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The effect of picking time and postharvest treatments on fruit quality of mango (*Mangifera indica* L.)

Dissertation submitted in fulfilment of the requirements
for the degree of Doctor of Philosophy
in Agricultural Science

by
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2012

Dissertation thesis of the University of Hohenheim, Faculty of Agricultural Sciences, for the acquisition of the degree of a “Doktor der Agrarwissenschaften (Dr. sc. agr.)” (Ph. D. in Agricultural Sciences).

Date of oral examination: 08. 11. 2012.

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Acknowledgements

I would like to express my sincere thanks to Prof. Dr. Jens N. Wünsche for accepting me as his PhD student, his unreserved support and advice in the conduct of this study. Without him the research could not have been completed.

I would like to give special thanks to Dr. Martin Hegele and Dr. Patrick Winterhagen, who introduced me to the lab analyse and comments on my thesis. I would like to express my gratitude to Assoc. Prof. Dr. Pham Thi Huong who gave me permission to work and to use the facilities in Department of Horticulture, Hanoi Agriculture of University. I wish to thank Prof. Dr. Nguyen Van Dinh for the initiation of this study. I appreciate the support in various way given by all my colleagues in Vietnam, and all staff members at the Institute of Crop Science, Section of Crop Physiology of Specialty Crops during my study.
I am great acknowledgement to Vietnamese friends in Hohenheim as well as German friends and the Upland program's colleagues for their warm relationship, encouragement and helpful support which gave me strength to cope with many difficulties.

I would like to express my gratitude to the DFG though the 'Sonderforschungsbereich 564' and DAAD for financial support during my study period.

Finally, I am most grateful to my parents and family who have always supported me with their love and concern. I could not have finished my study without their encouragement, patience, sacrifice and sympathy.

Table of Content

List of abbreviations ..... **VII**

List of Tables ..... **VIII**

List of Figures ..... **IX**

Summary ..... **XIII**

Zusammenfassung ..... **XV**

1. Introduction **1**

2. Literature reviews **3**

2.1. Impact of preharvest condition to fruit quality **3**

2.2. Fruit ripening and control of postharvest quality **5**

2.2.1. Maturity on post harvest of fruit 5

2.2.2. Physiological and chemical change during fruit ripening 7

2.2.3. Temperature and fruit ripening 8

2.2.4. Role of ethylene in fruit ripening 9

2.2.5. Effect of 1-Methylcyclopropen to fruit ripening 11

2.3. Quality control of postharvest mango fruits in Vietnam **13**

2.4. Working hypothesis **15**

3. Materials and Methods **17**

3.1. Study area and plant materials **17**

3.2. Experimental design **18**

3.2.1. The effect of harvest time and storage temperature on fruit quality of 'Tron' and 'Hoi' 18

3.3.2. The effect of 1-MCP on mango fruit quality 22

3.3.3. Effect of ethrel postharvest applications on mango ripening 29

3.3.4. Hot water treatment 29

3.4. Data analysis 30

4. Results 31

4.1. The effect of harvest time and storage temperature on fruit quality of 'Tron' and 'Hoi mango 31

4.2. Effect change of 'Tron' and 'Hoi' fruit ripening by 1-MCP 37

4.3. Effect of ethrel postharvest applications on ripening of 'Tron' and 'Hoi' 39

4.4. Hot water treatment to some external ripe parameters of 'Tron' and 'Hoi' . 44

5. Discussion 46

5.1. The effect of harvest time and storage temperature on fruit quality of 'Tron' and 'Hoi mango 46

5.1.1. Maturity in relation of appropriate pick for an optimal quality at harvest 46

5.1.2. The advantageous pick with proper storage treatments for optimal mango quality 48

5.2. Effect of 1-Methylcyclopropen on ripening of 'Tron' and 'Hoi' fruits 52

5.2.1. Influence of maturity to efficiency of 1-MCP 52

5.2.2. Impact of 1-MCP concentration on ripening 53

5.3. The effect of ethrel treatment on fruit quality of 'Tron' and 'Hoi' 55

5.4. Hot water treatment to some external ripe parameters of 'Tron' and 'Hoi' . 57

6. Conclusions and outlook 59

7. References 60

Declaration of Originality

Curriculum Vitae

List of abbreviations

HWT	Hot water treatment
HW	Hot water
1-MCP	1-Methylcyclopropen
TA	Titrable acidity
TSS	Total soluble solid concentration
FAO	Food and Agriculture Organization
IFPRI	International Food Policy Research Institute
IU	International unit
HPLC	High performence liquid chromatography
UV	Ultraviolet

List of Tables

Table 1. Some agronomic characteristics and chemical components of ‘Tron’ and ‘Hoi’ fruit 15

Table 2. Criteria for consumer preference 19

List of Figures

Figure 1. The effect of storage condition (0 day at ambien, 5 and 10 days at 20ºC and 10, 20 and 30 days at 12ºC, respectively) on fresh weight (A), skin disorder (B), flesh firmness (C) of 'Tron' and 'Hoi' cultivar, each averaged over three picks; the effect of pick and storage condition on average dry matter (D) of both cultivar in 2008. Columns represent instutrumental values, whereas symbols represent consumer preference. The $LSD_{(0.05)}$ bars indicate cultivar * storage condition interactions in A, B, and C; and main effects (pick, storage condition) in D. 32

Figure 2. The effect of storage condition (0 day at ambien, 5 and 10 days at 20ºC and 10, 20 and 30 days at 12ºC, respectively) on skin hue angle (A) and flesh hue angle (B) of 'Tron' and 'Hoi' cultivar, each averaged over three picks in 2008. Columns represent instutrumental values, whereas symbols represent consumer preference. The $LSD_{(0.05)}$ bars indicate cultivar * storage condition interactions. 33

Figure 3. The effect of storage condition (0 day at ambien, 5 and 10 days at 20ºC and 10, 20 and 30 days at 12ºC, respectively) on total soluble solid concentration (A) and titrable acidity (B) of 'Tron' and 'Hoi' cultivar, each averaged over three picks in 2008. Columns represent instutrumental values, whereas symbols represent consumer preference. The $LSD_{(0.05)}$ bars indicate cultivar * storage condition interactions. 34

Figure 4. The effect of storage condition (0 day at ambien, 5 and 10 days at 20ºC and 10, 20 and 30 days at 12ºC, respectively) on starch (A), fructose (B), glucose (C) and sucrose (D) of 'Tron' and 'Hoi' cultivar, each averaged over three picks in 2008. 35

Figure 5. The effect of storage condition (0 day at ambien, 5 and 10 days at 20ºC and 10, 20 and 30 days at 12ºC, respectively) on vitamin C (A) and β-

carotenoid (B) of ‘Tron’ and ‘Hoi’ cultivar, each averaged over three picks in 2008. 35

Figure 6. The effect of storage condition (0 day at ambien, 5, 10, 15, 20 and 25 days at 12ºC, respectively) on skin disorder (A) and flesh hue angle (C) of ‘Tron’ and ‘Hoi’ cultivar at 1st and 2nd pick, each averaged over 1-MCP concentration; the effect of 1-MCP concentration (250, 500, 1000 $nL \cdot L^{-1}$ 1-MCP and non-treated as control) and storage condition on average flesh firmness (B) of both cultivar at 1st and 2nd pick; the effect of 1-MCP concentration on skin hue angle (D) of ‘Tron’ and ‘Hoi’ cultivar at 1st and 2nd pick, averaged over storage duration in 2008. The $LSD_{(0.05)}$ bars indicate cultivar ∗ pick ∗ storage duration interactions in A and C; pick ∗ 1-MCP concentration ∗ storage duration interactions in B; cultivar ∗ pick ∗ 1-MCP concentration interactions in D. 37

Figure 7. The effect of storage condition (0 day at ambien, 5, 10, 15, 20 and 25 days at 12ºC, respectively) on total soluble solid concentration (A), (0 day at ambien, 5 and 10 days) on titrable acidity (B), sucrose (C) and carotenoid (D) of ‘Tron’ and ‘Hoi’ cultivar at 1st and 2nd pick, each averaged over 1-MCP concentration in 2008. The $LSD_{(0.05)}$ bars indicate cultivar ∗ pick ∗ storage duration interactions. 39

Figure 8. The effect of ethrel concentration (0.4%, 0.8% ethrel and water as control) on flesh firmness (A), skin disorder (B) of ‘Tron’ and ‘Hoi’ cultivar stored at 12ºC and 20ºC, each averaged over storage duration; the effect of storage condition (0 day at ambien, 1, 3, 5, 7 and 9 days at 12ºC and 20ºC, respectively) on skin hue angle (C) of ‘Tron’ and ‘Hoi’, averaged over ethrel concentration; the effect of ethrel concentration and temperature (12ºC and 20ºC) on average skin and flesh hue angle (D) of both cultivar and storage duration in 2008. The $LSD_{(0.05)}$ bars indicate cultivar ∗ temperature ∗ ethrel concentration interactions in A, B; cultivar ∗ temperature ∗ storage duration interactions in C; temperature ∗ ethrel concentration interactions in D. 40

Figure 9. The effect of storage condition (0 day at ambien, 1, 3, 5, 7 and 9 days at 12ºC and 20ºC, respectively) on total soluble solids concentration (A) and titrable acidity (C) of 'Tron' and 'Hoi' cultivar, each averaged over ethrel concentration; the effect of ethrel concentration (0.4%, 0.8% ethrel and water as control) on vitamin C (D) of 'Tron' and 'Hoi' cultivar stored at 12ºC and 20ºC, averaged over storage duration in 2008; the effect of ethrel concentration on average of TSS of both cultivar and storage condition in 2008 and 2009. The $LSD_{(0.05)}$ bars indicate cultivar ∗ temperature ∗ storage duration interactions in A and C; main effect (ethrel concentration) in B; cultivar ∗ temperature ∗ ethrel concentration interactions in D. 41

Figure 10. The effect of storage condition (0 day at ambien, 1, 3, 5, 7 and 9 days at 12ºC and 20ºC, respectively) on glucose (A) and carotenoid (C) content of 'Tron' and 'Hoi' cultivar, each averaged over storage temperature; the effect of cultivar ('Tron' and 'Hoi') on average sucrose, fructose and glucose concent (B) of ethrel concentration and storage condition in 2008; the effect of ethrel concentration (0.4%, 0.8% ethrel and water as control) on starch content (D) of 'Tron' and 'Hoi' cultivar, averaged over storage condition in 2008 and 2009. The $LSD_{(0.05)}$ bars indicate cultivar ∗ ethrel concentration ∗ storage duration interactions in A and C; main effects (cultivar) in B and (ethrel concentration) in D. 43

Figure 11. The effect of storage condition (1, 3, 5, 7 and 9 days at 12ºC and 20ºC, respectively) on skin disorder (A) of 'Tron' and 'Hoi' cultivar, averaged over water temperature in 2008; the effect of water application condition (45ºC, 48ºC, 50ºC water treated and non-treated fruit for 3 and 6 min) on skin disorder (B), skin hue angle (C) and fruit weight loss (D) of 'Tron' and 'Hoi' cultivar, each averaged over storage condition in 2009. The $LSD_{(0.05)}$ bars indicate cultivar ∗ pick ∗ storage condition interactions in A; cultivar ∗ water temperature ∗ water application duration interactions in B, C, and D. 45

Summary

Mango production in Northern Vietnam is mainly in the upland areas. The two locally grown cultivars are ‘Tron’ and ‘Hoi’ with limited yearly production due to poor traditional crop management practices by ethnic minorities. Both cultivars possess excellent fruit aroma and taste properties, yet there is a need to further improve fresh fruit quality to meet high domestic demand and consumer expectations in the market place, thereby exploiting more products of preferred quality. Assessment of quality parameter and consumer preference can assist to precisely determine optimum harvest time and suitable storage regime for a given cultivar. Furthermore, specific postharvest treatments such as applications of hot water, 1-MCP or ethrel for manipulating fruit ripening and shelf-life may help to enhance economic returns and thus to make mango production in the long term more profitable.

The research work on both cultivars was carried out on farmer orchards near the township of Yen Chau, Son La Province, Vietnam, in 2007, 2008 and 2009. The research objectives were to (1) monitor internal and external fruit quality changes in relation to varying select picks throughout the harvest period and to a range of storage temperatures; (2) investigate the effect of 1-MCP on various fruit ripening parameters for maintaining fruit quality and extending shelf-life; (3) evaluate applications of aqueous ethrel solution in cool storage for accelerating fruit ripening; and (4) assess the responses of several external fruit criteria to hot water treatments and subsequent cool storage. At each select pick, fruit was immediately taken to the laboratories at Hanoi University of Agriculture for fruit quality assessment at harvest, and following various postharvest treatments, ex-store. Chemical analyses of fruit tissue samples were performed at the University of Hohenheim. Various physicochemical quality parameters such as fruit weight, skin disorder, skin and flesh colour, flesh firmness, total soluble solids concentration, titrable acidity, as well as concentrations of soluble sugars, starch, vitamin C and carotenoids were evaluated.

The results of the first part indicated that key quality criteria for determining the optimal harvest time of ‘Tron’ and ‘Hoi’ were determined. ‘Hoi’ fruit was at best quality when harvested late, preferably in the 2nd or 3rd pick, whereas 1st pick fruit was relatively immature with less than 8% total soluble solid concentration and did not properly ripen when stored at 12ºC. In contrast, ‘Tron’ fruit should be picked early in the harvest period since the 3rd pick

with tree-ripened fruit was only suitable for direct local marketing without storage time. The results also indicated that 'Tron' fruit of the 1st and 2nd pick and 'Hoi' fruit of 2nd and 3rd pick continued the ripening process to full maturity when stored at 12ºC. Consequently, fruit from these picks were suitable for distant markets when handled within 5-10 days at 20ºC or up to 20 days at 12ºC. Generally, 'Hoi' had a greater postharvest potential than 'Tron' but ex-store fruit quality of both cultivars was best with flesh firmness ranging from 70.5 to 96.1 N, skin hue angle from 71.4º to 85.4º, flesh hue angle from 70.1º to 78.5º and total soluble solid concentration from 16.8 to 19.6%.

The results of the second part clearly showed that 1-MCP is a useful tool to delay fruit ripening and in particular softening of both cultivars during the postharvest period. Both cultivars treated with 1000 $nL \cdot L^{-1}$ 1-MCP delayed considerably the decrease in TA, skin and flesh hue angle as well as the loss of flesh firmness in the 1st and 2nd pick for about 10 days of storage at 12ºC compared to control. Both cultivars were more sensitive to 1-MCP applications in 1st rather than the 2nd pick. In addition, 1-MCP applications were more effective on 'Tron' fruit than 'Hoi' fruit.

The results of the third part indicate that 0.8% ethrel accelerated fruit ripening on fruit from the 1st pick of both cultivars while stored at 12ºC. Ex-store fruit quality was acceptable and met consumer preference. The efficacy of ethrel application on 'Hoi' fruit was greater than that on 'Tron' fruit.

The results of the fourth part showed that the degree of skin disorder was considerably decreased when 'Tron' and 'Hoi' fruit were treated with either 48ºC or 50ºC water for 6 min and stored at 12ºC. This treatment delayed skin colour development of 'Hoi' when compared to other treatments.

In conclusion, this study demonstrates that lack of proper whole chain fruit quality management systems is the key factor for the limited production of mangoes in Northern Vietnam. Improved fruit quality management can result in more consistent and higher quality particularly for distant markets. Based on the results of this work, 'Tron' and 'Hoi' fruit should be harvested using well-defined and recommended harvest quality indices and thereafter undergo appropriate postharvest management systems to attain higher fruit quality. This will help farmers to better manipulate fruit ripening processes, to deliver high quality fruit to the market and to achieve greater returns and thus livelihoods.

Zusammenfassung

Der Mangoanbau konzentriert sich in Nordvietnam hauptsächlich auf die Hochlandregion. Die zwei lokal angebauten Sorten ‚Hoi' und ‚Tron' erzielen aufgrund von wenig produktiven traditionellen Anbaumaßnahmen durch die ethnischen Minderheiten sehr limitierte Erträge. Zwar zeichnen beide Sorten sich durch exzellentes Aroma und Geschmacksattribute aus, dennoch besteht die Notwendigkeit zur Verbesserung der Frischequalität um den nationalen Ansprüchen und den Erwartungen der Konsumenten am Markt zu entsprechen, indem verstärkt die bevorzugten Qualitäten verwendet werden. Die Kontrolle von Qualitätsparametern und Verbraucherpräferenz können helfen den optimalen Erntezeitpunkt und die passenden Lagerbedingungen für eine bestimmte Sorte präzise zu bestimmen. Des Weiteren können spezifische Nacherntebehandlungen wie beispielsweise Behandlungen mit heißem Wasser, 1-MCP oder Ethrel eventuell helfen die wirtschaftlichen Gewinne zu erhöhen und somit den Mangoanbau auf lange Sicht profitabler zu gestalten.

Die Versuche an beiden Sorten wurden auf Pflanzungen nahe der Stadt Yen Chau, Son La Provinz, Vietnam, in 2007, 2008 und 2009 durchgeführt. Ziel der Arbeiten war es (1) interne und externe Fruchtqualitätsänderungen im Zusammenhang mit gewählten Probenahmen während der Ernteperiode und unter verschiedenen Lagertemperaturen zu dokumentieren, (2) den Effekt von 1-MCP auf verschiedene Fruchtreifeparameter, zwecks Aufrechterhaltung der Fruchtqualität und Verlängerung der Haltbarkeit, zu untersuchen, (3) die Applikation von wässrigen Ethrel-Lösungen unter Kühllagerbedingungen zu evaluieren um eine beschleunigte Fruchtreife zu erzielen und (4) die Reaktion mehrerer externer Fruchtkriterien auf Behandlungen mit heißem Wasser und nach Kühllagerung zu untersuchen. Nach jeder Probenahme wurden die Früchte unverzüglich zu den Laboratorien der Agrarwissenschaftlichen Universität Hanoi transportiert, um dort die Fruchtqualitätsuntersuchungen zur Erntezeit und, nach erfolgten Nacherntebehandlungen, nach Lagerung durchzuführen. Chemische Analysen von Fruchtgewebeproben wurden an der Universität Hohenheim durchgeführt. Verschiedene physiochemische Qualitätsparameter wie Fruchtgewicht, optische Beeinträctigung der Schale, Schalen- und Fruchtfleischfarbe, Fruchtfleischfestigkeit, Konzentration der gesamt löslichen Feststoffe, titrierbare Säuren, so wie die Konzentration löslicher Zucker, Vitamin C und Karotenoiden wurden untersucht.

Die Ergebnisse des ersten Teils weisen darauf hin, dass Schlüsselkriterien für die Feststellung des optimalen Erntezeitpunktes für ‚Tron' und ‚Hoi' gefunden wurden. ‚Hoi'-Früchte besaßen

die höchste Qualität wenn sie spät geerntet wurden, vorzugsweise in der zweiten und dritten Probenahme, wobei die Früchte der ersten Probenahme mit 8% Gesamtgehalt löslicher Stoffe noch relativ unreif waren und auch nicht vollständig nachreiften, wenn sie bei 12°C gelagert wurden. Im Gegensatz dazu sollten ‚Tron'-Früchte zu einem früheren Zeitpunkt in der Erntezeit geerntet werden, da die zur dritten Probenahme am Baum ausgereiften Früchten nur für den unmittelbar lokalen Markt ohne Lagerzeit nutzbar sind. Die Ergebnisse zeigten auch, dass ‚Tron'-Früchte der ersten und zweiten sowie ‚Hoi'-Früchte der zweiten und dritten Probenahme vollständigen Reifeprozess durchliefen, wenn sie bei 12°C gelagert wurden. Folglich waren Früchte dieser Probenahmen für weiter entfernte Märkte geeignet, wenn sie innerhalb von 5-10 Tagen bei 20°C oder bis zu 20 Tagen bei 12°C gehandelt werden. Generell hat ‚Hoi' ein größeres Nacherntepotenzial als ‚Tron', und nach Lagerung erzielten beide Sorten für Fruchtqualität die besten Werte für Fruchtfleischfestigkeit mit 70.5 bis 96.1 N, für den Huewinkel der Fruchtschalen von 71.4º bis 85.4º, für den Huewinkel des Fruchtfleisches von 70.1º bis 78.5º und gesamt löslichen Feststoffe von 16.8 bis 19.6%.

