	13.2
Total Esters	163.9	181.6	62.5	35.4	38.1	16.9
Total Ketones	33.7	34.8	39.0	48.4	43.2	37.4
Total Norisoprenoids	14.8	0.0	8.7	29.4	23.8	27.6
Total Volatiles	2091.1	1832.4	2822.8	1352.1	1328.4	1753.5

[Z] Total Volatiles calculated as the absolute value of the sum of all volatiles minus the areas of the internal standards; n.d. – not detected, the peaks not integrated into all reps in the sample selection.

[Y]Listed volatiles are significant contributors to the aroma profile of carambola found in initial samples. Volatiles have been tentatively identified using Kovats Retention Index.

[X]Within each treatment (n = 3 fruit/rep, 2 reps averaged), value represents area of curve as a percentage of the area of the internal standard (D6-phenol).

CHAPTER 6
INFLUENCE OF AQUEOUS 1-METHYLCYCLOPOPENE APPLICATION TO ‘ARKIN’ CARAMBOLA FRUIT FIRMNESS AND VOLATILE PROFILE

Introduction

Mechanical injury and stress caused an increase in respiration and decreased the shelf life of fruits. Mechanical injury and stress trigger an ethylene response. Stress induced ethylene production auto-inhibits (down-regulates) ethylene production and up-regulates respiration. 1-methylcyclopropene (1-MCP) is an ethylene antagonist. 1-MCP works by out-competing ethylene and binding to ethylene receptor sites. By doing this, 1-MCP prevents the increase in respiration that is caused by ethylene exposure (Sisler et al., 1996). 1-MCP can maintain the firmness of climacteric and non-climacteric fruits when applied postharvest (Jiang et al., 2004; Bregoli et al., 2005; Martinez-Romero, 2003).

A previous report showed that ‘Fwang Tung’ carambola treated with a 24-h treatment of gaseous 1-MCP maintained color. The experiment also showed that 1-MCP decreased fruit respiration and but did not extend the number of days till the fruit were ripe (Teixeira and Durigan, 2006). 1-MCP is also effective when used as an aqueous dip. An aqueous application does not require as much exposure time as a gaseous application, there is also no need for an airtight container or room (Choi and Huber, 2008).

Two experiments are reported in this chapter. The objective of the first experiment was to determine the effect of a postharvest aqueous 1-MCP treatment (200 ug of 1-MCP a.i. (active ingredient) L^{-1}) on selected parameters of carambola fruit quality. Based on the results of the first experiment, the objective of the second experiment was to determine the effectiveness of aqueous 1-MCP treatments at lower concentrations (50, 100, and 200 ug of 1-MCP a.i*L^{-1}).

Material and Methods

Plant Material

'Arkin' carambolas were hand-harvested into plastic containers at 1/4 yellow, 1/2 yellow and 3/4 yellow color stages in Pine Island, FL on the morning of February 5th, 2008 (for the first experiment) and August 28th, 2008 (for the second experiment). The fruit were placed on their side in the container up to three layers deep. The commercial grower was Brooks Tropicals (Homestead, Fla.). Harvested fruits were transported in their plastic containers by car the same day to the Postharvest Horticulture Laboratory at the University of Florida, Gainesville. The fruit were stored in the containers at 10 ^{o}C overnight.

The following morning, fruits were sorted based on color stage, washed and randomized into respective treatments; fruit were segregated for respiration measurements and initial firmness.

Treatment with Aqueous 1-MCP

Fruit were submerged in aqueous 200 ug*L^{-1} 1-methylcyclopropene (1-MCP) for 1 min. The solution was prepared from formulation AFxRD-300 (2% active ingredient, AgroFresh, Inc., Rohm and Haas, Philadelphia, PA). The solution was prepared with 200 ug of 1-MCP a.i. (active ingredient) L^{-1}. The powder was suspended in 10 L of water in a plastic bucket and stirred lightly. The solution was used within 30 min after preparation. Treated fruit were wiped dry with a paper towel and placed onto plastic trays lined with paper towels.

Storage

Fruits were stored on plastic trays lined with paper towels at 5 or 20 ^{o}C. Relative humidity was maintained (85% to 95% RH) by covering the fruit with thin plastic sheets. Fruit were considered to be at the peak ripeness when they were 1/4 orange (Figure 3-2). Orange was defined as having a positive a-value on a handheld colorimeter. Once fruits were at peak ripeness stage they were subjected to destructive analyses.

Quality Analyses

Fruit were rated subjectively based on Table 3-1. Preparation for compositional analysis for soluble solids content (SSC), total titratable acidity (TTA) and pH were done according to the methods described in the Material and Methods section of chapter 2.

Firmness

In this experiment, a 10-mm thick slice of fruit was taken from the equator of the fruit with a sharp, stainless steel knife, and then the slice was immediately placed on a stationary steel plate. Internal firmness of the fruit was evaluated using an Instron Universal Testing Instrument (Model 4411, Canton, MA, USA) equipped with a convex-tip probe (8.0 mm diameter) and 5-kg load cell using a crosshead speed of 50 $mm*mm^1$. There were two measurements per fruit slice, at the midpoint of the locule, avoiding seeds or points with an abundance of vascular tissue, and maximum boiyield through 7 mm deformation of a 10-mm cross section was recorded in Newtons (N).

Volatile Analysis

Volatiles were measured according to the methods described in Chapter 3.

Statistical Analyses

Statistical analyses were performed according to procedures outlined in Chapter 2.

Results: Experiment 1

Respiration

The respiration rate of carambola harvested at the 1/4 yellow stage and stored at 20 ^oC was suppressed by the 1-MCP treatment for 9 days (Figure 6-1). Respiration for these fruit ranged from 20.3 to 28.2 ml CO_2 $kg^{-1}h^{-1}$ for controls and from 15.7 to 23.9 ml CO_2 $kg^{-1}h^{-1}$ for 1-MCP treated fruit during 9 d of storage.

Respiration was not significantly suppressed by 1-MCP treatment for fruit harvested at 1/2 yellow and 3/4 yellow when stored at 20 ^{o}C, for any number of days. Therefore, data were presented only for Day 3 of storage that shows overlapping standard error bars for fruit harvested at the 1/2 and 3/4 yellow stages (Figure 6-2).

Days to Peak Ripeness and Weight Loss

For fruits stored at 5, 10, and 20 ^{o}C, 1-MCP extended days to 1/4 orange only for fruit harvested at 1/4 yellow and 1/2 yellow. The fruit harvested at 3/4 yellow and treated with 1-MCP reached the 1/4 orange stage in the same length of time as the untreated controls; 9 d after transfer from 5 ^{o}C, 3 d after transfer from 10 ^{o}C, and 7 d when stored at 20 ^{o}C constantly. All fruit within a treatment were considered orange on the day when the majority of the fruit showed 1/4 orange.

Weight loss ranged from 2.25 to 4.20 % of initial weight in fruits stored at 5 ^{o}C, 1.19 to 3.91 % at 10 ^{o}C, and 1.19 to 2.71 % at 20 ^{o}C (Table 6-1). For the fruit stored at 5 ^{o}C, and treated with 1-MCP had higher weight loss, while for fruits stored at 10 and 20 ^{o}C, 1-MCP treated fruit had similar weight loss to the controls.

Appearance Ratings

The 1-MCP-treated fruit had better appearance as indicated by lower incidences of fin browning, stem-end shriveling, and surface pitting/ browning (Table 6-2). However, for treated fruit, at the 1/4 orange stage fin margins were persistently green.

Firmness

Fruit treated with 1-MCP remained firmer than the controls, irrespective of harvest maturity or storage temperature (Table 6-3). Upon reaching 1/4 orange stage, fruit firmness ranged from 5.6 to 9.7 N for the untreated fruit, and from 9.1 to 16.4 N for 1-MCP treated fruit. Because the analysis for firmness was done using a destructive method, the initial values were collected 1 d after harvest.

Compositional Analysis

There were no treatment effects on the compositional parameters of the fruit (Table 6-4). The soluble solids content of the fruit ranged from 6.40 to 7.12 ^{o}Brix. The fruit harvested at the 1/4 yellow stage had the lowest soluble solids content (6.40 ^{o}Brix), the fruit harvested at 1/2 yellow and 3/4 yellow stages had higher soluble solids content (7.08 and 7.12 ^{o}Brix, respectively). The total titratable acidity (TTA) ranged from 0.271 to 0.307. Fruit harvested at the 1/4 yellow stage had the highest titratable acidity content (0.307), fruit harvested at the 1/2 yellow stage had lower total titratable acidity (0.271), the fruit harvested at the 3/4 yellow stage had a total titratable acidity of 0.229. The sugar-to-acid ratio ranged from 20.85 to 31.09 and increased significantly as harvest maturity increased.

Volatiles

Initial volatiles were measured in the harvest maturity experiment of Chapter 4 (Table 4-3). For this experiment, fruit were analyzed upon reaching the peak ripeness stage (1/4 orange). For the fruit stored at 5 ^{o}C, 1-pentanol was found only in the control fruit harvested at 1/2 yellow (Table 6-5). 1-pentanol was found in all of the treated and control fruit that were stored at 20 ^{o}C. 1-octanol was found in all of the samples except the fruit treated with 1-MCP and stored at 20 ^{o}C. Beta ionone was the only norisoprenoid compound found in the samples from this experiment and was only found in fruit that were stored at 20 ^{o}C.

The fruit harvested at 1/4 yellow, treated with 1-MCP, and stored at 5 ^{o}C had an abnormally high amount of nonanal (623% higher than the next highest amount reported). Data showed that 1-MCP treatment suppressed total volatiles for fruit harvested at 1/2 yellow and stored at 5 ^{o}C by 40%. The data also showed that 1-MCP suppressed total volatiles produced by all fruit stored at 20 ^{o}C, for fruit harvested at the 1/2 yellow stage total volatiles were suppressed by 28%. Apart from the outlier of the 1/4 yellow fruit treated with 1-MCP and stored at 5 ^{o}C, there is a clear trend that 1-MCP suppressed total volatile production, regardless of harvest maturity or temperature. Excluding the outlier of nonanal, the fruit stored at 20 ^{o}C had higher total volatiles than the fruit stored at 5 ^{o}C. Fruit harvested at 1/2 yellow, not treated, and stored at 5 ^{o}C had volatile production suppressed by 42% compared to fruit harvested at the same color stage and stored at 20 ^{o}C.

Discussion: Experiment 1

Respiration

Respiration was suppressed by the 1-MCP treatment (Figures 6-1and 6-2). The respiration rate of the fruit harvested at the 1/4 yellow stage was reduced by 15 to 23%. This was more than the fruit harvested at the 1/2 yellow and 3/4 yellow stages, which did not show significant reductions in respiration from the 1-MCP treatment. These results are in agreement with the experiments with 1-MCP and carambola fruit by Teixeira and Durigan (2006) with ‘Fwang Tung’ treated with gaseous 1-MCP.

Days to Peak Ripeness and Weight Loss

Weight loss was not directly affected by the 1-MCP treatment but fruit treated with 1-MCP lost more weight that the untreated controls (Table 6-1). This was due to the fruit requiring more time to reach the 1/4 orange stage. The longer the storage time more weight was lost by the fruit. Wills and Ku (2002) reported that 1-MCP delayed ripening and increased shelf life of tomatoes and that weight loss was not affected. The results of Teixeira and Durigan (2006), showed that 1-MCP did not significantly delay ripening in fruit harvested at the 1/2 yellow stage.

Appearance Ratings

The 1-MCP helped to maintain the chlorophyll in the present experiment in the fruit that were treated had a greener appearance and persistently green fins. Persistently green fins were more evident in fruit that were harvested at 1/4 yellow.1-MCP decreased the activity of chlorophyllase and peroxidase, causing green color maintenance of broccoli florets (Gong and Mattheis, 2003). Color maintenance was also reported in avocado epidermis (Choi et al., 2008), tomatoes (Choi and Huber, 2008 Wills and Ku, 2002), and ‘Fwang Tung’ carambola (Teixeira and Durigan, 2006).

Firmness

The firmness of carambola was significantly maintained by the 1-MCP treatment (Table 6-2). The initial firmness of the fruit decreased with the harvest maturity as also reported by Chin et al. (1999) for carambola fruit, due to changes in cell wall composition as the hemicellulose and pectins decreases and cellulose increases. These results confirm the results reported previously that 1-MCP can maintain the firmness of climacteric and non-climacteric fruits when applied postharvest (Jiang et al., 2004; Bregoli et al., 2005; Martinez-Romero, 2003).

Compositional Analysis

Compositional parameters tested were not significantly affected by 1-MCP treatment (Table 6-3). The firmness and sugar-to-acid results indicate that if fruit were harvested in the 1/2 yellow color stage and treated with 1-MCP then the fruit would taste significantly sweeter and have a crisper texture.

