EVALUATION OF POSTHARVEST LOSSES AND POTENTIAL NEW METHODS FOR THE HARVEST, TRANSPORT AND TEMPERATURE MANAGEMENT OF HAITIAN MANGOS DESTINED FOR EXPORT MARKETS

By

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Dedicated to my wife Freetzie D. Bonicet, my son Arthuro Bonicet, and my daughter Heloisha F. Bonicet

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LIST OF ABBREVIATIONS

ANEM	Association Nationale des Exportateurs de Mangues
FAS	Foreign Agricultural Service
FAO	Food and Agricultural Organization
IARI	Indian Agricultural Research Institute
M / T	Million Metric Tons
NAS	National Academy of Science
NMB	National Mango Board
OECD	Organization for Economic Cooperation and Development
PUFA	Polyunsaturated Fatty Acid
USAID	United State Agency for International Development
USDA	United State Department of Agriculture
USDA-APHIS	United State Department of Agriculture – Animal Plant Health Inspection System
USDA-APHIS-PPQ	United State Department of Agriculture – Animal Plant Health Inspection System - Plant Protection Quarantine
WINNER	Watershed Initiative for National Natural Environment Resources

Abstract of Thesis Presented to the Graduate School
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Postharvest handling and temperature management are very challenging and if not properly applied can lead to very high rates of loss. New materials and procedures were studied in relation to Haitian mango harvest and animal and truck transport; a second study investigated hydrocooling following heat treatment as an alternative to reduce the postharvest losses during export. In the harvest operations, use of a cutting pole/basket fitted with a V-cutter increased exportable fruit 340% compared to those harvested with the picking pole. This increase reduced the potential for the later development of sap burn. Moreover, and independent of the harvest aid use, trees of 15 m height had lower rates of fruit harvested with stems compared to those of 10 and 12 m. Use of plastic crates and new pack frame increased exportable fruit as much as 53% at the collection center compared to the traditional woven bag system. Also, use of plastic crates increased exportable fruit by 60% compared to those bulk-loaded on the truck upon arrival at the packinghouse.

Hydrocooling fruit within 30 to 90 min following the mandatory phytosanitary heat treatment showed good potential as an alternative to the current practice of room

cooling. Following export from Port-au-Prince to Miami, Florida, and ripening at 20°C, hydrocooled fruit showed an increase of 30% in shelf life and 16% in total carotenoids content as compared to room-cooled control fruit.

CHAPTER 1
INTRODUCTION

Mango (Mangifera indica L) is a tropical and subtropical fruit originated in Southeast Asia where it has been grown for over 4,000 years. Mango is the most important tropical fruit crop before pineapple, papaya and avocado. Mango is a member of the family Anacardiaceae; this family has numerous other species such as, cashew (Anacardium occidentale L), pistachio (Pistachio vera L) and several Spondias species. The genus Mangifera consists of 69 species, but other than mango only a few species bear edible fruit, such as Mangifera altisima Blanco. Mangifera foetida Lour., Mangifera lagenifera Griff,. Mangifera odorata Griff. Mangifera zeylanica Kooker., Mangifera caesia Jack and Mangifera sylvatica Roxb (Paul and Duarte, 2011). Geographically, two races of mango are recognized: the polyembryonic race distributed throughout Southeast Asia, including the region of the greatest species diversity within the genus, and the monoembryonic race thought to have originated in northeastern India (Ploetz et al.1994).

Mango is propagated by sexual and asexual methods. Mango seeds should be planted while they are still fresh, because they lose their viability within a few weeks. Asexual propagation methods include cuttings, grafting, budding or air-layering. But grafting is the most common method of propagation of mango. Grafted trees start to produce a good crop 3-5 years after planting while sexually propagated trees will take 5-7 years to produce commercially. Trees require, in tropical climate, a dry period to stop growing vegetatively and start to initiate blooming. Flowers are very susceptible to the fungal disease anthracnose, caused by Colletotrichum gloeosporiode, particularly when

rainfall occurs during flowering, and thus low rainfall is preferred at this stage (Paul and Duarte, 2011).

The world production of mango was estimated at 38.7 million tons in 2011 by FAO (2012); with more than 98% were produced by developing countries. India was the world's largest producer (16.3 m/t) followed by China (4.3 m/t), Thailand (2.5 m/t), Pakistan (1.8 m/t), Mexico (1.6 m/t) and others. The production of Haiti was estimated in the same time at 0.2 m/ t.

Worldwide, more than 95% of the production was consumed locally. The import market represented less than 5% of the worldwide production and was shared by the U.S.A (43.2%), China (10.18%), Netherlands (7.5%) and others. Most of the mangos sold in the United States were imported from Mexico, South America, Central America and the Caribbean, including Haiti. The top ten mango exporting countries in 2011 were Mexico, Philippines, Pakistan, Brazil, India, Netherlands, Peru, Guatemala, France and Haiti (CIA World Fact book online, 2012). In Haiti, scientists have identified more than 100 varieties of mango. Unfortunately, due to a lack of research studies, only a few varieties are exported to the International market. The most important variety is 'Madame Francique', which was found in Haiti, although mangos represent the largest percentage of the tree population throughout Haiti, postharvest losses remain very high. Many factors can cause losses in mango from the harvest step until the final consumer, but packaging and transport conditions are two major factors that challenge postharvest scientists. Around the world, many research projects have been aimed at improving postharvest materials and methods used in order to reduce the losses to an acceptable level. It is very difficult to estimate losses, because this is a culture-dependent decision

(NAS, 1978). Haitian mango production in 2011 was estimated at 200,000 tons for all varieties (FAO, 2012). But the most important variety, Madame Francique, accounted for more than 40,000 tons, and from this amount only 20,000 tons reached the packinghouses that exported 10,000 tons yearly (ANEM, 2011). In Haiti mangos are generally grown on small farms where access to roads can be difficult. The fruit harvested in the field are typically transported by donkeys or mules to a collection center, which is any place where the supplier can collect the fruit transported from the field and vehicles have access to transport the fruit to the packinghouse. Commonly, the fruit are loaded into a two-sided woven bag, plus a sack of fruits on the top of each side. This method causes losses due to fresh mechanical injuries, such as bruising, cuts and punctures. In Haiti, the total rejection for mangos was estimated at 55% from the field to the packinghouses, but when divided into different segments, it has been reported that the losses are 15% at the collection centers (Medlicott, 2001).

The USAID/WINNER/PROJECT, under the leadership of its chief of party, Jean Robert Estimé, has targeted growers in the Cul de sac and Mirebalais regions of Haiti with the aim to improve the living conditions of the growers by providing them with improved techniques, methods and materials of production. In the mango sector, WINNER has been responsible for training people in grafting and has helped in reinforcement of grower associations. In 2011, the WINNER-project provided 1,500 plastic crates and several mobile collection points or packing sheds to different associations involved in mango production and export for the improvement of the handling and transport conditions, to name a few.

Also, In 2011 WINNER paid for research trips in three regions of mango production, Mirebalais- Saut d'Eau, Matheux and Gros-Morne. At that time the harvesting season was almost done. Thus, data could not be collected, but good connections were established for the next year.

Since the 1970's the demand for fruit has increased dramatically in the world, particularly in the USA. In fact, the demand for mango increased. In the U.S., fresh fruit consumption per capita increased at an average annual rate of 0.9% over the period of 1976- 1999 (Kader, 2002). From 1993 to 2009 the volume of mango imported by the U.S Market has been doubled to reach more than .30 m / t and worthed as much as $ 200 million. Over the same years the U.S. per capita mango consumption increased from .4kg to .9 kg (FAS, 2010, and Ward, 2011). These facts stimulated some entrepreneurs worldwide and particularly in Haiti to invest in the export market, particularly the USA one (the largest worldwide mango importer). Since, several mango exporter enterprises in Haiti were accredited by the USDA-APHIS to trade with importer enterprises located in the U.S. The last decade, Haiti exported about 20% of the national production of 'Madame Francique' to the U.S market according to the exporter JM. Buteau, owner of JMB, SA, a packinghouse facility in Port-Au-Prince. Even though, the national production of 'Madame Francique' was not enough to meet the full U.S. demand. However, a reduction of the postharvest losses should be useful, and Haiti will be allowed to increase the volume of mango for export and for the domestic markets.

CHAPTER 2
LITERATURE REVIEW

Background

Mango *(Mangifera indica L.)* is one of the most well-known fruits worldwide because of its attractive color, delicious taste and excellent nutritional properties (Ding and Syakirah, 2010; Medlicott et al., 1986). Mango is cultivated in the tropical and sub-tropical climates. It is marketed fresh, dried and as a juice, and used as a source of flavors, fragrances and colorants (Paul and Duarte, 2011). Mangos have been cultivated in the Malayan peninsula since the ancient times and spread from there throughout the tropics (Snowdon, 1990). Mangos grow on large, spreading and evergreen trees. Grafting is the preferred method of production as opposed to seedling (Singh, 1960; Snowdon, 1990). Without regular horticultural practices (pruning for example), a heavy crop is followed by a light crop season. Mango shows a climacteric pattern of respiration, and the onset of ripening is characterized by five-fold increase in heat production, four-fold in carbon dioxide production (respiration), and ten-fold in ethylene production, which can affect negatively the postharvest handling (Brecht, 2010; Krishnamurthy and Subramanyam, 1973). At the range of temperature of 10° to 15°C, mature-green mango can be kept for several weeks, and ripe fruit must be kept at 7° or 8°C.

The WINNER project that supports this research is implemented by Chemonics under contract with USAID in partnership with Subcontractors Ch2M Hill, the University of Florida (UF), Research Planning Inc, and Caudill Web. The project aims to improve the living conditions of people in the watersheds of Cul de Sac and in other watersheds, reducing threats of flooding, and invest in sustainable economic growth and in

protecting the environment. The main goals are: (1). Improve the livelihood of the population of target watersheds by increasing agricultural productivity and generating alternative sources of off-farm income, (2). Strengthen the governance of watersheds.

In its partnership with the University of Florida, eight scholarships were granted for masters and one of them had been decided to focus his research study on postharvest issues in mango in Haiti.

Harvest Maturity

Postharvest operations start at the moment when the grower will make the decision to cut the relationship between the fruit and the tree (Florkowski et al., 2009; Shewfelt and Prussia, 2009); this decision can depend on the maturity indices. The maturity at harvest is the most important factor that determines postharvest quality (Kader, 1996; Schouten et al., 2004). Fruit can be harvested at horticultural or physiological maturity. Normally, fruit destined to green market are picked at horticultural maturity, where fruit will be consumed or used without reaching a ripening stage. Therefore fruit destined for fresh market must be harvested at the physiological maturity; and must be able to ripen after harvest. Based on the distance between the final consumer and the producer; fruit can be harvested full ripe, semi-ripe or mature-green. Mangoes picked for nearby markets may exhibit color changes from dark-green to light green or even to yellow green. Fruit are harvested while they are still at the dark green stage before the start of the climacteric (i.e. ripening is divided by pre-climacteric, climacteric peak, climacteric and post- climacteric based on ethylene production of the fruit) if destined for distant market which requires several days of transit (Kader, 2002; Lakshminarayana, 1973; Snowdon, 1990). Understanding the complexity of quality production and the inherent variability in living fruits and vegetables will afford the

postharvest worker a greater appreciation for the challenges and limitations growers face in delivering consistently high-quality produce to the marketplace (Shewfelt and Prussia, 1993).

To determine the maturity, scientists and field workers consider many parameters: for fruit destined to green market the shape and size of the fruit are the most important, while for fruit destined to fresh market the time or the number of days after full bloom is taken into account to determine the harvesting period. For most mango cultivars, fruit can be judged to be mature once the shoulders have risen above the stem-end (Cheema et al, 1950; Snowdon 1990). Moreover, 16-22 weeks after the fruit set, the survivor fruit reaches physiological maturity. Changes in flesh texture (softening), flesh color; skin color, total soluble solids, and acidity have not proven to be useful, because they occur mostly after the proper harvest time for distant markets. Studies suggest that flesh color, starch content, and specific gravity might be useful indices for some cultivars (Kader, 2002). It can be concluded that the stage of maturity of mango at the time of harvest is crucial for the eating quality of the ripe fruit (Brecht et al., 2010). In addition, mango as a climacteric fruit is not considered to be of desired eating quality at the time it initially becomes mature, but requires a ripening period before it achieves the taste and texture desired at the time of consumption (Slaughter, 2009). Therefore, the eating quality will maintain the relationship between producer and consumer, and without this link, the mango channel would be broken. To sum up, there are many maturity indices. In Haiti, harvest indices for both domestic and export are based on nondestructive methods that consist in the observance of shape and color changes. Also harvesting period for mango ‘Madame Francique’ is linked to the

geographical site. For instance, in Mirebalais area (east) harvesting period starts mid-April, while it starts mid-May in Gros-Morne (north).