Die Ergebnisse des dritten Teils zeigten, dass 0.8% Ethrel die Fruchtreife der bei 12°C gelagerten Früchte der ersten Probenahme beider Sorten beschleunigt. Nach der Lagerung war die Fruchtqualität akzeptabel und entsprach den Wünschen der Konsumenten. Der Wirkungsgrad der Ethrelapplikation war bei ‚Hoi'-Früchten größer als der bei ‚Tron'-Früchten.

Die Ergebnisse des vierten Teils zeigten, dass die optische Beeinträctigung der Schale bei ‚Tron' und ‚Hoi'-Früchten deutlich vermindert sind, wenn sie 6 Minuten mit 48°C oder 50°C heißem Wasser behandelt und bei 12°C gelagert wurden. Diese Behandlung verzögert Farbveränderungen der Schale von ‚Hoi'-Früchten im Vergleich mit anderen Behandlungen.

Folglich demonstrierte diese Studie, dass das Fehlen eines ausreichenden und umfassenden Fruchtqualitätsmanagementsystems der Schlüsselfaktor zur begrenzten Mangoproduktion in Nordvietnam ist. Verbessertes Fruchtqualitätsmanagement kann, im Besonderen für weiter entfernte Märkte, zu einer konsistenteren und höheren Qualität führen. Basierend auf den Ergebnissen dieser Arbeit sollten ‚Tron' und ‚Hoi'-Früchte mithilfe klar definierter und empfohlener Erntequalitätsindices geerntet werden und nachfolgend ein angemessenes Nacherntemanagementsystem durchlaufen, um höhere Fruchtqualität zu erreichen. Dies wird den Mangoanbauern helfen, den Fruchtreifeprozess besser zu manipulieren, Früchte mit hoher Qualität auf den Markt zu bringen und somit höhere Gewinne und einen besseren Lebensstandard zu erreichen.

1. Introduction

Mango (*Mangifera indica* L.) is well-known due to its attractive appearance, delicious taste, excellent flavor, high nutritional value, variety diversification, year-round production and wide adaptability on different growing conditions. In addition, mango contains over 20 different vitamins and minerals, and presents a rich source of vitamins C and A, both of which are important antioxidants. Mango is currently the fifth major fruit crop in term of total production. The world production of mango was 31.7 million tons in 2009 and was estimated to be 34.4 million tons in 2010 (FAO, 2011). Mango is commercially grown in 90 countries and known as the most important tropical fruit crop of Asia. The major production countries are India, China, Thailand, Indonesia, Philippines, Pakistan, and Mexico (FAO, 2011).

In Vietnam, mango production ranks third among the fruit crops. The most popular cultivars in South Vietnam are Cat Hoa Loc, Cat Chu, Thanh Lai and Cat Moc. There are not many research results available on genetic improvement of mangoes in Vietnam. Though, a previous study of FAO (2004) reported that most of the local cultivars were accidentally selected from seedlings, leading to the fact that some of them having superb taste and aroma.

In North Vietnam, the mango production areas have relatively low temperatures from November to February due to cold northwesterly winds. Additionally, cloudy skies and drizzling rain are common at mango flowering season in January. This causes poor fruit set, and a high incidence of diseases that affects mango production. However, recent research (Dang, 2008, FAO, 2004) has shown that some newly imported cultivars such as GL1, GL2, and GL6 bloom quite late in April, resulting in increased pollination, fertilization and production. These cultivars, however, are used for the canning industry and not for fresh consumption.

Mango production in Vietnam was 540,000 tons in 2009 and was estimated to be 662,100 million tons in 2010 (FAO, 2011). The planted area and productivity of mango in the North Vietnam increased considerably from 2001 to 2006: from 5,801 to 11,300 ha and from 6,904 to 29,800 tons, respectively (Dang, 2008). The mango is mainly cultivated in the provinces of Nghe An, Quang Tri, Quang Ninh, Ha Giang and Son La. In fact, there has been a proposal to cultivate more mangoes in the North in order to supply the local market as well as to be less dependent on supplies from the South. However, up to now mango is not grown commercially

year-round in the North (FAO, 2004), while transportation from the South to the North increases the cost for the consumers.

The main problems in Northern Vietnam consist of the unavailability of good cultivars and the deficit in orchard management, which often lead to low yield and poor fruit quality. It is suggested that there is high domestic demand for the locally grown mango varieties 'Tron' and 'Hoi' due to superb taste and aroma. These cultivars are mainly cultivated in Truong Sai (Moc Chau), Thuan Chau, Mai Son and Yen Chau districts in the Son La province in Northern Vietnam (Dang, 2008). Consumers prefer mango in Yen Chau district with an estimated production area of 495 ha for 'Tron' and 'Hoi' and an annual productivity of 1,980 ton in 2004 (Huong, 2004). Potential to expand the commercial mango area in Northern Vietnam still exists. Most of the 'Tron' and 'Hoi' trees were grown from seeds. Until 2007, grafted 'Tron' and 'Hoi' trees were only grown on 1 ha by a co-funded project by the Ministry of science and technology (Vietnam) and the Upland programs (Germany) in Yen Chau (Huong, 2008a). 'Tron' and 'Hoi' trees are grown on the red and yellow soil (*Ferralsols* and *Leptosols*) on steep hillsides (Wezel et al., 2002). Basically, farmers do not apply standard techniques such as fertilizer and pesticide control, pruning and irrigation. As a result, mango trees develop tall and bushy canopies, leading to difficulties in crop management and harvest. The common age of trees ranges from 15 to 40 years (Tuc and Lu., 1994). 'Tron' and 'Hoi' trees usually bloom in January and fruits develop from February to May with typical harvest dates from the end of May to July for 'Tron' and in August for 'Hoi'. Due to the fact that fruit growth occurs mostly among the dry season in Son La, water deficit can cause fruitlet drop, and affect fruit size, yield and quality (Spreer et al., 2007 and 2009). Moreover, pests and diseases such as aphids, thrips, anthracnose (*Collectotrichum gloeosporioides*), powdery mildew (*Oidium mangiferae*) and sooty molds (*Capnodium mangiferae*) cause serious problems among January and February, resulting in poor quality and low fruit set (Binh, 1999). Consequently, these lead to reduced production and profitability.

Nowadays, mango becomes a commercially important fruit crop in Vietnam, particularly in the mountainous areas of Northern Vietnam. However, mango quality of 'Tron' and 'Hoi' is degraded detrimentally due to poor traditional crop management practices of ethnic minorities. It is, therefore, necessary to improve fruit quality to meet consumer expectations in the market place. Moreover, studies are needed to investigate how consumer preference behavior can be explored to produce more products of preferred quality.

2. Literature reviews

2.1. Impact of preharvest condition to fruit quality

Many preharvest factors such as the environment, agrochemicals, nutrition, management systems and maturity contribute to the fruit qualities of horticultural crops (Mattheis and Fellman, 1999) e.g. mango (L´echaudel and Joas, 2006, Lalel et al. 2003), apple (Poll et al., 1996). Various orchard management practices such as pruning, fertilizer application, crop load and abiotic factors affect fruit growth (Poll et al., 1996, Huong, 2008b).

Canopy and crop load management: Canopy management is one of the important techniques in many fruit crops for improving the yield and the quality of fruit crops. Canopy management is defined as the control of tree canopy to optimize the production of quality fruits. That includes both training and pruning which enhance the quantity of sunlight intercepted by trees due to the tree shape regulates the exposure of leaf area to incoming radiation. Consequently, better light penetration into the tree canopy improves tree growth, productivity, yield and fruit quality (Ahmad et al., 2006). Capturing and conversion of sunlight into the fruit biomass is an essential process in fruit production. Better canopy management practices can optimize tree canopy light interception and carbohydrate partitioning for fruit development. Open tree canopies can support high fruit numbers, large fruit sizes and good fruit color and quality of apples (Wünsche and Lakso, 2000). Light is an essential factor for growth and development of trees and fruits. The green leaves absorb the sunlight to induce carbohydrates and sugars synthesis which are translocated to the buds, flowers, fruits. Carbon supply also contributes to quality and maturity of fruits. The onset of maturation can be postponed due to the shortage of assimilate supply. Even the difference in fruit size and density depends on assimilate supply (L´echaudel and Joas, 2006). Because of its crucial role, canopy management on the one hand should aim for maximal utilisation of light by regulating the growth, optimal productivity with quality fruit production. In contrast, it should help to avoid microclimate, that is advantageous for diseases and pest infestation. Economical aspects in obtaining the required canopy architecture and convenience in carrying out the cultural practices should also be paid attention to (Srivastava, 2007).

Crop load is the canopy's ability supporting to ripen fruits and it shows that balance may also be considered as the amount of leaf area required to ripen a unit of crop weight. In many cases, yield has considerably soared up, however the increase in productivity without

appropriate canopy and crop load management have produced trees that yield high crop load but small size of fruits (Whiting et al., 2006). Improved fruit quality and greater percentages of large fruit were known by thinned treatments (Einhorn et al., 2011). One technique of crop load management is thinning of spurs, buds, flowers and/or fruits to produce sustainable yield and to increase the fruit size. The removal of fruiting spurs from side branches has been suggested for the improvement of balance between vegetative growth and fruit load in cherry trees . As a result, it leads to an increase in fruit size, colour and to a decrease in brown rot incidence (Lauri, 2005). The reduction in crop loads of apple trees improved quality in terms of color, size and firmness (Link, 2000, Daugaard and Grausland, 1999, Poll et al., 1996). In case of apple trees. Light crop load also advances fruit maturity as background color, starch - iodine score, and soluble solid content (Palmer et al., 1997, Wünsche et al., 2005). High leaf to fruit ratio contributes to higher total soluble solids and greater concentration of sucrose and malic acid. Fruit of low leaf to fruit ratio inhibits the onset of maturation as well as the intensity of maturation (L´echaudel and Joas, 2006). Huong (2008a) reported that flower and fruitlet thinning increased fruit set, yield, and decreased diseases in mango.

Fertilizer application: Optimal fertilizer utilisation plays a key function in obtaining high yield and quality of crops, especially in terms of balanced and integrated fertilization of different nutrients through soil and plant analysis . It is suggested that, fertilizer formulas can be chosen according to plant requirement as a tool to increase the yield and to improve the quality (Rezk et al., 2005). Inorganic mineral nutrients can affect the quality of fruit crops in different aspects, principally in physiological fruit disorders (Ferguson and Boyd, 2002). High amount of nitrogen in soil-applied or foliar-sprayed led to greater quality criteria such as volatile production in apples (Mattheis and Fellman, 1999). Fouad et al., (2003) found that applying a congenial amount of potassium fertilization on mango trees can positively improve fruit weight, dimensions, total soluble solids, total sugars and ascorbic acid content. Moreover, both macro- and micronutrients contribute to achieve the great productivity and quality of fruit trees (Abo EI-Komsan et al., 2003). Yield of grape was remarkable increased in response to foliar application of magnesium (Mg), iron (Fe), and boron (B) (Usha and Singh, 2002). Tariq et al. (2007) suggested that foliar spray Zinc + Magnesium or Zinc + Bo in combination with urea can improve yield and quality of citrus fruit. Proper application of macro nutrients and foliage fertilizer after fruit set can raise mango yield (Huong, 2008). Even pre-harvest calcium sprays on mango can prolong fruits storage (Singh, 1993).

Abiotic factors as temperature and water: It is reported that high fruit temperature caused by long and intensive sunlight has an considerable impact on fruit quality. This can break down skin pigments and/or skin damage in avocado (Woolf et al., 2000a), apple (Wünsche et al., 2000, Schrader et al., 2003). Sun exposed sides of avocados show greater flesh firmness and higher dry matter content. As a result, these fruits require longer time to ripen (Woolf et al., 1999, 2000b). High temperature in spring can cause a faster decrease in flesh firmness of pear fruit (Lötze and Bergh, 2005). However, strongly accumulated heat units priority to harvest can enhance total soluble solid levels in pears due to risen carbohydrate assimilation (Frick, 1995). Many management practices are applied to avoid high temperature damage to fruit such as bagging (Huong, 2008a), kaolin and shading treatments (Yazici and Kaynak, 2009), particle films, sprinkler cooling or prunning.

Limited water supply may also affect yield and quality. Sustainable irrigation such as regulated deficit irrigation and partial root-zone drying can save considerable amount of water but these irrigation methods may cause reduction of mango yield compared to the fully irrigated control. However, average weight of mango fruits and their postharvest quality are not obviously affected in the long term (Speer et al., 2007, 2009). Water stress of fruit trees is directly contributed by crop load. Both deficit irrigation and crop load causes plant water stress. In some cases, irrigation deficit reduces fruit size but does not affect yield or fruit quality in apple trees (Neilsen et al., 2010). In trees applying deficit irrigation, with increasing crop load the degree of water stress was more serious. Fruit fresh weight of peach was decreased by water stress at all kinds of crop load (Berman and Dejong, 1996).

Based on results mentioned above, further studies are required to precisely evaluate the effect of these production factors in mango and identify which factor has the greatest effect on fruit quality, so that both fruit quality and yield can be managed better to meet consumers' expectations.

2.2. Fruit ripening and control of postharvest quality

2.2.1. Maturity on post harvest of fruit

Commercial maturity of a plant or plant part is a stage of development at which those parts are ready for use by consumers for a specific purpose (Johnson and Hofman, 2009, Dhatt and Mahajan, 2007). It is not easy to pinpoint the right harvest time for all fruit crops because it really depends on the individual commodity in particular conditions (Watada et al., 1984).

Maturity at harvest plays an important role for postharvest life and eating quality, in particular for climacteric fruits where ripening is regulated by ethylene (Dhatt and Mahajan, 2007, Lelièvre, 1997). Harvest date, a parameter going along with maturity of fruit, contributes to quality and maturity of fruit. Fruits harvested at an immature stage may not achieve normal ripening characteristics (Léchaudel and Joas, 2006). On the other hand, an overripe fruit may deteriorate quickly after harvest (Tefera et al. 2007). Fruits take more time for lesser mature fruits, which ripen at the same thermal regime. If fruits are harvested too early as shown for green skin papaya, its consumption quality is not acceptable (Bron and Jacomino, 2006). Jha et al. (2006a) reported that the storage longevity of fruits was closely related with the level of maturity at which the fruit was harvested. Maturity stage of fruit contributed to quality not only of fresh fruits but also of processing products as canned and canned puree fruit (Olaeta et al., 2003). Normally, several harvest indices are used to determine picking times such as size, skin and pulp color, acidity, sugar content, flesh firmness, and calendar day from bloom to harvest (Crane et al., 2009). Léchaudel and Joas (2006) claimed that total soluble solids, sucrose, and malic/citric acid ratio could be used for determination of physiological maturity; fresh weight, density, and pulp dry matter content for harvesting mango fruit. Furthermore, a recent study by Jha et al. (2006b) suggested that measuring fruit firmness and yellowness at pre- and postharvest were essential indicators to determine the proper harvest time. Notably, non-invasive techniques such as spectroscopy (Guthrie and Walsh, 1997) and nuclear magnetic resonance spectroscopy (Gil et al., 2000), sound velocity technique (Subedi and Walsh, 2009) have been used to assess mango fruit maturity and quality. Mango fruits are generally harvested during their physiological maturation to get optimum fruit quality (Crane et al., 2009, Jha et al., 2006a). However, variation in maturity between fruits can be determined by different cultivars due to non-simultaneous flowering or the position of fruit attached on the tree (Johnson and Hofman, 2009). It is suggested that crop management before harvest to schedule optimum maturity may create advantages for postharvest applications.

Fruit maturity also contributes to the efficiency of technical applications such as 1-MCP or ethylene treatment to postharvest stage. The effects of 1-MCP on apple fruits are highly correlated to fruit maturity and 1-MCP concentration (Lima et al., 2007). The stage of maturity is a key factor in treatment of 1-MCP to banana as an example (Harris et al., 2000). Not only 1-MCP but also ethylene treatment is dependent on fruit maturity. Loquat fruit

(*Eriobotrya japonica* Lindl.) is more susceptible to ethephon at maturity stage than at the immature stage. Ethephon treated fruit induced color change earlier than untreated fruit (Undurraga and Olaeta, 2003). In addition, harvesting fruit at optimum maturity in combination with maintaining proper sanitation procedures, and storage under optimum temperature and relative humidity can delay postharvest deterioration (Lee et al., 1996).

2.2.2. Physiological and chemical change during fruit ripening

Fruit ripening is an irreversible process engaging a series of physiological, biochemical, and organoleptic changes. It results in soft edible ripe fruit with desirable quality (Prasanna et al., 2007).

Biochemical changes in fruits after harvest still occurs. From consumers' point of view, some changes are expectable (color and flavor improvement), but other parameters (e.g. respiration, transpiration, etc.) can cause postharvest losses in fresh weight, appearance, texture and nutritional value (Lee et al., 1996). In term of ripening mechanisms, fruits can be divided into two groups: climacteric fruits, in which ripening is accompanied by a peak in respiration and a concomitant burst of ethylene, and non-climacteric fruits, in which respiration shows no sharp change and ethylene production remains at a very low level (Romero et al., 2003, Prasanna et al., 2007). Climacteric fruits such as mango, papaya, banana quickly change their sweetness, aroma and softening during the ripening process. Furthermore, the decrease of chlorophyll content and the building up of carotenoid and phenolic compounds occur due to the differentiation of chloroplast into chromoplast in the ripening process of fruit (Chisari et al., 2009). Additionally, cell wall degradation and fruit softening are associated with ripening progression,. Accordingly, the activity of polygalacturonase during fruit ripening correlates with cell wall disassembly, high activity of polyphenoloxidase and changes of color (Chisari et al., 2009). An increase in aroma during fruit ripening is mainly caused by the mixture of volatile compounds such as ocimene and myrcene (Lizada, 1993). Ripe mango holds more than 300 volatiles (Pino et al., 2005) and Prasanna (2007) reported that the development of flavor is induced by breakdown of bitter, flavonoids and tannins. The taste development is marked by increase of gluconeogenesis, hydrolysis of polysaccharides, especially starch, and decrease of acidity (Lizada, 1993, Prasanna, 2007, Brecht and Yahia, 2009). In immature fruit, sucrose is almost absent but it shows a significant increase during ripening and becomes the major carbohydrate constituent in the ripe fruit (Wang et al., 1996). Concentration of common sugar such as sucrose has been shown to be an important indicator for fruit quality

assessment. It is reported that sugars and acids ratio could be influenced on tester's perception in mango flavor (Malundo et al., 2001). Thus, consumer preference and interviews should be exploited to understand consumer's purchase behaviors.