Volatiles

Ripening carambola at 20 ^{o}C did not hinder synthesis or aroma volatiles. To isolate the effect of 1-MCP on the volatile profile of carambola, the best example is the fruit held at 20 ^{o}C (Table 6-5). Total volatiles were suppressed by the 1-MCP treatment. This parallels data reported by Porat et al. (1999), who also reported an increase in off-flavor formation. Total volatiles were suppressed by the 1-MCP treatment because the 1-MCP slowed physiological functions, such as color development, which produce volatiles.

Results: Experiment 2

Based on the results from the first experiment using 1-MCP, a second experiment was designed to examine the effects of 1-MCP at a lower range of concentrations. 1-MCP treatment at 200 ug of 1-MCP a.i.*L^{-1} maintained firmness, but suppressed volatile production and caused the fruit to keep the green appearance of their fins. Aqueous solutions of 1-MCP were prepared as above at concentrations of 50, 100, and 200 ug of 1-MCP a.i.*L^{-1}.

Respiration

The respiration rates of 1-MCP treated fruit were similar to controls (Figure 6-3). Respiration was not significantly suppressed by 1-MCP treatment for fruit harvested at 1/2 yellow and 3/4 yellow when stored at 20 ^{o}C. Respiration of fruit harvested at the 1/2 yellow stage ranged from 20.79 to 31.50 ml CO_2 $kg^{-1}h^{-1}$ for fruit during 6 d of storage.

Days to Peak Ripeness and Weight Loss

For fruit harvested at 1/4 yellow and 1/2 yellow, treated with the highest concentration of 1-MCP (200 ug*L^{-1}), the time at 5 ^{o}C days required to reach 1/4 orange were extended by 2 d. Fruit harvested at 3/4 yellow and treated with 1-MCP took the same amount of time to reach the 1/4 orange stage as the controls. The lower concentrations of 1-MCP (50 and 100 ug*L^{-1}) had no effect on days to 1/4 orange for fruit stored at 5 ^{o}C.

For fruits stored at 20 ^{o}C, the highest concentration of 1-MCP (200 ug*L^{-1}) extended days to 1/4 orange by 3 and 4 d for fruit harvested 1/4 yellow stage and 1/2 yellow stage, respectively. 1-MCP treatments at the lower concentrations (50 and 100 ug*L^{-1}) extended the days to 1/4 orange by 3 d only for fruit harvested at the 1/4 yellow stage.

Weight loss ranged from 1.99 to 5.79% in fruit stored at 5 ^{o}C (Table 6-6). Weight loss ranged from 2.43 to 7.88% in fruit stored at 20 ^{o}C. Generally fruit harvested at the 1/4 quarter yellow stage lost more weight (5.98%) than the fruit harvested in the 1/2 yellow stage (4.50%), and fruit harvested in the 3/4 yellow stage lost the least amount of weight (2.75%).

Appearance Ratings

Fruit harvested at the 1/4 and 1/2 yellow stages and stored at 5 ^{o}C were unmarketable due to high incidence of fin margin browning and stem-end shriveling (Table 6-7). These fruit also had high incidence of surface pitting/ browning. Fruit treated with 100 and 200 ug*L^{-1}1-MCP and stored at 20 ^{o}C had persistently green fins rated as 2 and 3 respectively.

Firmness

Initial fruit firmness decreased sharply with each harvest maturity (Table 6-8). Fruit harvested at the 1/4 yellow stage had the highest initial firmness (26.0 N), fruit harvested at the 1/2 yellow stage were less firm (20.1 N), and fruit harvested at the 3/4 yellow stage were the softest (14.0 N). The firmness of the fruit decreased with the storage period; however, fruit treated with the highest concentration of 1-MCP (200 ug*L^{-1}) maintained firmness significantly over the controls for all harvest maturities when stored at 5 ^{o}C. Firmness of the fruit that were stored ranged from 7.3 to 16.2 N. The 200 ug*L^{-1} 1-MCP treatment helped to maintain firmness over controls for fruit harvested at the 1/4 yellow stage and stored at 20 ^{o}C. Firmness decreased slightly for fruit harvested at 3/4 yellow.

Compositional Analysis

There were no treatment effects on the compositional parameters (Table 6-9). The soluble solids content ranged from 6.64 to 7.74 ^{o}Brix. The soluble solids content increased significantly between fruit harvested at each color stage. The total titratable acidity ranged from 0.224 to 0.242. The sugar-to-acid ratio increased significantly between fruit harvested at the 1/4 yellow stage and the fruit harvested at the 3/4 yellow stage, but not between the fruit harvested at the 1/4 yellow stage and 1/2 yellow stage or between 1/2 yellow stage and 3/4 yellow stage.

Discussion: Experiment 2

Respiration

Respiration rates were not suppressed by 1-MCP treatment in fruit harvested at the 1/2 yellow stage (Figure 6-3). This confirms data from experiment 1. For the treated fruit the higher respiration rates may have been caused by the fruits being damaged by a tropical storm nine days before harvest leading to an increase in respiration due to stress. Lee (2005) reported increased respiration in cucumbers subjected to impact stress.

Days to Peak Ripeness and Weight Loss

Weight loss was affected by the harvest maturity (Table 6-6). Fruit harvested at the 1/4 yellow stage took longer to reach the 1/4 orange stage, the longer storage time led to an increase in weight loss. These results are similar to the findings of Teixeira and Durigan (2006), who reported that 1-MCP did not significantly delay ripening (time required to reach ripe stage) in fruit harvested at the 1/2 yellow stage. In the present experiment, the highest concentration of 1-MCP treatment did significantly delay days to 1/4 orange, but only for fruit harvested in the 1/4 and 1/2 yellow stages. Days to orange for fruit harvested in the 3/4 yellow stage was not affected by 1-MCP treatments. This is probably due to the fruit being very close to reaching the 1/4 orange stage prior to the 1-MCP treatment; therefore, the 1-MCP application was not early enough to delay the onset of the 1/4 orange stage.

Appearance Ratings

Fruit harvested at the 1/4 and 1/2 yellow stages and stored at 5 ^{o}C were unmarketable due to a high incidence of fin margin browning and stem-end shriveling (Table 6-7). This was due to damage caused by a tropical storm nine days before harvest, the low temperature storage likely exacerbated the browning and shriveling. In this experiment fruit that were treated with the highest 1-MCP concentration had a greener appearance and also persistently green fins. Fruit treated with the lower concentrations of 1-MCP (50 and 100 ug*L^{-1}) had a less green appearance. A previous report showed that 1-MCP suppressed chlorophyllase and peroxidase enzymes in broccoli florets (Gong and Mattheis, 2003).

Firmness

The highest concentration of 1-MCP treatment was the most effective treatment for maintaining firmness, except for fruit harvested at the 3/4 yellow stage and stored at 20 ^{o}C (Table 6-8). This was likely because the fruit already started ripening toward the 1/4 orange stage. Lower concentrations of 1-MCP (50 and 100 ug*L^{-1}) had a minimal effect on firmness. The firmness of fruit decreased with harvest maturity as also reported by Chin et al. (1999), due to changes in cell wall composition as the hemicellulose decreased and pectins increased. The highest concentration of 1-MCP likely saturated the ethylene receptor sites while the lower concentrations did not. These results confirm the results reported previously that 1-MCP can maintain the firmness of climacteric and non-climacteric fruits when applied postharvest (Jiang et al., 2004; Bregoli et al., 2005; Martinez-Romero, 2003).

Compositional Analysis

Titratable acidity was not affected by 1-MCP treatment (Table 6-9). This was likely due to a similar storage time for the fruits. Campbell et al. (1987) and Siller-Cepeda et al. (2004) both reported that acidity decreased with storage time. The fruit had a slightly different pH depending on the harvest maturity. Sugar-to-acid ratio is an important indicator of sweetness. This ratio was not significantly influenced by the harvest maturities between 1/4 yellow and 1/2 yellow, nor between 1/2 yellow and 3/4 yellow. The fruit with the lowest ratio was the 1/4 yellow; the 3/4 yellow fruit had the highest ratio. This reflects the statement made by Narain (2001) that sugar-to-acid ratio increases with each color stage.

Conclusions

The 1-methylcyclopropene (1-MCP) treatments were beneficial in maintaining fruit firmness. The 1-MCP treatment had no significant effect on the compositional parameters of the fruit, but did suppress volatile production. The 1-MCP at 200 $ug*L^{-1}$ prevented the outer edges of the fruit fins from turning yellow. 1-MCP treatments at 50 and 100 $ug*L^{-1}$ had similar effects but at lower magnitudes. Firmness was maintained, but only slightly over the controls. Total volatile production was also suppressed by the 1-MCP treatment. The fins of the fruit had a slightly less green appearance with the lower concentrations of 1-MCP. Because 1-MCP helped to maintain firmness of treated fruits and extended shelf-life it could be a valuable treatment for carambola that are harvested at the 1/2 yellow stage.

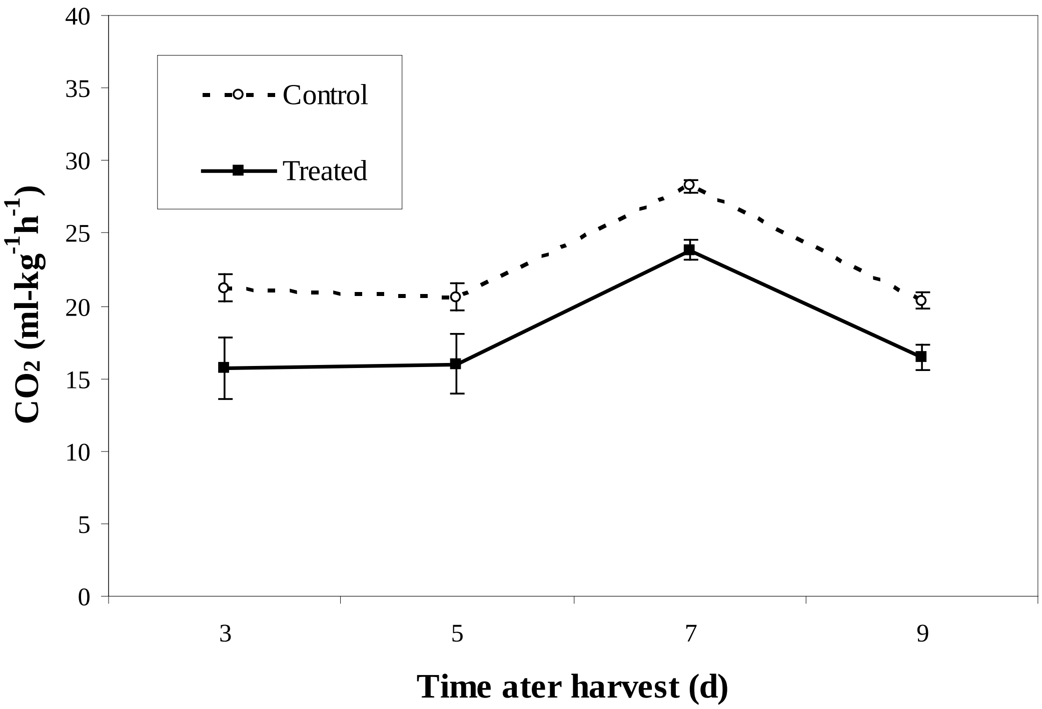

Figure 6-1. Respiration rate of ‘Arkin’ carambola harvested at 1/4 yellow stage during ripening at 20 ^{o}C. (n=3 fruits).

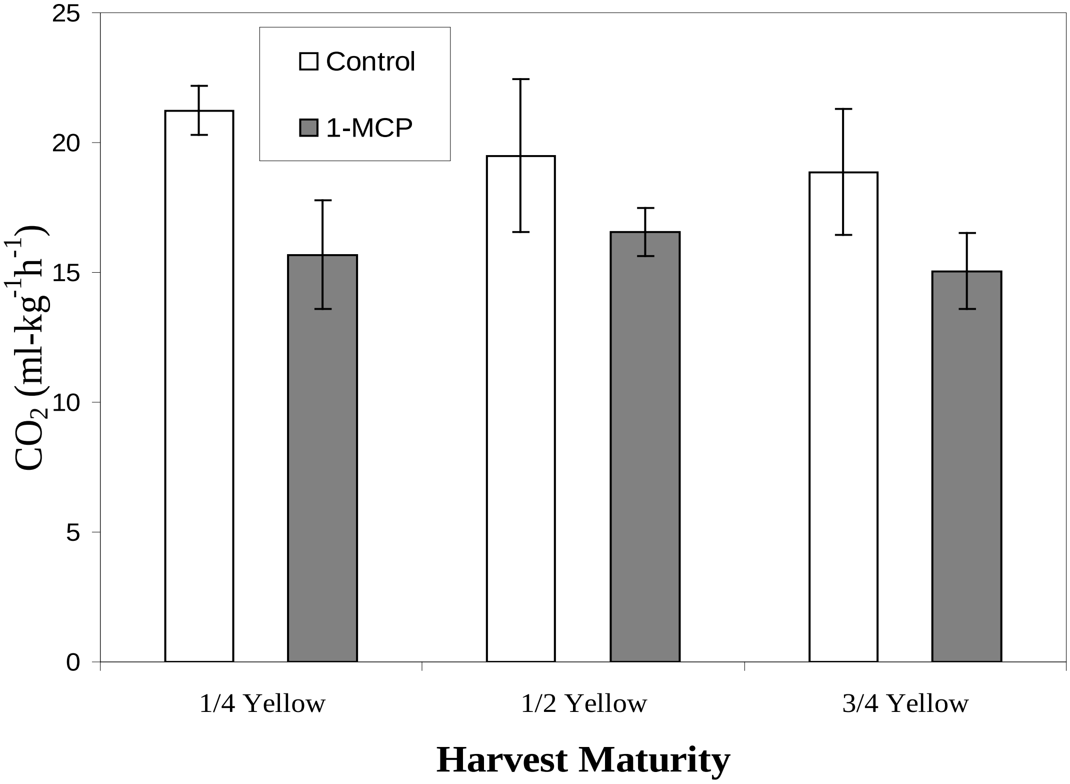

Figure 6-2. Respiration rate of 'Arkin' carambola harvested at three stages of maturity and stored at 20 ^{o}C. Three days after treatment (n=3 fruits).