Methods of Harvest

Harvesting practices should cause as little mechanical damage to produce as possible. Harvesting results in the loss of water and sugars as storage time increases and vital processes such as respiration and transpiration continue (Zerbini, 2008). Harvesting is the first step in ensuring quality, and must be performed properly to reduce losses (Kitinoja, 2002). Harvesting at the optimum maturity is best for consumption quality (Florkowski et al., 2009). Poor harvesting techniques can negatively affect the good work of the whole season. Picking of fruit before or after the ideal picking date, and any of the practices that can result in bruising and damages to the fruit affect the quality of the fruit (Yahia, 1999). Early morning harvesting is important because these are the coolest hours of the day, and allow for lower temperatures and respiration rates. Therefore, some citrus are damaged if they are handled when they are turgid in the morning (Eckert and Eaks, 1989; Florkowski et al., 2009).The methods of harvesting may vary depending on the horticultural practices applied in the grove. Fruit located at the lower part of the trees, regularly pruned and maintained as short (3 to 5 m) as possible, can be picked by hand using a pair of scissors, prior to be loaded into any container and avoided to be physical damaged. Mangos located at the upper part of the trees are usually picked by a long poll with a net at the end. The net must be built with a V-cutter, in order to cut the stem of the fruit with about 5 cm, and avoided the latex to fall down onto the peel, and then decreased postharvest losses due to sap burn. Prior to transport fruit harvested with stem to the collection center or the packinghouse, the long stem should be trimmed to the abscission zone (with 1 cm) and place the fruit

with the stem end down to allow latex to drip without touching the fruit's peel (Brecht et al., 2010). The current practice of harvest in Haiti consists of three steps:

1. A picker climbs the tree with a long picking pole with basket; he pulls over the peduncle of the fruit estimates mature. When two to four fruits fall into the basket, he brings the basket to him, and then he drops the fruit one by one to the Catcher.
2. A catcher steps under the tree with a flat sack then catches on it the fruits drop by the picker to avoid them to reach the ground and be physical damaged.
3. A "disaper" collects the fruit on the flat sack, cuts their stems if the fruit reach the ground with stems, and then turns all fruit stem down to drain latex.

Transport from the Field to the Collection Center

In Haiti mangos are generally grown on small farms where access to roads is generally difficult. The fruit harvested in the field is typically transported by donkeys or mules to a collection center where vehicles have access to transport to packinghouse. Commonly, the fruits are loaded into two-sided woven bags, plus a sack of fruits on the top of each side. This method causes losses due to fresh mechanical Injuries, such as bruising, cuts and punctures.

Transport from the Collection Center to the Packinghouse

In the collection center, after a second pre-sorting (Figure 2-1), selected fruit are transported to the packinghouse by truck, where the fruits are loaded in bulk in the truck bed where contacts among the fruits are dense, and do not allow regular air circulation, also mechanical injuries may result from this type of transport due to compression and vibration.

Packaging

Packaging is the enclosure of products, items or packages in a wrapped pouch, bag, box, cup, tray, can, bottle or other container to perform the following functions: containment; protection; and or preservation; communication and utility or performance

(Chakraverty et al., 2003). Modern packages for fresh fruits are expected to meet a wide range of requirements which may be summarized as follows:

- The packages must have sufficient mechanical strength to protect the contents during handling and transport and while stacked.
- The construction material must not contain chemicals that can transfer to the produce and cause it to become toxic to humans.
- The package must meet handling and marketing requirements in term of weight, size and shape. The current trend is to reduce many sizes and shapes of packages by standardization.
- The package should allow rapid cooling of the contents by a good circulation of the cooling medium (air, water) through the packages. Furthermore the permeability of plastics films to respiratory gases may also be an important requirement.
- The security of the package or its ease of opening and closing may be important in some marketing situations.
- The package should identify its contents.
- The packages may be required either to exclude light or to be made from transparent materials.
- The package may be required to aid retail presentation.
- The package may need to be designed for ease of disposal, reuse and recycling.
- The cost of the package should be as low as possible (Smith et al., 2003).

Packaging is an important component in the market chain. Usually, packages style and type are function of produce, materials available, segment in the market chain, and target market and transport system. Some produce requires small package (e.g. berries), because they have little mechanical resistance (Florkowski et al., 2009). Packaging may occur directly in the field or in specially designed facilities called packinghouses (Shewfelt and Prussia, 1993). Bulk packaging is the most common method of transport of mango in Haiti to packinghouse. Recently introduced in this

segment, the plastic crate is bringing significant improvement in terms of reduction of loss due particularly to mechanical injuries (Buteau, JMB.SA, Personal Communication).

Harvest method could be improved by the introduction of a picking pole, and transport by the introduction of plastic field crates. However, these materials were not easily appreciated. In the past, growers have used a kind of harvest aid with cutter that allowed cutting the peel of the fruit. Therefore, after several trials with the new harvest aid, they were convinced that the current model is different to the previous one. Because the picking pole had allowed the picker to cut the peduncle of the fruit with a few lengths of stem that avoided the spurting of the sap onto the peel of the fruit, and protected the fruit from sap burn. Consequently, the picker showed enthusiasm for the introduction of the picking pole in their harvesting practices.

Other critical point of losses in the segment field to collection center is the transport. Losses occur when the fruit were loaded in woven straw baskets mounted on the backs of donkeys or mules for transport down hillsides (Medlicott, 2001). The plastic field crates loaded into an appropriate pack-frame could be a relevant alternative to the woven bag in this segment where losses due to fresh mechanical and heat injuries must be important. Medlicott (2001) estimated that the losses at the collection centers when traditional woven bags were used should vary from 10 to 25% (Table 2-1). The use of plastic field crates may reduce the loss by at least to 5%.

Rejection Types and Causes

About one-third of fresh produce harvested worldwide is lost at various points in the distribution system between production and consumption site. While it may be impossible and uneconomical to completely eliminate these losses, it is possible to

reduce them by 50% (Kader, 2002). For each postharvest operation there is a possibility of some losses either in quantity or in quality of crop product. For cereals, the overall postharvest losses are usually estimated to be in the range of 5-20%, whereas for fruits and vegetables it may vary from 20% to 50% (Chakraverty et al., 2003). In developing countries, poor handling and inadequate cooling and temperature maintenance are the most important causes of postharvest losses. For vegetables and fruits like mangoes, grapes, stone fruits, bananas, apples, tomato, melons and citrus, the principal causes of postharvest losses and poor quality are in order of importance as follows: Bruising, over-ripeness and excessive softening at harvest, water loss, chilling injury, compositional change and decay (Kitinoja and Kader, 2002). Some causes can be more relevant depending upon the point they are found in the mango chain. For instance, in the field most fruits are rejected due to mechanical injury, immaturity, misshapen, stain and disease. However, sap burn and mechanical injury are the predominant causes in collection centers and in packinghouses. Postharvest diseases and disorders such as anthracnose, black spot, black mould-rot, stem-end rots, multiple injuries, internal breakdown, to name a few. They are more relevant, while the ripeness is occurred. However, it would be preferable to prevent their occurrence by pre- and postharvest measures such as good horticultural practices in the field (good management of canopy and fertilization, pre-harvest antifungal spraying) and postharvest treatment.

Postharvest Treatment

Washing is useful to control sap burn, and disease. Nevertheless, the water must be clean, potable and sanitized to kill any potential microbes that can contaminate the fruit. Water chlorination is currently the best, approved way to continuously sanitize water in hydrocoolers (Ferreira et al., 1996). In Haiti, fruit destined for export were

washed at the collection point for the control of sap burn, with little consideration for disease control. Most packing operations included a means of removing foreign objects, sorting to remove substandard items, sorting into selected size categories, inspecting samples to ensure that the fruit or vegetable lot met a specified standard of quality (Shewfelt and Prussia, 1993).

USDA- APHIS Requirements for Exportation

Fresh mangos cannot be exported to the U.S. if the fruit were not correctly treated according to USDA-APHIS regulations. This is to avoid the introduction of live larvae of various fruit flies (*Anastrepha suspensa, A. oblique*) into the U.S. that can be detrimental for the U.S agriculture, particularly in the southern regions where the climactic conditions can allow the insects to spread. Much research has been done on the topic of mango heat treatment for insect quarantine. Now each grade (based on weight and shape) has its own requirements in terms of hot water treatment procedures (Table 2-2). The heat treatment can negatively affect the quality of the fruit, which is a big concern for the consumers, the retailers, the wholesalers, and the National Mango Board. The final goal is the satisfaction of the consumer because if he/she is not satisfied the entire channel will be compromised. Heat treatment can be one of the main causes of quality losses in mangoes during marketing. For example, heat injury can result in surface scald, internal discoloration, and internal air pockets and tissue collapse. While we cannot avoid the hot water treatment yet, the post hot water cooling can help in the reduction of the bad effects of heat treatment. Therefore, the respect of the requirements for heat treatment must be followed such as the maturity of the fruit, the size and the shape of fruit. In the packinghouses in Haiti, the packers treat the fruits at 46.1°C for 75 to 90 minutes depending on the size of the fruits (Table 2-2), then

remove them from the tank and let them cool slowly at the room temperature (25- 35°C) for about 24 hours. Currently USDA-APHIS authorizes people to use faster methods to cool the fruits in order to improve the quality of the fruits. The hydrocooling is the fastest method of cooling for mango. USDA proposes two methods: First, add 10 minutes on the heat treatment time (75-90 min+10) and hydrocooled immediately after heat treatment or do the normal heat treatment then leave at ambient temperature for at least 30 minutes, following by hydrocooling. In both cases the hydrocooler water temperature cannot be below 21.1˚C. Hydrocooling slows down the metabolic rate of the fruit (de Leon et al., 1997). As a consequence, it delays the ripening initiation, and may reduce heat-related disorders.

Impact of Heat Treatment on Quality

Hot water treatments increased the respiration rate, water loss, and carotene content in mango (Yahia and Pedro-Campos, 2000). Heat treatment can damage either the external appearance or the quality of the fruit (Figures 2-2 and 2-3). Normally, heat injury results from exceeding the time and /or temperature combinations recommended for decay and /or insect control (Brecht et al., 2010). Immature fruit are more sensitive to heat injury than mature fruit, at normal treatment temperature, immature fruit can be damaged. Symptoms of heat injury are as follows: lenticel spot, uneven ripening, shoulder collapse, blotchy coloration, and skin scald and void spaces in the flesh due to tissue death (Brecht et al., 2010).

Effect of Hydrocooling Treatment on Quality

Most commodities should be quickly cooled for removal of field heat to an appropriate temperature for successful shipment over long distance (Ferreira et al., 2006; Sargent et al., 1991). Hydrocooling removes heat faster than any other methods

of cooling. A given volume of water can remove more heat than the same volume of air at the same temperature (Ferreira et al., 2006; Thompson et al., 2002). However, hydrocooling should only be applied to commodities that are tolerant to direct contact with water and not be sensitive to sanitizing chemicals, such as chlorine (Ferreira et al., 2006; Kays et al., 1991). Hydrocooling does not remove water from the produce when compared with forced-air cooling for example; it can even revive slightly wilted produce (Thompson et al., 2008). Molinu et al., (2010) had showed that hydrocooling improved the keeping quality of pears (*Pyrus communis*); the pulp of the fruit remained more firm than those that were not hydrocooled, and internal breakdown in early ripening pears was delaying. Studying the effect of hydrocooling on ripening related quality of sweet cherry fruit *(Prunus avium L.),* Manganaris et al., (2007) found that hydrocooling delayed the deterioration and senescence, reduced stem browning and surface shriveling, but soluble solids content were not affected by hydrocooling, then the hydrocooled retained their quality for a further 3 days at room temperature. Hydrocooling as a rapid method of cooling is applicable for many types of fruit, particularly mango. But the water must potable to avoid any contamination of the fruit by infiltration of water into the pulp of the fruit treated.

Nutritional Value and Chemical Properties of Mango

Mango cultivars showed different tendency for vitamin A and vitamin C contents during ripeness stages. Vitamin C content varied from 19 mg/100g in Tommy Atkins to 125 mg/100g in ‘Ataulfo’ (Perkins-Veazie, 2007). Total carotenoid concentrations in the mango pulp are usually in the range of 900–9,200 µg/100 g (Litz, 1997). Carotenoids are yellow, orange and red pigments present in many eaten fruits and vegetables (Astorg, 1997; Holden et al., 1999). More than 600 carotenoids have been identified, but

the five most known and studied are: α-carotene, β-carotene, lycopene, lutein and β-cryptoxanthin (Holden et al., 1999). Mercadante et al., (1997) found for cultivar 'Keitt' 5,500 µg/100 g. The Indian cultivar 'Alphonso' showed high values of up to 11,000 µg/100 g (Padmini and Prabha, 1997). Khurdiya and Roy (1988) reported respectively, 16,199, 9,525, and 11,956 µg/100 g for 'Amrapali', 'Mallika' and 'Dashehari', three Indian cultivars, when they reached full- ripe stage at room temperature in 7 to 9 d. Mango behaves differently in terms of vitamin C and vitamin A concentration during the ripening period, where the concentration of vitamin A increased while the fruit ripened (John et al., 2010). Mango showed an increased in β-carotene the first three days of storage that may be due to an increase in mevalonic acid and geraniol syntheses (Mitra and Baldwin, 1997). In contrast, the fruit decreased dramatically in Vitamin C content while it ripened. The concentration in ascorbic acid of 'Mallika' varied from 32.2 to 20.1 mg/100 g over a period of 9 d .i.e. from the mature green-stage to full ripening stage (Khurdiya and Roy, 1988). Aina (1990) attributed this decline in Vitamin C to the tendency of the molecule to oxidative destruction.