2.2.3. Temperature and fruit ripening

Decreasing temperature is a common method to reduce all metabolic activities and biochemical reactions. Low temperature is an effective means to prolong storage and shelf-life of fruits thanks to significantly reducing both respiration and ethylene synthesis (Lee et al., 1996, Crane et al., 2009). It is reported that when storage temperature increases 10ºC over the optimal storage temperature of fresh produce, it will speed up deterioration of fresh produces by a factor of 2-3 times (Thompson et al., 2008, Wang, 1990). However, when storage temperature is too low, physiological injury can take place. The symptoms of chilling damage may give rise to surface pitting, discoloration, internal breakdown and decay (Wang, 1990). An optimal storage temperature is the temperature at which deterioration reactions are minimized without causing any chilling disorders (Lee et al., 1996). Typical tropical fruits such as mangoes are quite sensitive to cold temperature. It is subjected to chilling injury with temperature below 13ºC for mature green mangoes and below 10ºC for partially ripe mangoes (Kader and Mitcham, 2008, Johnson and Hofman, 2009). Mature mango fruits can extend shelf-life for transportation or for being kept at retail markets for some days or some weeks without symptoms of chilling injury at temperature 10 - 13ºC (Crane et al., 2009, Soe et al., 2006). However, at higher temperature, climatic fruits ripen intensively due to the fact that ethylene production increases as soon as the temperature rises. To promote ripening and improve skin color, mango fruits should be stored at a temperature range from 15.5 to 18ºC (Kader and Mitcham, 2008) or from 20 to 23ºC (Paull and Chen, 2004).

The use of heat treatments in postharvest management is applied to many kinds of fruits to prevent fungal and insect eradication (Paull, 1994, Lurie, 1998). A significant benefit of heat treatment is that no chemical residues remain on the fruits. Commercially applied heat treatments are hot water (HW), vapor or air respectively. Methods of heat treatment may influence the response of the commodity as well as the length of exposure to achieve a desired effect. HW is a heat transfer medium, which is more efficient than hot air (Shellie and Mangan, 1994). Furthermore, HW dip effectively controls fungal pathogens even after only a few minutes (Paull, 1994). Effects of heat treatments on the physiology of fruit after harvest are various, including delaying processes of ripening (Woolf et al., 1995), slower rates of

flesh softening and pectin solubilization (Klein et al., 1990), reduced ethylene production (Klein and Lurie, 1990, Paull and McDonald, 1994). Postharvest heat disinfestation treatments can cause injury and thus it may cause reduction in the quality of fresh fruits (Lurie, 1998, Jacobi et al., 2001). Many kinds of fruits can tolerate temperatures of 50 - 60ºC for up to 10 min (Barkai-Golan and Phillips, 1991) but it takes 60 min or more if temperatures are below 50ºC (Lurie, 1998) for heat treated disinfestation. Recommended temperature for heat treatment of mango ranges between 22 - 48ºC for up to 110 min (Jacobi et al., 1995, 2000), while it is at 50ºC, 4 h for papaya (Shellie and Mangan, 1994) or grapefruit at 43.5ºC for 4.5 h (Miller and McDonald, 1992).

Pre-treatment of heat can also reduce the incidence of heat injury symptoms in fruits due to too low or too high temperature (Wild, 1993, Jacobi et al., 2001). In case of grapefruit, a short-duration in 53 - 59ºC water is capable of preventing peel injury (Ritenour et al., 2003). In addition, grapefruit treated with HW prior to storage at 4.5ºC in controlled atmosphere shows not only a strong reduction of peel pitting development but also an increase in peel total soluble and non-reducing sugar levels (Ezz et al., 2004). Sometimes, pre-treatment with heat is necessary to reduce injury and maintain better postharvest quality. HW pre-treated mango at 55ºC for 5 min stored under controlled atmosphere at 8ºC for 45 days and displays no symptoms of morphological chilling injury and ripened normally at ambient conditions (Niranjana et al., 2009). For papaya, fruit heat tolerance is increased and heat injuries are decreased or eliminated if fruits are treated at 38 - 42ºC for 60 min after HW immersion at 49ºC for 70 min (Paull and Chen, 1990). Similarly, benefit of prior temperature conditioning in 37 or 39ºC air before a 46º or 47ºC HW disinfestation is a reduction in heat damage on avocados (Jacobi et al., 1995, Woolf et al., 1995) and mangos (Joyce and Shorter, 1994).

2.2.4. Role of ethylene in fruit ripening

Ethylene, a fruit ripening phytohormone, is usually associated with many biochemical activities. It can trigger at low concentration many events of cell metabolism including initiation of ripening and senescence, particularly in climacteric fruits (Arteca, 1996, Prasanna et al., 2007). Ethylene can be generated by the application of exogenous ethylene. Consequently, it induces an accelerated rate of ripening (Johnson and Hofman, 2009). Ethylene gas or ethephon/ethrel liquid can be used for commercial fruit treatment. The benefits of ethylene treated fruits are better color and aroma before releasing them to the market (Montalvo et al., 2007). Some kinds of fruits are quite sensitive to ethylene, for

example even low concentration of ethylene (0.01 $\mu L \cdot L^{-1}$) can promote the ripening process in mango (Johnson and Hofman, 2009). However, very high concentration of ethylene (1000 $\mu L \cdot L^{-1}$) results in improper ripening of fruits (Montalvo et al., 2007). To accelerate fruit ripening of avocados, bananas, mangoes, honeydew melons, kiwifruit, mango, stone fruit, ethylene exposure of 10 to 1000 $\mu L \cdot L^{-1}$ are commercially used (Saltveit, 1999, Kader and Mitcham, 2008). Similarly, direct exposure of kiwi to ethylene after harvest or at any time up to 6 weeks can promote ripening (Lallu et al., 1989).

The regulatory effect of ethylene on fruit metabolism is one of the key issues in postharvest preservation. Exogenous ethylene may increase respiration rate and the activity of enzymes such as polygalacturonases, polyphenol oxidase, phenylalanine ammonialyase, peroxidases, lipidoxygenases and α-amylase. These enzymes allow fruit to ripen in a dependent manner (Lee et al., 1996). At the onset of climacteric fruit ripening, changes in colour, aroma, texture, flavor is mainly initiated by the sharp increase in ethylene production (Lelièvre et al., 1997). Barmore (1974) recommended that mature mango should be exposed to ethylene 5 - 10 ppm for 24 - 48 h at 30ºC with high humidity (95% RH) . Otherwise, treatment with ethephon at 1000 - 4000 $\mu L \cdot L^{-1}$ for 1 or 2 min can increase soluble solids content (Sergent et al., 1993). In spite of being kept at 13ºC for 4 days, applying ethylene 100 $\mu L \cdot L^{-1}$ to mango can promote the synthesis of ACC, an intermediate of ethylene synthesis. Inversely, ethylene production ensures more homogeneous external color and earlier ripening (Montalvo et al, 2007). In case of long-term storage, the presence of exogenous ethylene in the storage chamber is harmful to both climacteric and pseudo-climacteric fruits. However, fruits that are non-climacteric, such as strawberry, citrus, grapes and cherries, are less sensitive to ethylene (Lelièvre et al., 1997).

The level of ethylene biosynthesis and postharvest ripening is greatly influenced by storage temperature. Low temperatures are usually used to extend the storage life of fruit, but low temperatures can also accelerate ethylene synthesis and induce premature ripening in some temperate fruits (Lelièvre et al., 1997, Wang, 1990). The capacity to convert ACC into ethylene is induced more rapidly at 0-5ºC than at 20ºC during storage of pre-climacteric apples (Jobling et al., 1991, Larrigaudiere and Vendrell, 1993). Lelièvre et al. (1995) reported that low temperatures could also promote autocatalytic ethylene production in climacteric fruits. Ethylene production as well as the ability to convert ACC to ethylene of mango fruit were maintained at low temperatures (0 - 5ºC), which lead to chilling injury to the peel (Lederman et al., 1997). Chomchalow et al. (2002) showed that both applications of ethylene

after storage at chilling temperature (2.5ºC) and optimal temperature (12.5ºC) delayed ripening of tomato fruit. However, the marketable life of tomatoes stored at 2.5ºC is extended by pre-storage ethylene treatment, but not by post-storage ethylene treatment. Storage at low temperatures above the chilling injury threshold, in modified atmosphere or oxidizing ethylene with $KMnO_4$ can restrict the exposure of fruits to ethylene (Lelièvre et al., 1997, Lee et al., 1996).

2.2.5. Effect of 1-Methylcyclopropen to fruit ripening

An important inhibitor of ethylene perception in plant tissues is 1-Methylcyclopropene (1-MCP). Mechanism of its action is proposed to be through binding irreversibly to ethylene receptors, thus delaying the normal action of ethylene and extending the storage life of produces (Blankenship and Dole, 2003). Recently, 1-MCP is applied to many fruits in postharvest management to reduce respiration, ethylene production and maintain flesh firmness (Watkins, 2006, Blankenship and Dole, 2003).

The effect of 1-MCP on some crops depends on a relationship between concentration, time, temperature, and application method (Blankenship and Dole, 2003). Pear fruits, which are exposed to 100 $nL \cdot L^{-1}$ 1-MCP and stored at -1ºC, have extended storage life and low superficial scald development. However, treating with higher concentration of 1-MCP (1000 $nL \cdot L^{-1}$) to pear fruits results in failure of fruits to soften (Ekman et al., 2004). Apple fruits treated with 1-MCP considerably decrease ethylene production and respiration rates, resulting in extended storage and shelf-life. Moreover, apple fruits treated with 1-MCP has less reduction of fruit firmness and titrable acidity than the control ones (Fan, 1999). Likewise, 1-MCP treated plums has less weight loss, less reduction in flesh firmness and soluble solid/ titrable acidity ratio, and lower color changes during cold storage compared to controls (Romero et al., 2003). Exposing litchi to 1-MCP prevents browning and maintains color at cold storage. Furthermore, 1-MCP treated litchi greatly reduces the polyphenol oxidase and peroxidase activity, maintains membrane integrity and delays the decrease of pericarp color (Reuck et al., 2009). Comparably, 1-MCP treated papaya prevents the increase in ethylene evolution and delays partial softening and color development (Moya-León et al., 2004). Treatment of avocado fruits with 1-MCP at 20ºC extends their shelf-life up to 20 days. However, the effect of 1-MCP to delay ripening is hardly observed if the fruit initiates softening (Adkins et al., 2005).

In fact, 1-MCP re-treating may achieve a better inhibitory effect on ethylene production. Avocado, that is treated twice with 100 $nL \cdot L^{-1}$ 1-MCP, is more beneficial in reducing ethylene-induced mesocarp discoloration than only once (Pesis et al., 2002). Similar effects can be achieved when mango fruits are applied once with 1-MCP at high concentration at harvest or twice at low dosage at harvest and 14 days later at 11ºC (Lima et al., 2006). Re-treating 1-MCP to pears shows that its recovery of ethylene sensitivity is delayed after a period of green fruit storage and it is quite insensitive to additional 1-MCP if it already starts to ripen (Watkins, 2006). Loss in postharvest effect of pre-harvest 1-MCP application to apples is reinstated by exposing fruits to gaseous 1-MCP on the day of harvest. The results imply that pre-harvest 1-MCP sprays may have less utility in some cultivars that quickly generate new ethylene receptors since fruit ripening (McArtney et al., 2009).

The degree of inhibition caused by 1-MCP depends on cultivar, maturity level and storage conditions (Watkins et al., 2006). Applying the same concentration of 1-MCP to control ripening of many apples cultivars (1000 $nL \cdot L^{-1}$) can totally inhibit ripening of pears. Hence, lower concentrations of 1-MCP might be necessary for pear to achieve desirable eating quality (Ekman et al., 2004). Fruits that are more mature and more rapid ethylene producers are often less responsive to 1-MCP (Mir et al., 2001). Internal ethylene levels can contribute to the efficacy of 1-MCP at suppressing ripening of climacteric fruits after initiation of ripening (Zhang et al., 2009). Long 1-MCP exposure at low temperature gives similar results in delaying ripening of apple when compared to short 1-MCP exposure at high temperature (Mir et al., 2001, Fan and Mattheis, 2001). It is supposed that the affinity of the binding site for 1-MCP is weaker at lower temperatures (Mir et al., 2001).

Combination of 1-MCP treatment and other postharvest application is more effective in controlling quality. Application of 1-MCP in combination with the use of polyethylene bags can extend the postharvest life of mango at 20ºC up to 30 days (Jiang and Joyce, 2000). Combined application of controlled atmosphere and 1-MCP for stored apple also brings about more benefit. Accordingly, controlled atmosphere can extend the impact of 1-MCP on physical and sensory responses of apple fruits (Rupa-Singhe et al., 2000, Watkins et al., 2000). 1-MCP becomes more efficient when being applied at temperatures ranging from 20 - 25ºC (Blankenship and Dole, 2003).

1-MCP slows down fruit ripening not only through postharvest treatment but also through preharvest treatment in some crops. Basically, preharvest 1-MCP spray to apple can maintain postharvest quality parameters (McArtney et al., 2009). It is also recommended that the 1-MCP treatment is useful for a crop like apples, where the purpose is to retain the crunchy texture from harvest through to consumption (Watkins, 2008). In case of other fruits like mangoes, where the aim is to have an evolution in texture between harvest and consumption, 1-MCP application should delay but not inhibit ripening.

2.3. Quality control of postharvest mango fruits in Vietnam

Mango is a highly and shelf-life perishable fruit due to rapid ripening and softening that limits the storage of the fruit. Normally, fruits need to be distributed to consumers in different markets and far from where fruits are grown. Therefore, control of postharvest quality of fruit is essentially important. Lee (1996) reported that postharvest losses could be 10 - 20% in industrialized countries and 30 - 40% in the developing countries. The main reason for postharvest loss is the lack of sufficiently and adequately equipped storage facilities (Soe et al., 2006).

In Southern Vietnam, Cat Hoa Loc mango fruits are available in large quantities from February to May (Fig. 0) while other cultivars can extend the fresh market season to July. Moreover, new technical applications for off-season production can supply mango year-round, but prices in off-season are always higher than in season.

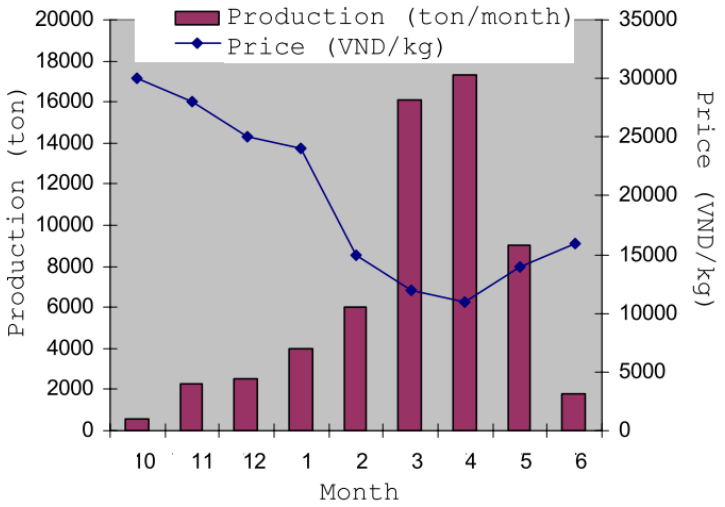

Figure 0. Production and price of mango cv. 'Cat Hoa Loc' in 2004 *(Source: modified from Hien et al., 2006).*

Mango fruits are handpicked in Vietnam by climbing up the tree or using a picking pole. Fruit maturity is determined by the appearance, the length of time after flowering, fruit color and aroma. The fruit needs to reach market as soon as possible because of its perishability (FAO, 2004). 'Tron' and 'Hoi' fruits are sometimes harvested with tree vibration and subsequently, they are seriously bruised.

After harvest, mango is graded, wrapped good grade mangoes in paper and packed into bamboo or plastic baskets and delivered to distant markets or nearby traders by trucks with or without air conditioning. Mango usually sell as soon as possible after harvest. Depending on markets, fruits can be treated with different methods: for example, applying calcium carbide (CaC_2) for accelerating ripening (Hien et al., 2006; Binh, 1999) or using coated film and stored at about 12ºC for increasing storage time (Hoa and Ducamp, 2008, Hung et al., 2006). Recently, a commercial postharvest chain management system that can keep mango for 30 days has been developed by Can Tho University (Hoa, 2007). Moreover, under the Metro supermarket supports, a new supply chain has been launching for fruits and vegetables. Besides, AusAID project of Australia is implemented to get better supply chain for mango and pomelo. From those supports, the farmers would improve their fruit quality to meet the demand of the buyers (Hoa, 2008). Understanding details about ripening and postharvest characteristics of Vietnam mangoes may extend shelf-life and quality and then match better consumers' preference. There are several suggestions for post harvest strategies of fresh mango to maintain marketable quality and extend the storage life: (1) low temperature to slow down metabolic rate and fungal infection, (2) keeping up a high humidity of 90 - 95% RH to maintain desiccation, and (3) picking at optimal maturity (Lee et al., 1996).

In the North, especially in mountainous areas like Son La, farmers usually have no written contracts with wholesalers. Most of the producers sell their fruits through the collectors; price at farm is about half at markets and this lead to farmers and middle mans do not invest in storage facilities. 'Tron' and 'Hoi' mangoes have been harvested for three months, from May to July and they ripen intensively in one month. Some researches have been done on 'Tron' and 'Hoi' mangoes. Binh (1999) reported general agronomic characteristics and physiological fruit parameters of 'Tron' and 'Hoi' mango as described in Table 1.

Table 1. Some agronomic characteristics and chemical components of ‘Tron’ and ‘Hoi’ fruit

No.	Criteria	Tron	Hoi
1	Yield in of mature trees (kg/tree)	21.3	24.8
2	Fruit length (cm)	8.1	10.9
3	Fruit width (cm)	6.5	7.1
4	Fruit thickness (cm)	5.7	6.1
5	Fruit weight (g)	154.3	224.7
6	Shape	oval	ovoid-oblong
7	Skin colour	yellow green	yellow green
8	Flesh colour	dark yellow	dark yellow
9	Taste	very sweet, less fiber, strong flavor	very sweet, less fiber, quite strong flavor
10	Edible ratio (%)	55.6	55.6
11	Dry mater (%)	16. 6	17.2
12	Total sugar content (%)	13.9	13.0
13	Titrable acidity (%)	0.2	0.9
14	Fiber (%)	0.17	0.19
15	Vitamin C (mg/100g)	56.6	29.1
16	Carotenoid (mg/100g)	1.6	1.9

(Source: Binh, 1999).

Huong (2007) recommends treating with ethrel to mature fruits of ‘Tron’ and ‘Hoi’ at commercial harvest at ambient condition to improve skin colour, to reduce weight loss and spoilage. However, green mature fruits before commercial harvest have not been studied in details.

2.4. Working hypothesis

To determine the best time for harvesting ‘Tron’ and ‘Hoi’, one needs to understand which characteristics of fruit quality meet market requirements by setting up a detailed consumer preference research approach. This, in turn, requires determination of specific qualitative fruit

maturity parameters not only to find out optimum harvest strategies but also to improve postharvest storage and shelf-life behavior. Therefore, aim of this study is to determine the optimal time for harvesting Tron and Hoi mangoes and quality changes of these mangoes due to their different storage temperatures.

It is known that 1-MCP can delay ripening on many fruits. 1-MCP application can extend the storage life of fruit with or without cool storage combination. The research needs to investigate the effect of 1-MCP on various fruit ripening parameters of ‘Tron’ and ‘Hoi’ mangoes. Storage experiments were carried out to determine a suitable treatment procedure for the use of 1-MCP on ‘Tron’ and ‘Hoi’ mango in the Son La province of northern Vietnam.

Moreover, mango is a typical climacteric fruit that ripens fast and thus becomes soft and deteriorate in short time, which constrains the deliver to more profitable markets than the remote markets near the production area. Green mature mango can be firmed and stabilized during transportation. Using ethrel approach for mango can hasten fruit ripening when needed. This brings more advantages for distribution to distant and more profitable markets. The effect of ethrel exposure on ripening of ‘Tron’ and ‘Hoi’ mango varieties is not known when fruits have been stored in cool condition. The application of aqueous ethrel solution on cool storage ‘Tron’ and ‘Hoi’ mangoes needs to be evaluated. Additionally, hot water treatment is contributory to storage life of fruits.