Table 6-1. Days taken to reach 1/4 orange stage and weight loss for ‘Arkin’ carambola after treatment with aqueous 1-MCP plus 14 d at respective storage temperature plus ripening at 20 ^{o}C.

Harvest Maturity	Storage Temperature (^{o}C)	Treatment	Days to 1/4 Orange (after transfer to 20 ^{o}C)	Weight Loss
1/4 Yellow	5	C[Z]	9	2.47 bc[Y]
1/2 Yellow	5	C	9	2.25 c
3/4 Yellow	5	C	9	2.23 c
1/4 Yellow	5	T	11	4.20 a
1/2 Yellow	5	T	11	4.00 a
3/4 Yellow	5	T	9	3.32 ab
1/4 Yellow	10	C	9	2.73 bc
1/2 Yellow	10	C	9	3.22 ab
3/4 Yellow	10	C	3	1.19 d
1/4 Yellow	10	T	11	3.91 ab
1/2 Yellow	10	T	11	2.90 b
3/4 Yellow	10	T	3	1.58 c
1/4 Yellow	20	C	12	1.19 d
1/2 Yellow	20	C	7	1.24 cd
3/4 Yellow	20	C	7	1.32 cd
1/4 Yellow	20	T	14	2.71 b
1/2 Yellow	20	T	12	1.27 cd
3/4 Yellow	20	T	7	1.23 cd

[Z]C = untreated control; T = 1-MCP treated.

[Y] Within each treatment (n = 4 fruit/treatment) values followed by different letters within weight loss column are significantly different at the P<0.05, according to Duncan’s Multiple Range Test.

Table 6-2. Subjective appearance ratings for 'Arkin' carambola fruit subjected to 1-MCP treatments and various storage temperatures. Fruit rated once upon reaching the peak ripeness stage (1/4 orange).

Harvest Maturity	Storage Temperature (^{o}C)	Treatment	Appearance Categories: Fin Margin Browning	Stem End Shriveling	Surface Pitting/ Browning	Persistent Green Fins
1/4 Yellow	5	C[Z]	3[Y]	3	2	1
1/2 Yellow	5	C	2	3	2	1
3/4 Yellow	5	C	1	1	1	1
1/4 Yellow	5	T	2	2	1	4
1/2 Yellow	5	T	1	2	1	3
3/4 Yellow	5	T	1	1	1	3
1/4 Yellow	10	C	2	2	2	1
1/2 Yellow	10	C	1	2	2	1
3/4 Yellow	10	C	1	1	1	1
1/4 Yellow	10	T	2	2	1	2
1/2 Yellow	10	T	1	1	1	2
3/4 Yellow	10	T	1	1	1	2
1/4 Yellow	20	C	2	2	1	1
1/2 Yellow	20	C	1	1	1	1
3/4 Yellow	20	C	1	1	1	1
1/4 Yellow	20	T	1	1	1	2
1/2 Yellow	20	T	1	1	1	2
3/4 Yellow	20	T	1	1	1	2

[Z]C = control, untreaded; T = treated with 1-MCP (200 ug*L^{-1})

[Y]Appearance ratings based on table 3-1. 1 = none or very little, 2 = slight, 3 = moderate, 4 = severe

Table 6-3. Firmness (maximum force through 7 mm of a 10-mm of cross-section) of ‘Arkin’ carambola fruit at initial stages and upon reaching the peak ripeness stage (1/4 orange).

Harvest Maturity	Storage Temperature (^{o}C)	Initial Firmness (N)	Final Firmness (N) Control	Final Firmness (N) Treated
1/4 Yellow	5	25.5 a^{Z}	9.7 a	16.4 a
1/2 Yellow	5	19.0 b	5.6 c	9.6 b
3/4 Yellow	5	15.8 c	5.9 c	12.3 ab
1/4 Yellow	10	25.5 a	6.4 b	13.7 a
1/2 Yellow	10	19.0 b	6.2 b	9.1 a
3/4 Yellow	10	15.8 c	7.5 b	13.3 a
1/4 Yellow	20	25.5 a	7.3 b	11.2 a
1/2 Yellow	20	19.0 b	8.4 b	12.5 a
3/4 Yellow	20	15.8 c	7.6 b	15.2 a

^{Z} Values within each column followed by different letters are significantly different at P<0.05, according to Duncan’s Multiple Range Test. (n = 4 fruit/treatment)

Table 6-4. Selected compositional quality parameters for ‘Arkin’ carambola harvested at three ripeness stages, treated with 1-MCP, and analyzed at the peak ripeness stage (1/4 orange).

Compositional Parameter^{z}	Harvest Maturity 1/4 Yellow	1/2 Yellow	3/4 Yellow
SSC (^{o}Brix) ^{y}	6.40 b	7.08 a	7.12 a
TTA (%)	0.307 a	0.271 b	0.229 c
pH	3.77 b	3.98 a	4.05 a
SSC/TTA ratio	20.8 c	26.1 b	31.1 a

^{Z}Within each treatment (n = 4 fruit/treatment) values followed by different letters between ripeness stages are significantly different at the P<0.05, according to Duncan’s Multiple Range Test.

^{y}SSC = Soluble Solids Content; TTA = Total Titratable Acidity (malic acid equivalent).

Table 6-5. Headspace aroma volatiles (relative areas) analyzed at the peak ripeness stage (1/4 orange) for 'Arkin' carambola harvested 1/4 and 1/2 yellow, as affected by 1-MCP treatment and harvest maturity.

		Storage Temperature (°C)							
		5				20			
		1-MCP treatment (ug*L^{-1})							
		0		200		0		200	
Volatile[ZY]	RI[X]	1/4 Y[W]	1/2 Y	1/4 Y	1/2 Y	1/4 Y	1/2 Y	1/4 Y	1/2 Y
Alcohols									
1-Pentanol	763	n.d.[V]	7.0	n.d.	n.d.	10.2	9.7	7.2	12.0
Heptanol	974	n.d.	n.d.	76.5	n.d.	n.d.	n.d.	n.d.	n.d.
1-Octanol	1071	6.3	8.8	23.2	34.7	11.8	13.6	n.d.	n.d.
1-Nonanol	1167	n.d.	n.d.	23.2	n.d.	n.d.	n.d.	n.d.	n.d.
Aldehydes									
Pentanal	687	n.d.	n.d.	16.9	n.d.	n.d.	n.d.	n.d.	n.d.
Hexanal	801	n.d.	n.d.	8.9	n.d.	n.d.	22.4	12.3	n.d.
Nonanal	1108	n.d.	n.d.	248.7	n.d.	25.3	30.2	21.7	39.9
2-Hexenal	860	n.d.	n.d.	36.9	n.d.	n.d.	n.d.	n.d.	n.d.
Alkanes									
Undecane	1101	n.d.	n.d.	n.d.	7.7	n.d.	5.3	4.3	5.2
Tetradecane	1393	n.d.	28.8	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
D6-Phenol	978	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Ethyl benzoate	1179	n.d.	n.d.	60.1	9.7	n.d.	n.d.	n.d.	n.d.
Toluene	771	n.d.	n.d.	n.d.	n.d.	10.2	9.7	7.2	12.0
1,3-Diethenyl Benzene	1128	n.d.	n.d.	n.d.	n.d.	65.5	27.6	75.9	n.d.
1,4-Diethenyl Benzene	1142	n.d.	n.d.	n.d.	n.d.	n.d.	4.3	n.d.	n.d.
Esters									
Acetate (E)- 2-Hexen-1-ol	1015	n.d.	n.d.	11.6	n.d.	n.d.	n.d.	n.d.	n.d.
Ketones									
Acetone	510	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	5.8
3-Pentanone	684	n.d.	n.d.	16.9	n.d.	n.d.	n.d.	n.d.	n.d.
2-Methyl-3-Pentanone	745	n.d.	42.1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Table 6-5. Continued

		Storage Temperature (°C)							
		5				20			
		1-MCP treatment (ug*L^{-1})							
		0		200		0		200	
Volatile[ZY]	RI	1/4 Y	1/2 Y	1/4 Y	1/2 Y	1/4 Y	1/2 Y	1/4 Y	1/2 Y
Norisoprenoids									
Beta Ionone	1498	n.d.	n.d.	n.d.	n.d.	47.8	26.0	18.7	32.1
Total Alcohols		6.3	15.8	122.9	34.7	22.0	23.3	7.2	12.0
Total Aldehydes		0.0	0.0	311.4	0.0	25.3	52.6	34.0	39.9
Total Alkanes		0.0	28.8	60.1	17.4	75.7	46.9	87.4	17.2
Total Esters		0.0	0.0	11.6	0.0	0.0	0.0	0.0	0.0
Total Ketones		0.0	42.1	16.9	0.0	0.0	0.0	0.0	5.8
Total Norisoprenoids		0.0	0.0	0.0	0.0	47.8	26.0	18.7	32.1
Total Volatiles		6.3	86.7	506.1	52.1	170.7	148.9	147.4	106.9

[Z]Within each treatment (n = 1 fruit/rep, 4 reps averaged), value represents area under the curve as a percentage of the area of the internal standard (D6-phenol).
[Y]Listed volatiles are significant contributors to the aroma profile of carambola found in samples from Chapter 4. Volatiles have been tentatively identified using Kovats Retention Index.
[X]RI = Kovats Retention Index Number
[W]1/4 Y = 1/4 Yellow, 1/2 Y = 1/2 Yellow
[V]n.d. = not detected in all replicate samples of a treatment

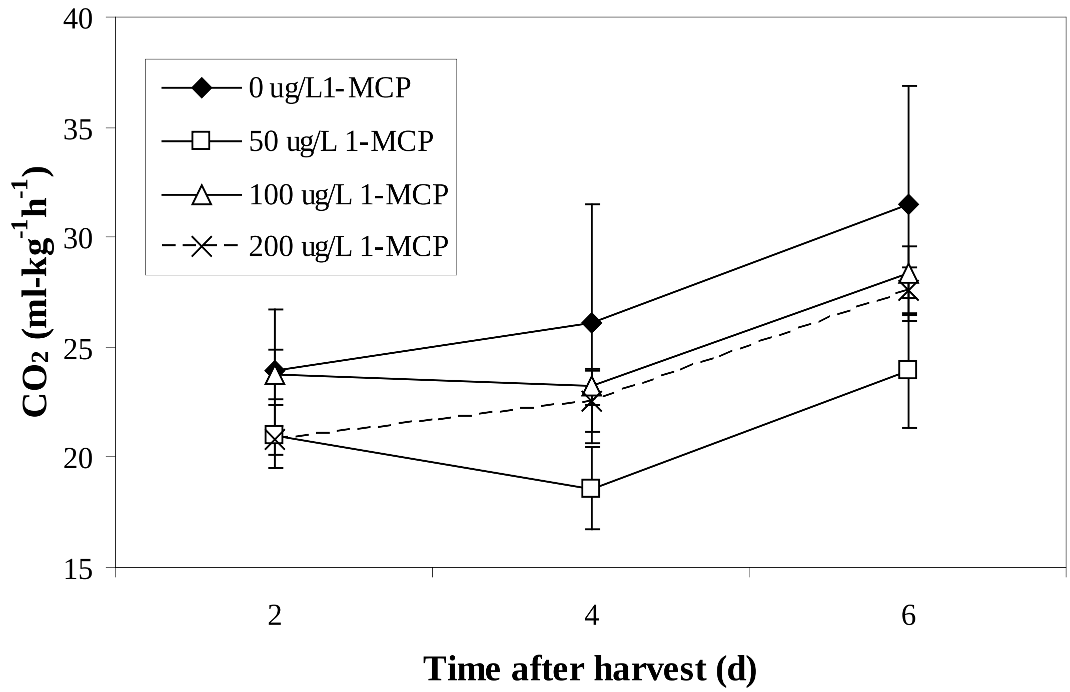

Figure 6-3. Respiration rate of ‘Arkin’ carambola harvested at 1/2 yellow stage during ripening at 20 oC. (n=3 fruits). Data points with standard error bars.