According to Perkins-Veazie (2007) fruit soluble solids content varied from 14% to 18% and pH from 3.8 to 4.1. Total Soluble Solids in 'Alfonso' cultivar at full ripeness varied from 14.6 to 19.2% and the Acidity from 0.38 to 0.65% (Roy and Joshi, 1988). Total titratable acidity (citric acid) decreased with storage (Palejwala et al., 1988). Thus, the pH increased with storage. Toraskar and Modi (1988) found the pH of unripe mango was about 2-3 whereas, it was about 5-6 in ripe fruit. The acidity of two Pakistani cultivars was found in the range of 0.16 - 0.33 % and 0.19 – 0.30% respectively for cultivars 'Sinhri' and 'Chaunsa' (Maqbool et al., 2009).

Sorting and Grading

Sorting and grading can be done by hand and/or mechanically. Incoming produce is placed in the sorting bin, sorted by one worker into the packing bin, and finally packed by a second worker. A firm rubber pad for the floor can help reduce fatigue, if workers must stand to sort produce (Kitinoja and Kader, 2003). Hand sorting can be used to segregate product by color, size, and grade. It demands good equipment design, and the design should have adequate space for sorting personnel (Kader, 2002). Many kinds of mechanical seizers are used. All segregate by weight or dimension. Traditional dimension seizers measure the product by two, three, or four point contact. Electronic seizers capture several video images of each piece of product as it moves over a load cell. A properly selected seizer must have adequate capacity and accuracy, and it must not injure the product (Kader, 2002). Sizing mangos for hot water treatment may be accomplished manually or automatically by weight or dimension. If dimensional sizing is used, fruit weights must be checked frequently to ensure that the proper fruit weight classifications are being achieved (Brecht et al., 2010; USDA-APHIS PPQ, 2010). By grading mangos the packers try to avoid sending undesirable product to the consumers. Numerous criteria are usually used to grade mango like physical injuries, and evidence of decay. OECD (1993) graded fruit into three classes, extra, class I and II. And based on market quality OECD made three groups also, superior quality, good quality and marketable quality. The grading is based on the appearance, the shape, the coloring and the defects. So, fruit of superior quality must show the appearance, the shape and the color characteristic of the variety, and very slight superficial skin defect is allowed. Fruit of good quality must show appearance, shape and color of the variety but slight skin defect of 3 to 5 cm^2 is

allowed. However, fruit of marketable quality are keeping with minimum requirements and skin defects can vary from 5 to 7 cm^2.

Research Goal and Objectives

The goal of this research project was to evaluate selected technologies that have the potential to reduce the postharvest losses during harvest, handling and packing of Haitian mangos in order to increase the volume of mangos both for international and domestic markets. The specific objectives were:

1. Estimate the actual postharvest losses of mango due to the traditional methods of harvesting, transport and packaging in Haiti.
2. Evaluate the use of a picking pole with cutter and new pack frame and crates to reduce postharvest losses during harvesting, transport, and packing.
3. Compare hydrocooling shortly after heat treatment with room cooling and effects on fruit quality following export to Florida.
4. Propose new materials and methods based on the results for the improvement of the Haitian value chain.

Table 2-1 Estimation of rejection at each handling step of Haitian mango.

Area	Rejection	Rejected by	For export	Causes of rejection
Tree or Field	20 %	Grower	80%	Maturity, on-tree scarring
Collection center	15%	Grower/ Buyer	65%	Mechanical injury, maturity
Packinghouses reception	20%	Exporter	45%	Mechanical damage, maturity
Packed prior to shipment	20%	Exporter	25%	Over-ripe, heat injury Maturity
Total	75%[z]		25%	

Adapted from Medlicott. 2001. Postharvest improvement program for the Haitian mango industry. USAID/DAI/HAP. Technical study. pdf.usaid.gov/pdf docs/PNACL742.pdf

[z]rejected for export but not 100% for local market.

Table 2-2 Hot water treatment requirements.

Mango shape	Fruit weight(grams)	Time required (minutes)
Rounded varieties:	≤ 500	75
T. Atkins, Kent, Haden, Keitt	501-700	90
	701-900	110 (Mexico)
Flat varieties: Madame	≤375	65
Francique, Ataulfo, Manila	376-570	75

Adapted from USDA. 2009. National Nutrient data base. http://www.nutrition-and-you.com/mango-fruit.htmlSource, USDA, 2009

Table 2-3 Mango fruit nutrient content values per 3.5 oz. (100g of fresh weight).

Item	Value	Unit	Item	Value	Unit
Water	82	%	Vit B-6	0.13	Mg
Calories	70	Kcal	Riboflavin	0.06	Mg
Protein	0.50	G	Calcium	10	Mg
Total lipid	0.27	G	Magnesium	9	Mg
Dietary Fiber	1.80	G	Phosphorus	11	Mg
Vit C	27.7	Mg	Potassium	156	Mg
Vit A	765 or 0.23	IU or mg	Iron	0.13	Mg
Folate	0.01	Mg	Sodium	2	Mg

Adapted from USDA. 2009. National Nutrient data base. http://www.nutrition-and-you.com/mango-fruit.htmlSource, USDA, 2009

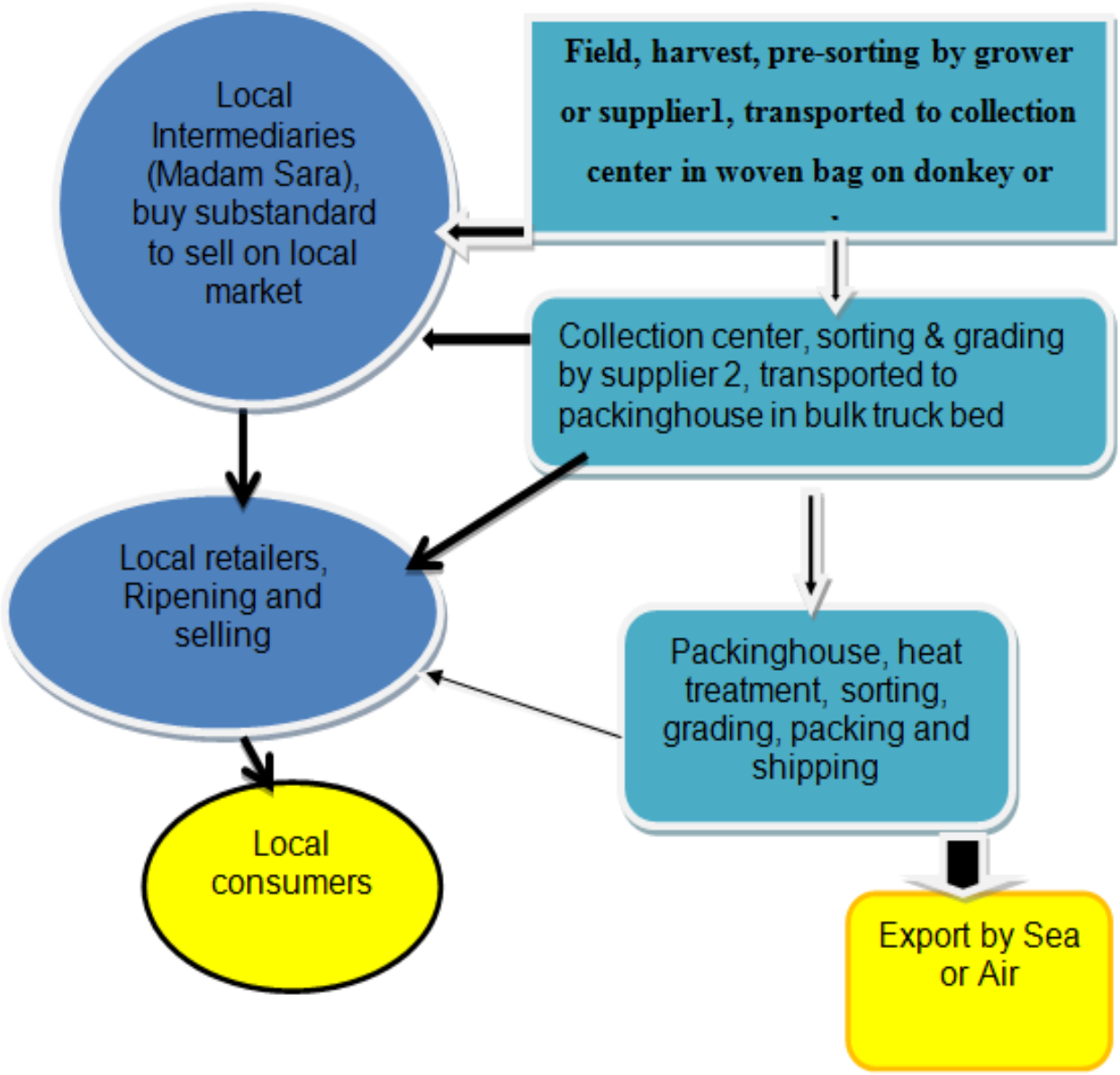


Figure 2-1 Value chain and postharvest handling of the Haitian mango for domestic and export markets.

Figure 2-2 Lenticel spot due to heat injury. (Adapted from Brecht et al., 2010. Mango postharvest best management manual. Page 54, Figure 5. UF/IFAS Publications)(Brecht(ed), 2010)

Figure 2-3 Stem-end cavities due to heat injury. (adapted from Brecht et al., 2010. Mango postharvest best management manual. Page 55, Figure 4. UF/IFAS Publications)

CHAPTER 3
EVALUATION OF HARVEST METHOD AND TRANSPORT METHOD FROM FIELD TO PACKINGHOUSE FOR THE IMPROVEMENT OF THE HAITIAN MANGO QUALITY

Background

Mango is the second crop for export in Haiti, after coffee. Haiti exports yearly more than 10,000 tons of mango 'Madame Francique' to the U.S. market that is worth more than $ 10 million, and the country exports important quantity to Dominican Republic and less to Europe and Canada (ANEM, 2010). According to FAO (2012) the annual yield is about 200, 000 tons for all cultivars.

'Madame Francique', the most esteemed cultivar grown in Haiti, represents more than 40,000 tons. However, due to important postharvest loss due to mishandling, those in the industry (growers, suppliers, packers), mainly the growers, cannot get the best profit from mango. By improving materials and methods of handling, important loss reduction can be recorded. Usually, fruit are not rejected in the field due to latex, because the latex will burn the peel of the fruit after some hours of exposure. The field is the best place to resolve the latex burn issue, because fruit are affected by latex during the harvesting operations. With harvest aids that allow the pickers to cut the peduncle with five cm or more (Brecht et al., 2010) contact of the peel of the fruit with latex can be avoided. Also, plastic field crates may help in reduction of loss due to mechanical injury in transport and packaging segments.

Mango cultivar 'Madame Francique' (*Mangifera indica,* L) was discovered in Haiti and it is grown throughout the country. 'Madame Francique'is a polyembryonic race of mango growing mainly in Haiti. Although Haiti has more than one hundreds varieties of mango; 'Madame Francique' is known internationally as the Haitian mango. The tree can reach over than 20 meters. In Haiti, depending on the region, 'Madame Francique'

season starts in November to end in August, depending on the growing area. Nevertheless, the peak season is early March to June. ‘Madame Francique’ is very sensitive to fruit fly, anthracnose disease and latex (sap burn).

In Haiti donkey and mule are the two most popular animals used in the rural transport system. In some regions donkey is more popular, in some other mule is more popular. In Cabaret the mule is the dominant animal. Since it was very difficult to find a donkey in this region a mule was used for transport.

Thirty six experiments were conducted in the region of Matheux (Cabaret) where the Winner- project was working. Also two methods of truck loading were used to transport the mangos from the collection center to the packinghouse, i.e. bulk packaging and plastic crate packaging. The objectives were to:

1. Estimate the actual postharvest losses of mango due to the traditional methods of harvesting, transport and packaging in Haiti.
2. Evaluate the use of a picking pole with cutter and new pack frame and crates to reduce postharvest losses during harvesting, transport, and packing.

Materials and Methods

Plant Material

The fruit (*Mangifera indica L*.) ‘Madame Francique’ used as plant material in this research was grown under traditional conditions on isolated farms in Cabaret, region of Matheux, located at about 30 km north of Port-Au-Prince where trees do not receive any care like irrigation, fertilization, pest management and pruning. The trees were generally older than 50 years and their height higher than ten meters. Most often, they were growing in association with other trees like oak and coconut tree and their canopy shaded the mango tree.

Physical Materials

The physical materials were:

1. The traditional harvest aid or picking pole (Figure 3-1), a long wooden pole with a cylindrical bag on one end whose head is made of a rigid, circular wire. To harvest the fruit the peduncle is pulled and the fruit allowed to drop into the bag. However, detachment without a stem allows the latex to exude from the fruit and contact the peel of the fruit.

2. The new harvest aid (Agri-Valley, Inc. Clip-N-Pick, Stuart, FL, USA) was selected for the purpose of the research in order to reduce the incidence of sap burn. It has the same shape as the traditional harvest aid, but the difference is a pair of inverted V blades (Figure 3-2) that are used to cut the peduncle of the fruit picked with 5 to 10 cm of stem in order to avoid any ejection of latex on the peel of the fruit harvested.

3. The traditional handcrafted woven bag (Figure 3-3) made of palm strips; used in Haiti as a regular container in the animal transport system. It can transport 60 to 90 fruits per bag depending on the fruit size.

4. The plastic field crate (Plastech Solutions S.A. P-Au-P, Haiti) that this research project aimed to introduce in the segment from field to collection center in the mango channel. Each crate can transport 13 to 15 kg, and its sizes are L50 x W 33 x H28.5 cm (Figure 3-4).