Objectives of the study

The main objective of this study was to assess the impact of different postharvest treatments to control mango ripening and fruit quality. The sub-objectives of the study were as follows:

- Define quality parameters for determining the optimal harvest time for ‘Tron’ and ‘Hoi’.
- Control postharvest ripening of ‘Tron’ and ‘Hoi’ by (1) Cool storage and hot water treatment, (2) 1-Methylcyclopropen application for delaying mango ripening and (3) Ethrel application for accelerating mango ripening

The research activities were integrated in an international research cooperation “Sonderforschungsbereich 564” (DFG) entitled "Sustainable land use and rural development in mountainous regions of Southeast Asia" between Vietnam and Germany.

3. Materials and Methods

3.1. Study area and plant materials

Son La, the third largest Province in the country, is located in the north-western region of Vietnam. The Province is home to more than one million people of 12 ethnic groups, including Ma, H'mong, Dao, Muong, Kinh, Khmer, Tay, Thai, and others, of which the majority live on subsistence farming.

Eighty percent of the Province's natural area is covered with mountains. The topography includes forests, high mountains, narrow valleys, small plains, and springs. Son La Province is situated approximately 20º39' - 22º02' N and 103º11' - 105º02' E at 600 – 700 m above sea level and covers 14,125 km^2, with drastic dissection of terrain. Mango production has been practiced in the mountainous tropical area with cool climatic condition in the winter time from October to April. The annual average temperature is about 21.1ºC in Son La city and 23ºC in Yen Chau district.

Yen Chau district of Son La Province is surrounded by mountains. Consequently, the weather is drier and warmer than in the lowlands in January and February which favours fruit set of mango. During this time, the lowland area has low temperature, high humidity and drizzle, leading to diminished fruit set of mango. Moreover, the dry and hot winds in Yen Chau from February to May not only cause drop of young fruit but also lead to shorter shelf-life and unattractive skin colour.

In Yen Chau, temperatures are cooler in the dry season from November to April (between 17ºC and 23ºC), particularly in the highlands. In the rainy season (May - September), temperature ranges between 23ºC and 27.4ºC. The average annual maximum and minimum temperatures are 27.4ºC and 17.5ºC, respectively. The average annual rainfall is 1,156 mm and relative humidity is about 75 – 78%.

Between 2007 and 2009, the research work had been carried out on farmer orchards in the Tu Nang and Chieng Khoi commune, Yen Chau district, Son La, Vietnam (20º56' - 10º66' N; 104º28' - 13º12' E).

Representative ten year old 'Tron' and 'Hoi' trees, developed from seeds, were planted at a distance of 5m x 6m. 'Tron' was harvested on 06/06/2007, 20/06/2008, 25/05/2009 and 'Hoi'

on 15/06/2007, 29/06/2008, 03/06/2009, respectively. After harvest, fruit was immediately moved to Hanoi University of Agriculture at 25ºC. Fruit was washed with water and soft cloth and dried at ambient temperature prior to being designed experiments.

3.2. Experimental design

3.2.1. The effect of harvest time and storage temperature on fruit quality of 'Tron' and 'Hoi'

3.2.1.1. Fruit samples and treatments in 2007

In 2007, a survey approach included 10 orchards in Tu Nang commune and Chieng Khoi with 8 representative trees for each cultivar at each orchard. Ten fruits from each tree were randomly harvested. Representative ten fruits of 'Tron' and 'Hoi' were collected randomly throughout the canopy at 10 days before commercial harvest, at commercial harvest and at 10 days after commercial harvest. There were 160 fruits per orchard at each picking time of the two cultivars and a total of 4,800 fruit were harvested and used for detail fruit quality assessment and consumer preference analysis at harvest and following various post-storage durations.

A 133 fruit sample of each cultivar was stored either for 5 and 10 days at 20ºC or for 10, 20 and 30 days at 12ºC, with relative air humidity of about 70%. Air temperature and humidity inside the storage rooms were logged by an Onset Hobo logger. Fruits were held for 24 h at 20ºC prior to fruit quality assessment.

Data collection

Each treatment used a 33 of 133 fruit for consumer preference and left 100 fruits for the following criteria:

At each assessment date, 100 fruits were recorded fruit weight (g), flesh weight (g), dry flesh weight (g) by digital scales and fruit size (mm) by caliper (model 19975 Shinwa rules Co., LTD., Japan).

Skin disorders of 100 fruit caused by insects, sapburn, mechanical scratch before harvest and disease incident were evaluated based on a scale from 1 to 5; 1 - no disorder, 2 - slightly affected (1-5% surface area), 3 - medium damage (5-15%), 4 - severe damage (>15%) and 5 - spoiled (black colour and sunken skin).

Total soluble solid concentration (TSS) (%) of 100 fruit was measured by a portable refractometer (E-line 90, Bellingham and Stanley, UK).

Firmness was determined with a handheld penetrometer (model FT 327, Wagner Instruments, Italia) with a cylindrical probe of 8.5 mm diameter. After fruit peel was removed, flesh was penetrated with 100 fruits. Only one determination from each fruit was performed in 2007 and results were reported in Newton (N).

Consumer preference

The consumer preference was carried out by 7 panellists, who tested colour, odour, taste and texture parameters in each sample. Testers were trained before assessment. At assessment day at Hanoi University of Agriculture (HUA), the fruits were sent to each tester. They were asked to rate their perceptions of each criteria by using a scale from 1 to 5 as described in Table 2 and testers would choose a score within this satisfaction scale to reflect their perception of the fruit. In addition, each tester evaluated the overall preference of the whole fruit from a consumer's point of view. From the perceptions, the highest proportional frequencies (%) of answers in each quality criteria were calculated to reflect the preference ratio.

Panellist investigation points out that: higher score (1 - 5) is more preferable for appearance, skin and flesh colour and taste. Medium score (3) is the most preferable for flesh firmness and juiciness.

Table 2. Criteria of mango for consumer preference

Criteria	Rating level				
	1	2	3	4	5
Appearance	not attractive	less attractive	fair	attractive	very attractive
Skin colour	green	yellow green	greenish yellow	yellow	orange yellow
Flesh colour	white	light yellow	yellow	dark yellow	orange yellow
Taste	very sour	sour	fair	sweet	very sweet
Flesh firmness	fully soft	soft	right	hard	extremely hard
Juiciness	much juicy	juicy	fair	little juicy	not juicy

3.3.1.2. Fruit samples and treatments in 2008

In 2008, a repeated survey was carried out at 5 representative orchards of 'Tron' and 'Hoi' in the Tu Nang commune. Six fruits per tree from 6 trees of each cultivar at each orchard were collected three times, as in 2007, at 10-day intervals. A total number of 1,080 fruits were collected. A 30 fruit per treatment of each cultivar was stored either for 5 and 10 days at 20ºC or for 10, 20 and 30 days at 12ºC, with relative air humidity of about 70%. Each treatment used 20 of the 30 fruits for consumer preference and left 10 fruits for other criteria.

All criteria of cool storage experiment in 2007 were repeated. In which, flesh firmness measured twice per fruit; dry flesh weight was stopped to collect (g); carotenoid; vitamin C; carbohydrate (fructose, glucose, sucrose and starch) were analyzed; and number of testers increased from 7 to 21 persons for consumer preference.

Sample preparation for chemical analysis. In the laboratory of Hanoi University of Agriculture, 10 mango fruits were peeled at each assessment date of storage treatment. A 1/4 flesh of 10 fruits was cut into small pieces and pooled together for one bulk sample, then immediately soaked into liquid nitrogen and stored at -20ºC. In the laboratory of Food Industries Research Institute (Vietnam), at analysis day, about 50g of the bulk sample was ground homogenously and used for analysing carotenoid, vitamin C, and carbohydrates.

Vitamin C

Vitamin C of 5 g mango sample was extracted with 50 mL of 5% metaphosphoric acid ($H_3PO_4 \rightarrow HPO_3$) solution to make the supernatant after centrifuging at 2168 g for 10 min. Then 2 mL of extract was added to 2 mL of 5% metaphosphoric acid containing 2% thiourea (H_2NCSNH_2) solution with some drops indophenol ($C_{12}H_9NO_2$) solution until pink colour stay for 1 min to prevent further oxidation of reducing vitamin C. Then reacted with 0.5 mL of 2,4-dinitrophenylhydrazine solution to form osazone for 16 - 17 h at room temperature. Produced osazone was added to 2 mL of 2% diethylether ($C_2H_5OC_2H_5$), shaken 10 min and took upper phase into test tube. The lower phase was added diethylether again, shaken 10 min and took upper layer into test tube (repeating 3 - 4 times). 2 g of sodiumsulfate anhydrous (Na_2SO_4) was added to the upper layer about and then the sample was shaken slightly to remove water. This solution was transferred into a rotary flask and diethylether was evaporated by rotary vacuum evaporator (at 35 - 36ºC) and then finally dried by nitrogen (N_2) flow. The residue was dissolved with 2 mL ethylacetate ($CH_3COOC_2H_5$) and filtered through

0.2 μm filter, then injected and measured by Shimadzu SPD-M10AVPvp HPLC with UV-Detector.

Carotenoid

β-carotenoid of 5 g mango sample were saponified directly by adding 3% pyrogallol ($C_6H_3(OH)_3$) ethanol (C_2H_5OH) solution and 60% potassium hydroxide (KOH) solution, then heated at 56ºC in water bath for 30 min and stirred every 10 min. Samples were cooled at room temperature and 1% sodium chloride (NaCl) solution, 2-propanol (C_3H_7OH) and 15 mL of ethyl acetate ($CH_3COOC_2H_5$) + n-hexane (C_6H_{14}) (in which ethyl acetate : n-hexane was 1 : 9 v/v) was added and shaken for 10 min. After centrifugation at 2168 g for 10 min, the upper phase was collected into flask. From the lower phase, β-carotenoid was extracted repeatedly for 3 - 4 times. The extracts were evaporated by rotary vacuum evaporator (at 35 - 36^{o}C). The residue was dissolved with 2 mL of ethanol and filtered through 0.2 μm filter, then injected and measured by Shimadzu RID-10A HPLC with RI- Detector.

Carbohydrates

Starch of 5 g mango sample was hydrolyzed by adding 40 mL of water and 5 mL of solution hydrogen chloride (HCl) 37%, shaking 1 min, and then heating at 100ºC in water bath with occasional stirring for 3 h. Sample was placed at room temperature (about 25ºC) after hydrolysis. Sample was neutralized with sodium hydroxide (NaOH) solution (pH = 7), then transferred into 100 mL volumetric flask and water was added up to 100 mL. Solution was filtered through filter paper, then through 0.2 μm membrane and used for HPLC analysis with RI-Detector. Produced glucose is measured by Shimadzu RID-10A HPLC with RI- Detector then multiplied by factor 0.9 (the ratio molecular weight glucose/ molecular weight starch) to convert into starch (Gomez et al., 2003, 2007).

Sucrose, glucose and fructose was dissolved in 50 mL of water. Solution was filtered through filter paper, then through 0.2 μm membrane and injected HPLC with RI- Detector. Sucrose, glucose and fructose was measured by Shimadzu RID-10A HPLC with RI- Detector.

Titrable acidity

Five grams of mango sample was added into 30 mL of water and homogenized. Total acidity was titrated with NaOH 0.1 N using phenolphthalein as an indicator. Titrable acidity (TA)

was expressed as % citric acid and calculated from amount of used NaOH 0.1 N (A) (AOAC, 1984).

Titrable acidity expressed as citric acid (%) = A ∗ 0.0064 ∗ 100/1.

Colour measurement

The colours of mango skin and flesh in terms of the luminance (L*), green or red colour (a*) and blue or yellow colour (b*) values was determined using a colourimeter (Nippon, Japan, Model NP-3000). L* measures lightness and varies from 100 for perfectly reflective white to zero for perfectly absorptive black; a* measures redness when positive, gray when zero, and greenness when negative; and b* measures yellowness when positive, gray when zero, and blueness when negative. Mango fruits were cut longitudinally and the colour of skin and flesh was measured in three different points of each fruit. Hue angle calculation: h^o = arctan (b*/a*)

Hue angle is expressed on a 360º grid where 0º = bluish – red, 90º = yellow, 180º = green, and 270º = blue.

Consumer preference

Consumer preference was done by 21 testers and the same testers assessed all criteria as the Table 2 and described procedures in 2007.

3.3.2. The effect of 1-MCP on mango fruit quality

3.3.2.1. Fruit samples and treatments

In 2009, fruits of 'Tron' and 'Hoi' were collected at 10 days prior commercial harvest and at commercial harvest. Ten fruits per tree of 'Tron' and 'Hoi' cultivar from 4 orchards in Tu Nang commune were harvested with five representative trees for each orchard, respectively. Fruits were either exposed to 250, 500 and 1000 $nL \cdot L^{-1}$ 1-MCP for 12 h in 0.5 m^3 glass chambers with circulating fan inside at ambient conditions (about 30ºC and 75% relative humidity). Untreated fruits, kept under the same conditions, were used as control treatment. Fruits were then sealed in plastic bags and stored at 12ºC and a relative humidity of approximately 70%. Following 5, 10, 15, 20 and 25 days of storage, 10 fruits per treatment were removed from the storage facility, kept for 24 h at 20ºC to simulate shelf life condition and then analysed for various quality parameters.

3.3.2.2. Data collection

At each assessment date, fruit weight (g), skin disorders, flesh firmness, TSS (%), skin and flesh colour of 10 mango fruits were measured as previously described in section 3.3.1.2.

Total acidity

30 mL of water were added to 5 g of mango sample and homogenized. Total acidity was measured by titrating with NaOH 0.1 N (Schott, Titroline easy, Germany). Titrable acidity was expressed as % citric acid and calculated from the amount of used NaOH 0.1 N (A). Titrable acidity expressed as citric acid (%) = A ∗ 0.0064 ∗ 100/1.

Vitamin C: Enzymatic method (PMS-method)

Sample preparation: At the laboratory of HUA, 9 mango fruits of each treatment were divided into 3 replications for each ex-storage date (3 fruits /replication). Fruits of each replication were peeled, then a quarter of the fruit flesh was cut into small pieces and mixed together as a bulk sample. The samples were then immediately shock-frozen in liquid nitrogen. Frozen mango flesh was packed into separate plastic bags and stored at -20ºC. Next these samples were packed with dry-ice for maintaining temperature below -20ºC, then transported and protected by thick styrofoam boxes to Hohenheim University by airplane. At the laboratory of Hohenheim University, samples were homogenously ground in liquid nitrogen, and then stored at -80ºC until analysis. Just before analysis, the samples were defrosted in the dark at 4ºC.

For extraction: Following buffers were prepared for the assay:

A: meta phosphoric acid (MPA-HPO_3) 6%, ethylene diamine tetraacetic acid (EDTA) ($C_{10}H_{14}N_2Na_2O_8 \cdot 2H_2O$) 5 $mM \cdot L^{-1}$, polyvinyl polypyrrolidone (PVPP) 1%, pH = 3.5, adjusted by KOH 10 M.

B: Meta phosphoric acid (MPA-HPO_3) 1,5%, pH = 3.5, adjusted by KOH 10 M.

0.1 g of each sample was dissolved in 1000 µL buffer A. The samples were shaken for 30 min while being cooled on ice and kept in darkness, then centrifuged at 0ºC with 2890 g for 15 min (Heraeus instruments, Megafuge 1.0R, Germany). The supernatant was collected and passed through a 0.45 µm filter (Macherey-Nagel, Germany) right before analysis. The assay was executed by pre-dispensing 68 µL of pre-heated (37ºC)

3-(4,5-dimethylthiazolyl-2)-2,5,diphenyltetrazolium bromide (MTT) (dissolved in buffer solution : sodium phosphate/citrate buffer, pH ~ 3.5 as provided in the kit) and 24 µL distilled water in a well. To quantify selectively the amount of ascorbic acid blank assays were executed in which 24 µL distilled water was substituted with 24 µL of ascorbate oxidase solution (approx. 1.25 IU). After being heated up to 37ºC for 5 min, 100 µL of the extracted solutions were transfered into microplate wells or 100 µL of ascorbic acid standard solution were added to specific wells as a positive control check the assay for correct performance. Therefore 10 $mg \cdot L^{-1}$ of L-ascorbic acid was dissolved into buffer B and thereafter served as standard solution. Samples were mixed and incubated for 6 min at 37ºC and then read the absorbance at 578 nm of blanks and samples (A_1). Finally 8 µL of 5-methylphenazium methosulfate (PMS) solution were pipetted to the reaction medium. Microplates were loaded into the iEMS reader (Labsystems, 1401, Finland) and the absorbances of blanks and samples were measured again (A_2). All reagents used are available as a commercial kit ENZYTEC™ L-Ascorbic Acid (Id-Nº: 1267 - 10029411, R-Biopharm, Germany).

Vitamin C calculation: The absorbance values at 578 nm were measured before and after the addition of PMS and corrected for the absorbance difference ΔA of blanks according to following formula:

$$\Delta A = (A_2 - A_1)_{sample} - (A_2 - A_1)_{blank}$$

$$C = \frac{V * MW}{\varepsilon * d * v} * \Delta A_{Vitamin C}[g/L]$$

where V = final volume [mL]; MW = molecular weight of vitamin C [g/M]; ε = extinction coefficient of MTT-formazan at 578 nm (16900 [$l * mol^{-1} * cm^{-1}$]); d = light path [cm]; v = sample volume [mL].

The content (mg /100 g) is calculated according to the amount of weighed sample as follows:

$$Content\ of\ L\text{-}ascorbic\ acid = \frac{C_{Vitamin C}[mg/L] * 100}{P_{Sample}[g/L]}\ [mg/100\ g]$$

where $C_{Vitamin\ C}$ = vitamin C of sample solution [mg/L].

P_{Sample} = weight of sample within the solution [g/L].

Carotenoid (modified from Internationale Fruchtsaft-Union (IFU) Nr. 59, 1991)

For sample analysis, samples of 5 g each were thawed at 5ºC and homogenized with 50 mL of water at low light intensity. 1 mL of 15% $K_4[Fe(CN)_6]$ and 1 mL of 3% $ZnSO_4$ were added to each sample, then stirred, incubated for 2 min at 4ºC and centrifuged for 5 min at 2890 g. After the aqueous phase was decanted, 40 mL of acetone was added to each sample and shaken for 5 min for the first carotenoid extraction. The samples were centrifuged for 5 min at 2890 g and the supernatant was transfered into separation funnels containing 50 mL petroleum benzine (so-called petrolium ether). 20 mL of acetone were added to the pellet for a second carotenoid extraction and if necessary for a third repeat. The extracted solution was shaken 4 times and the valve of the separation funnels was opened each time to releasing build up gas pressure. The solution was given 5 min to separate into 2 phases of water/acetone and petroleum benzine. The lower, transparent water /acetone phase was released and discarded. Finally, some Na_2SO_4 was added to completely absorb the water in the extract before transfering it into a 100 mL flask. The extract was filled up with petroleum benzine to a total volume of 100 mL. To quantify the amount of carotenoid, 1 mL of assay solution was pipetted into a quartz cuvette to determine the absorbance values (λ) at a wave length of 450 nm by using a UV/V spectrophotometer (Philips, PU 8735, England), with petroleum benzine serving as blank.

$$Total\ carotenoid = \frac{\lambda * 4 * 1000}{w[g]}\ [\mu g/100g]$$

where λ = absorbance values; w = weight of flesh in gram (g).

Starch, fructose, glucose and sucrose analysis (modified from Gomez et al., 2007)

Sample preparation and chemicals used: Mango pulp samples were freeze-dried and then finely ground (<1 μm, using mortars and pistils precooled by liquid nitrogen). The pulp powder was dried at 50ºC in an oven until constant in weight and then kept in a desiccator at room temperature before the assay samples were weighed.