Table 6-6. Days taken to reach 1/4 orange stage and weight loss for 'Arkin' carambola after treatment with aqueous 1-MCP plus 14 d at respective storage temperature plus ripening at 20 ^{o}C.

Harvest Maturity	Storage Temperature (^{o}C)	1-MCP Treatment (ug*L^{-1})	Days to 1/4 orange (after transfer to 20 ^{o}C)	Weight Loss
1/4 Yellow	5	0	9	4.79 a[Y]
1/2 Yellow	5	0	9	4.84 a
3/4 Yellow	5	0	6	2.55 c
1/4 Yellow	5	50	9	5.22 a
1/2 Yellow	5	50	9	3.62 b
3/4 Yellow	5	50	6	2.64 c
1/4 Yellow	5	100	9	5.79 a
1/2 Yellow	5	100	9	4.46 ab
3/4 Yellow	5	100	6	2.61 c
1/4 Yellow	5	200	11	3.90 b
1/2 Yellow	5	200	11	3.90 b
3/4 Yellow	5	200	6	1.99 c
1/4 Yellow	20	0	12	7.21a
1/2 Yellow	20	0	7	4.98 b
3/4 Yellow	20	0	7	2.75 c
1/4 Yellow	20	50	15	6.81 a
1/2 Yellow	20	50	7	4.65 b
3/4 Yellow	20	50	7	2.43 c
1/4 Yellow	20	100	15	7.88 a
1/2 Yellow	20	100	7	4.60 b
3/4 Yellow	20	100	7	2.80 c
1/4 Yellow	20	200	15	6.24 a
1/2 Yellow	20	200	11	4.96 b
3/4 Yellow	20	200	7	4.20 bc

[Z]1-MCP treatment concentration of a.i. (ug*L^{-1}).

[Y] Within each treatment (n = 4 fruit/treatment) values followed by different letters within column are significantly different at the P<0.05, according to Duncan's Multiple Range Test.

Table 6-7. Subjective appearance ratings for ‘Arkin’ carambola fruit subjected to 1-MCP treatments of different concentrations and two storage temperatures. Fruit rated once upon reaching the peak ripeness stage (1/4 orange).

			Appearance Categories			
Harvest Maturity	Storage Temperature (^{o}C)	1-MCP Treatment ($ug*L^{-1}$)	Fin Margin Browning	Stem End Shriveling	Surface Pitting/ Browning	Persistent Green Fins
1/4 Yellow	5	0	4^{Z}	4	3	1
1/2 Yellow	5	0	4	4	3	1
3/4 Yellow	5	0	3	4	2	1
1/4 Yellow	5	50	2	4	1	1
1/2 Yellow	5	50	2	2	1	1
3/4 Yellow	5	50	2	2	1	1
1/4 Yellow	5	100	2	3	1	2
1/2 Yellow	5	100	2	3	2	2
3/4 Yellow	5	100	3	2	1	1
1/4 Yellow	5	200	2	3	1	2
1/2 Yellow	5	200	2	3	1	3
3/4 Yellow	5	200	2	2	1	1
1/4 Yellow	20	0	2	1	1	1
1/2 Yellow	20	0	2	1	1	1
3/4 Yellow	20	0	2	1	1	1
1/4 Yellow	20	50	2	1	1	1
1/2 Yellow	20	50	1	1	2	1
3/4 Yellow	20	50	1	1	1	1
1/4 Yellow	20	100	2	1	1	2
1/2 Yellow	20	100	2	1	2	2
3/4 Yellow	20	100	2	1	1	2
1/4 Yellow	20	200	2	1	1	3
1/2 Yellow	20	200	2	1	1	3
3/4 Yellow	20	200	1	1	1	3

Based on Table 3-1. 1=little or none, 2=slight, 3=moderate, 4=severe

Table 6-8. Firmness (maximum force throught 7 mm of a 10-mm cross-section) of 'Arkin' carambola fruit at initial stages and upon reaching the peak ripeness stage (1/4 orange).

Harvest Maturity	Storage Temperature (^{o}C)	Initial Firmness (N)	Final Firmness (N) 1-MCP Concentration ($ug*L^{-1}$) 0	50	100	200
1/4 Yellow	5	26.0 a [Z]	9.1 c [Y]	10.6 b	8.6 c	10.8 b
1/2 Yellow	5	20.1 b	7.3 d	8.5 c	10.1 b	9.1 c
3/4 Yellow	5	14.0 c	8.7 c	9.6 bc	9.5 bc	9.9 b
1/4 Yellow	20	26.0 a	8.0 d	8.5 c	7.6 cd	8.7 c
1/2 Yellow	20	20.1 b	11.1 b	9.1 c	8.7 c	8.7 c
3/4 Yellow	20	14.0 c	15.6 a	11.9 ab	14.9 a	16.2 a

[Z] Values within Initial column followed by different letters are significantly different at P<0.05, according to Duncan's Multiple Range Test. (n = 4 fruit/treatment)
[Y] Within each treatment (n = 4 fruit/treatment) values followed by different letters within the final firmness columns are significantly different at the P<0.05, according to Duncan's Multiple Range Test.

Table 6-9. Selected compositional quality parameters for 'Arkin' carambola harvested at three ripeness stages, treated with 1-MCP at three concentrations, and analyzed at the peak ripeness stage (1/4 orange).

Compositional Parameter[z]	1/4 Yellow	1/2 Yellow	3/4 Yellow
SSC (^{o}Brix) [y]	6.64 c	7.11 b	7.74 a
TTA (%)	0.224 b	0.227 b	0.242 a
pH	3.91 b	4.06 a	4.07 a
SSC/TTA Ratio	29.667 b	31.329 ab	32.030 a

[Z]Within each treatment (n = 4 fruit/treatment) values followed by different letters between ripeness stages are significantly different at the P<0.05, according to Duncan's Multiple Range Test.
[y]SSC = Soluble Solids Content; TTA = Total Titratable Acidity (malic acid equivalent).

CHAPTER 7
EFFECTS OF POSTHARVEST TREATMENTS OF AQUEOUS 1-MCP AND ETHYLENE TO 'ARKIN' CARAMBOLA FRUIT QUALITY

Introduction

In previous experiments (Chapter 6) postharvest application of aqueous 1-methylcyclopropene (1-MCP) was shown to be an effective agent in maintaining fruit firmness and extending shelf-life (Chapter 6). The 1-MCP treatments that were most effective in maintaining fruit firmness also caused persistently green fins. 1-MCP has been reported to maintain fruit firmness and extend the shelf-life of other types of fruit (Sisler et al., 1996a; Sisler and Serek, 1999; Jiang et al., 2004). 1-MCP has been reported to maintain color in 'Fwang Tung' carambola fruit, but this was not described as a negative effect (Teixeira and Durigan, 2006).

Exogenous ethylene applications are used commercially to degreen non-climacteric fruits. Climacteric fruits frequently treated with ethylene include tomatoes and bananas; non-climacteric fruits frequently treated with ethylene include oranges, grapefruits, and lemons. Generally optimal ripening conditions for fruits are; 18 to 25 ^{o}C, high relative humidity (90-95%), and ethylene concentrations ranging from 10 to 100 ppm (Reid, 2002). In the experiment outlined in Chapter 5 the 100 ppm treatment had the highest degreening effect for carambola. Exogenous ethylene stimulates chlorophyllase and peroxidase activity which degrade chlorophyll and cause degreening (Amir-Shapira et al., 1987). Postharvest ethylene treatments did not affect soluble solids content or titratable acidity of carambola fruit or other non-climacteric fruits (Sargent and Brecht, 1990; Tian et al., 2000). Exogenous ethylene treatments were associated with fruit developing over-ripe flavor volatiles and causing an increase in stem-end shriveling and surface pitting/ browning (Chapter 5). The objective of this experiment was to determine the effectiveness of exogenous ethylene treatment applied post 1-MCP treatment. The hypothesis was that exogenous ethylene would aid in overcoming the persistent green fins caused by 1-MCP.

Material and Methods

Plant Material

'Arkin' Carambolas were hand-harvested into plastic containers (up to three layers deep) at 1/4 yellow, 1/2 yellow and 3/4 yellow color stages in Pine Island, FL on the morning of February 5th, 2008. The commercial grower was Brooks Tropicals (Homestead, Florida). Harvested fruit was transported in the plastic containers to the Postharvest Horticulture Laboratory at the University of Florida, Gainesville by car the same day. The fruit were stored overnight in the plastic containers in at 10 ^{o}C.

The following morning, fruits were then selected based on color stage, washed and randomized into respective treatments; fruit were segregated for respiration and initial firmness measurements.

Treatment with Aqueous 1-MCP

Aqueous application of 1-MCP was performed as described in Chapter 6.

Storage and Ethylene Treatment

Carambola fruit were stored in 175 L sealed containers on plastic trays with flow-through air containing 100 ppm ethylene for 24 or 48 h at 20 ^{o}C, 90% R.H. The mixed gasses were humidified by bubbling through a water-filled jar before entering the chamber. After the gassing treatments the fruit were stored at 20 ^{o}C until reaching the 1/4 orange stage. There were no 3/4 yellow fruit used in 20 ^{o}C storage treatment because the fruit would have reached the 1/4 orange stage prior to the ethylene treatment.

Quality Analyses

Fruit was rated subjectively for appearance based on Table 3-1. Preparation for compositional analysis for SSC, TTA and pH were done as described in Chapter 2. Firmness was measured as described in Chapter 6. Volatiles were measured as described in Chapter 3.

Statistical Analyses

Statistical analyses were performed according to the procedures outlined in Chapter 2.

Results

Days to Peak Ripeness and Weight Loss

Days to reach peak ripeness (1/4 orange), after 14 d storage at 5 ^{o}C, including the ethylene treatment, ranged from 7 to 13 d for fruit stored at 5 ^{o}C (Table 7-1). Days to reach the 1/4 orange stage for fruit stored at 20 ^{o}C ranged from 2 to 7 d. For fruit harvested at the 1/4 and 1/2 yellow stages, stored at 5 ^{o}C, the 1-MCP treatment delayed days to 1/4 orange by 3 d. Fruit harvested at the 3/4 yellow stage took the same amount of time to reach the 1/4 orange stage whether they were treated with 1-MCP or not.

Weight loss ranged from 1.69 to 7.80% of initial weight in fruit stored at 5 ^{o}C after the 1-MCP treatment. Weight loss ranged from 3.93 to 11.43% of initial weight in fruit stored at 20 ^{o}C. For the fruit stored at 5 ^{o}C and then gassed for 48 h, the 1-MCP treatment increased weight loss. Fruit harvested at the 1/4 and 1/2 yellow stages which were treated with 1-MCP, stored at 20 ^{o}C and gassed for 48 hours lost the most weight.

Appearance Ratings

Persistent green fins remained on fruit treated with 1-MCP (Table 7-2). Persistently green fins were rated as a 4 for fruit harvested at the 1/4 and 3/4 yellow stages and treated with 1-MCP, even when treated with 48 h ethylene. The 48 h ethylene treatment increased the incidence of surface pitting/ browning. The 48 h ethylene treatment also increased the incidence of fin margin browning for fruit stored at 20 ^{o}C.

Firmness

Initial firmness values ranged from 24.7 to 14.9 N (Table 7-3). Fruit harvested at the 1/4 yellow stage (24.7) were significantly firmer than fruit harvested at the 1/2 yellow stage (18.6 N) and 3/4 yellow stage (14.9 N). Fruit firmness decreased with the storage period. Final fruit firmness ranged from 5.3 to 12.8 N. 1-MCP treated fruit were significantly firmer than non-1-MCP treated fruit when stored at 5 ^{o}C and treated with 48 h ethylene. 1-MCP treated fruit were also significantly firmer than non-1-MCP treated fruit when stored at 20 ^{o}C and treated with 24 h ethylene.

Compositional Analysis

There were no treatment effects on the compositional parameters of the fruit (Table 7-4). The soluble solids content of the fruit ranged from 6.70 to 8.02 ^{o}Brix. Fruit harvested at the 1/4 yellow stage had the lowest soluble solids content (6.70 ^{o}Brix), while fruit harvested at the 1/2 and 3/4 yellow stages had higher soluble solids content (7.16 and 8.02 ^{o}Brix respectively).

The total titratable acidity ranged from 0.231 to 0.286. Fruit harvested at the 1/4 yellow stage had the highest total titratable acidity (0.286), while fruit harvested in the 1/2 and 3/4 yellow stages had lower total titratable acidity (0.264 and 0.231), respectively. The sugar-to-acid ratio ranged from 23.819 to 35.666 and increased significantly at each harvest maturity.

Volatiles

Initial volatiles were measured in the harvest maturity experiment of Chapter 4. For this experiment fruit were analyzed upon reaching the peak ripeness stage (1/4 orange). For fruit harvested at the 1/4 yellow stage ethanol was detected only when fruit were treated with 24 h ethylene, regardless of 1-MCP treatment (Table 7-5). 1-pentanol was found only in the fruit not treated with 1-MCP and treated with 48 h ethylene. Norisoprenoid compounds are associated with carotene breakdown and off-flavor formation (Table 4-3), were found to be highest in fruit that received the 48 h ethylene treatment.