5. The pack frame was constructed of reinforced steel bar designed by the Department of Agricultural and Biological-Engineering (ABE) of UF. This pack frame was designed to hold up to five plastic crates (Figure 3-4).

Methods

In Cabaret (Matheux, Haiti) mangos estimated to be mature were harvested from May 26 to June 02, 2012 using both the traditional and the new harvest aids. Thirty-six experiments were conducted. At least three people were necessary for the harvesting operations: a picker who climbed the tree and used a long pole with inverted bag to detach the fruit that dropped into the bag, then dropped each fruit to a catcher who caught the failing fruit using a flat sack to avoid hitting the ground and physically damage, and finally, another person called a “disaper” who removed the stem (if present) and turned the fruit upside-down to drain the latex, avoiding contact with the

epidermis of the fruit. Experiments were designed as two treatments, tree height (3 levels, 10, 12 and 15 m) and harvest aid type (2 levels, picking and cutting pole) with four replicates for each trial. For harvest operations fruit harvested with traditional harvest aid was treatment 1 and those harvested with new harvest aid were considered as treatment 2. Fruit were considered properly harvested having the peduncle (five to ten cm) and those without the peduncle were considered potential candidates for sap burn. In each trial, the same amount of fruit (n=100) were harvested with each harvest aid and for each tree height (10, 12 and 15 m) and made a separate lot.

For transport from the field to the collection center, the same design was followed, two factors, distance (3 levels, 2, 3 and 4 km) and package type (2 levels, woven bags and plastic crates). From the field to the collection point, both the traditional saddle with woven bag and the new pack frame with plastic field crates were used.

For truck transport system two factors distance (54 and 60 km) and two types of load (bulk and crates) were considered. For the purpose of this research, careful sorting was made in the field where wholesome fruit were selected for transport to the collection point. Most of the fruit rejected were considered acceptable for the local market. For the transport study, the selected sample was split into two identical groups. One was transported in traditional conditions, i.e. loaded into woven bags and the other group was packed into plastic field crates loaded onto the pack frame. Experiments were designed as two treatments with four replicates for each segment. For transport from the field to the collection center, transport in woven bag was treatment 1 while transport using plastic field crates was treatment 2. Distances traveled were: 2, 3 and 4

km. At the collection center most attention was paid to the fruit affected by mechanical injury and latex burn, but minuscule losses (less than 1%) were recorded for other causes (immaturity misshapes, undersize).

From the collection center to the packinghouse comparison was made between transport in bulk packaging and transport in crates. Sorted at the collection center for physical injury and latex, the selected fruit were considered as very good for export market; 1,050 fruit were bulk-loaded into the back bed of a pick-up truck where banana strips were put on the bottom and on the top of the fruit. The strips were considered as cushion to reduce the vibration, shock and impact velocity and as sunblock to avoid sunburn on the peel of the fruit transported. By this means, the aim was to duplicate the common way that mangos are transported from the collection center to the packinghouse. The collection center was located in the production area (Cabaret) and the packinghouses located in Port-Au-Prince. The distance was about 50 to 60 km. The same amount was transported over the same distance, with the exception that the crates were covered by a large plastic bag to shade the fruit during transport and avoid sunburn. Upon arrival at the packinghouse, an experienced inspector sorted the fruit based on commercial grade criteria such as size, shape, maturity and defects used currently by the packinghouse.

Data Analysis

Statistical analyses were carried out using data analysis functions in JMP Start Statistics 5th Edition (Sall et al. 2012). Significant differences between the results were calculated using 2 x 3 factorial analysis design. The results were interpreted using p-value at α=0.05.

Results

Effect of Tree Height and Type of Harvest Aid on Mango Harvested with Stem

Analyzing the least square mean table for the three levels (10, 12 and 15 m) of factor1 (tree height), no significant difference was recorded in terms of impact on stem retention between tree of 10 m and tree of 12 m. However, the 15-m tree showed 41 and 25% less fruit harvested with stem, compared to the other two heights (Table 3-1)

The type of harvest aid used to pick the fruit had a significant effect ($p \leq 0.05$) on mangos harvested with stem. When mangos were harvested with the picking pole (PP), the percentage of fruit harvested with stem was about 15%. However, for fruit that had been harvested with the cutting pole (CP), the percentage increased dramatically from 15 to 66%. No significant differences ($p \leq 0.05$) were found between tree heights of 10 and 12 m both with picking pole and cutting pole. But, significant differences were observed for tree of 15 m compared to those of 10 and 12 m. Thus, it can be concluded that the height of the tree negatively influenced the rate of fruit harvested with stem: the taller the tree, the lower the percent of fruit harvested with the stem. This happened because the picker was not comfortable to pick the fruit or cut the peduncle with the blades when the tree was too tall, since the stem of fruit from tall tree could have been cut or damaged by shock upon falling onto the catcher's flat sack (Table 3-1)

Effect of Transport Container

Field to collection center

In the segment field to collection center, an important rate of loss was observed due to mechanical injury characterized by cuts, punctures and bruising. Mules and donkeys are employed in the transport system in this segment that traditionally consists of the two-sided hand-woven bag made of palm strips to package and transport the fruit,

as previously described. The results showed significant difference between the traditional method of transport and the new method using a pack frame, with a capacity of four or five plastic field crates. About 12.2 % of loss was due mainly to bruising when the traditional woven bag was used to transport from the field to the collection center (Table 3-2). Cuts and punctures were not a major cause of mechanical injury, with about 1.8%, while sap burn caused by latex accounted for 4.17%.

The distance between the field and the collection center had significant effect on the mechanical injury rate. For example, for 2 km of transport the percentage of loss due to bruising was 4.6%, whereas it was 5.9% for 3 km, and 8.1% for 4 km. And total losses were, respectively 8.5%, 12.60% and 15.5% for 2, 3 and 4 km (Table 3-3). Compared to transport using the plastic field crate, the improvement was very significant. Transport in the crate decreased loss by more than half, which was respectively 4.6, 5.1 and 7.5% for distances of 2, 3 and 4 km, respectively (Table 3-4). These findings showed the same trend as Medlicott, but he did not state about the distance, which has effect also on the rate of lost at the collection center. He suggested that the use of plastic field crates could allow improvement of about 5% in the reduction of losses at the collection center. Further improvement was recorded, because in this present study more attention was paid in the field to the fruit to be sent to the collection center, where the effect of the transport container was studied.

Collection center to packinghouse

From the collection point to the packinghouse, vehicles are employed to transport instead of donkey or mule, and depending on the type of truck loading (bulk or plastic crates), there was significant difference in losses between the two truck loading systems. In fact, the total loss recorded at the packinghouse when fruit were

transported in bulk was about 22% (table 3-5) for a distance of 57 km. Bruising was the major cause of rejection and accounted for more than 13%. However, when the fruit were transported in plastic crates over the same distance, total loss decreased from 21 to 9.5% (Table 3-6). These findings prove the usefulness of the plastic crates in the transportation system as a good way to improve the postharvest handling. Additional losses were recorded in the packinghouse, where the last and most critical sorting and grading occurred. At this point, sap burn and heat injury due to inappropriate management of the temperature as required by USDA-APHIS were the two major causes of rejection.

Discussion

Harvest Aid and Tree Height

Careful picking and handling will help to reduce crop losses (Kitinoja and Kader, 2002). While it may be impossible and uneconomical to completely eliminate the losses, it is possible and desirable to reduce them (Kader, 2002). It these tests it was clearly demonstrated that the cutting pole had helped to reduce losses by picking the fruit with five to ten cm of stem and then avoid the bad effect of latex in terms of sap burn. Even with a lack of training with the new equipment, pickers harvested more than 66% of the fruit with stem compared to only 15% for the traditional harvest aid without cutter, which is revolutionary for Haitian growers. However, 66% is still too low as a possible improvement due to the harvest aid with cutter. In fact, other factors such as the height of the trees and the skill or ability of the pickers to manipulate the materials negatively affected the rate of fruit harvested with stem. At $p \leq 0.05$, no significant differences were found between tree of 10 and 12 m in term of percentage of mango harvested (n-100) with stem. However, for tree of 15 m, the percentages of fruit harvested with stems were

significantly lower than those harvested from tree of 10 and 12 m. All fruits harvested with stem are potentially good for progressing into the marketing channel. On the other hand, no one can say that all the fruit harvested without stem will be affected by latex, but, they are more likely to be burned by latex if quick and specific steps to remove latex were not applied, such as turning the fruit upside down to drain the sap and quick washing. Washing the fruit in chlorinated water (100 – 200 ppm) immediately after harvest in the field could also possibly help to prevent the sap burn, and reduce potential microbial contamination as well, but in this research, this method was not used.

Crate and Distance Effects

The results in Tables 3-2 to 3-6 show how mechanical injuries are the major concern in transport and handling. Thus, damage due to mechanical injuries is more prevalent when fruit are transported in the traditional woven bags (no protection of fruit contact and less air circulation among fruits) than those that were transported in plastic field crates. The transport distance also significantly affected the rate of loss in transport. In fact, mangos transported either in woven bags or in crates had higher rate of loss with increased distance. The percentage of losses were respectively 8.53%, 12.60% and 15.50% for 2, 3 and 4 km for fruit loaded and transported in traditional woven bag (Table 3-2). In contrast, they were respectively 4.62%, 5.11% and 7.54% for 2, 3 and 4 km in plastic field crates (Table 3-3). Improvements due to the implementation of plastic field crates are very important and confirm the observations of Buteau (personal communication, 2011). By introducing the plastic field crates in the segment field to collection center, losses could be reduced by at least 5% according to

Medlicott (2001). The results showed a reduction of losses of about 6% considering an average of three km of distance of transport.

Important loss reduction was also recorded at the packinghouse. When plastic crates were used to transport the mangos instead of bulk loading, where loss varied from 19 to 24% (Table 3-7), however when fruit were shipped from collection point to packinghouse in bulk loading physical damages accounted for more than 50% of the causes of losses, specifically bruising. In bulk loading fruit located in the middle on the truck bed were damaged by those located on the top, and those in the bottom were compressed by those located both in the middle and on the top load. Also, lack of air circulation in bulk loading can be another cause of loss. For the same path, but packed in plastic crates the losses varied from 8.4 to 10%, a reduction of more than 100% in losses. Bulk loading may allow transportation of more fruit in one trip, which in short terms could appear advantageous for the collection point operators who do not want to store the fruit in their facilities to avoid over ripening issues and surveillance fees. Also, the plastic crates cost is high at ($6.00 - $9.00, each). But it is multifunctional, has long shelf life and guarantees the cleanliness of the product. Most important, the lost reduction can compensate the loss in quantity of fruit transported by trip in crates-loading versus bulk loading. According to the suppliers the cost of transport is the same for both traditional (bulk loading) and modern (crates-loading) transport. However, by trip a regular truck could transport 21,000 fruits each trip using bulk loading; whereas the same truck transports about 18,200 fruits when they were loaded in crates. The comparison showed that when 21,000 fruit were transported traditionally 4,620 or 22% of them were rejected at the packinghouse, and 16,380 (78%) were marketable. On the

other hand, when 18,200 fruits were transported in crates using the same path, 1,729 or 9.5% were rejected and 16,471 were marketable.

In the current commercial practice, the rate of loss at the reception in the packinghouse is estimated at 20% (Medlicott, 2001 and ANEM, 2011). So, the results are conformed to the literature. But the reduction in loss recorded went beyond the Medlicott expectation of about 5%.

Thus improvement was recorded in terms of quantity and in food safety, potentially reducing postharvest losses during field harvest, animal transport and truck transport. Based on the findings it can be concluded that:

- The tree height should be maintained lower as 10 m to increase the percentage of fruit harvested with stem;
- The cutting pole allowed improving the percentage of fruit harvested with stem by 340% compared to the traditional picking pole;
- Use of the pack-frame with crates reduced losses at the collection center by 53% compared to woven bags;
- At the packinghouses, fruits transported in crates by pick-up truck had a 60% reduction in losses as compared to those transported in bulk.

Table 3-1 Effect of tree height and harvest aid type on fruit harvested with stems with 5- to 10 cm (n=100).

Tree height (m)	% with stem, PP[z]	% with stem, CP[y]	% Improvement
10	15a[x]	75a	400
12	19a	70a	268
15	10b	54b	440
Mean	15	66	340
Std. error.	0.99	0.99	

[Z]PP= traditional harvest aid without cutter (picking pole).
[Y]CP=fruit harvested with harvest aid with cutter (cutting pole).
[X]the same letter in the same column means there is no significant difference between the treatments.

Table 3-2 Cause of rejection at the collection center for mangos loaded in woven bags and transported by mule (n=210).

Distance(km)	Mechanical Injury (%)[z]			
	Bruising	Cuts/punctures	Latex	Total
2	4.60a[y]	1.42a	2.50a	8.53
3	5.95b	2.14b	4.50b	12.60
4	8.10c	1.90c	5.50c	15.50
Average	6.22	1.82	4.17	12.21
Std. dev.	1.90	0.64	1.34	

[Z]Mechanical injuries included bruising and cuts and punctures.
[Y]the same letter in the same column means there is no significant difference between the treatments.

Table 3-3 Rate of rejection at the collection center for mangos packed in crates and transported by mule (n=210).