Following solutions were used in the assay:

Solution S1: for one microplate, 12 mL of buffer (pH 7.6), 1.5 mL of the adenosin triphosphat (ATP) solution and 1.5 mL of the nicotinamide adenine dinucleotide (NAD) solution were mixed. In which, buffer pH 7.6 was made by dissolving 55.9 g of triethanolamine and 2.5 g of

magnesium sulphate heptahydrate in 500 mL of water, then adjusted the pH to 7.6 using HCl and NaOH. ATP solution was made by dissolving 600 mg ATP and 600 mg sodium bicarbonate in 6 mL of water. NAD solution was made by dissolving 120 mg NAD in 6 mL of water.

Solution S2: for one microplate, 33 µL glucose-6-phosphate dehydrogenase (G6PDH) (kit 1,000 U/ 1ml), 33 µL of hexokinase (HK) (kit 1,500 U/ 1ml), 934 µL ammonium sulfate solution 2.5 $mol \cdot L^{-1}$ and 2 mL ultrapure water were mixed in a test tube.

Solution S3: 20 µL phosphoglucose isomerase (PGI) (kit 10 mg/ 1mL) were dissolved in 14 mL water to be used for 7 microplates.

Solution S4: 4 mg of β-fructosidase were dissolved in 2 mL water to be used for one microplates.

Solution S5: for each sample tube to be assayed, 2.25 mg of amyloglucosidase were dissolved in 2.55 mL of buffer pH 4.6. In which, buffer pH 4.6 was made by dissolving 12 g of 100% acetic acid and 4.9 g of NaOH in 500 mL of water, pH adjusted to 4.6 by using HCl.

Solution S6: for each sample tube to be assayed, 0.8 mL of buffer pH 7.6, 0.1 mL of ATP solution and 0.1 mL of NAD solution were mixed.

Standard sugar solutions: glucose [0.003; 0.0075; 0.012; 0.016; 0.02 $g \cdot L^{-1}$]; fructose [0.01; 0.02; 0.03; 0.04; 0.05 $g \cdot L^{-1}$] and sucrose [0.02; 0.05; 0.1; 0.12; 0.15 $g \cdot L^{-1}$].

Standard glucose solutions for starch analysis: 0.005; 0.01; 0.025; 0.05 and 0.1 $g \cdot L^{-1}$.

The iEMS reader can execute 96 spectrophotometric measurements (in under 10 s) at a defined wavelength by specific filters. Therefore the kinetics of an enzymatic or colourimetric reaction could be measured at the end point of several reactions and results were stored in Ascent (Ascent software Ver. 2.6, Thermo Labsystems Oy, Finland) and then transferred to Excel for further calculations.

Soluble sugar analysis

Five mg of mango pulp powder were weighted in a calibrated 2 mL tube. Then 1 mL of a methanol–water solution (1:1, v/v), followed by 300 µL of chloroform were added. The tube was vortexed, placed under constant agitation on a wheel for 20 min at 4ºC and then

centrifuged for 5 min (24,000 g, 4ºC). The upper liquid part was used for soluble sugar analysis and the residue pellet was used later for starch analysis.

Precisely 750 µL of the methanol–water supernatant were recovered and placed in a 1.5 mL Eppendorf tube. After evaporation under vacuum, the dried pellet was returned to its soluble form by repeated vortexing in 750 µL of water for 20 min at 4ºC. The aqueous extract was then combined with 10 mg polyvinyl polypyrrolidone (PVPP) to eliminate any residual phenols. After repeated shaking with a vortex for 20 min at 4ºC, the tube was centrifuged for 5 min (24,000 g, 4ºC) and the supernatant was analysed using the microplate method as described below.

Each well of the microplate was filled with 150 µL of assay sample and 100 µL of solution S1. Absorbance (A_a) at 340 nm was measured prior to the addition of 20 µL of solution S2 followed by shaking for 30 s. After two hours of incubation at 30ºC, when the reaction was completed, the plate was shaken for 30 s and a second measurement (A_b) was performed. The increase in absorbance ($A_b - A_a$) following the formation of NADH was directly proportional to the build up of glucose in the extract. 20 µL of solution S3 was then added to each well followed by shaking for 30 s. A third measurement (A_c) was executed after another 2 h of incubation at 30ºC, when the reaction was again completed. The enzyme produced phosphoglucose from phosphofructose, and the resulting production of NADH in the presence of glucose-6-phosphate dehydrogenase was proportional to the initial fructose content in the extract. Thus the difference in absorbance ($A_c - A_b$) was directly proportional to the increase of glucose originating from the turnover of fructose in the extract.

The addition of 20 µL solution S4, followed by shaking for 30 s, produced glucose and fructose from the sucrose present in the extract. After incubation for 3.5 h at 30ºC and shaking for 30 s absorbance A_d was measured. Because of the presence of hexokinase, phosphoglucose isomerase and glucose-6-phosphate dehydrogenase in the mixture, the difference in absorbance ($A_d - A_c$) was directly proportional to the increase in glucose as a result of splitting of sucrose into fructose and glucose followed by the turnover of fructose into glucose. The molecular weights of sugars was taken into account when calculating the initial sucrose concentration from the glucose produced.

Starch analysis

The residual pellet after extraction of the soluble fraction was cleaned by adding 750 µL of MeOH to the mixture and after continuous agitation (20 min, 4ºC). Tubes were centrifuged for 5 min (24,000 g, 4ºC) to eliminate the supernatant. Then 0.2 mL of ethanol was added to the pellet before being stored at -20ºC until further analysis.

The alcohol in the pellet was evaporated by rotary vacuum evaporator for 60 min. The dry residue was re-suspended in 1 mL of water and autoclaved (2 bar, 120ºC, 2 h) to disperse the starch. After cooling down, the dispersed starch was hydrolysed by the addition of 0.1 mL of solution S5 while kept in a water bath at 56ºC for 1.5 h. The tube was then plunged into boiling water for 5 min to halt the enzymatic activity. Once it had returned to ambient temperature, total weight of the tube was recorded as value P. After centrifugation for 5 min (24,000 g, 4ºC), 0.5 mL of the supernatant were removed and stored in tube at −20ºC for later determination of the glucose arising from the hydrolysis of the starch.

150 µL of the sample and 100 µL of solution S6 were mixed in the wells. The absorbance at 340 nm was measured prior to the addition of 20 µL of solution S3 (A_a) and following 2 h of incubation at 30ºC, when the reaction was finished (A_b). It was important to agitate the microplate well after the addition of enzymes. The increase in absorbance ($A_b - A_a$) at 340 nm following the formation of $NADH^+$ was directly proportional to the transformation of the glucose in the extract, the level of which was calculated from the glucose calibration standards (0.005 – 0.1 $g \cdot L^{-1}$).

Calculation of starch content in the sample for each 100 mg of dry matter was performed according to the following equation:

$$Y = X * 0.9 * d * (V/S) * 100$$

where Y = percentage of starch in the sample (g /100 g); X = glucose concentration in the assayed extract ($mg \cdot mL^{-1}$); 0.9 = the ratio of the molecular weight of glucose to the molecular weight of starch; d = the dilution factor of the extract; S = the weight of the test sample (mg); V - the volume of the extract (mL) = P − (T + S) was calculated as by weighing on the basis of equal density at 1, with T being the weight of the empty tube (g) and S that of the test sample (g).

3.3.3. Effect of ethrel postharvest applications on mango ripening

3.3.3.1. Fruit samples and treatments

2008: Ten fruits from each of 6 trees per cultivar in each of 5 orchards were randomly picked at 10-days before commercial harvest. A total of 300 fruit each cultivar were used for fruit quality assessment. Fruits were trenched for 30 min in 0.4% or 0.8% ethrel (2- Chloroethylphosphonic acid - $C_2H_6ClO_3P$) solution or in water, respectively and then stored at either 20ºC or 12ºC and a relative humidity of approximately 70%. Fruit samples were removed following a storage period of 1, 3, 5, 7 and 9 days. Fruit quality was assessed after 24 h at 20ºC.

2009: The same experimental design was employed, but ethrel treatments were applied at either 0.8% or 1.6%. Fruits were kept in 12ºC only and sampled after 3, 6, 9, 12 and 15 days of storage for quality assessment.

3.3.3.2. Data collection

At each assessment date, fruit weight (g), skin disorders, flesh firmness, TSS (%), TA, skin and flesh colour, vitamin C, carotenoid, sugars and starch of mango fruits was determined as mentioned in section 3.3.2.2 of the 1-MCP treatment.

3.3.4. Hot water treatment

3.3.4.1. Fruit samples and its treatments

2008: Five orchards with 6 representative trees of each cultivar per orchard were selected in Tu Nang commune. Six fruits per tree of each cultivar and in total 360 fruits were collected at commercial harvest. Fruit was wiped with a soft cloth soaked with water and dried at ambient temperature before being treated by HW.

Fruit of each cultivar was divided randomly into two batches, one batch was immersed in 50ºC water for 5 min, while the other one served as control. After being treated fruits were dried at ambient temperature and then each batch was divided into two treatments. 45 fruit of each treatment was kept in plastic baskets without cover and stored either at 12ºC or 20ºC with 70% relative humidity. At a 3 day interval, the same fruit was used for data collection until fruits were almost decayed.

2009: Seven fruits per tree of each cultivar were selected from 4 orchards with 5 representative trees of each cultivar at each orchard. A total of 280 fruits picked at commercial harvest time were used for the experiment. Fruit was wiped with a soft cloth soaked with water and dried at ambient temperature before being treated by hot water. 140 fruits of each cultivar were divided randomly into 7 treatments. 20 fruits were immersed in 45ºC, 48ºC or 50ºC water for either 3 or 6 min respectively, while 20 fruit served as control. After treated, fruits were dried at ambient temperature, kept in plastic basket covered with a plastic sheet and stored at 12ºC and approximately 70% relative humidity. At a two-day interval, fruits were used for data collection, starting at day 2 of storage time.

3.3.4.2. Data collection

At each assessment date, fruit weight (g), skin disorders and skin colour (only in 2009) were recorded as previously described in section 3.3.1.2.

3.4. Data analysis

Data were analysed by ANOVA using the statistical package Genstat (Version 14, VSN International Ltd., UK). The least significant difference ($LSD_{0.05}$) was used to determine significant differences among treatments at $P \leq 0.05$.

4. Results

4.1. The effect of harvest time and storage temperature on fruit quality of 'Tron' and 'Hoi mango

All parameters were highly significantly affected by all factors and the resulting interactions, except skin disorder was not affected by cultivar.

Weight loss: In 2008, average fresh weight of 'Hoi' and 'Tron' at harvest was 230 g and 152 g, respectively. Fresh weight of 'Hoi' was significantly greater than that of 'Tron' (Fig. 1A), indicating a genetically greater fruit size potential. Fresh weight of 'Tron' and 'Hoi' decreased considerably with storage duration at 12ºC and 20ºC chamber conditions; however, 'Hoi' lost more weight compared to 'Tron' at each removal date (Fig. 1A). Averaged over cultivars and picks, no significant weight loss was found when fruit was stored for 5 days at 20ºC or 10 days at 12ºC. Averaged over cultivars and treatments, fresh weight was greater in the 2nd pick (196.5 g) than in the 1st and 3rd pick (185.5 and 189.8 g). The fruit weight loss in 2008 was similar to that in 2007.

Skin disorder: In general, 'Tron' and 'Hoi' had the same level of skin disorder but the 1st pick of 'Tron' had remarkably lower skin disorders than 'Hoi'. There was a degree of skin disorder of mango fruit at each pick but the intensity of skin blemishes increased from the 1st to the 3rd pick (3.9 - 4.4 score). The level of skin disorders of both cultivars averaged over three picks had a score of 3.1 - 3.2 at harvest; however, it reached a score of 5 when stored for 30 days at 12ºC (Fig. 1B). Moreover, skin disorders were more intense at 20ºC compared to 12ºC when stored for 10 days (Fig. 1B). Skin disorder in 2008 was similar to that in 2007.

Flesh firmness: Flesh firmness declined with storage duration (Fig. 1C) and from the 1st to the 3rd pick. The average flesh firmness of 'Hoi' (56.1 N) was substantially higher than that of 'Tron' (38.0 N), especially at harvest (121.4 vs. 96.1 N,). Fruit was almost complete softening for 10 days at 20ºC or for 30 days at 12ºC and it could be realized by inconsiderable difference and low value of flesh firmness in both cultivars (Fig. 1C). Flesh firmness in 2008 was similar to that in 2007.

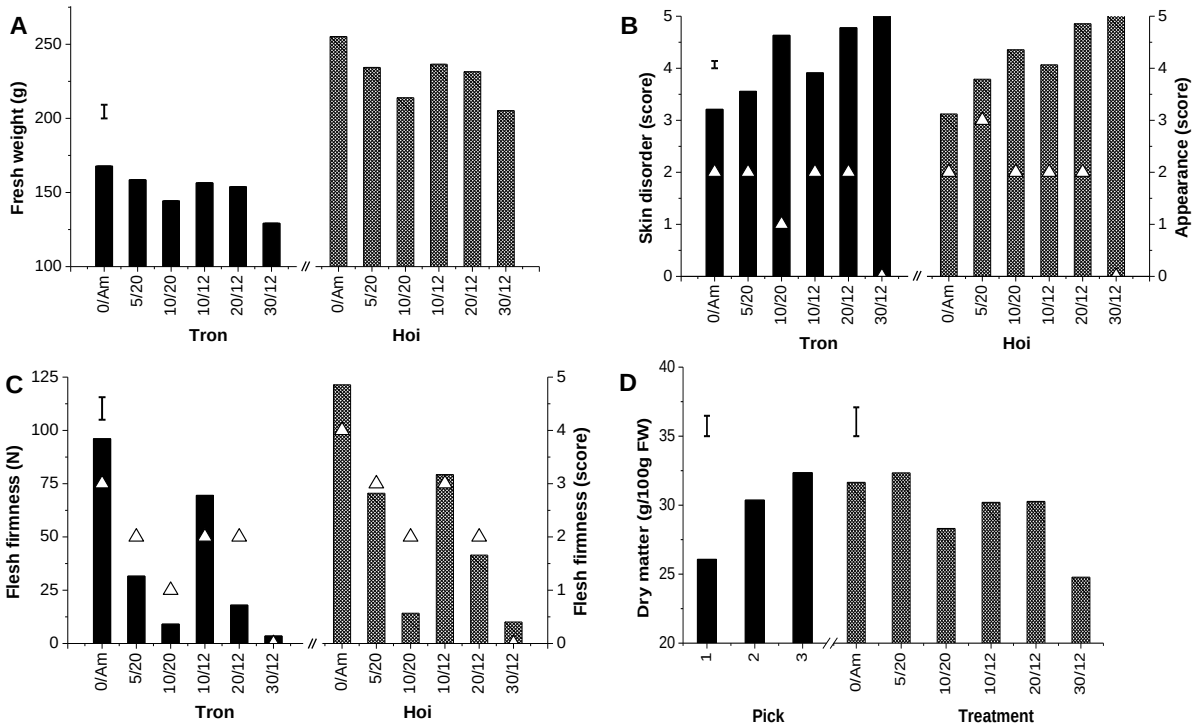

Figure 1. The effect of storage condition (0 day at ambien, 5 and 10 days at 20ºC and 10, 20 and 30 days at 12ºC, respectively) on fresh weight (A), skin disorder (B), flesh firmness (C) of 'Tron' and 'Hoi' cultivar, each averaged over three picks; the effect of pick and storage condition on average dry matter (D) of both cultivar in 2008. Columns represent instutrumental values, whereas symbols represent consumer preference. The $LSD_{(0.05)}$ bars indicate cultivar ∗ storage condition interactions in A, B, and C; and main effects (pick, storage condition) in D.

Dry matter: Flesh firmness showed a an contrasting trend to that of dry matter; flesh firmness decreased whereas dry matter increased from the 1st to the 3rd pick (Fig. 1C, D). Average percent dry matter was at 36% for 'Hoi', whereas at only 23% for 'Tron'. Fruit of both cultivars stored for 10 days at 20ºC and 30 days at 12ºC decreased substantially dry matter (Fig. 1D).

Skin and flesh colour: 'Tron' and 'Hoi' changed colour initially from green to yellowish, then to yellow and finally to dark yellow during ripening; thus both cultivars decreased skin and flesh hue angle during the ripening process. 'Tron' had significantly lower skin and flesh hue angle compared to 'Hoi', clearly indicating cultivar differences in the appearance at harvest time. From the 1st to the 3rd pick, the skin and flesh hue angle were greatly reduced (87.8 -

73.5º and 86.2 - 79.2º, respectively) due to the increased fruit maturity. The decrease in skin hue angle was greater than that of flesh hue angle. Averaged over picks, there was no significant difference of skin hue angle between 'Tron' and 'Hoi' at harvest and after harvest 10 days at 12ºC (Fig 2A, B).

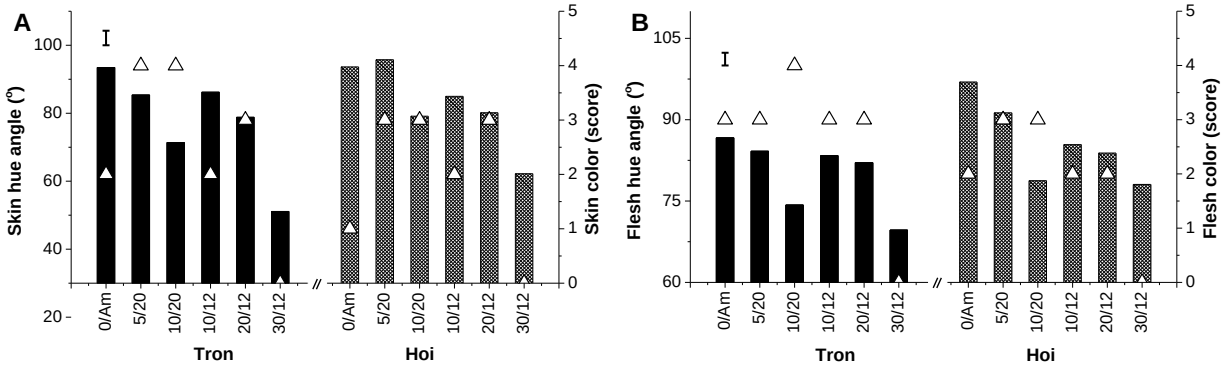

Figure 2. The effect of storage condition (0 day at ambien, 5 and 10 days at 20ºC and 10, 20 and 30 days at 12ºC, respectively) on skin hue angle (A) and flesh hue angle (B) of 'Tron' and 'Hoi' cultivar, each averaged over three picks in 2008. Columns represent instutrumental values, whereas symbols represent consumer preference. The $LSD_{(0.05)}$ bars indicate cultivar ∗ storage condition interactions.

Total soluble solid concentration: TSS of 'Hoi' increased with storage duration at both temperature conditions; an effect that was seen to a similar extent with the cultivar 'Tron'. TSS of both cultivars increased remarkably from the 1st to the 3rd pick (14.1 - 20.3% and 13.7 - 17.2%, respectively). In average, 'Tron' fruit tended to have greater TSS (17.5%) than 'Hoi' fruit (15.2%), especially at harvest it was great different (6.1 and 11.6%, respectively). However, the two cultivars had a similar level of TSS after 10 days storage at 20ºC (Fig. 3A). As expected, after 10 days storage TSS was 2.6% for Hoi and 4.1 % for Tron higher at 20ºC than at 12ºC. From 1st to 3rd pick, TSS of 'Tron' and 'Hoi' at harvest were 9.5, 8, 17% and 5, 5, 8%, respectively and these results showed no significant difference of TSS between 1st and 2nd pick at harvest of each cultivar.

Titrable acidity: Titrable acidity declined notably in all treatments after harvest, during the fruit ripening period. After 10 days in cool storage, TA was significantly lower at 20ºC than at 12ºC. TA of 'Tron' was lower than 'Hoi' in each treatment (Fig. 3B).