For fruit not treated with 1-MCP, the 48 h ethylene treatment increased total volatile formation by 64% over the 24 h ethylene treatment. For fruit treated with 1-MCP, the 48 h ethylene treatment increased total volatile formation by 134% over the 24 h ethylene treatment.

Ethanol was not detected in any of the fruit harvested at the 1/2 yellow stage (Table 7-6). There were higher amounts of 1-octanol and 1-nonanol in fruit treated with 48 h ethylene than fruit treated with 24 h ethylene. Nonanal was higher in fruit treated with 48 h ethylene than in fruit treated with 24 h ethylene. For non-1-MCP treated fruit, nonanal was 167% higher in fruit treated with 48 h ethylene over the fruit treated with 24 h ethylene. For 1-MCP treated fruit, nonanal was 206% higher in fruit treated with 48 h ethylene over fruit treated with 24 h ethylene. The same trend existed for tetradecane.

For non-1-MCP treated fruit, the 48 h ethylene treatment increased total volatile formation by 96% over the 24 h ethylene treatment. For fruit treated with 1-MCP, the 48 h ethylene treatment increased total volatile formation by 71% over the 24 h ethylene treatment.

Total volatiles were higher in fruit harvested at the 1/4 yellow stage than fruit harvested at the 1/2 yellow stage. When comparing fruit harvested at the 1/2 yellow stage to fruit harvested at 1/4 yellow that were not treated with 1-MCP, total volatiles were 229% and 175% higher for fruit treated with 24 and 48 h ethylene, respectively. When comparing fruit treated with 1-MCP and harvested at the 1/2 yellow or 1/4 yellow stage total volatiles were 232% and 355% higher for fruit treated with 24 and 48 h ethylene respectively.

Discussion

Days to Peak Ripeness and Weight Loss

Days to peak ripeness (1/4 orange) were delayed by 1-MCP treatments for fruit harvested at the 1/4 and 1/2 yellow stages and stored at 5 ^{o}C (Table 7-1). The days to 1/4 orange were also delayed by the 1-MCP treatment for fruit harvested at 1/4 and 1/2 yellow, stored at 20 ^{o}C, and exposed to 48 h ethylene.

Generally, fruit with the longest storage time lost the most weight. Also, fruit stored at 20 ^{o}C lost more weight than fruit stored at 5 ^{o}C. This was possibly caused by slower metabolic rates in fruit stored at the lower temperature. These results are similar to those reported by Campbell et al. (1989) who reported that carambola stored for 44 d at 5 or 10 ^{o}C lost more weight than fruit stored for 14 d at the same temperatures. They also reported that color change and ripening were delayed in fruit stored at 5 ^{o}C compared to those stored at 10 ^{o}C. These also parallel the results in Chapters 3, 5, and 6.

Appearance Ratings

The 1-MCP treatment maintained the green color of the fruit (Table 7-2). In previous reports 1-MCP has been shown to reduce chlorophyllase and peroxidase activities, both of which are responsible for chlorophyll degradation and degreening

(Gong and Mattheis, 2003). Color maintenance has been reported in ‘Fwang Tung’ carambola (Teixeira and Durigan, 2006). In the present experiment the ethylene treatment after the storage period did little to degreen the fruit that were treated with 1-MCP. It is possible that the ethylene was not binding to the receptor sites on the fruit because they were already occupied by 1-MCP. The ethylene treatment reduced the visual quality of the fruit, making the fin margins and surface more brown. This was likely due to ethylene stimulating production of phenolics. Ethylene treatments have been reported to increase the incidence of peel scald, stem-end breakdown, fin browning, and mold growth for carambola fruit treated prior to cold treatment (Miller and McDonald, 1997).

Firmness

The firmness of carambola fruit was maintained by 1-MCP treatments only for specific combinations of temperature and ethylene exposure (Table 7-3). For fruit stored at 5 ^{o}C and then subjected to 48 h ethylene, the 1-MCP treatment helped maintain firmness significantly over fruit not treated with 1-MCP. The 1-MCP treatment also maintained firmness for fruit stored at 20 ^{o}C and then subjected to 24 h ethylene. The 1-MCP treatments probably maintained turgidity of the fruit as they were subjected to the ethylene treatments. A previous report showed that 1-MCP treatments to vegetables including; bok choy and choy sum can maintain their turgidity postharvest (Thomson et al., 2003), which parallels the results shown here.

Compositional Analysis

The compositional parameters were not significantly affected by treatments (Table 7-4). Ethylene did not affect the SSC of carambola in a previous report (Sargent and Brecht, 1990). Similarly, ethylene treatments on strawberry fruit that have been treated with 1-MCP have been shown not to affect the soluble solids content (Tian et al., 2000).

Volatiles

Ethanol was detected only in fruit which were harvested at the 1/4 yellow stage, not treated with 1-MCP, stored at 5 ^{o}C, and for 24 h with ethylene (Table 7-5). The ethanol was likely a byproduct of anaerobic respiration caused by a high metabolic rate and long storage time. Ethanol production has been associated with high respiration rates in apples (Forney et al., 2000). The norisoprenoid compounds were higher in fruit treated with ethylene for 48 h. This was likely due to an increase in carotene production and breakdown from extended ethylene exposure. A previous report showed that exogenous ethylene application stimulated carotene formation in citrus fruit (Rodrigo and Zacarais, 2006). The total volatiles were higher in fruit treated with 48 h ethylene. This was likely due to specific effects of ethylene on some volatile biosynthetic pathways as well as a general increase in the rate of physiological processes, which produced an increased amount of volatiles. For fruit harvested at the 1/2 yellow stage, total volatiles were also higher in the fruit treated with 48 h ethylene than in fruit treated with 24 h ethylene (Table 7-6). Similar results for an increase in metabolic rate after ethylene exposure have been reported in citrus (Eaks, 1970).

Conclusions

When ethylene was used as an antidote to the 1-MCP treatment, the outer fins of the fruit were only slightly degreened. Since this treatment occurred 14 d after the 1-MCP treatment, surface pitting/browning and fin margin browning were exacerbated. The ethylene treatment post 1-MCP treatment and storage caused the fruit to produce aroma volatiles associated with over-ripe fruit. Therefore, ethylene treatment post 1-MCP treatment and storage is not beneficial.

Table 7-1. Days to reach 1/4 orange stage and weight loss for 'Arkin' carambola after treatment with aqueous 1-MCP, 14 d storage at respective temperature, and ethylene treatment at 20 ^{o}C.

Harvest Maturity	Storage Temperature (^{o}C)	1-MCP Treatment (ug*L^{-1})	100 ppm Ethylene Treatment (h)	Days to 1/4 Orange^{Z}	Weight Loss (%)
1/4 Yellow	5	0	24	10	4.67 c^{Y}
1/2 Yellow	5	0	24	10	4.44 c
3/4 Yellow	5	0	24	7	2.11 d
1/4 Yellow	5	0	48	10	2.55 d
1/2 Yellow	5	0	48	10	1.69 d
3/4 Yellow	5	0	48	7	2.13 d
1/4 Yellow	5	200	24	13	7.80 b
1/2 Yellow	5	200	24	13	4.71 c
3/4 Yellow	5	200	24	7	5.56 bc
1/4 Yellow	5	200	48	13	6.34 bc
1/2 Yellow	5	200	48	13	6.22 bc
3/4 Yellow	5	200	48	7	4.91 c
1/4 Yellow	20	0	24	2	7.87 b
1/2 Yellow	20	0	24	2	4.68 c
1/4 Yellow	20	0	48	2	5.51 c
1/2 Yellow	20	0	48	2	4.92 c
1/4 Yellow	20	200	24	2	3.93 cd
1/2 Yellow	20	200	24	2	5.43 c
1/4 Yellow	20	200	48	7	11.43 a
1/2 Yellow	20	200	48	7	6.09 bc

^{Z}Days to reach 1/4 orange stage after 14 d storage period.

^{Y}Within each treatments (n = 4 fruit/ treatment) values followed by different letters within column are significantly different at the P<0.05, according to Duncan's Multiple Range Test.

Table 7-2. Subjective appearance ratings for 'Arkin' carambola fruit subjected to 1-MCP treatments at 5 and 20 ^{o}C. Fruit rated once reaching the peak ripeness stage (1/4 orange).

				Appearance Categories			
Harvest Maturity	Storage Temperature (^{o}C)	1-MCP Treatment (ug*L^{-1})	Ethylene Treatment (h)	Fin Margin Browning	Stem End Shriveling	Surface Pitting/ Browning	Persistent Green Fins
1/4 Yellow	5	0	24	3	2	2	3
1/2 Yellow	5	0	24	1	2	1	2
3/4 Yellow	5	0	24	1	2	2	1
1/4 Yellow	5	0	48	3	2	2	3
1/2 Yellow	5	0	48	1	2	1	2
3/4 Yellow	5	0	48	1	2	2	3
1/4 Yellow	5	200	24	2	2	2	4
1/2 Yellow	5	200	24	2	2	2	3
3/4 Yellow	5	200	24	1	2	3	4
1/4 Yellow	5	200	48	3	2	3	4
1/2 Yellow	5	200	48	1	2	1	3
3/4 Yellow	5	200	48	1	2	4	4

Table 7-2 Continued

Harvest Maturity	Storage Temperature (°C)	1-MCP Treatment (ug*L^{-1})	Ethylene Treatment (h)	Appearance Categories: Fin Margin Browning	Stem End Shriveling	Surface Pitting/ Browning	Persistent Green Fins
1/4 Yellow	20	0	24	2	2	2	1
1/2 Yellow	20	0	24	2	2	2	2
1/4 Yellow	20	0	48	3	3	1	1
1/2 Yellow	20	0	48	3	2	1	1
1/4 Yellow	20	200	24	2	2	2	3
1/2 Yellow	20	200	24	1	2	2	3
1/4 Yellow	20	200	48	1	1	3	4
1/2 Yellow	20	200	48	2	2	2	3

Based on Table 3-1. 1=little or none, 2=slight, 3=moderate, 4=severe

Table 7-3. Firmness (maximum force of cross-section) of 'Arkin' carambola fruit at initial stages and upon reaching the peak ripeness stage (1/4 orange).

Harvest Maturity	Storage Temperature (°C)	1- MCP 2- Treatment (ug*L^{-1})	Ethylene Treatment (h)	Initial Firmness (N)	Final Firmness (N)
1/4 Yellow	5	0	24	24.7 a[Z]	9.6 a[Y]
1/2 Yellow	5	0	24	18.6 b	5.9 cd
3/4 Yellow	5	0	24	14.9 c	6.3 c
1/4 Yellow	5	0	48	24.7 a	9.8 a
1/2 Yellow	5	0	48	18.6 b	5.3 d
3/4 Yellow	5	0	48	14.9 c	6.2 c
1/4 Yellow	5	200	24	24.7 a	7.6 bc
1/2 Yellow	5	200	24	18.6 b	9.8 a
3/4 Yellow	5	200	24	14.9 c	10.0 a
1/4 Yellow	5	200	48	24.7 a	8.4 b
1/2 Yellow	5	200	48	18.6 b	7.9 b
3/4 Yellow	5	200	48	14.9 c	8.2 b
1/4 Yellow	20	0	24	24.7 a	7.2 c
1/2 Yellow	20	0	24	18.6 b	6.8 c
1/4 Yellow	20	0	48	24.7 a	6.7 c
1/2 Yellow	20	0	48	18.6 b	6.9 c
1/4 Yellow	20	200	24	24.7 a	12.8 a
1/2 Yellow	20	200	24	18.6 b	11.9 a
1/4 Yellow	20	200	48	24.7 a	6.2 c
1/2 Yellow	20	200	48	18.6 b	7.7 bc

[Z] Within each treatment (n = 4 fruit/treatment) values followed by different letters within the initial column are significantly different at the P<0.05, according to Duncan's Multiple Range Test.

[Y] Within each treatment (n = 4 fruit/treatment) values followed by different letters within the final firmness columns are significantly different at the P<0.05, according to Duncan's Multiple Range Test.

Table 7-4. Selected compositional quality parameters for 'Arkin' carambola harvested at three harvest maturities, treated with 1-MCP and ethylene, and analyzed at the peak ripeness stage (1/4 orange).

Compositional Parameter ^{z}	1/4 Yellow	1/2 Yellow	3/4 Yellow
SSC (^{o}Brix) ^{y}	6.70 c	7.16 b	8.02 a
TTA (%)	0.286 a	0.264 b	0.231 c
pH	4.07 c	4.17 b	4.30 a
SSC/TTA ratio	23.819 c	27.904 b	35.666 a

^{z}Within each treatment (n = 6 fruit/treatment) values followed by different letters between ripeness stages are significantly different at the P<0.05, according to Duncan's Multiple Range Test.
^{y}SSC = Soluble Solids Content; TTA = Total Titratable Acidity (malic acid equivalent).