	Mechanical injuries (%)[z]			
Distance(km)	Bruising	Cuts/punctures	Latex	Total
2	1.90a[y]	0.71a	2.00a	4.62
3	1.90a	0.71a	2.50b	5.11
4	2.38b	1.66b	3.50c	7.54
Average	2.06	1.03	2.67	5.76
Std. dev.	0.53	0.51	0.74	

[Z]Mechanical injuries included bruising and cuts and punctures.
[Y]the same letter in the same column means there is no significant difference between the treatments.

Table 3-4 Rate of rejection at the collection center for mangos loaded in woven bags vs crates.

Distance(km)	% with Woven bag	% with Crates	% reduction of loss
2	8.53a[z]	4.62a	46
3	12.60b	5.11b	59
4	15.50c	7.54c	51
Average 3	12.21	5.76	53

[z]the same letter in the same column means there is no significant difference between the treatments.

Table 3-5 Rate of rejection at the packinghouse, for bulk-loaded on pick-up truck (n=1050).

Distance(km)	Mechanical injuries(%)[z]		Latex	Total
	Bruising	Cuts/punctures		
54	12.10a[y]	1.90a	5.50a	19.5
60	14.50b	2.5b	7.0b	24.0
Average	13.30	2.20	6.25	21.75
Std. dev.	1.2	0.3	0.75	2.25

[Z]Mechanical injuries included bruising and cuts and punctures.

[Y]the same letter in the same column means there is no significant difference between the treatments.

Table 3-6. Rate of rejection at the packinghouse for crates loaded on pick-up truck (n=1050).

Distance(km)	Mechanical injuries (%)[z]			
	Bruising	Cuts/punctures	Latex	Total
54	6.10a[y]	0.80a	1.50a	8.4
60	6.20a	1.3b	1.50a	9
Average	6.15	1.05	1.50	8.70
Std. dev.	0.05	0.25	0.0	0.3

[Z]Mechanical injuries included bruising and cuts and punctures.
[Y]the same letter in the same column means there is no significant difference between the treatments

Table 3-7 Total rate of rejection at the packinghouse bulk- loaded on truck vs crates-loaded on truck (n=1050).

Distance (km)	% with Bulk truck loading	% with Crates truck loading	% Improvement
54	19.5a[z]	8.4a	56.92
60	24.0b	9.0a	62.5
Average	21.75	8.70	59.71

[z]the same letter in the same column means there is no significant difference between the treatments.

Figure 3 -1 Traditionnal harvest aid without V-cutter (picking pole). (Bonicet)

Figure 3-2 Cutting pole or harvest aid with V-cutter. (Bonicet)

Figure 3-3 Transport in hand-made woven bag (Bonicet).

Figure 3-4 Transport in plastic field crate on pack frame (Bonicet).

CHAPTER 4
EFFECT OF HYDROCOOLING FOLLOWING HOT WATER TREATMENT ON MANGO QUALITY AND RIPENING AFTER MARINE SHIPMENT

Background

In developed countries demand for fresh fruit is increasing year after year. But, most of these countries cannot grow tropical fruit due to their climatic conditions. Less than 2% of the world mango production is grown in developed countries. Thus, importation is the unique option to satisfy the demand. Hot water treatment for quarantine security is mandatory for some markets, because of the threat of fruit fly. For the U.S market for example, USDA-APHIS requirements must be strictly observed. Fresh mango destined for the U.S. must be hot water treated to avoid fruit fly spreading. Consumers complain about poor quality of fresh imported mango, and hot water treatment could be a potential cause of bad quality. Surface scald and lenticel damage are some of the symptoms of hot water damage (Brecht et al., 2010). Trying to solve this issue, consideration can be put on temperature management post hot water treatment as a viable option. In fact, USDA-APHIS authorized a hydrocooling protocol after heat treatment in order to improve fruit quality (Figure 4-1). This research aimed to compare hydrocooling shortly after heat treatment with room cooling and effects on fruit quality following export to Florida.

Materials and Methods

Separate tests were conducted at two packinghouses located in Port-au-Prince (AGROPAK and Germain Paul- Export) with fruit samples of ‘Madame Francique’. Fruit were harvested on May 01, 2012 in the Saut d’eau area (based on the traceability code) and were provided freely by each packinghouse. Four crates from each packinghouse (n=20 fruits/crate) of light mature green fruit (weighing 400 to 500 g) were graded, free

of any visible damage. These were loaded into the hot water tank (Figures 4-2 and 4-3) for treatment as required by USDA-APHIS at 46.1°C for 90 min (USDA-APHIS PPQ, 2012). Immediately after removal from the hot water tank, the crates were collected and removed to hydrocooling area. There, the samples were split into four treatments (n=20).

Hydrocooling Procedures

Two insulated coolers (49.2 L) were half-filled with treated water at 200 ppm of free chlorine and by adding ice made from potable water; the temperature was maintained at 21°C during the cooling test. The water pH was around the neutral 7.0. For each treatment 18 fruits were submerged simultaneously and maintained under the water by agitating the water by hand. Two fruits were removed from the initial heat treated samples, one to measure the pulp temperature immediately after removal from the hot water tank and the other to measure the pulp temperature just before submerging the sample to the hydrocooler. Two digital thermometers (EXTECH® – 113728. Models RH300 and RH305. www.extech.com.) were used during the cooling test. During the hydrocooling test, one was used to constantly measure the temperature of the water by introducing a probe into the cooler tank, and the other to measure the pulp temperature of the fruits at different moments (after hot water treatment, before dropping to cooling tank, during the cooling test, and after removal from the cooling tank) during the test by inserting a probe into both sides of the pulp of sample of fruit from each lot or treatment (Figures 4-4 and 4-5).

Fruit destined to be used as control were not dipped into the hydrocooled tank but were left to cool overnight at room temperature (25-30°C) until packing (n=10) prior to export (current commercial handling method). The three crates were separated into

three treatments, T1, T2 and T3 based on the time delays to hydrocooling after removal from the hot water tank (30, 60, 90 min) (Table 4-1). The delays to hydrocool the mangos were based on the minimal time following the heat treatment permitted by the APHIS protocol (30 min).

After hydrocooling treatment all the samples were dried cooled for about 30 min by blowing air on them using a domestic fan and stored at room temperature (25-30°C) for about 24 hr. Then, the fruit from all treatments were cooled to about 20°C by blowing air from a domestic fan prior to packing 10 fruits of 400 to 500 g in each corrugated cartons (L30 x W27 x H10 cm; capacity: 4.5 kg or 9, 10 or 12 mangos depending upon size, Figure 4-6) and loaded onto the top of two pallets into two marine containers (CMCU, 555616 and CMCU, 554424). Container temperature was set to 13°C during the 3 days shipping time from Port-Au-Prince to Miami (May 04-07, 2012). Data for air temperature and relative humidity during the trip were recorded using a Hobo data logger (HOBO RH8 /Temp/2xExternal data logger, MicroDAQ, USA) in each box.

After the voyage (3 days) to Miami, Florida samples were retrieved from the importer's enterprise (Caribbean Fruit Connection, 8190 NW 84th Street, Medley, FL 33166) and brought to the Postharvest Horticulture Laboratory, Horticultural Sciences Department, University of Florida- IFAS in Gainesville. Samples were maintained at 20°C until the fruit reached full ripe-stage (based on firmness). Unfortunately, samples from Germain Paul- Export, shipped to Simple & Fresh Produce (924 NW, 2nd Street, Miami, FL 33127) could not be retrieved in Miami, because two treatments were lost during the voyage.

Fruit firmness was assessed nondestructively using a Texture Analyzer (Texture Technologies Corp. TA.HD, PLUS, NY, 10583) with an 11 mm, convex probe and 3 mm of deformation. Two firmness measurements were taken per fruit (opposite sides, n=10) every 2 days until fruit reached 10 N, considered the value for full-ripe stage. Also, based on this experiment, 25 to 30 N was considered the limit of marketability stage of 'Madame Francique', because this is the limit where the fruit is firm enough to be handled properly without damage. At full-ripe stage (10 N) the peel and pulp of the fruit had turned completely yellow or orange, characteristic of 'Madame Francique' (Figures 4-7 and 4-8). At this stage fruit samples (n=5 per treatment) were peeled, and the pulp of each fruit was blended and poured into 3 tubes (50 mL) and then stored at -20°C for later analysis of Vitamin A and Vitamin C, Soluble Solids Content (SSC), Total Titratable Acidity (TTA), and pH .

Compositional Analyses

Total carotenoids were determined by spectrophotometer (Biotek Instruments, power wave-XS2.USA) according to Talcott and Howard (1999) with some modifications, using a good extraction procedure to release all the carotenoids from the tissue. When extracting carotenoids from biological samples such as foods, which contain large amounts of water, a water-miscible organic solvent (e.g. ethanol) should be used to allow better solvent penetration. Carotenoids are fat soluble pigments and are extracted in non-water miscible solvent (e.g. ethanol). Butylated hydroxytoluene (BHT) as an antioxidant or $MgCO_3$ as neutralizing agent are often added to neutralize oxygen and acids liberated during tissue disintegration in order to prevent isomerization and degradation. Samples were read in a spectrophotometer at absorbance of 470 nm and absorbance values were introduced into the Talcott and Howard equation to

determined total carotenoids content. In fact, four reagents were used: ethanol (95%), Hexane (98.5%), BHT (200mg/L) and $MgCO_3$. The final mixture was made of ethanol-hexane: 1:1, BHT and $MgCO_3$. 10 steps were followed in the analyzing procedure:

a) Weigh of 3.0 g of fresh homogenate mango tissue in a 50 mL tube;

b) Add 20 mL of ethanol-hexane (1:1) freezing at - 30°C for one week;

c) Vortex the tubes for 30" to extract all the carotenoids;

d) Take out the supernatant (only hexane) in another tube;

e) Add again 20 mL of mixture ethanol-hexane, then repeat steps c and d;

f) Put 20 mL of deionized water (DI) into the pellet, vortex the tubes for 30" to extract all the carotenoids remain in the tissue. Recover the supernatant for extraction pool;

g) Place 20 mL of DI water into the extraction pool, vortex the tubes for 30" to wash the carotenoids extraction and also help the separation phase and

h) Take out of the freezer the tube and place them into crushed ice. Then transfer the hexane washed (liquid phase) in a clean tube and add hexane to 15 mL;

i) Read at 470 nm in a spectrophotometer.

Total carotenoids were calculated using Talcott and Howard equation:

Where:

$$Total\ carotenoids = \frac{AV * 10^6}{A^{1\%} * 100 * G}$$

A = Absorbance at 470 nm

V = Total volume of extract

$A^{1\%}$ = Extinction coefficient for a mixture of solvent arbitrarily set at 2500

G = sample weigh in grams

Ascorbic acid was determined by the Dinitrophenylhydrazine (DNPH) method as a standard method for ascorbic acid (AA) in biological materials. In this method, AA is oxidized to the osazone by incubation with DNPH in a dilute acid solution. Ascorbic acid

reacts with DNPH during a 3 hr incubation at 60°C. Samples were read using a spectrophotometer (Biotek Instruments, power wave-XS2. USA), at absorbance of 540 nm.

The tubes destined for SSC, pH and TTA were thawed then centrifuged at 2520 g_n for 20 minutes at 4°C. The supernatant was filtered using cheesecloth and stored in scintillation vials at -20°C for later analysis. SSC expressed in °Brix, was determined by placing several drops of juice extract onto the prism of a refractometer (Abbe Mark II, Reichart-Jung, Buffalo, NY). pH and TTA, expressed as a percent of citric acid, were determined by titration of a solution with 0.1 N NaOH to and end point on pH= 8.1 using an automatic titrimeter (Metrohm, Total Care Hotline, Bunk Mann 888-92, USA) . The solution was obtained by dilution of 6 grams of juice with 50 ml of deionized water.

Data Analysis

Statistical analyses were carried out using data analysis functions in JMP Start Statistics 5th Edition (Sall et al., 2012) and significant differences between the results were calculated by analysis of variance (ANOVA) and LSD test. Differences at $P \leq 0.05$ were considered to be significant. The experiment was set up using a completely randomized design.

To compare the differences among the treatments (Control, T1, T2 and T3), two types of test were carried out: a With Control Dunnett's that allowed comparing the control to the treatments, and an Each Pair Student's t that compared the treatments one-to-one. The statistical results are presented as follows. Each diamond shape in the resulting figures contains a central line that represents the group mean, and the vertical endpoints form the 95% confidence interval for the mean. If the confidence intervals of the groups do not overlap, the means are significantly different.

Results

Time to Full-Ripe Stage

Fruit for all four treatments were harvested on the same day, shipped during 3 d at an average of 17± 4.65°C, and 85 ± 7.08% relative humidity (Appendix A and B). In the Postharvest Horticulture Laboratory, fruit of the four treatments were stored under the same conditions, at 20°C. After 10 d of storage at 20°C, fruit of the control reached full ripeness (10 N). However, it took an additional 3 d (Figure 4-9) for the hydrocooled fruit to reach the same full ripe stage, regardless of delay to cooling (30, 60, 90 min following heat treatment). Based on the experiment, the limit of marketability firmness should be found from 25 to 30 N. This limit of marketability was reached after 6 to 8 d after storage at 20°C. The pulp temperatures after removal from the hot water tank were between 44 and 46°C, and then were between 39 and 43°C prior to hydrocooling.