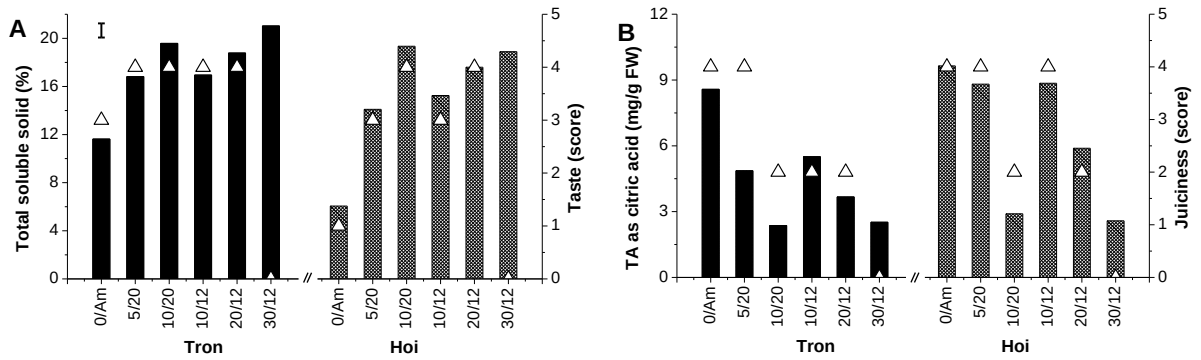

Figure 3. The effect of storage condition (0 day at ambien, 5 and 10 days at 20ºC and 10, 20 and 30 days at 12ºC, respectively) on total soluble solid concentration (A) and titrable acidity (B) of 'Tron' and 'Hoi' cultivar, each averaged over three picks in 2008. Columns represent instutrumental values, whereas symbols represent consumer preference. The $LSD_{(0.05)}$ bars indicate cultivar ∗ storage condition interactions.

Carbohydrate: Fruit starch content decreased throughout the storage period. Fruit starch levels after 10 days of storage at 20ºC and 12ºC were 1.5 and 3.8 g/100g for 'Tron' and 1.8 and 1.9 g/100g for 'Hoi', respectively, lower when compared to at-harvest values (Fig. 4A). This starch reduction was due to largely an increase of sugar from harvest to the end of the storage period (Fig. 4B, C, D). This in turn was the causing for the steady increase in TSS with the highest value after 10 days of storage at 20ºC and 30 days of storage at 12ºC (Fig. 3A). Fructose concentration after 10 days of storage at 20ºC and 12ºC increased 17 and 12 mg/g for 'Tron' and 14 and 6 mg/g for and 'Hoi', respectively, when compared to that at harvest (Fig. 4B). Both, glucose and sucrose concentration of both cultivars reached a plateau (Fig.4C, D) before it increased further for 'Tron' to 52 mg/g and 71 mg/g at 30 days of storage at 12ºC.

Vitamin C and carotenoid: Vitamin C of both cultivars remained stable throughout the storage period at both 20ºC and 12ºC, except for 'Tron' fruit that was kept at 20ºC for 10 days. The mean concentration of vitamin C, average for all treatments, was 18.1 mg/100g lower for 'Hoi' than that of 'Tron' (Fig. 5A).

β-carotenoid concentration of both cultivars increased sharply during ripening and attained highest values on day 10 at 20ºC and day 30 at 12ºC. Moreover, β-carotenoid concentration of 'Hoi' and 'Tron' were 3 and 4 times higher at the end of the storage period when compared to

values at harvest (Fig. 5B). β-carotenoid concentration increased substantially more at 20ºC than at 12ºC after 10 days of storage. This increase was 35.7 µg/100g for 'Tron' and 65.6 µg/100g for 'Hoi'.

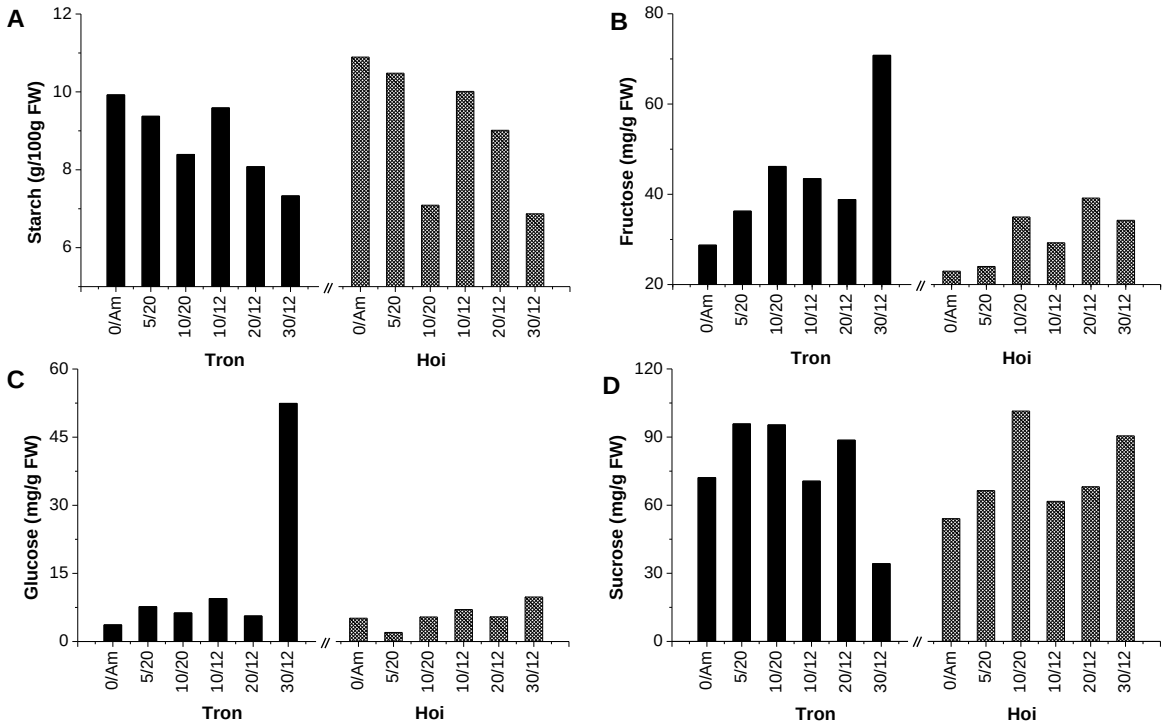

Figure 4. The effect of storage condition (0 day at ambien, 5 and 10 days at 20ºC and 10, 20 and 30 days at 12ºC, respectively) on starch (A), fructose (B), glucose (C) and sucrose (D) of 'Tron' and 'Hoi' cultivar, each averaged over three picks in 2008.

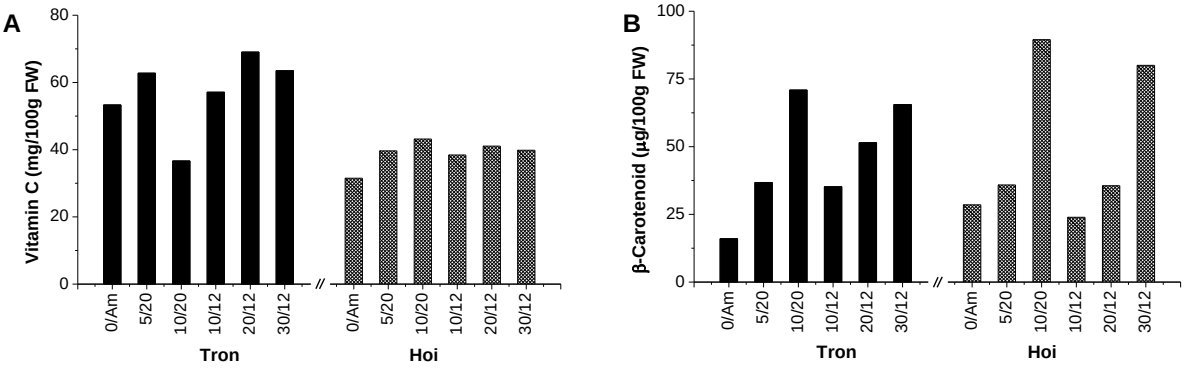

Figure 5. The effect of storage condition (0 day at ambien, 5 and 10 days at 20ºC and 10, 20 and 30 days at 12ºC, respectively) on vitamin C (A) and β-carotenoid (B) of 'Tron' and 'Hoi' cultivar, each averaged over three picks in 2008.

Consumer preference: Mango fruits stored for 30 days at 12ºC were unacceptable for further evaluation, thus these fruits were not used for consumer preference analysis.

Skin disorder correlated closely to the appearance of the fruit, thereby largely contributing to consumer preference. Skin disorder score was usually greater than '3' in 2008. Subsequently, the score for fruit appearance was at '2' in most treatments. The lowest appearance score was obtained with '1' for 'Tron' after 10 days at 20ºC and with '3' for at 20ºC for 5 days (Fig. 1B).

Firmness score and flesh firmness reduced rapidly during storage. Only 'Tron' at harvest and 'Hoi' at 20ºC for 5 days and 12ºC for 10 days met the expectations of the trained panel with firmness values of 70.5 - 96.1 N (Fig. 1C)

Skin and flesh colour are important criteria for ripening indicator. Only 'Tron' reached skin and flesh colour expectation after 10 days of storage at 20ºC, with values ranging from 71.4º - 85.4º and 70.1º - 78.5º respectively. 'Hoi' did not satisfy the skin and flesh colour expectations in any treatment, but reached the best score of 3 when stored at 20ºC for 5 - 10 days (Fig. 2A, B).

Taste scores of 'Tron' fruit remained consistently stable and sweetness met the testers' preference in all treatments with a TSS from 16.8 to 19.6% except at harvest (Fig. 3A). In contrast, the taste of 'Hoi' fruit was only acceptable when stored at 20ºC for 10 days and at 12ºC for 20 days when TSS were 19.3% and 17.6%, respectively (Fig. 3A). 'Hoi' fruit of the 1st pick held at 20ºC for 5 days and at 12ºC for 10 days showed generally lower TSS instrumental values than those obtained from consumer preference. In the 1st pick , taste of 'Hoi' did not satisfied in consumer preference analysis when stored at 12ºC event extending for 10 or 20 days and subsequently it was denied by the testers (Fig. 3A). The rejection of this 'Hoi' fruit was assisted with low TSS value. TSS of 'Hoi' fruit was 6.1% that was almost triple times lower than preferable TSS (17.6%).

The evaluation panel preferred mango fruit with less juice. Juiciness expectations were met at 20ºC for 0 day at ambien and 5 days for both cultivars and at 12ºC for 10 days for 'Hoi' only (Fig. 3B).

4.2. Effect change of ‘Tron’ and ‘Hoi’ fruit ripening by 1-MCP

All parameters were highly significantly affected by all factors and the resulting interactions, except fresh weight, carotenoids and vitamins (1-MCP concentration); fructose (pick ∗ 1-MCP concentration ∗ storage condition); sucrose (cultivar ∗ 1-MCP concentration) and starch and titrable acidity (cultivar).

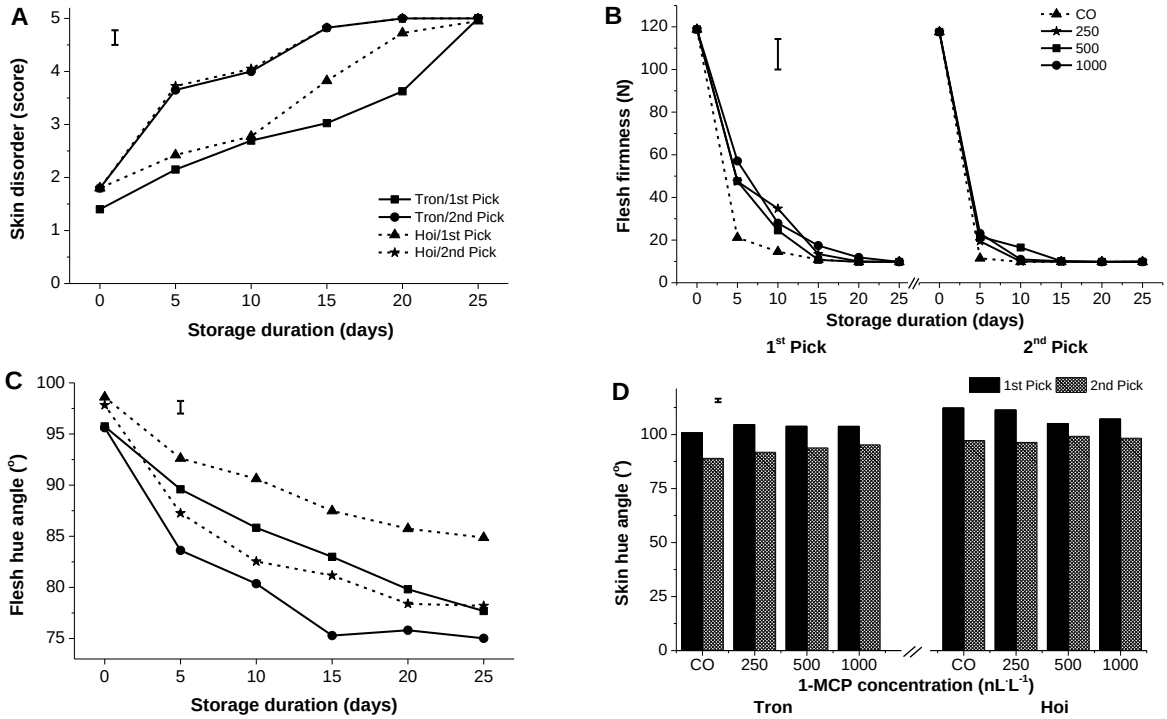

Figure 6. The effect of storage condition (0 day at ambien, 5, 10, 15, 20 and 25 days at 12ºC, respectively) on skin disorder (A) and flesh hue angle (C) of ‘Tron’ and ‘Hoi’ cultivar at 1st and 2nd pick, each averaged over 1-MCP concentration; the effect of 1-MCP concentration (250, 500, 1000 $nL \cdot L^{-1}$ 1-MCP and non-treated as control) and storage condition on average flesh firmness (B) of both cultivar at 1st and 2nd pick; the effect of 1-MCP concentration on skin hue angle (D) of ‘Tron’ and ‘Hoi’ cultivar at 1st and 2nd pick, averaged over storage duration in 2008. The $LSD_{(0.05)}$ bars indicate cultivar ∗ pick ∗ storage duration interactions in A and C; pick ∗ 1-MCP concentration ∗ storage duration interactions in B; cultivar ∗ pick ∗ 1-MCP concentration interactions in D.

Both cultivars had less skin disorders in the 1st pick than in the 2nd pick (Fig. 6A), and ‘Hoi’ showed more skin disorders than ‘Tron’ in the 1-MCP and control treatments. In the 1st pick,

1-MCP treated ‘Tron’ indicated a significantly lower score of skin disorder than control fruit. In contrast, ‘Hoi’ treated with 1000 $nL \cdot L^{-1}$ of 1-MCP had a greater score of skin disorder (3.6) than control (3.3). Skin disorder was not significantly different between the two cultivars in the 2nd pick.

1-MCP treated fruits maintained significantly greater flesh firmness than control fruit but flesh firmness did not differ considerably among 1-MCP treated fruits. Flesh firmness of the 1st pick was greatest in the 1000 $nL \cdot L^{-1}$ 1-MCP treatment (Fig. 6B). Flesh firmness of ‘Hoi’ and ‘Tron’ harvested in the 1st and 2nd pick declined considerably over the first 10 and 15 days of storage in all treatments. Flesh firmness was reduced to low value such as 10 N within 20 days of storage in the 1st pick and within 15 days of storage for the 2nd pick (Fig. 6B). Moreover, higher maturity showed clearly effectiveness on fruit softening. Flesh firmness of 2nd pick maintained much greater than 25 N at harvest only; however, that of 1st pick could extend up to 10 days.

Despite being treated with 1-MCP, skin and flesh (Fig. 6C) hue angle of ‘Tron’ and ‘Hoi’ fruit decreased with storage time, but 1-MCP treated fruit had averagely higher values than non-treated fruit in both picks (Fig. 6D). In more details of all treatments, averaged over picks and treatments, ‘Tron’ fruits indicated lower skin and flesh (Fig. 6C) hue angle than ‘Hoi’ at each removal date and therefore skin and flesh colour of ‘Tron’ was more yellowish than ‘Hoi’ when performed on the colour chat.

In the 1st pick, 1-MCP treated ‘Tron’ had significantly greater skin hue angle than control fruit, whereas in the 2nd pick, skin hue angle of ‘Tron’ increased steadily with higher concentration of 1-MCP (Fig. 6C). 1-MCP applications of 500 and 1000 $nL \cdot L^{-1}$ to ‘Hoi’ fruit had skin hue angles that were considerably lower for the 1st pick and higher for the 2nd pick when compared to 250 $nL \cdot L^{-1}$ (Fig. 6D).

1-MCP treatments decreased more substantially TSS than control. Averaged over storage durations, ‘Tron’ fruits treated with 500 and 1000 $nL \cdot L^{-1}$ 1-MCP had lower TSS than control fruits in the 1st picks but this was only the case in the 2nd pick of ‘Hoi’. Averaged over treatments, TSS increased for each pick and cultivar combination until 5 to 10 days after storage and thereafter remained relatively constant (Fig. 7A).

Both cultivars reduced TA with storage time but no significant differences were found between ‘Tron’ and ‘Hoi’ at each pick (Fig. 7B).

Fruit sucrose concentration of 'Tron' increased considerably with storage time for the 1st pick but decreased after 10 days of storage for the 2nd pick. In contrast, sucrose concentration of 'Hoi' steadily increased with storage time for both picks (Fig. 7C). Fruit harvested in the 2nd pick tended to have greater sucrose concentration than that in fruit from the 1st pick.

Carotenoid concentration increased steadily with storage time with greater values for 'Tron' than those of 'Hoi' for each pick and removal date (Fig. 7D).

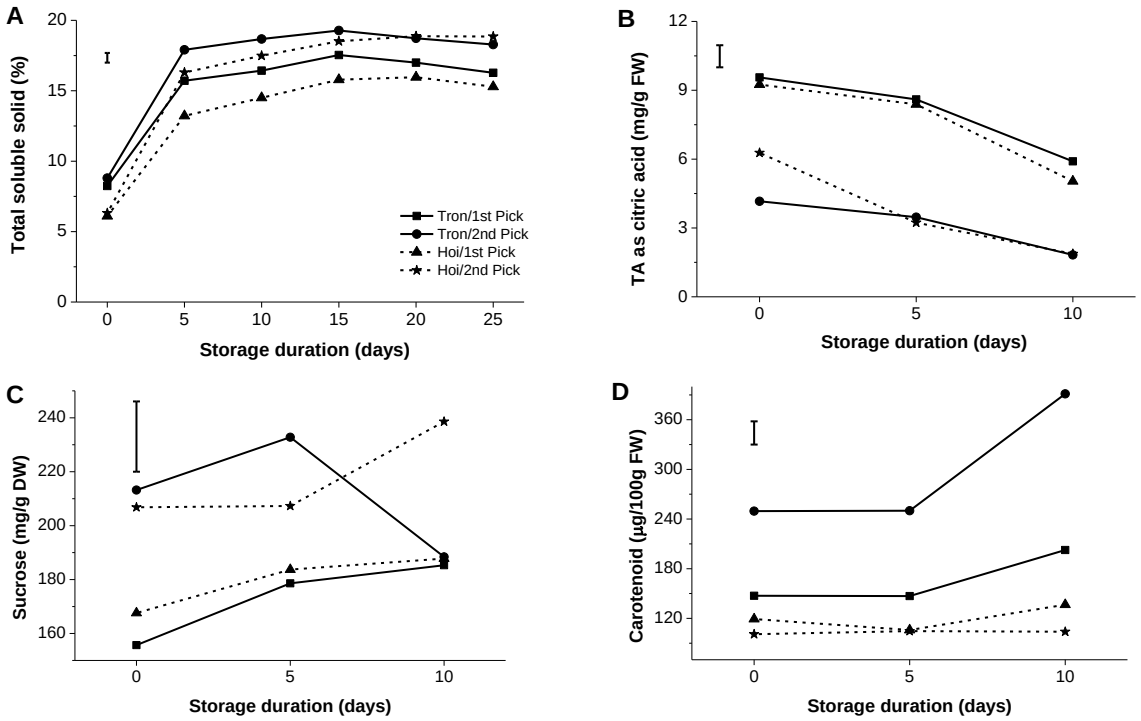

Figure 7. The effect of storage condition (0 day at ambien, 5, 10, 15, 20 and 25 days at 12ºC, respectively) on total soluble solid concentration (A), (0 day at ambien, 5 and 10 days) on titrable acidity (B), sucrose (C) and carotenoid (D) of 'Tron' and 'Hoi' cultivar at 1st and 2nd pick, each averaged over 1-MCP concentration in 2008. The $LSD_{(0.05)}$ bars indicate cultivar ∗ pick ∗ storage duration interactions.