Table 7-5. Headspace aroma volatiles (relative areas) for ‘Arkin’ Carambola harvested at 1/4 yellow, as affected by 1-MCP treatment, storage at 5 ^{o}C, and ethylene treatment analyzed at full-ripe stage.

		Treatment Combination			
Volatile[Z]	RI[Y]	MCP+24 Eth[X]	Water+48 Eth	MCP+24 Eth	Water+48 Eth
Alcohols					
Ethanol	491	39.1	n.d.[W]	60.2	n.d.
1-Pentanol	763	n.d.	3235.3	n.d.	n.d.
1-Octanol	1071	21.8	42.5	82.5	89.9
1-Nonanol	1167	59.1	64	97	76.3
Aldehydes					
Pentanal	687	11	20.5	16.3	17.3
Hexanal	801	15	17.2	39	22.9
Nonanal	1108	2130	720.5	1722.4	4682.9
2-Hexenal	860	22.8	130.5	330.4	252
Alkanes					
Nonane	906	5.7	n.d.	n.d.	472.4
Decane	1006	13.6	n.d.	n.d.	19.3
Undecane	1101	41.6	n.d.	n.d.	n.d.
Tetradecane	1393	n.d.	11.7	18	53.3
Aromatic Benzene Derivatives					
D6-Phenol[V]	978	100	100	100	100
Esters					
Ethyl butyrate	797	309.1	55.5	99.4	173.2
Ethyl ether	516	n.d.	n.d.	15.8	14
Ketones					
3-Pentanone[V]	684	11	20.5	16.3	17.3
4-Heptanone	877	47.7	70.7	61.3	74.9
Norisoprenoids					
Megastigma-4,6(E)(8)Z-triene	1370	8.3	65.2	26.3	71.7
Beta Ionone	1498	n.d.	44	16.2	16.6
Total Alcohols		120	3341.8	239.7	166.2
Total Aldehydes		2178.8	888.7	2108.1	4975.1
Total Alkanes		4406	60.9	11.7	18
Total Esters		1313	309.1	55.5	115.2
Total Ketones		47.7	70.7	61.3	74.9
Total Norisoprenoids		8.3	109.2	42.5	88.3
Total Volatiles		2724.8	4477.7	2584.7	6036.7

[Z]Within each treatment (n = 1 fruit/rep, 3 reps averaged), value represents area of curve as a percentage of the area of the internal standard (D6-phenol).Listed volatiles are significant contributors to the aroma profile of carambola found in initial samples. Volatiles have been tentatively identified using Kovats Retention Index (RI).

[Y]RI = Kovats Retention Index

[X]Treatment combinations: Water = untreated control, MCP = treated with 200 ug*L^{-1} aqueous 1-MCP, +24 = 24 h ethylene treatment post-storage, +48 = 48 h ethylene treatment post-storage.

[W] n.d. = not detected in all replicates of the same treatment.

[V] Internal standard added to tentatively quantify peak areas. Only D6-phenol was used in calculating relative areas.

Table 7-6. Headspace aroma volatiles (relative areas) for 'Arkin' carambola harvested at 1/2 yellow as affected by 1-MCP treatment, storage at 5 ^{o}C, and ethylene treatment analyzed at full-ripe stage.

		Treatment Combination			
Volatile[Z]	RI[Y]	MCP+24 Eth[X]	Water+48 Eth	MCP+24 Eth	Water+48 Eth
Alcohols					
1-Octanol	1071	43.1	70.4	33.5	52.7
1-Nonanol	1167	74.9	113.2	48	84
Aldehydes					
Pentanal	687	15	17.1	18.7	68.7
Hexanal	801	13.5	20.1	19.9	21.8
Nonanal	1108	377	1005.9	244.9	748.5
2-Hexenal	860	101	127.1	175.3	172.3
Alkanes					
Tetradecane	1393	7.9	22.2	7.8	11.3
Aromatic Benzene Derivatives					
D6-Phenol[V]	978	100	100	100	100
Esters					
Ethyl butyrate	797	20.7	n.d.[W]	n.d.	n.d.
Ethyl ether	516	17.3	9	29.3	n.d.
Ketones					
3-Pentanone[V]	684	15	17.1	18.7	68.7
4-Heptanone	877	45.9	57	52.3	57.1
Norisoprenoids					
Megastigma-4,6(E)(8)Z-triene	1370	86.8	137.6	58.9	88.2
Beta Ionone	1498	25.9	48.5	89.1	23.1
Total Alcohols		118.0	183.6	81.5	136.7
Total Aldehydes		506.5	1170.2	458.8	1011.3
Total Alkanes		7.9	22.2	7.8	11.3
Total Esters		38.0	9.0	29.3	0.0
Total Ketones		60.9	74.1	71.0	125.8
Total Norisoprenoids		112.7	186.1	148.0	111.3
Total Volatiles		829.3	1628	777.7	1327.7

[Z]Within each treatment (n = 1 fruit/rep, 3 reps averaged), value represents area of curve as a percentage of the area of the internal standard (D6-phenol).Listed volatiles are significant contributors to the aroma profile of carambola found in initial samples. Volatiles have been tentatively identified using Kovats Retention Index (RI).

[Y]RI = Kovats Retention Index

[X]Treatment combinations: Water = untreated control, MCP = treated with 200 ug*L^{-1} aqueous 1-MCP, +24 = 24 h ethylene treatment post-storage, +48 = 48 h ethylene treatment post-storage.

[W] n.d. = not detected in all replicates of the same treatment.

[V] Internal standard added to tentatively quantify peak areas. Only D6-phenol was used in calculating relative areas.

CHAPTER 8
COST OF APPLYING 1-MCP TO PERMIT 'TREE-RIPE' HARVEST OF 'ARKIN' CARAMBOLA IN FLORIDA

Introduction

The tropical fruit industry in Florida is worth an estimated value of $75 million. Carambola constitutes 13% ($9.5 million) of the total annual revenues for all tropical fruit produced in Florida (Kahout, 2004; J.H. Crane, personal communication). The Florida crop of carambola has two major harvest seasons: August to September and December to February. The trees can be strategically pruned and manipulated to bear fruit in the off season, however since the cost of labor is high this is not done on a large scale commercially (Nunez-Elisa and Crane, 2000).

'Arkin' is a sweet variety of carambola, selected during the 1970's by Morris Arkin. Currently 'Arkin' constitutes 95% of the Florida crop (J. Crane, personal communication). Carambolas are fairly well known by consumers. Only mangos, avocados, and papayas were rated as more familiar tropical fruits (Degner, 1997). Retailers can greatly influence the way carambolas are sold. Some grocery stores stock carambola to make the produce section more visually appealing even though they do not expect to sell many of them, therefore they do not stock the fruit continuously. Other grocery stores stock the fruit whenever it is in season; they also purchase fruit grown in foreign countries to supplement the supply from Florida. If the carambolas are not sold promptly, then they may be sliced and added to fresh-cut fruit salads (S. McManus, personal communication).

For produce buyers quality is the top concern, especially the appearance of the fruit. The biggest complaint that buyers have about carambola is bruising of the ribs (Degner, 1997). As demonstrated in this research, postharvest 1-MCP treatments can help to prevent bruising by maintaining the fruit firmness. Data from the experiments in Chapter 6 demonstrated that a postharvest 1-MCP treatment for carambola can limit postharvest losses. 1-MCP treatments extended days to peak ripeness stage by 2 d when fruit harvested at 1/4 and 1/2 yellow were stored at 5 or 10 ^{o}C. There was a similar trend for fruit harvested at 1/4 and 1/2 yellow and stored at 20 ^{o}C. 1-MCP treatment maintained firmness of fruit over the controls, which may help to prevent bruising. 1-MCP treatments might make it feasible to have a harvest later than the 1/4 yellow stage.

Harvesting the fruit later than the 1/4 yellow stage will yield sweeter fruit (Chapter 4). However, the fruit would have to stay on the tree up to ten days longer and they may be subjected to possible wind damage. Also, if fruit are left on the tree longer the harvest season might start later and the new fruit set might be suppressed. This can be overcome by selective pruning. Selective pruning techniques can promote an earlier harvest season (Nunez-Elisa and Crane, 2000).

It is difficult to estimate the actual costs of implementing 1-MCP treatments. The gaseous treatment is sold as the SmartFresh Quality System, which is a service provided by the AgroFresh Company. Gaseous applications of 1-MCP have similar effects to aqueous applications (Choi et al., 2008). Representatives from AgroFresh were unable to quote the cost of the service. A conservative estimate of the cost per box is $2, which would make it beneficial to producers and buyers to purchase the service. The 1-MCP treatment could potentially reduce shrink and extend shelf-life.

The objective of this analysis was to create a sensitivity formula to evaluate the costs of adding a postharvest 1-methylcyclopropene (1-MCP) treatment to carambola.

Postharvest 1-MCP treatments have proven to be effective in maintaining fruit firmness and extending shelf-life by extending days to peak ripeness.

Current Costs

The current production cost per acre for carambola in Florida is $15,838 (Based on a 50-acre operation). Harvest and marketing costs constitute $9,750 of the per-acre cost (Univ. of Fla. /IFAS, 2008). Economies of scale dictate that larger operations are able to control costs better and be more vertically integrated. A vertically integrated tropical fruit company may have its own packinghouse and therefore is able to apply postharvest treatments to their products. A larger and horizontally integrated company also has an advantage with labor. Keeping seasonal labor available would be easier for larger companies that also produce other crops. Larger companies can provide a permanent source of work and do not have to rely on third party labor companies for seasonal help (Roka, 2002).

Methods

A sensitivity analysis was performed to determine the costs of adding postharvest 1-MCP treatments to carambola. Since liquid 1-MCP is not available commercially, cost data was based on use of the gaseous application method. The cost of application was estimated in a range from $0.00 to $3.50 per box. A large range was used to ensure that the actual cost of 1-MCP treatment per box of carambola would fall within the range. The estimated cost of application was added to the average price per box of terminal markets in seven major U.S. cities. The average price per box was attained by averaging the price per box of carambola shipped from Florida for 3 weeks: the weeks of September 6, October 11, and November 1, 2008 (State of Florida, 2008b). The lowest price for a box containing 25 fruit was $8.00 in Philadelphia during the week of September 6th,

2008. The highest price for a box containing 25 fruit was $27.50 in Pittsburgh during the same week. Prices per box were separated according to fruit size. The terminal markets were: Atlanta, Chicago, Columbia, Dallas, Detroit, Philadelphia, and Pittsburgh. The price per box fluctuated with season and location of the terminal market. To calculate the price increase from the additional 1-MCP treatments a sensitivity calculator was developed. The calculator can be used for specific input variables (Object 8-1). The sensitivity formula was calculated according to Equation 8-1.

$$\mathbf{Y} = \frac{\mathbf{(M + P_{box})}}{\mathbf{(n)}} * \mathbf{[1.0 + \%\ Markup} \qquad (8\text{-}1)$$

where

Y = the retail price per fruit;

M = the cost per box of 1-MCP treatment;

P_{box} = the wholesale price per box of carambola;

n = the number of fruit in a box or sizing number of fruit in a box (20s = 20 fruit per box);

Markup = the percentage markup of the retailer.

Percent markup was added to the price per box at the terminal markup. Thirty-four percent of fresh produce is sold to retailers from terminal markets, 24.6% of fresh produce is sold to retailers from broker/dealers, and 41.1% of fresh produce is sold to retailers directly from shippers. Percent price-markup changes depending on the distribution channel a product takes. Larger grocery retailers (more than $1.5 billion in annual sales) are more likely to purchase fresh produce directly from producers, while smaller grocery retailers purchase fresh produce from wholesalers and/or distributors that are supplied by terminal markets (McLaughlin and Perosio, 1994). Distributors' price-markup ranges from 25% to 30%, wholesalers' price-markup ranges from 10% to 20%, and retailers' price-markup ranges from 30% to 50% (Wolfe, 1999). These markups are compounded and the price-markup range from the terminal price is 30% to 115%.

Results

For a 20-count box of carambola the additional cost of 1-MCP treatment per fruit was calculated to range from $0.03 to $0.18 at the break-even level (Table 8-1). For a 25-count box of carambola the additional cost of 1-MCP treatment per fruit ranged from $0.02 to $0.14 at the break-even level (Table 8-2). During the months September through November 2008, 25-count boxes were the median size for carambola sales in the United States. For a 30-count box of carambola the additional cost of 1-MCP treatment per fruit ranged from $0.01 to $0.11 at the break-even level (Table 8-3). The price range of an individual fruit at the retail level is affected by the percent markup; the range gets wider as the percentage markup increases.

Discussion

Results from this present study have shown that postharvest 1-MCP treatments for carambola have proven to be beneficial for maintaining fruit firmness and extending shelf-life. The cost of adding postharvest 1-MCP treatments has proven to be feasible. Since a box of carambola typically contains 20 to 30 fruit the increase in break-even price for a box of treated fruit would only be 7 to 18 cents per fruit. This increase is small enough to easily be passed on to the end consumer. The retail price of fresh produce swings more than other items sold in a grocery store due to production season and supply. The retail prices of fresh and lightly processed produce increase faster than they decrease in response to the increase in terminal prices (Sexton et al., 2003).