Total Carotenoids

'Madame Francique' mango fruit hydrocooled after the hot water treatment as required by USDA-APHIS for export to the USA (46.1°C for 90 min) had significantly higher total carotenoids content at the full-ripe stage (10 N) than those that were room cooled (Table 4-2 and Figure 4-10). Total carotenoids content for the control fruit (17,789 µg/100g of fresh fruit) was an average of 14% lower than that of fruit from the hydrocooling treatments T1, T2, T3 which averaged of 20,708 µg/100g. However, regardless of the different time delays prior to hydrocooling, no significant differences were observed among the hydrocooling treatments (T1, T2 and T3). According to these findings, the hydrocooling treatment had beneficial effects on total carotenoid content of the mango 'Madame Francique' (Table 4-2 and Figure 4-10).

Ascorbic Acid Content

Fruit that were hydrocooled after 30 min delay following the heat treatment had approximately 13% lower in ascorbic acid content (T1=26.94 mg/100g) than the control (30.60 mg/100g) and T2 (29.42mg/100g) and T3 (32.55mg/100g) (Table 4-3 and Figure 4-11).

Soluble Solids Content

The SSC estimates the sweetness or the blandness of the fruit. Based on these findings (Figure 4-12), both the treatments T1 (15.65) and T2 (15.65) did not show significant difference compared to the control (15.68). However, T3 (17.35) was significantly higher from T1, T2 or the control with a SCC that was about 11% higher. So fruit hydrocooled 90 min after removal from the hot water tank would have had sweeter flavor at full ripe stage than those hydrocooled after 30 or 60 min or those cooled at room temperature.

Total titratable acidity (TTA)

The dominant acid in mango is citric acid. The results showed that the sooner the fruit were hydrocooled after removing them from the hot water tank, the higher the acidity was. In fact, the TTA of T1 (30 min) in which the fruit were hydrocooled after only 30 min was significantly different from T2 (60 min), T3 (90 min) and the control (Figure 4-13). T1 fruit had TTA when fully ripe that was 32%, 46% and 15% higher than the control, T2, and to T3 fruit, respectively.

SSC/TTA

The flavor of the fruit, one of the most attractive characteristics of mango can be estimated by the ratio SSC/TTA: the higher the ratio, the sweeter the flavor. Treatment T2, in which the fruit were hydrocooled 60 min following hot water treatment, recorded

the highest SSC/TTA value and seemed to be the best treatment for flavor (Figure 4-14).

pH

Based on the Dunnett's 0.05 (i.e., comparison of the three treatments with the control), the hydrocooling the mango after hot water treatment seemed to result in higher pH of the fruit. In fact, the results showed that the control fruit had significantly lower pH (5.69) than both the T1 (5.88) and the T2 (5.90) fruit (Table 4-3). Fruit that were hydrocooled after 30 or 60 min of removal from hot water tank had a higher pH. In other words, they were less acidic than those that were in air at room temperature. However, the statistical analysis did not reveal a significant difference between the control and T3 (5.78) (Figure 4-1). Comparing for each pair using Student's t ($P \leq 0.05$), there were no differences between the three treatments.

Discussion

Firmness

Low temperature storage is one of the most widely used postharvest treatments for prolonging the marketable life of horticultural commodities (Kader, 2002). Hot water treatment is mandatory for export of Haitian mangos to the U.S. However, it decreases the postharvest shelf life of the commodity by increasing the respiration rate that corresponds to the destruction of carbohydrates (sugar) content and production of heat by the fruit. Hydrocooling mango fruit after hot water treatment decreased the pulp temperature much more rapidly, and has been demonstrated to slow the metabolic rate of the fruit (de Leon et al., 1997; Mitcham and Yahia, 2009 and Shellie and Morgan, 2002).

In this study it was found that hydrocooled fruit reached full ripeness 3 d later than those that were cooled at room temperature. These findings are in agreement with many authors' findings such as Molinu et al., (2010) who showed that the pulp of hydrocooled pears *(Pyrus communis*) remained firmer than those that were not hydrocooled. Manganaris et al., (2007) found that hydrocooling delayed the deterioration and senescence of cherry fruit (*Prunus avium L*). Thus, hydrocooling should have beneficial effects for the export market by delaying the ripening period of the fruit treated. However, sanitation management of the hydrocooling water is critical to avoid transfer of decay pathogens between fruit (Brecht et al., 2010).

Total Carotenoids

Hydrocooled fruit had higher total carotenoids content compared to the control that was room cooled. But no significant differences were found among the three hydrocooling treatments regardless of the time delay following hot water heat treatment. Thus, hydrocooling seems to increase the total carotenoid content in mango.

Ascorbic Acid Content

The fruit that were hydrocooled 30 min after removal from the hot water treatment showed the lowest ascorbic acid content, and were significantly different from the control, T2 and T3. Ferreira et al., (2006) reported for strawberry that ascorbic acid showed no differences related to cooling method. Boonprasom and Boonyakiat (2010) found that at low storage temperature the Vitamin C content of broccoli was higher than those stored at higher temperature. Thus, results from the present study contrasted with those found by previous authors working with different commodities like broccoli and strawberry, both temperate commodities in contrast to mango, which is a tropical and subtropical fruit. In addition, the hydrocooling temperature (21°C) and the exposure time

may not have been enough to induce significant changes in the structure of the ascorbic acid. Ascorbic acid is heat labile, so the fruit that remained for more time at the ambient temperature prior to be hydrocooled, like the control, should show higher ascorbic acid content than the treatments (T1, T2, and T3).

Soluble Solids Contents (SSC)

Fruit hydrocooled 30 or 60 min following removal from the hot water treatment did not show significant difference in term of SSC compared to the control. But when they were hydrocooled after 90 min (T3), a slight increase in SSC was recorded. These findings are similar to Manganaris et al., (2007) who reported that SSC of sweet cherry was not affected by hydrocooling.

Total Titratable Acidity (TTA)

After harvest and during storage, the concentration of total organic acids tends to decline (Kays and Paull, 2004). Fruit hydrocooled 30 min (T1) following hot water treatment showed the highest TTA (Table 4-2 and Figure 4-12). But no significant differences ($P \leq 0.05$) were found between T1 and T3. Also the control and T2 did not show significant difference, but they had less TTA than T1 and T3. A high TTA is related to a low perception of sweetness, while fresh mango is looking for its sweetness. Based on these results, hydrocooling the fruit after 30 and 90 min (T1 and T3) following removal from the hot water tank maintained higher TTA. T2 did not show significant difference from the control; thus, the three methods of hydroccoling tested in this current research did not help in the improvement of the sweetness of mango. The same trend was observed by Hevia et al., (1998) who found that hydrocooling did not have significant impact on TTA in red and purple sweet cherry. This was contrary to Albert et al., (1976) who reported that with increasing ripeness of peaches the SSC increased

with a corresponding decrease in acidity. Based on the results, the hydrocooling procedures used in this current research are not useful for the improvement the sweetness of mango.

Ratio SSC/TTA

The treatment T2 in which hot water treatment was followed after 60 min by hydrocooling gave the best results for the improvement of the flavor of the fruit. Because this treatment showed a very high level of SSC, and the lowest TTA, it appears that T2 could be adopted as a good method of hydrocooling to improve the flavor of mango.

pH

The three hydrocooling treatments showed increasing pH compared to the control. The control was not significantly different from the T3 and both control and T3 had an average pH of 5.73. Also T1 and T2 did not show significant difference and had an average pH of 5.90.Overall, T1 and T2 had an increase in pH of 3% compared to the control and the T3 fruit. Statistically, T1 and T2 were different from control and T3, but practically there was no difference between control and hydrocooling treatments. These findings confirm the report of Ferreira et al., (2006) who found that hydrocooled strawberry showed an increase in pH compared to other treatments. After harvest and during storage, the concentration of total organic acid tends to decline (Kays and Paull, 2004).

Summary

Studies were conducted on the effect of hydrocooling on the quality attributes of heat-treated mango fruit. The objective of this research was to determine if hydrocooling the fruit following heat treatment could significantly improve:

1. The postharvest shelf life of mango destined for distant export market.
2. The nutritional value of the fresh fruit exported.

The results showed a 30% increase in the postharvest shelf life of the rapidly cooled fruit compared to the room-cooled control. In fact, hydrocooled fruit from all three delays after heat treatment reached full ripe stage based on firmness 3 d later than the control. Possibly, other indices of ripeness, color change for example, would show significant differences. Thus, hydrocooling could be adopted as a new method of cooling mango when the ripening stage needs to be delayed for best postharvest handling. In addition, the total carotenoids content of the hydrocooled fruit were significantly increased as compared with the control. An increase of about 16% in the total carotenoids content was recorded for the hydrocooling treatments. For other attributes of quality such as AA, SSC, TTA, and ratio SSC/TTA, the hydrocooling treatments did not appear to be detrimental to fruit nutritive value and flavor; they were generally comparable to the control.

Table 4-1 Different time delay to hydrocooling following by hot water treatment (min).

Treatments	TD-AHWT[z]	Water temperature	PT-AHT[y]
Control	n/a	n/a	n/a
T1	30	21°C	29°C
T2	60	21°C	27°C
T3	90	21°C	27°C

[Z]Time delay in min after hot water treatment before hydrocooling.
[Y]Pulp temperature after hydrocooled treatment.

Table 4-2 Effect of time delays to hydrocooling following heat treatment on selected quality parameters[z] of 'Madame Francique' mango.

Treatment	T. Car (µg/g)	A. A (mg/100 g)	SSC (%)	TTA (%)	SSC:TTA	pH
Control	17,780c	30.60b	15.68b	2.15c	7.3b	5.69 b
T1	20,187b[y]	26.94c	15.65b	2.85a	5.5c	5.88 a
T2	20,971a	29.42b	16.65ab	1.94d	8.6a	5.90 a
T3	20,966a	32.55a	17.35a	2.48b	7.0b	5.78 b

[Z]T.Car: Total Carotenoids; A.A: Ascorbic Acid; SSC: Soluble Solids Content (%)
TTA: Titratable Acidity (citric acid).
[Y]The same letter in the same column means there is no significant difference between the treatments, $p \leq 0.05$.

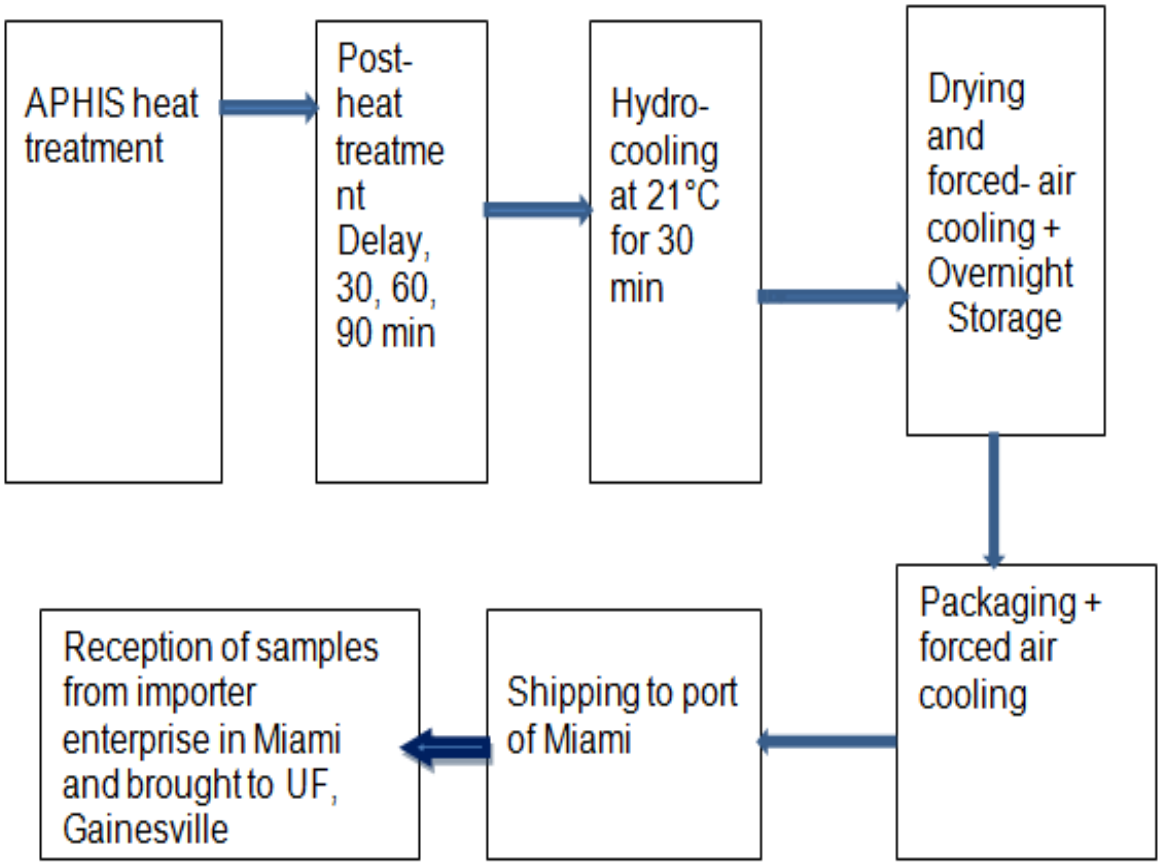


Figure 4-1 Steps in the hydrocooling treatments.

Figure 4-2 Selected crates of mangos before loading into hot water tank.

Figure 4-3 Removal of mangos from the hot water tank. (Bonicet)

Figure 4-4 Maintenance of the temperature at 21°C by adding ice during hydrocooling. (Bonicet)

Figure 4-5 Measurement of the pulp temperature (Bonicet).