4.3. Effect of ethrel postharvest applications on ripening of 'Tron' and 'Hoi'

All parameters were highly significant affected by all factors and the resulting interactions, except skin disorder (ethrel concentration) as well as fructose and sucrose (temperature ∗ ethrel concentration) in 2008.

Mango fruit at 20ºC softened to a greater extent than those at 12ºC, irrespective of cultivar and ethrel treatment, but fruit treated with ethrel had considerably more flesh firmness decay

than control fruit (Fig. 8A). Flesh firmness of 'Tron' declined more substantially compared to 'Hoi' at both temperature regimes (Fig. 8A). Flesh firmness decreased steadily during the postharvest period and was three, four and six times lower at 5, 7 and 9 days of storage, respectively, when compared to at-harvest values. 'Tron' flesh firmness was not positively affected by ethrel treatments at 20ºC storage temperature but was considerably lower when treated with 0.8% than 0.4% ethrel at 12ºC. Flesh firmness of 'Hoi' was not affected by ethrel treatments at both temperature levels (Fig. 8A).

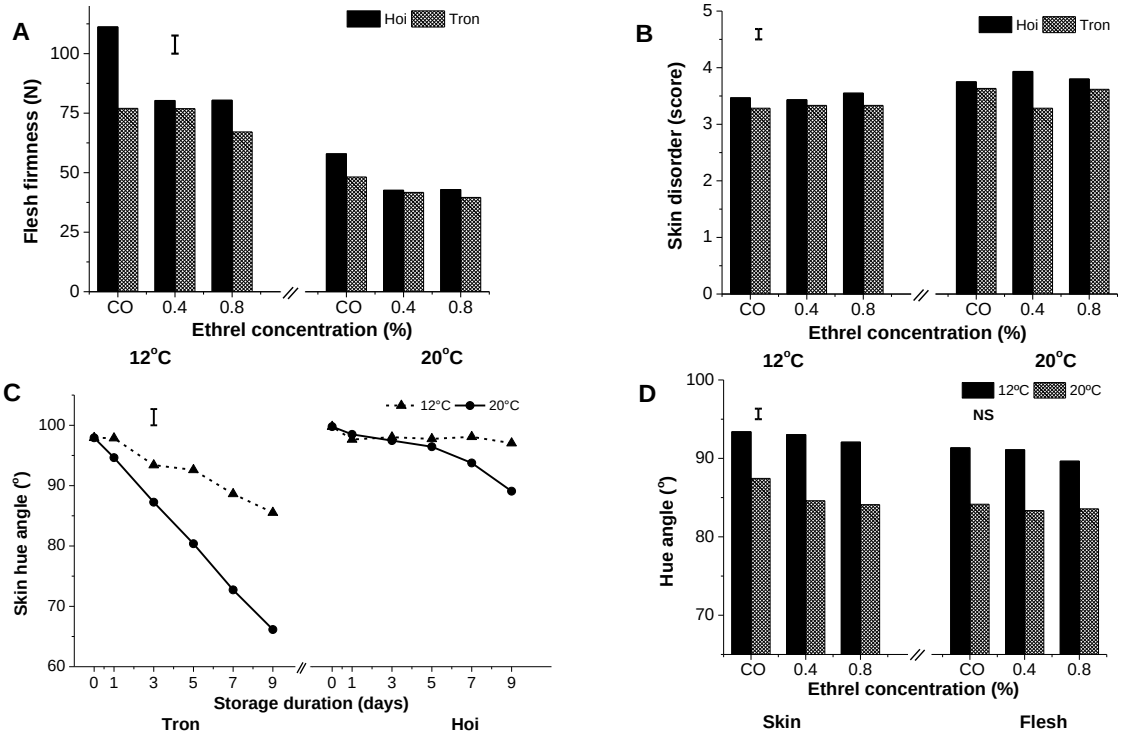

Figure 8. The effect of ethrel concentration (0.4%, 0.8% ethrel and water as control) on flesh firmness (A), skin disorder (B) of 'Tron' and 'Hoi' cultivar stored at 12ºC and 20ºC, each averaged over storage duration; the effect of storage condition (0 day at ambien, 1, 3, 5, 7 and 9 days at 12ºC and 20ºC, respectively) on skin hue angle (C) of 'Tron' and 'Hoi', averaged over ethrel concentration; the effect of ethrel concentration and temperature (12ºC and 20ºC) on average skin and flesh hue angle (D) of both cultivar and storage duration in 2008. The $LSD_{(0.05)}$ bars indicate cultivar ∗ temperature ∗ ethrel concentration interactions in A, B; cultivar ∗ temperature ∗ storage duration interactions in C; temperature ∗ ethrel concentration interactions in D.

'Hoi' showed a greater extent of skin disorders than 'Tron' at 12ºC and 20ºC. As expected, the degree of skin disorders of both cultivars was somewhat lower at 12ºC than at 20ºC (Fig. 8B).

'Hoi' skin (Fig. 8C) and flesh colour (data not shown) were higher than those of 'Tron' at each removal date, irrespective of storage temperature level. The hue angles at 12ºC were 12.3 and 22.6º higher for skin of 'Tron' and 'Hoi', respectively, and 14.2 and 21.3º higher for flesh of 'Tron' and 'Hoi', respectively, compared to 20ºC storage temperature. Applications of 0.8% ethrel improved substantially skin colour at 12ºC and 20ºC when compared to control; However, this effect was not seen at both 12ºC and 20ºC for flesh colour (Fig. 8D).

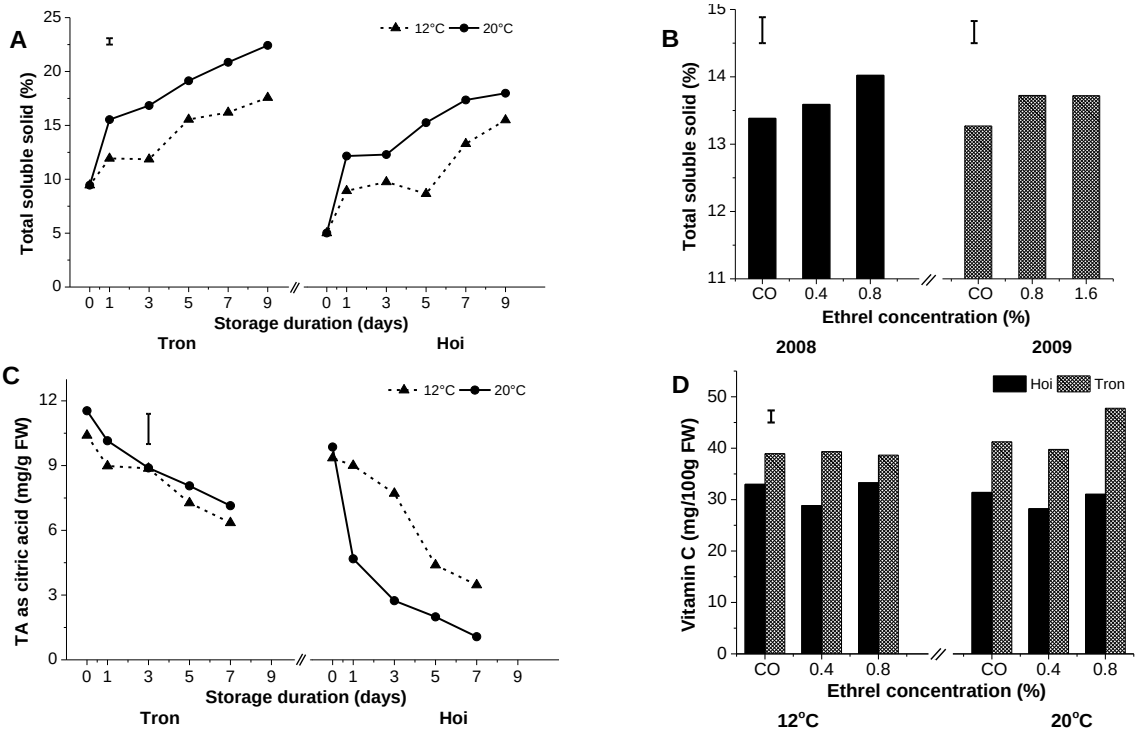

Figure 9. The effect of storage condition (0 day at ambien, 1, 3, 5, 7 and 9 days at 12ºC and 20ºC, respectively) on total soluble solids concentration (A) and titrable acidity (C) of 'Tron' and 'Hoi' cultivar, each averaged over ethrel concentration; the effect of ethrel concentration (0.4%, 0.8% ethrel and water as control) on vitamin C (D) of 'Tron' and 'Hoi' cultivar stored at 12ºC and 20ºC, averaged over storage duration in 2008; the effect of ethrel concentration on average of TSS of both cultivar and storage condition in 2008 and 2009. The $LSD_{(0.05)}$ bars indicate cultivar ∗ temperature ∗ storage duration interactions in A and C; main effect (ethrel concentration) in B; cultivar ∗ temperature ∗ ethrel concentration interactions in D.

TSS of both cultivars was significantly greater at 20ºC than at 12ºC at each removal date (Fig. 9A). Averaged over temperatures and treatments, TSS of 'Hoi' (5%) was lower than that of 'Tron' (9.5%) at harvest, but increased to 17% for 'Hoi' and 20% for 'Tron' during 9 days of the storage. At-harvest TSS values were increased 2-fold in 1 day and 3-fold in 7 days of storage for 'Hoi', whereas 'Tron' required 7 days of storage to double the TSS concentration. While TSS of fruit stored at 20ºC was not significantly influenced by ethrel applications, fruit stored at 12ºC had considerably higher TSS when treated with 0.8% ethrel than those of the control and 0.4% ethrel treatments. A further increase of ethrel concentration to 1.6% in 2009 at 12ºC resulted to no additional gain of fruit TSS (Fig. 9B).

TA of 'Tron' and 'Hoi' was steadily reduced throughout storage time and final average TA of 'Tron' was with 8.8 mg/g greater than that of 'Hoi' with 5.4 mg/g. While TA of 'Hoi' fruit was significantly higher when stored at 12ºC compared to 20ºC in 2008 (Fig. 9C), no such difference were found in 2009 (data not shown).

Figure 9D shows that the concentration of vitamin C in 'Tron' fruit was substantially higher than in 'Hoi', but in both cultivars they were slightly greater at 20ºC than 12ºC storage. However, ethrel treatments only increased effectively fruit vitamin C concentration when applied at 0.8% to 'Tron' with subsequent storage at 20ºC compared to the control. When averaged over treatments and temperatures, fruit vitamin C of both cultivars were initially reduced from day 1 to 5, rose on day 7 before declining again on day 9. In 2009, ethrel treatments led to a reduction of vitamin C concentration in 'Tron' fruit stored at 12ºC but had no effect at 20ºC and on cultivar 'Hoi' stored at both temperatures (data not shown).

In general, soluble sugars in fruit of both cultivars increased in agreement with the reduction of starch throughout the storage period. Fruit glucose concentration in 'Hoi' and 'Tron' steeply increased initially from 1 to 3 days of storage before declining toward the end of the storage period (Fig. 10A). Despite significantly lower sucrose concentration in 'Tron' compared to 'Hoi', 'Tron' had slightly higher glucose and fructose concentrations (Fig. 10B).

Fruit starch concentration seemed to be dependent on cultivar and seasonal growing conditions. Starch concentration of both cultivars decreased more rapidly at 20ºC than at 12ºC (data not shown). Ethrel treated 'Hoi' fruits showed lower starch concentration than control, an effect that was not seen in 'Tron' fruit (Fig. 10D).

In general, ‘Hoi’ fruit had a 2.5-fold higher carotenoid concentration than ‘Tron’ (Fig. 10C). Specifically, carotenoid concentration in ‘Tron’ fruit where highest at 5 days of storage in all treatments, whereas in ‘Hoi’ they continued to increase throughout the storage period (Fig. 10C). Carotenoid concentration in ‘Hoi’ fruit was increased by ethrel treatments compared to control (155 vs. 143 µg/100g), but this effect was not seen in ‘Tron’ treated fruit.

Higher storage temperature seemed to favour carotenoid synthesis (data not shown). Carotenoid concentration of both cultivars was increased by fruit treated with ethrel and stored at 20ºC compared to control (176 vs. 149 µg/100g), yet no treatment differences were found at 12ºC storage temperature.

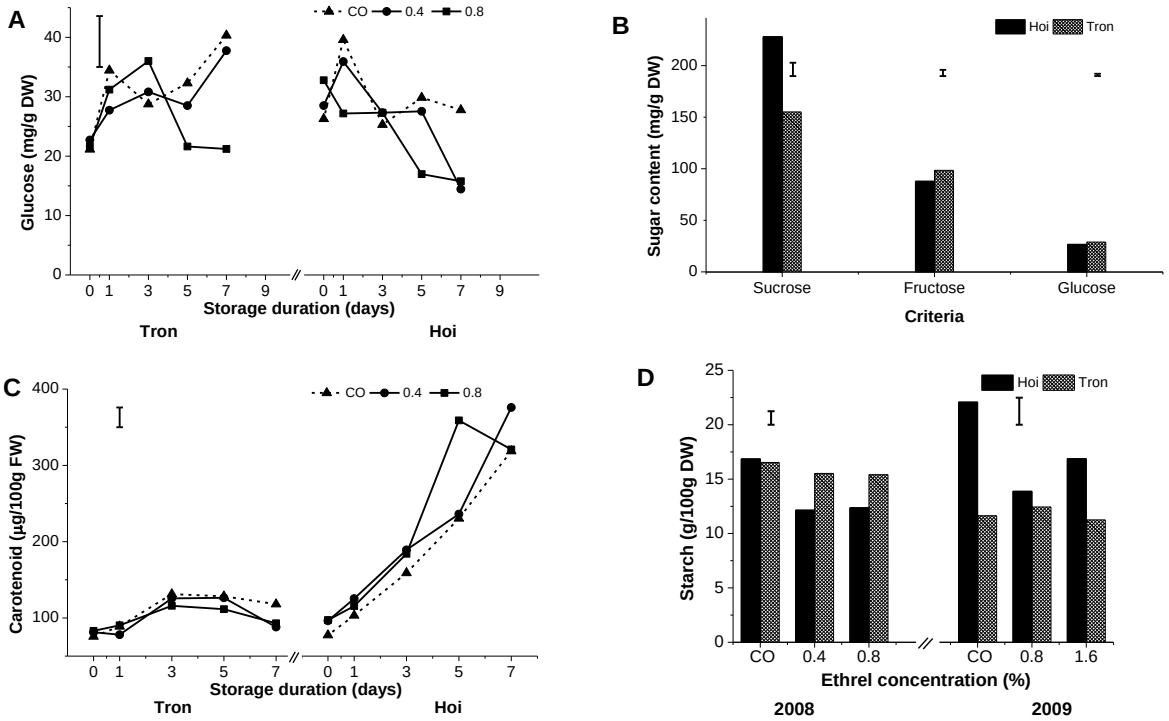

Figure 10. The effect of storage condition (0 day at ambien, 1, 3, 5, 7 and 9 days at 12ºC and 20ºC, respectively) on glucose (A) and carotenoid (C) content of ‘Tron’ and ‘Hoi’ cultivar, each averaged over storage temperature; the effect of cultivar (‘Tron’ and ‘Hoi’) on average sucrose, fructose and glucose concent (B) of ethrel concentration and storage condition in 2008; the effect of ethrel concentration (0.4%, 0.8% ethrel and water as control) on starch content (D) of ‘Tron’ and ‘Hoi’ cultivar, averaged over storage condition in 2008 and 2009. The $LSD_{(0.05)}$ bars indicate cultivar ∗ ethrel concentration ∗ storage duration interactions in A and C; main effects (cultivar) in B and (ethrel concentration) in D.

4.4. Hot water treatment to some external ripe parameters of ‘Tron’ and ‘Hoi’

All parameters were highly significantly affected by all factors and the resulting interactions, except fresh weight by treatment in 2008 as well as skin disorder and fruit weight loss by duration of hot water treatment (HWT) in 2009.

On average, HW-treated fruit had insignificantly fewer skin disorder than control (4.3 vs. 4.4 score). Moreover, skin disorder was greater at 20ºC (4.6 score) than at 12ºC (4.2 score) with differences that were more pronounced after 5 days of storage in 2008 (Fig. 11A). ‘Hoi’ treated with 50ºC water had significantly lower skin disorder than control fruit at both 3 and 6 min, an effect that was similar when ‘Tron’ fruit was treated with 48ºC water for 6 min (Fig. 11B).

In general, there were inconsistent effects of HWT on skin colour (Fig. 11C). There were significant cultivar differences with ‘Tron’ having more yellow skin colour compared to ‘Hoi’. HWT had little effect on improving skin colour, except that a lower skin hue angle was achieved when ‘Hoi’ fruit was immerged in 50ºC water for 3 min.

Figure 11D showed that ‘Hoi’ lost averagely more weight than ‘Tron’. Fruit weight loss tended to be lower when ‘Hoi’ fruit was exposed to 50ºC water for both 3 and 6 min and ‘Tron’ fruit to 48ºC for 6 min compared to controls. Other HWTs had no significant effects on fruit weight loss.