Conclusions

Visual quality is the most important concern for produce buyers. Carambola is a unique fruit that can benefit from postharvest 1-MCP treatments to maintain quality, particularly visual quality. Based on the assumptions used in this analysis, the costs of postharvest 1-MCP treatments for the fruit are small and the possible benefit from reducing postharvest losses is large. Therefore it is feasible to treat carambola grown in Florida with postharvest application of 1-MCP.

Table 8-1. Estimated retail price per fruit of 1-MCP treated carambola, including a range of markup percentages (based on $18.45 for a box of 20 carambola).

		Estimated retail price per fruit ($ per individual fruit)						
Increase in price per box ($)	New price per box (size 20/box)	Break Even	30% Markup	45% Markup	60% Markup	75% Markup	100% Markup	115% Markup
0.00	18.45	0.92	1.20	1.34	1.48	1.61	1.85	1.98
0.50	18.95	0.95	1.23	1.37	1.52	1.66	1.90	2.04
1.00	19.45	0.97	1.26	1.41	1.56	1.70	1.95	2.09
1.50	19.95	1.00	1.30	1.45	1.60	1.75	2.00	2.14
2.00	20.45	1.02	1.33	1.48	1.64	1.79	2.05	2.20
2.50	20.95	1.05	1.36	1.52	1.68	1.83	2.10	2.25
3.00	21.45	1.07	1.39	1.56	1.72	1.88	2.15	2.31
3.50	21.95	1.10	1.43	1.59	1.76	1.92	2.20	2.36

Table 8-2. Estimated retail price per fruit of 1-MCP treated carambola, including a range of markup percentages (based on $20.15 for a box of 25 carambola).

Increase in price per box ($)	New price per box (size 25/box)	Estimated retail price per fruit ($ per individual fruit)						
		Break Even	30% Markup	45% Markup	60% Markup	75% Markup	100% Markup	115% Markup
0.00	20.15	1.01	1.31	1.46	1.61	1.76	2.02	2.17
0.50	20.65	1.03	1.34	1.50	1.65	1.81	2.07	2.22
1.00	21.15	1.06	1.38	1.53	1.69	1.85	2.12	2.27
1.50	21.65	1.08	1.41	1.57	1.73	1.89	2.17	2.33
2.00	22.15	1.11	1.44	1.61	1.77	1.94	2.22	2.38
2.50	22.65	1.13	1.47	1.64	1.81	1.98	2.27	2.44
3.00	23.15	1.16	1.51	1.68	1.85	2.03	2.32	2.49
3.50	23.65	1.18	1.54	1.71	1.89	2.07	2.37	2.54

Table 8-3. Estimated retail price per fruit of 1-MCP treated carambola, including a range of markup percentages (based on $22.73 for a box of 30 carambola).

Increase in price per box ($)	New price per box (size 30/box)	Estimated retail price per fruit ($ per individual fruit)						
		Break Even	30% Markup	45% Markup	60% Markup	75% Markup	100% Markup	115% Markup
0.00	22.73	1.14	1.48	1.65	1.82	1.99	2.27	2.44
0.50	23.23	1.16	1.51	1.68	1.86	2.03	2.32	2.50
1.00	23.73	1.19	1.54	1.72	1.90	2.08	2.37	2.55
1.50	24.23	1.21	1.57	1.76	1.94	2.12	2.42	2.60
2.00	24.73	1.24	1.61	1.79	1.98	2.16	2.47	2.66
2.50	25.23	1.26	1.64	1.83	2.02	2.21	2.52	2.71
3.00	25.73	1.29	1.67	1.87	2.06	2.25	2.57	2.77
3.50	26.23	1.31	1.70	1.90	2.10	2.30	2.62	2.82

CHAPTER 9
CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

‘Arkin’ carambola is popular because of its sweetness and has potential to be harvested later than the 1/4 yellow stage to exploit its natural sweetness. In this study ‘Arkin’ carambola harvested at the 1/2 yellow color stage had a higher sugar-to-acid ratio (20.3) than when harvested at the 1/4 yellow stage (15.9). The fruit that was harvested when completely orange was attractive and had high sugar content; however, these fruit had high amounts of ethanol and norisoprenoids, which are aroma volatiles that indicate an over-ripe flavor.

Weight loss and color development were delayed and volatile production was suppressed by storage at 5 ^{o}C and high humidity (85% to 95 %). The carnauba-wax treatment also slowed weight loss. By limiting weight loss, stem-end shriveling and fin margin browning were also slowed. However, the wax used in this test limited gas exchange and led to anoxic conditions inside the fruit, causing tissue browning and off-flavors. The waxing treatment also prevented the outer fins from turning yellow during storage.

Carambola fruit were only slightly responsive to ethylene. None of the ethylene treatments accelerated ripening sufficiently to promote a uniform appearance during storage and ripening, nor were compositional parameters affected. When exposed to 100 ppm ethylene for 48 h at 20 ^{o}C the epidermis of the fruit was slightly degreened, but surface pitting/ browning of the fruit increased during subsequent storage for 14 d at 5 ^{o}C. Fruit treated with 25 or 50 ppm did not have this response. Total volatiles increased, notably norisoprenoids that are associated with carotene degradation and over-ripe flavors.

Aqueous 1-methylcyclopropene (1-MCP) treatment at 200 ug*L^{-1} for 1 min maintained firmness in fruit harvested at 1/4, ½ or 3/4 yellow as compared to untreated control fruit. It also extended shelf life by up to 3 d for fruit harvested at 1/4 and 1/2 yellow. The 1-MCP treatment had no significant effect on the compositional parameters of the fruit, but did suppress total volatile production and prevented the outer edges of the fins from turning yellow. 1-MCP treatments at lower concentrations (50 and 100 ug*L^{-1}) had similar affects on appearance but at lower magnitudes, and firmness was not significantly maintained over the untreated controls. Volatile production was also slightly suppressed.

To attempt to accelerate ripening following 1-MCP treatment, fruit were treated with 200 ug*L^{-1} aqueous 1-MCP, stored for 14 d at 5 ^{o}C then treated with ethylene (100 ppm at 20 ^{o}C for 24 or 48 h). Although the fins of the fruit were slightly degreened, surface pitting/browning and fin margin browning were exacerbated and fruit produced norisoprenoid aroma volatiles which are associated with carotene degradation over-ripe flavor.

The cost of adding a 1-MCP treatment was estimated over a large range (from $0.25 to $3.50 additional cost per box) and found to be feasible. The retail price for individual fruit would be increased by less than $0.40 in most scenarios and could potentially be passed on to the consumer. Small increases in the retail prices of fresh produce are common and rarely change the demand for a commodity.

The aqueous 200 ug*L^{-1} treatment concentration of 1-MCP was most successful when treating fruit harvested at the 1/2 yellow stage. Harvesting fruit in this stage yielded sweeter tasting fruit and the price sensitivity analysis showed it to be economically feasible. If fruit were to be harvested at the 1/2 yellow stage and treated with 1-MCP they would last as long as non-treated fruit harvested at the 1/4 yellow stage and be just as firm. The eye-catching appearance of the fruit can attract customers and the sweet taste can convince them to purchase carambola again.

More research is necessary to determine the effects of 1-MCP on firmness, particularly to determine the relationship between treatment and impact resilience. These results would give valuable insight into the feasibility of later harvests. Also, since 1-MCP affected firmness and the aroma profile, sensory analyses should be conducted to determine the effect of 1-MCP on flavor and texture.

APPENDIX
OUTPUT FROM VOLATILE ANALYSIS USING A GAS CHROMATOGRAM

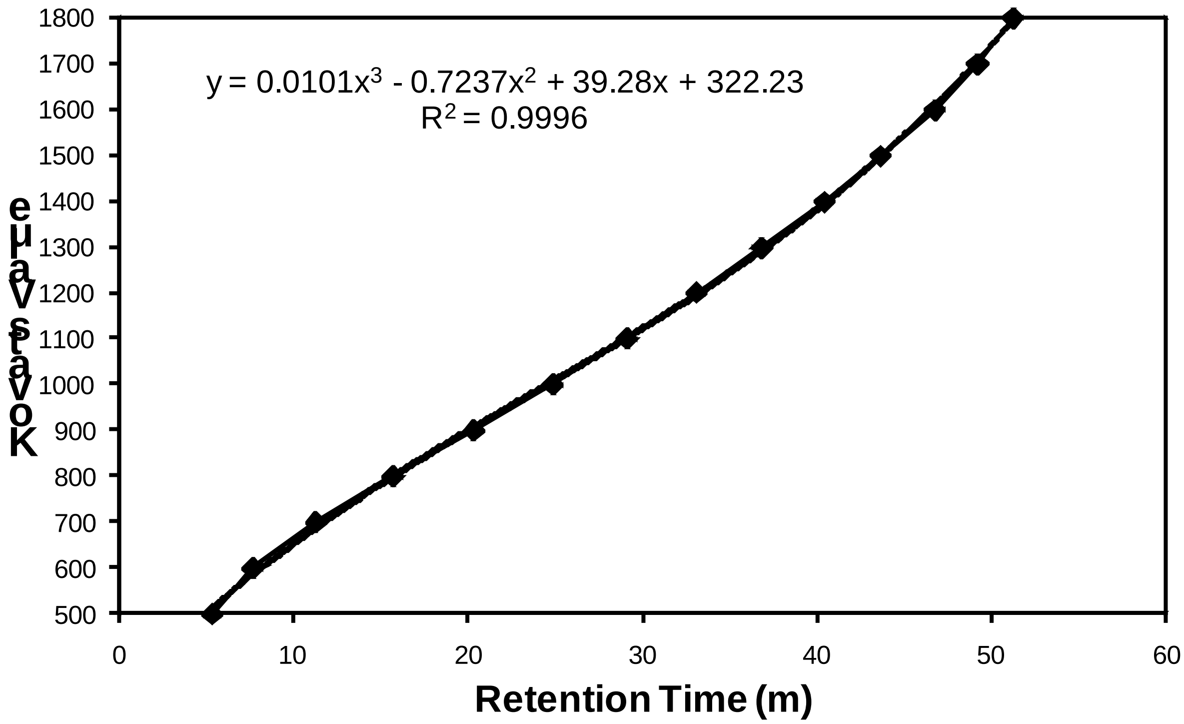

Figure A-1. Kovats retention index

A

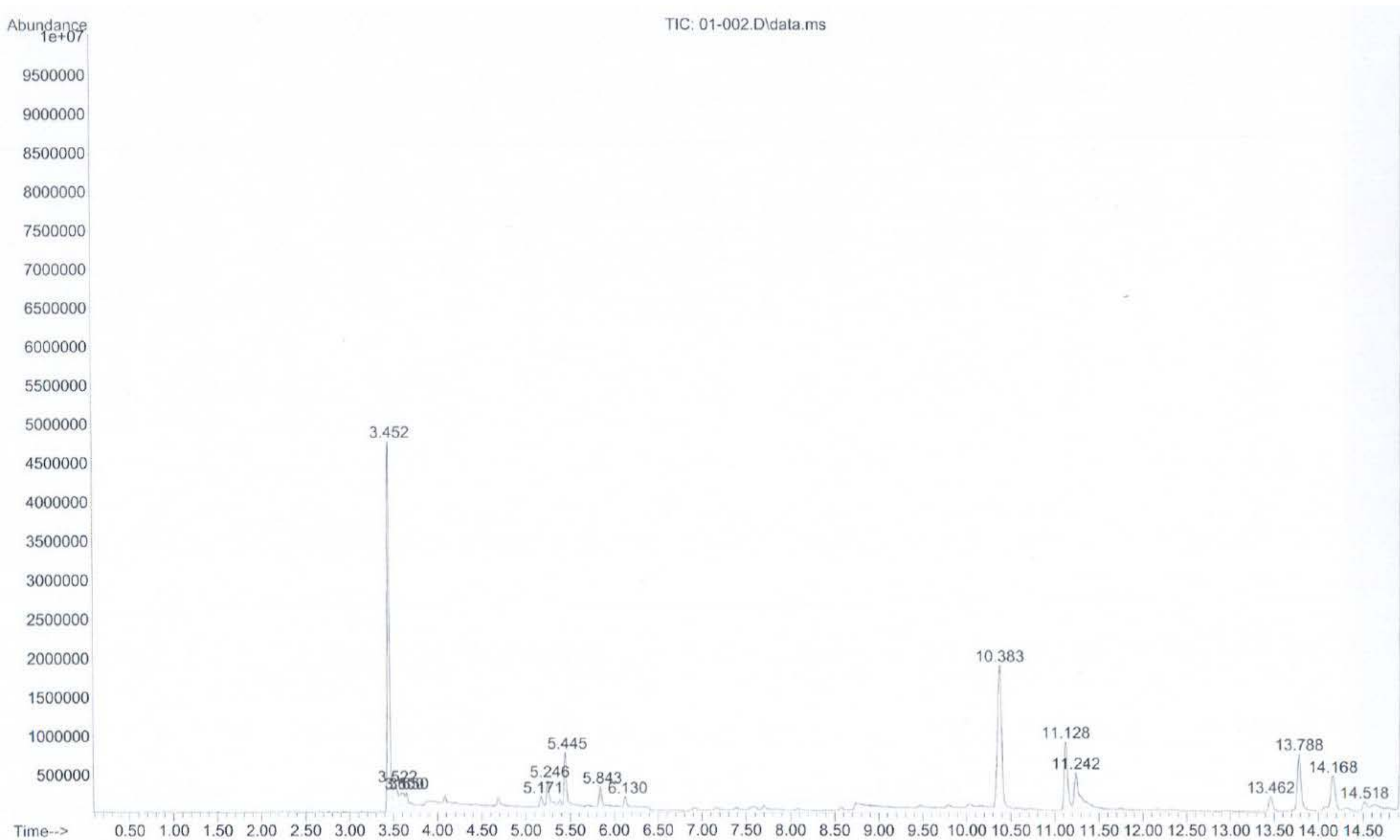

Figure A-2. Gas chromatograph of an initial sample harvested in the 1/4 yellow stage. A) Time 0 to 15 min; B) Time 15 to 30 min; C) Time 30 to 45 min; D) Time 45 to 60 min.