Figure 4-6 Corrugated shipping carton box of mango in an export packinghouse in Haiti. (Bonicet)

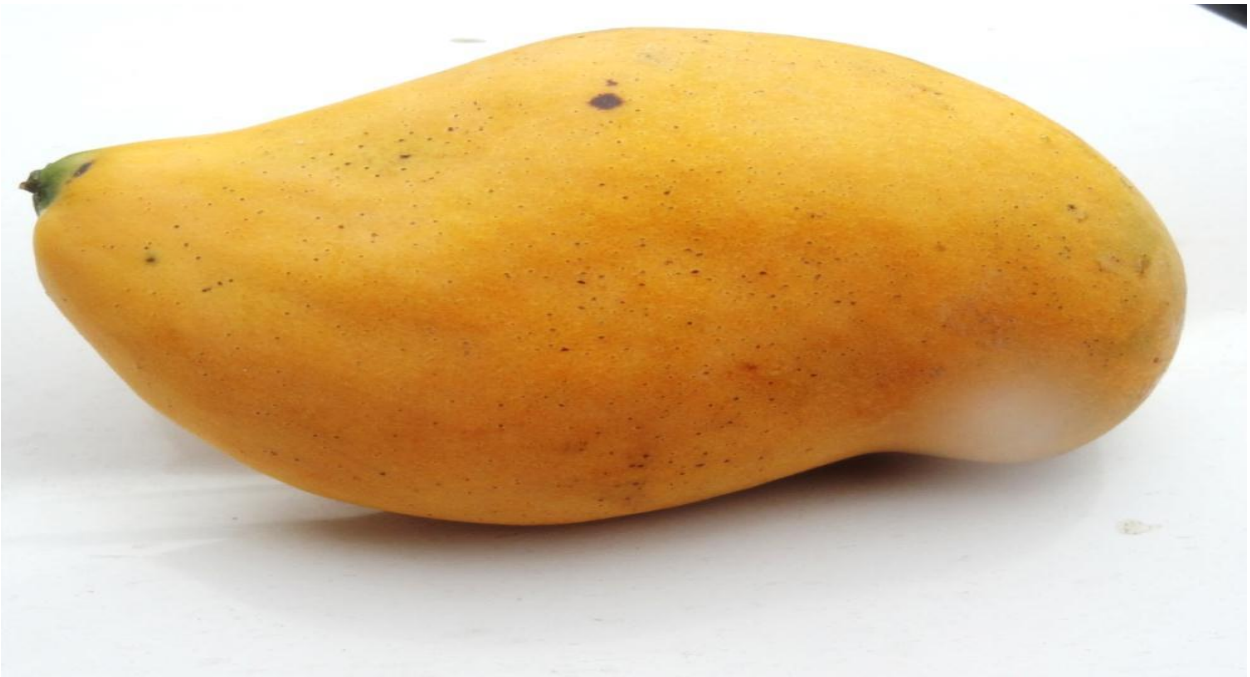
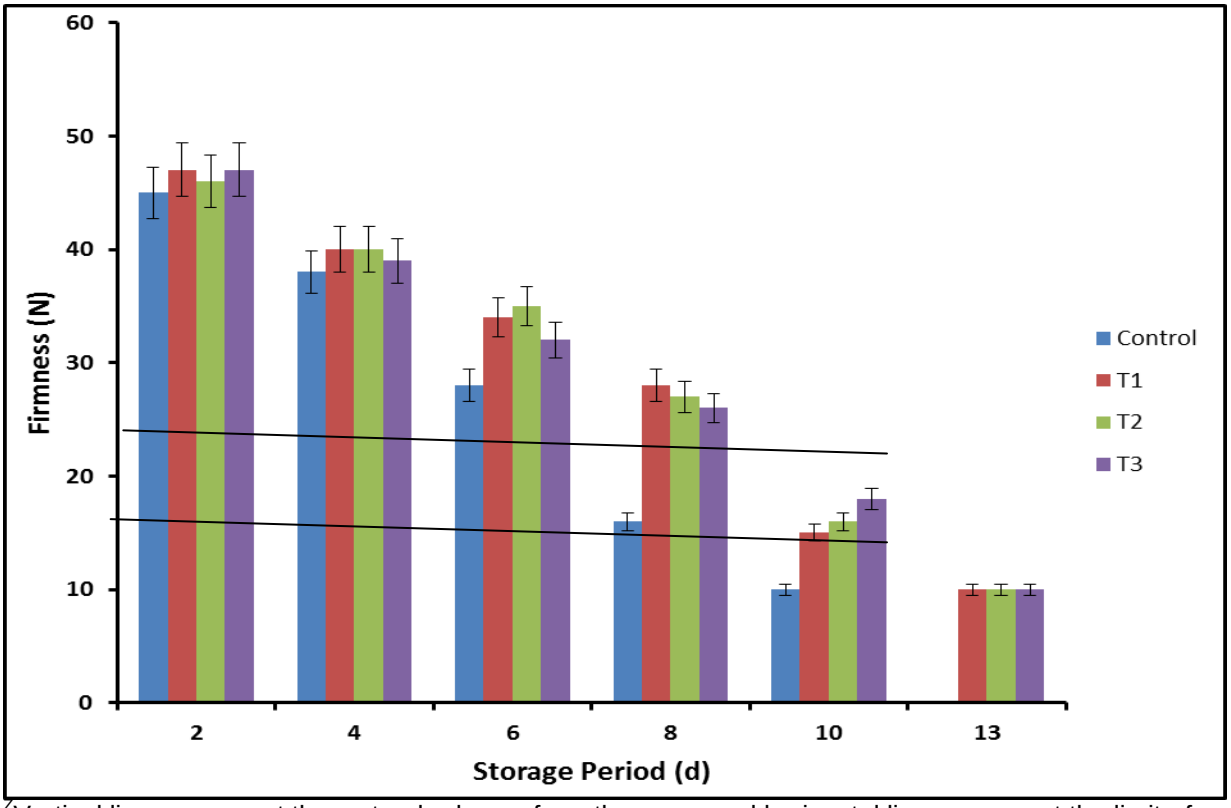


Figure 4-7 Characteristic peel color of the mango ‘Madame Francique’ at full-ripe stage (10 N). (Bonicet)

Figure 4-8 Pulp color of the mango ‘Madame Francique’ at full- ripe stage (Bonicet).



[Z]Vertical lines represent the ± standard error from the mean and horizontal lines represent the limit of commercial marketability for 'Madame Francique'

Figure 4-9. Effect of time delays to hydrocooling following hot water treatment on 'Madame Francique' mango firmness (N) during storage at 20˚C.

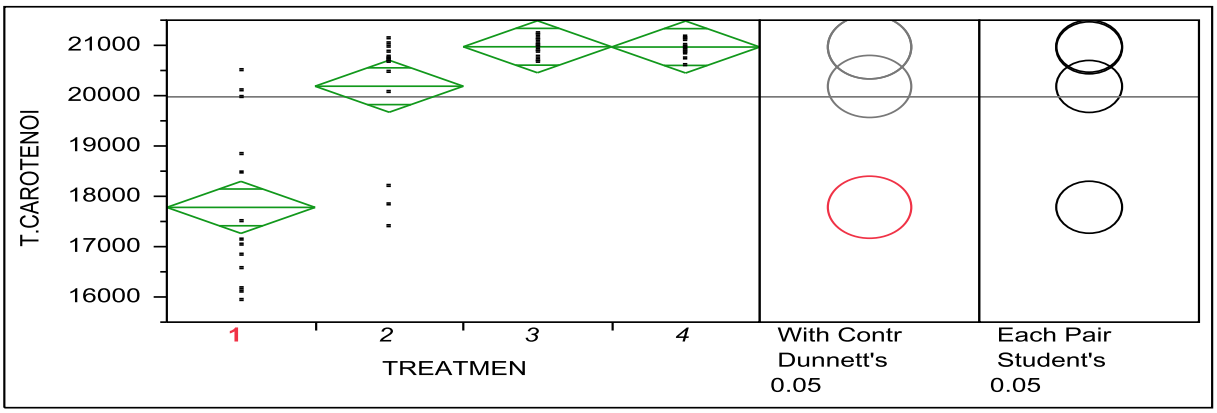


Figure 4-10. One-way Analysis, Comparison of Carotenoid Content for different time delayed of hydrocooling at 21°C following heat treatment.

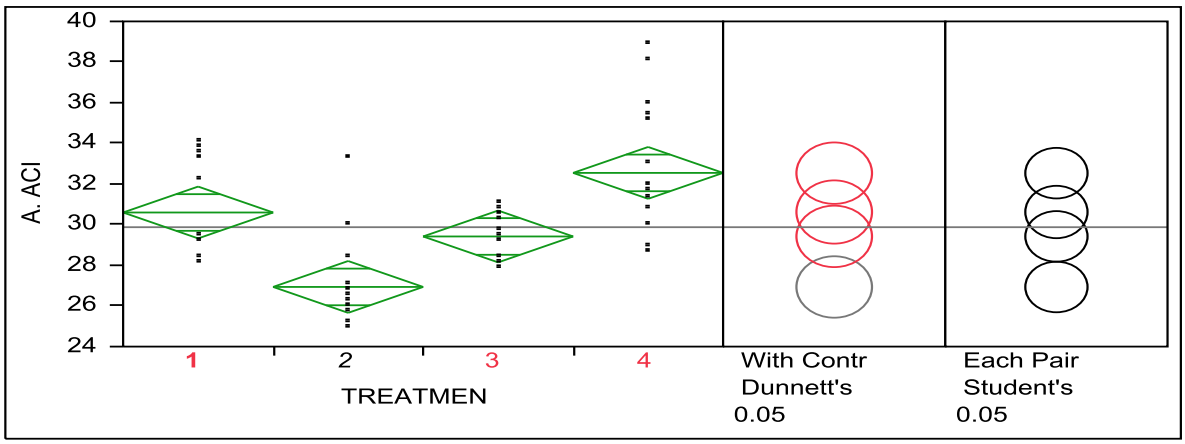


Figure 4-11. One-Way Analysis, comparison of ascorbic acid[z] content for different time delayed of hydrocooling at 21°C following heat treatment.

[z]number in the x-axis with the same color mean there are no significant differences among the treatments.

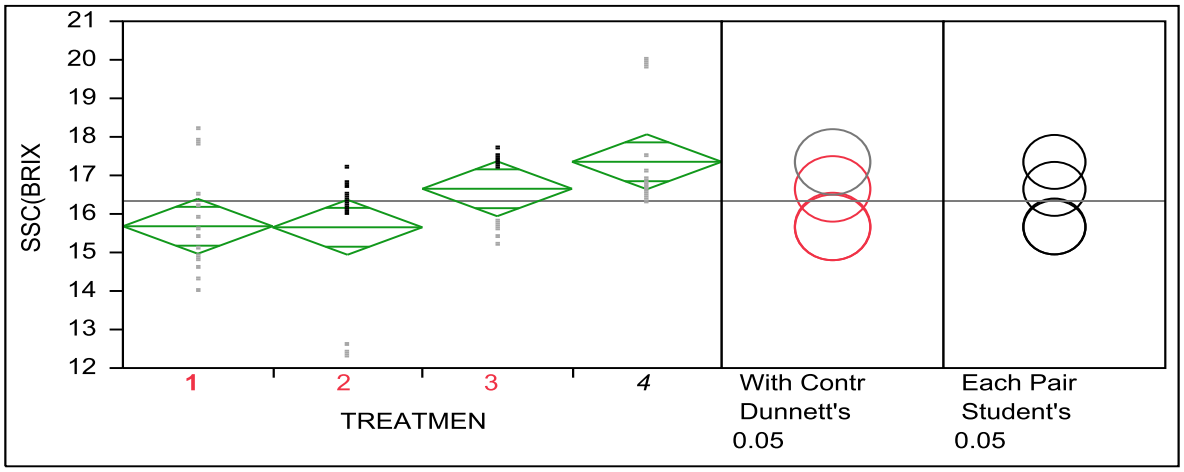


Figure 4-12 One-way Analysis, comparison of SSC (%) content for different time delayed of hydrocooling at 21°C following heat treatment.

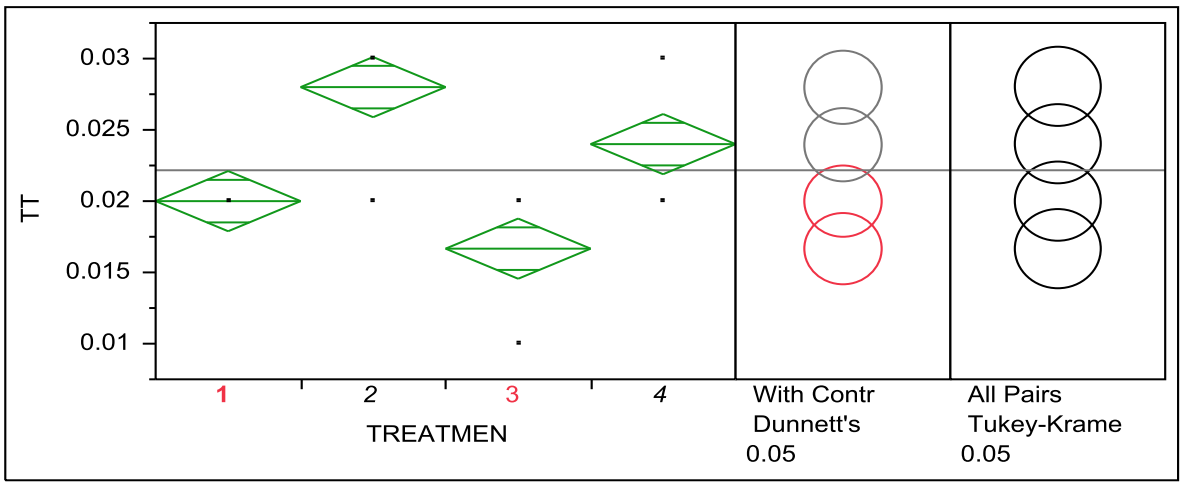


Figure 4-13 One-Way Analysis, comparison of TTA content for different time delayed of hydrocooling at 21°C following heat treatment.

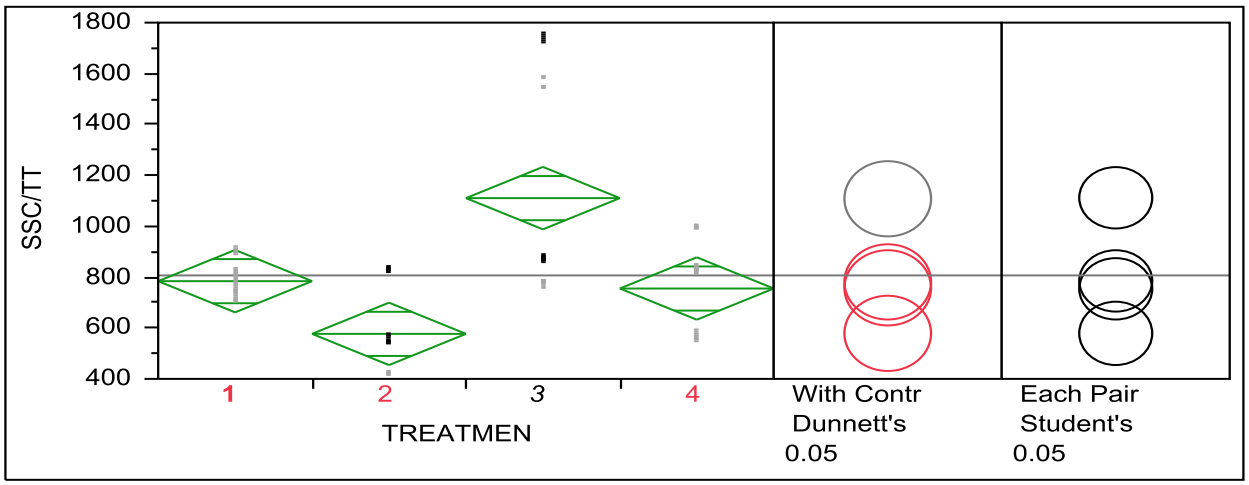


Figure 4-13 One-Way Analysis, comparison of SSC/TTA (flavor) for different time delayed of hydrocooling at 21°C following heat treatment.

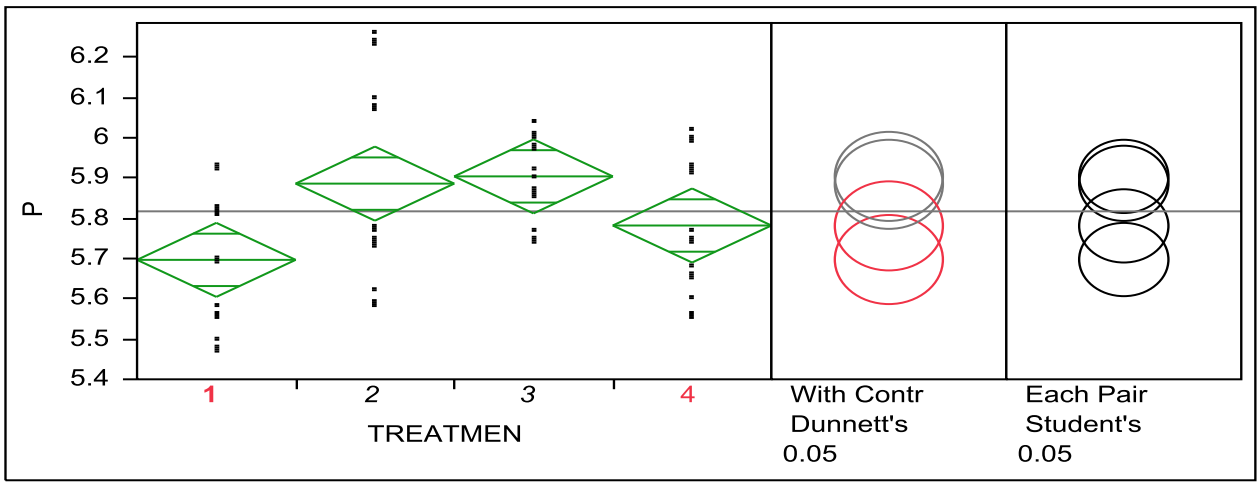


Figure 4-14 One-way Analysis, comparison of pH for different time delayed of hydrocooling at 21°C following heat treatment.

CHAPTER 5
CONCLUSIONS

Demand for fresh mango follows the same positive trend for consumers with higher income and higher education in developed countries. Unfortunately, rich countries produce less than 5% of their consumption. Thus, mango remains a lucrative export crop for developing countries. Mango is a climacteric fruit and a very perishable commodity; losses due to poor horticultural practices and postharvest handling and temperature management represent big challenges for the marketability of this fruit. Postharvest losses exceed 50% in developing counties like Haiti. The present study aimed to:

- Estimate the actual postharvest losses of mango due to traditional methods of harvesting, transport and packaging in Haiti.
- Evaluate the use of a picking pole with a cutter, a new pack frame and crates to reduce postharvest losses during harvest, transport and packing.
- Compare time delay to hydrocooling after heat treatment with room cooling on fruit quality following export to Florida.
- Propose new materials and methods based on the results for the improvement of the Haitian value chain.

The present study determined that the most important causes of losses for Haitian mangos are sap burn and mechanical injuries. Findings include:

- By using a cutting pole instead of the traditional picking pole at harvest operations, 66% of fruit were harvested with stem compared to only 15% for fruit harvested with picking pole. Thus, the incidence of latex (sap) burn on the epidermis was reduced as much as 340% when fruit were harvested with stems.
- The introduction of plastic crates in the segments field to collection center, and from the collection center to the packinghouse proved useful for this new method of transport and handling by further reducing losses. Mechanical injuries and sap burn were reduced by 53% at collection center and by 60% at the packinghouse.
- Following the phytosanitary heat treatment, hydrocooling after 30 to 90 min delay extended the ripening period by 30% compared to room cooled fruit; however

there were no significant differences due to the delays. Hydrocooled fruit also Increased by 16% the total carotenoids content when fully ripe.

- It is suggested that, with a better management of trees (pruning, fertilization, irrigation), and a better approach in postharvest handling system, significant improvement could be observed in the Haitian mango value chain prior to increasing the number of new groves and trees.

Suggestions for Future Research

Based on the findings, these suggestions can be made:

- Growers must be trained in order to cultivate the trees in the best conditions.
- Pickers must test other harvest technics of harvest to reduce losses at harvest. For example, for tree higher than 5 m, the use of a bucket to load the fruit harvested and a rope to drop the bucket to the ground can be a good alternative to the catcher.
- Establishment of specific groves of ‘Madame Francique’ mango can be studied in order to respond to the increasing demand for mango from the international market.
- The elimination of the collection center should be studied as an alternative to reduce postharvest losses (direct shipment from field to packinhouse).
- Training in procedure in food safety must be applied from field to packinghouse in order to guarantee the safety of the fruit to the consumer and then avoid any outbreak due to mango.
- In the packinghouse strict sorting based on size and maturity must be followed in order to treat each lot according to the USDA-APHIS requirements. This could help decreased the heat injury rate due, most often, to inappropriate application of the phytosanitary treatment (i.e. holding smaller fruit too long in the hot water tank).
- More research needs to be done on temperature management shortly after hot water treatment in order to reduce the heat effect on ripening and quality attributes.

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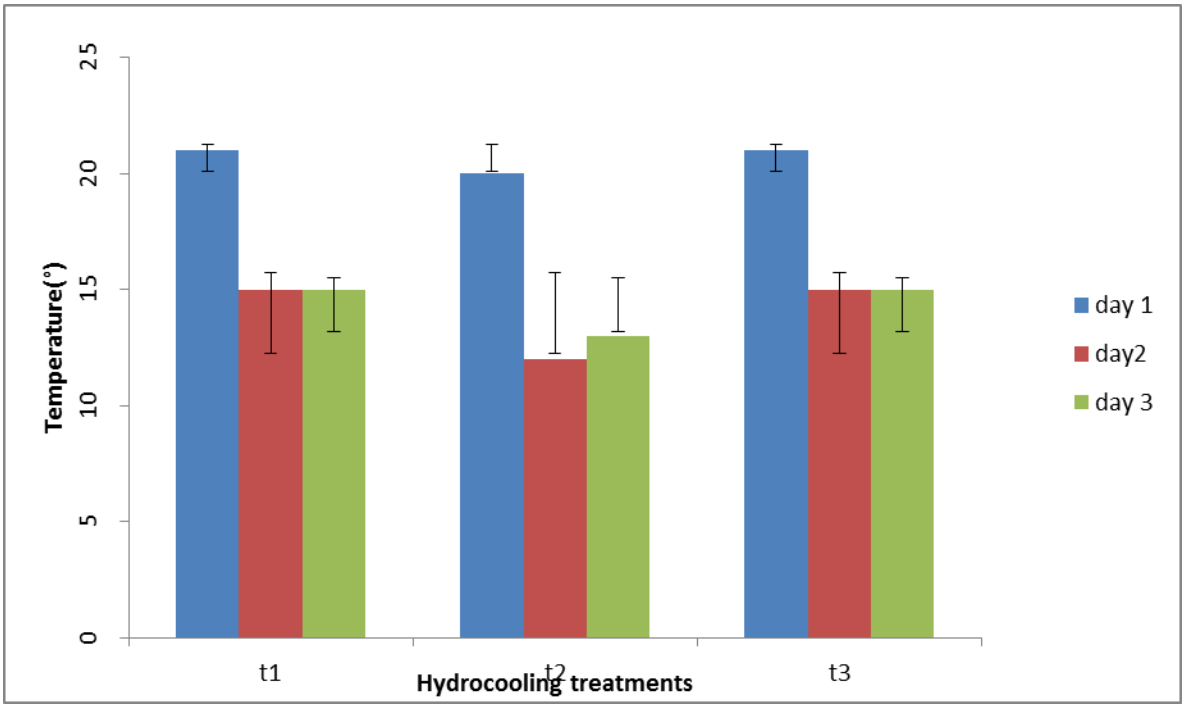
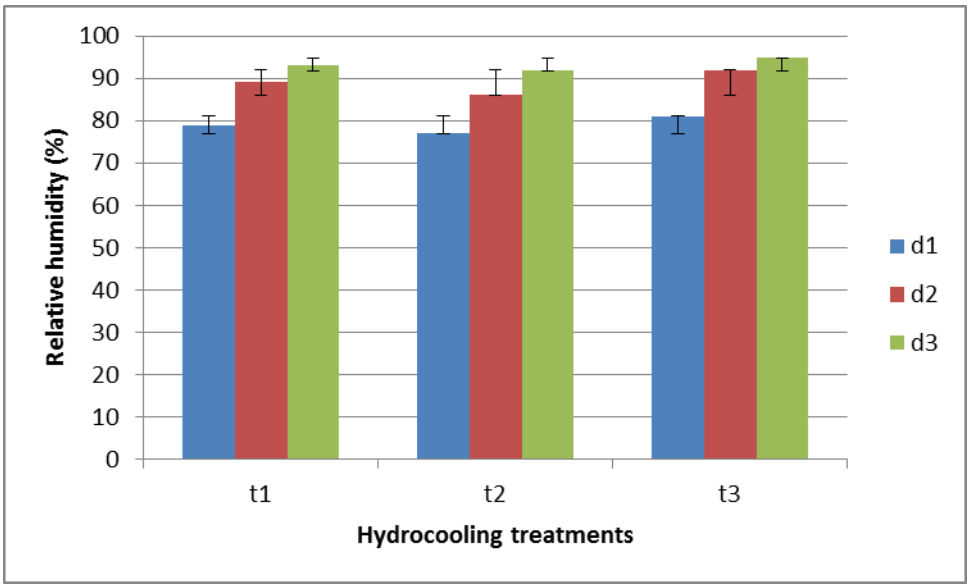
APPENDIX A
VARIATION OF TEMPERATURE



Variation of temperature during 3 d of voyage from Port-Au-Prince to Miami, Florida for hydrocooled Treatments[z].

[z]T1, T2 and T3 represent fruit hydrocooled after 30, 60 and 90 min respectively after removal from hot water tank. And vertical bars represent the standard deviations.

APPENDIX B
VARIATION OF RELATIVE HUMIDITY



Variation of relative humidity during 3 d of voyage from Port-Au-Prince to Miami, Florida for hydrocooled Treatments[z].

[z]T1, T2 and T3 represent fruit hydrocooled after 30, 60 and 90 min respectively after removal from hot water tank. And vertical bars represent the standard deviations

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BIOGRAPHICAL SKETCH

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