B

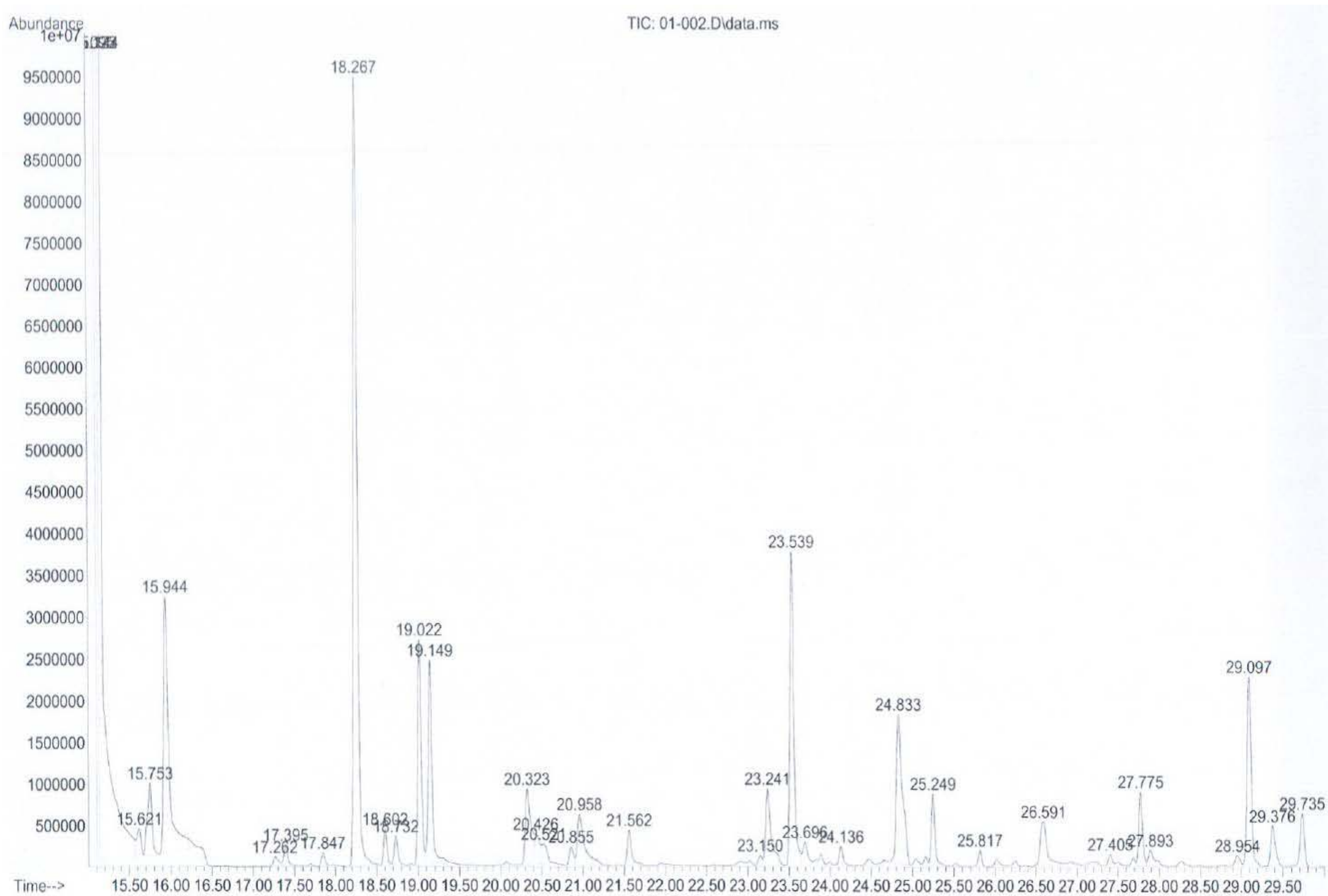

Figure A-2 Continued.

C

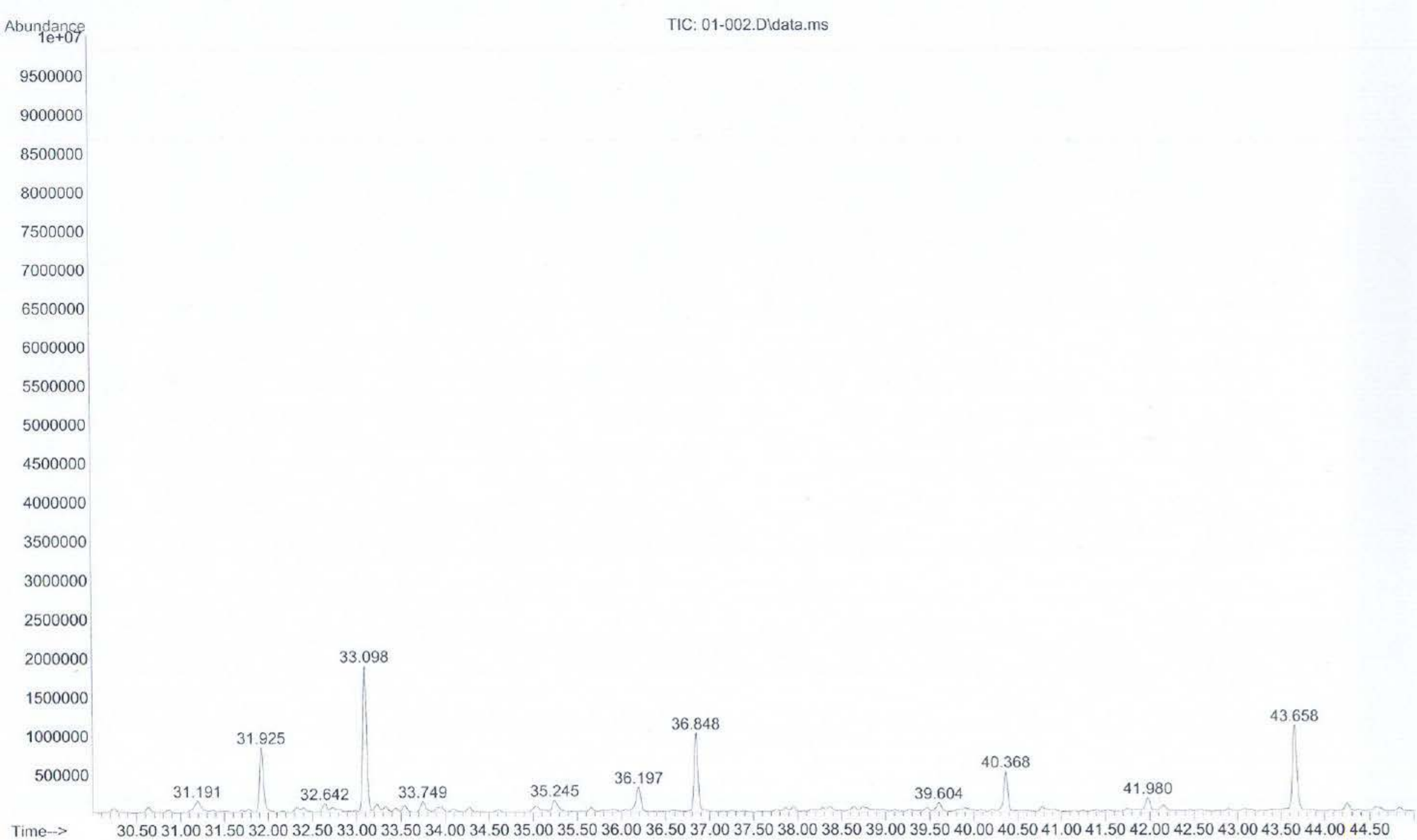

Figure A-2 Continued.

D

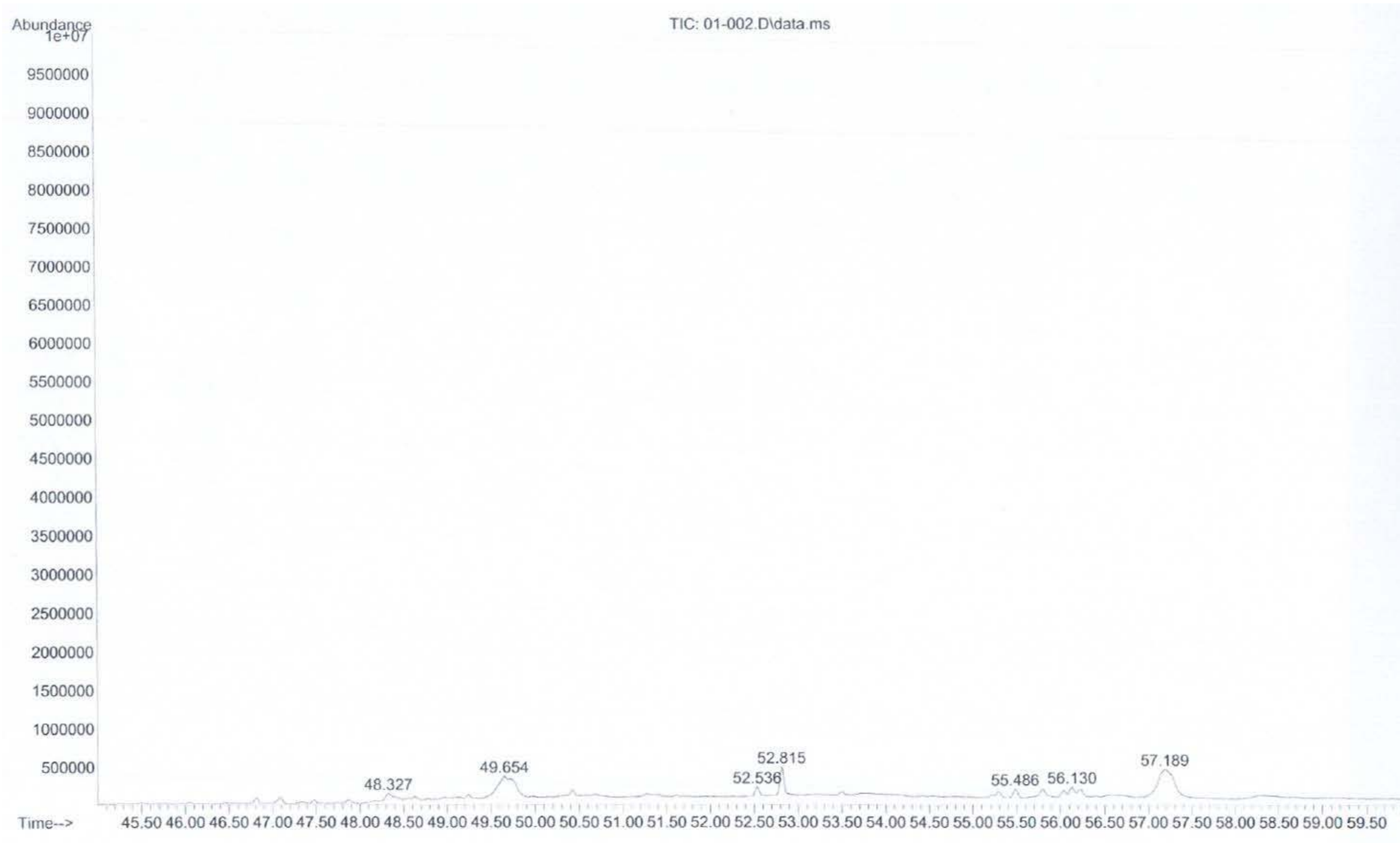

Figure A-2 Continued.

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BIOGRAPHICAL SKETCH

Oren Warren was born in Sydney, Australia. He graduated cum laude from the University of Florida in 2006 with a Bachelor of Science degree in horticultural science and a minor in business administration. Oren continued his education at the University of Florida and was awarded his Master of Science degree in horticultural science with a minor in agribusiness in May 2009.