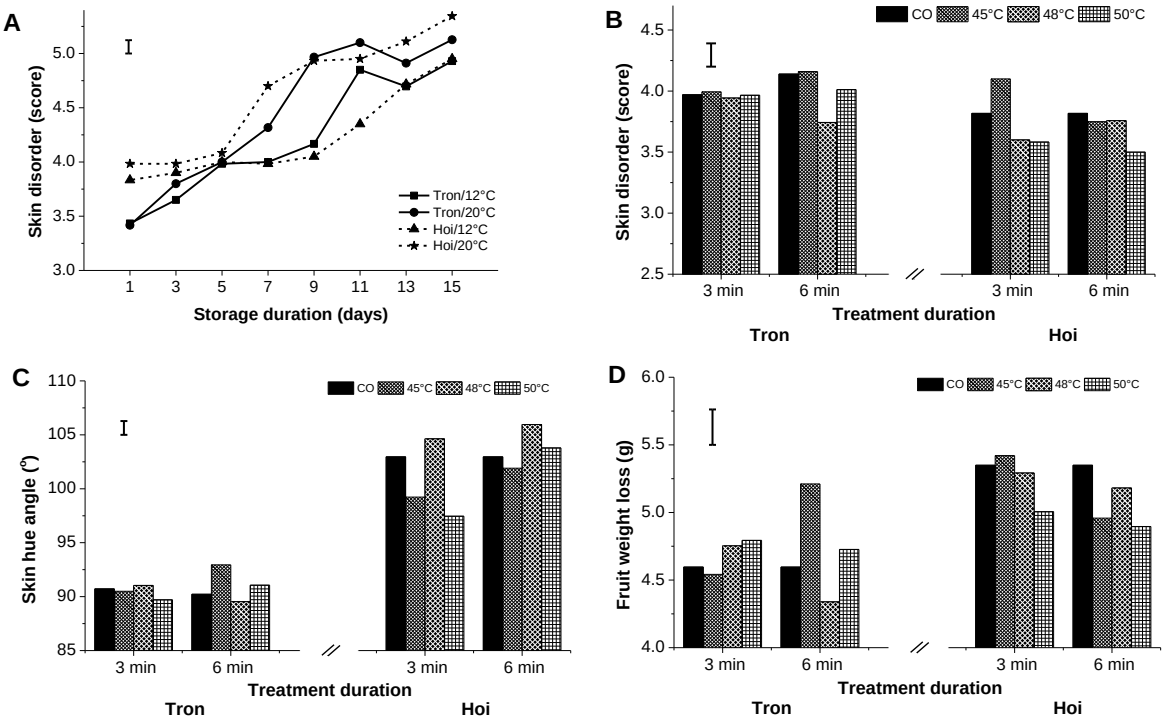

Figure 11. The effect of storage condition (1, 3, 5, 7 and 9 days at 12ºC and 20ºC, respectively) on skin disorder (A) of 'Tron' and 'Hoi' cultivar, averaged over water temperature in 2008; the effect of water application condition (45ºC, 48ºC, 50ºC water treated and non-treated fruit for 3 and 6 min) on skin disorder (B), skin hue angle (C) and fruit weight loss (D) of 'Tron' and 'Hoi' cultivar, each averaged over storage condition in 2009. The $LSD_{(0.05)}$ bars indicate cultivar ∗ pick ∗ storage condition interactions in A; cultivar ∗ water temperature ∗ water application duration interactions in B, C, and D.

5. Discussion

5.1. The effect of harvest time and storage temperature on fruit quality of 'Tron' and 'Hoi mango

5.1.1. Maturity in relation of appropriate pick for an optimal quality at harvest

TSS in relation to maturity level: TSS is used as indicator of mango ripening (Saranwong et al., 2004, Subedi et al., 2007, Mizrach et al., 1997, Crane et al., 2009) and more mature mango fruit has higher TSS (Medlicott et al., 1990, Jha et al., 2006). For both cultivars TSS increased from the 1st to the 3rd pick, however, 'Tron' fruit had higher TSS concentration than 'Hoi' fruit (Fig. 3A). This indicates that 'Tron' was not only a sweeter cultivar but also matured more advanced than 'Hoi'. Jha et al. (2006) recommended that mango should be harvested when TSS obtains at least 8%, so that fruit may achieve full ripening. At harvest (day 0), all three picks of 'Tron' had TSS values equal or greater than 8% but 'Hoi' achieved 8% only in the 3rd pick.

Color change in progress of fruit ripening: The color modification of mango is a consistent indicator to determine the range of fruit ripening (González-Aguilar et al., 2001). Furthermore, it is also important to determine the appropriate maturity for harvesting as well as consumption (Cocozza et al., 2004; Jha et al., 2006b). For mango cultivars such as cv. 'Tommy Atkins', 'Ataulfo', 'Kett', 'Irwin', skin hue angle increases during ripening because skin of color changes from green to green reddish and then to reddish yellow or yellowish (Brecht and Yahia, 2009). However, for cv. 'Tron' and 'Hoi' or other cultivars such as cv. 'Neelum', 'Nam Dokmai' (Ketsa et al., 1999) and 'Philippine', skin hue angle decreases during the ripening process. Both 'Tron' and 'Hoi', at the later pick showed a lower value of hue angle at harvest. In details, the value of the 3rd pick of 'Tron' (73.5º) was considerably lower compared to 1st and 2nd pick and it revealed additional evidence that 3rd pick of 'Tron' was too late for delivering to distant markets. On the other hand, 'Hoi' fruit was apparently unripe enough since their hue angle showed no further change during the time of the first two picks so. This recommended that harvesting 'Hoi' should start at the time of 3rd pick. Additionally, increase in carotenoid content also greatly connected to the decrease in skin and flesh hue angle during ripening process of mango fruits. Similar results, that hue angle decreases during ripening of fruits and this is associated with an increase in carotenoid synthesis as the fruit ripens, have been described previously (Saltveit, 1999, Brecht and

Yahia, 2009). Hence, it indicated that 3rd pick pointed out not only an improvement of hue angle but also a considerable increase in β-carotenoid content of both cultivars.

Flesh firmness and maturity: Flesh firmness of 'Hoi' was maximum at harvest for all picks even for more mature fruit, which were consequently rejected by testers in term of ready-to-eat fresh mango. Conversely, flesh firmness of 'Tron' in the 3rd pick (50.8N) had declined extremely at harvest compared to the 1st and 2nd pick (123.7 and 114.0N respectively). A similar change in flesh firmness with the stage of maturity cv. 'Dashehari' was reported by Jha et al., (2006b). The firmness keeps almost a plateau in the immature stages of fruit development and the firmness dramatically reduces after attaining the stage of maturity. The flesh firmness in the 3rd pick of 'Tron' was low and this might also indicate that harvest management for 'Tron' was not optimal and selected picks tended to be too late for distant markets. Moreover, this proved supplementary confirmation that 'Tron' ripened earlier than 'Hoi'.

Contribution of fruit maturity to ripening: Evaluating maturity and ripeness is an important issue for industrial mango production. Present size, sphericity, firmness, and total soluble solids are pre-criteria for estimation of maturity (Jha et al., 2006a) and major postharvest ripening is often assessed by respiration rate, skin color (Lalel et al., 2003) and texture softening (Yashoda et al., 2007). The quality of fruit at harvest may be improved by higher fresh weight, TSS, sugar content, vitamin C and carotenoid. In contrast, the quality will be more amended while the fruit has less skin disorder, starch, acidity, flesh firmness and hue angle of skin and flesh as reported by Brecht and Yahia (2009). 'Tron' showed lower fruit weight and size, lower skin and flesh hue angle, flesh firmness and higher TSS than 'Hoi'. That indicated that 'Tron' fruit matured earlier than 'Hoi' fruit as reported by Jha et al., (2006a, b). Consequently, cv. 'Tron' requires less time for ripening than cv. 'Hoi'. Fruits of both cultivars request more time for ripening at earlier picks. A similar result was reported by Dick et al., (2009) for cv. 'Kent' at 22ºC. Accordingly, it requires 10-18 days to reach full ripening when being harvested 100 – 76 days after full bloom, respectively. For other fruits like 'Golden' papaya, fruits required 3 - 7 days at 23ºC for reaching the edible condition at four stages regarding more yellow skin color (Bron and Jacomino, 2006). The fruit weight displayed no significant difference between the three picks of 'Tron', which implied that in the 1st pick, 'Tron' fruits were already mature. That was in contrast to 'Hoi', where the 2nd pick had greater fruit weight than the fruit of 1st pick indicating outgoing fruit growth.

In addition, the pick was optimal if fruits were mostly chosen by panellists in the consumer preference as it has been described for mango cv. 'Tommy Atkins', 'Palmer' (Nunes et al., 2007), and 'Kent' (Centurión Yah et al., 1998). In the frame of this study, quality of mango fruits at harvest (day 0) of these three picks was compared in order to specify optimal pick for both cultivars. Results suggest that the optimal fruit quality could be realized in the 3rd pick of 'Hoi', first two picks of 'Tron' and 3rd pick of 'Tron' for local market. According to testers' opinions, there was no difference in fruit appearance between the three picks. However, skin color, flesh color, taste, flesh firmness and juiciness were preferred the most in the 3rd pick. In general, 'Tron' was evaluated to be more desirable than 'Hoi'. Except for fruit weight and size. From our data, 'Tron' could be harvested 10 days before commercial harvest and harvest of 'Hoi' should start 20 days later than harvest of 'Tron'. In terms of time for fruit development, 'Tron' could be harvested about 100 - 110 days after full bloom.

5.1.2. The advantageous pick with proper storage treatments for optimal mango quality

Vitamin C change during storage phase: Generally, vitamin C of both cultivars slightly reduced during storage, in which vitamin C of 'Hoi' was quite stable at 20ºC and 12ºC throughout storage. Moreover, 'Tron' ripened earlier than 'Hoi' but vitamin C only went down steadily on day 10 at 20ºC (Fig. 5A), whereas no significant change in storage at 12ºC could be observed. In another report for cv. 'Guifei', it has been shown that vitamin C content after 12 days of storage at 20ºC did not considerably change (Wang et al., 2006). Relative vitamin C concentrations of cv. 'Haden', 'Irwin' and 'Keitt' at ripe stage decreased 16 - 23% during ripening at storage temperatures of 18ºC - 28ºC (Vazquez-Salinas and Lakshminarayana, 1985). Gomez and Lajolo (2008) reported that while fruit was on the tree, vitamin C content went down from the early stage of development to full maturity (harvest point). After harvest, vitamin C content remained unchanged, although it tended to decrease slightly at final ripening. In other fruits such as 'Golden' papaya, vitamin C content raised 20 - 30% during ripening and fully ripened fruit obtained 100 mg/100g ascorbic acid (Bron and Jacomino, 2006).

Carotenoid change during storage phase: After being picked, mango fruit hastened β-carotenoid synthesis corresponding to storage time. Higher temperature and longer storage time accumulated more carotenoid in 'Tron' and 'Hoi' (Fig. 5B). Vazquez-Salinas and

Lakshminarayana (1985) found that both total and β-carotenoids of cv. 'Haden', 'Irwin', 'Kent' and 'Keitt' at ripe stage increased with increase in storage temperature from 18ºC - 28ºC. Our result is also in agreement with the findings for cv. 'Kent', that it contains dramatically more carotenoid during storage at both 13ºC and 27ºC (Zamora et al., 2004). From this aspect, depending on markets and ripening expectation, temperature and storage time could be adjusted to meet consumer preference.

Skin disorder and color modification during storage phase: A decrease of hue angle in stored mango displays turning of flesh coloration from light yellow to orange as reported by Plotto et al. (2006). Changes in skin and flesh color of 'Tron' and 'Hoi' mango could be observed throughout storage period, particularly when fruits were kept at 20ºC. Skin and flesh hue angle decreased more slowly at 12ºC than at 20ºC. In agreement with this finding, cv. 'Ataulfo' showed lower values of skin hue angle at 25ºC than at 13ºC, indicating that skin hue angle decreased quicker at higher temperature (Montalvo et al., 2007). Paull and Chen (2004) suggested that, in order to achieve the best appearance, palatability and decay monitoring during ripening progress, green mature mangoes should be kept in the temperature range of 20ºC to 23ºC. However, Kader and Mitcham (2008) recommended mango fruits to be stored from 15.5ºC to 18ºC during ripening to achieve the most attractive skin color. However, flavor became less, if the fruits were not kept 2 - 3 additional days at 21 - 24ºC. According to another finding, mangoes have strong flavor attributes, if they are kept at 27 - 30ºC but ripening can be delayed when being stored above 30ºC. For 'Tommy Atkins' fruits, no matter whether they are held at 22, 27 or 32ºC, all expressed the progress of good quality characteristics in terms of high chlorophyll breakdown and high pulp carotenoid (Medlicott et al., 1986).

Independence of TSS on maturity level after harvest: Interestingly, for both temperature levels of 'Tron' and 'Hoi', TSS soared up over 17% in the end of storage phase even when TSS of 'Hoi' was as low as 5% at harvest of the 1st and the 2nd pick. This revealed that the increase of TSS was independent from maturity level after harvest. Similar results were described for cv. 'Amelie', 'Tommy Atkins', and 'Keitt' (Medlicott et al., 1990). Moreover, for each cv. 'Amelie', 'Kent' and 'Sesation' harvested at immature, half-mature or mature stage and stored at 12ºC, it attains equivalent TSS after 21 days (Seymour et al., 1990). The same trend is found in other typical tropical fruits like papaya. In spite of being harvested at four different

stages regarding yellow skin (0, 15, 16 - 25, 26 - 50%), the increase of TSS did not depend on maturity level (Bron and Jacomino, 2006).

Increase in softening though storage time: The first two picks of 'Tron' and all picks of 'Hoi' fruit were very firm at harvest; the fruit softening increased during storage in spite of the storage temperatures or cultivars. This was also reported in several other mango cultivars such as 'Tommy Atkins' and 'Palmer', which started to soft after storage of 2 - 3 days and absolutely softened after 8 days at 20ºC (Nunes et al., 2007). It has been pointed out for Cv. 'Kensington' mango that first indications of softening appeared after 4 days and complete softening after 11 days at 22ºC (Jacobi et al., 1998). In our study, fruit was totally soft after 10 days at 20ºC or 30 days at 12ºC.

Immature fruit and improper ripening during storage: The first pick of 'Hoi' did not attain normal full ripening. 'Hoi' fruits of the 1st pick stored at 12ºC had lower TSS than other treatments, even after extension of storage to 20 days TSS was lower than preferable TSS (17.6 - 19.3%) and subsequently fruit did not satisfy preference of consumer (Fig. 3A). On the other hand, 'Hoi' TSS of 1st pick could increase up to 18.8% at 12ºC if storage extended to 30 days but unacceptable skin disorder appeared (Fig. 3D). TSS of 'Kent' mango was 12% at harvest before reaching 20% after 2 weeks of storage at 20ºC (Islas-Osuna et al., 2010, Ornelas-Paz et al., 2007). This implied that 'Hoi' fruits of 1st pick could be not mature enough for harvest and kept at low temperature as 12ºC. Immature 'Amelie' mango could not ripen to full eating quality during the 21 days at 12ºC as well. The fruit of this cultivar showed higher acid levels, low TSS, some green coloration and incomplete softening (Medlicott et al., 1986).

Different pick and suitable storage condition: The most appropriate storage condition would be the one which had physically and chemically optimal characteristics that were accepted by consumer preference concerning almost all criteria with the longest storage time. Storage temperature considerably influenced general criteria during the ripening period. Lower temperature delayed mango ripening, and degradation of fruit was slowed down while storage time was extended. Normally, mango fruits should be harvested at the green mature stage and stored at low temperatures (10 - 15ºC) to expand their shelf-life (Snowdon, 1990). During storage, 'Tron' and 'Hoi' did not show symptoms of chilling damage while being stored at 12ºC.

Fruit appearance of both cultivars was unattractive at harvest day in the three picks mainly

due to poor management at preharvest. ‘Tron’ fruit stored at 20ºC for 10 days was unacceptable because of its over ripening, indicated by serious skin disorder and very low flesh firmness, and thus, this fruit was rejected by testers (Fig. 1B, C). Conversely, ‘Hoi’ fruit with too hard pulp expressed by maximum flesh firmness value and low TSS after storage at 12ºC after 10 days did not pass the consumer preference (Fig. 1C). Accordingly, these treatments and storage conditions were unacceptable. However ,‘Tron’ stored at 20ºC up to 5 days and ‘Hoi’ up to 10 days revealed appropriate quality parameters. Lower temperature condition such as 12ºC could extend ‘Tron’ and ‘Hoi’ shelf-life up to 20 days. Advantage of fruit stored at 12ºC for 20 days was confirmed by both analytical data and consumer preference. The results indicated by insignificant weight loss up to 5 days at 20ºC and upon 20 days at 12ºC, great improvement of TSS, sugar content, TA, carotenoid, skin and flesh color and also well maintained vitamin C, flesh firmness and acceptable skin disorder. Crane et al. (2009) found that mature mango fruits stored at 8-12ºC may delay ripening from some days to some weeks, or delay of ripening for 14 to 28 days was found when stored at 10 to 13ºC. ‘Irwin’ mangoes at commercial ripe stage packed by ethylene absorbing bag prolong their storage life up to 23 days without symptom of chilling injury at both 10 and 13ºC (Soe et al., 2006). From the results above, ‘Tron’ was likely tree-ripened in the 3rd pick, and thus, fruit had a very low value of firmness (28.0N and 50.8N in 2007, 2008 respectively). Therefore, it could be better appropriate for local market rather than delivering to distant markets. The other picks of both cultivars usually had high flesh firmness at harvest and their fruit was not yet fully ripened, which may benefit transportation to distant markets within 5 days at 20ºC before reaching the consumer. Furthermore, maintaining flesh firmness greater than 70 (N) after 5 days and around 14 (N) after 10 days for ‘Hoi’ could be of more advantage (Fig. 1C). Moreover, ‘Hoi’ did ripen abnormally in the 1st pick at 12ºC and the 1st and the 2nd pick of ‘Hoi’ showed a TSS of less than 8%; so ‘Hoi’ should start to be harvested from the time of the 3rd pick. If extensive longevity is necessary, fruit of ‘Tron’ and ‘Hoi’ should be kept in 12ºC and storage could be expanded up to 20 days. Our findings agree with the results of Paull and Chen (2004), who showed that mature-green mangoes can be held at 10ºC to 13ºC for 14 to 28 days. In addition, the same trend was found for cv. ‘Keitt’ but this cultivar has started to soften after 2 weeks if stored at 14 and 20ºC (Lederman et al., 1997). ‘Cat Hoa Loc’ mango coated by Xedabio or PEmpCH film can increase shelf-life 3 days under ambient conditions (21 - 31ºC and 65 -75% RH) (Hoa and Ducamp, 2008) or 30 days at 13ºC (Hung et al., 2006).

5.2. Effect of 1-Methylcyclopropen on ripening of ‘Tron’ and ‘Hoi’ fruits

5.2.1. Influence of maturity to efficiency of 1-MCP

Restriction of 1-MCP efficiency by maturity: Normally, more mature fruit will ripen more rapidly after harvest (Brecht and Yahia., 2009). The 2nd pick of ‘Tron’ and ‘Hoi’ was harvested 10 days later than the 1st pick, so ‘Tron’ and ‘Hoi’ fruits of the 2nd pick had a higher maturity level. Great contribution of maturity to the effects of exposure to 1-MCP also was found in bananas (Harris et al., 2000), avocado (Adkins at al., 2005), apple (Mir et al., 2001) and pear (Ekman et al., 2004). The results of the current study goes along with those findings because many indicators of the ripening process in ‘Tron’ and ‘Hoi’ mango show different effectiveness of the 1-MCP treatment depending on harvest time and fruit development.

In the 2nd pick, 1-MCP treatments of ‘Hoi’ did not well maintain flesh firmness. Moreover, ‘Tron’ fruits treated with 1-MCP were firmer than control fruits but only within 5 days after storage. However, in the 1st pick 1-MCP treated fruits of both cultivars indicated greater flesh firmness during the first 10 days of storage (Fig. 6B). Contribution of fruit maturity to efficacy of 1-MCP application is reported for ‘Pink Lady’ apples, where greater effects of 1-MCP are found in less mature fruit (Wilkinson et al., 2008).

Increase of 1-MCP concentration from 250 to 500 nL·L^{-1} showed greater effectiveness in slowing down the TA reduction of both cultivars in the 2nd pick, but not in the 1st one (Fig. 7B). Furthermore, a double or four times higher concentration than 250 nL·L^{-1} 1-MCP could reduce the color change of fruit skin in the 2nd pick, but only the application of lower concentration than 250 nL·L^{-1} 1-MCP could inhibit the color change in the 1st pick (Fig. 6D). Previously, it has been found that 1-MCP has less effect when applied to pears that are already starting to ripen (Fan and Mattheis, 2001, Baritelle et al., 2001).

Limitation of 1-MCP efficiency on storage duration: TSS of ‘Tron’ and ‘Hoi’ was almost unaffected by 1-MCP, which mirrors previous descriptions for 1-MCP treatments in mango (Hofman et al., 2001) apricots and plums (Dong et al., 2002), custard apples and apples (Rupasinghe et al., 2000, DeEll et al., 2005). Irrespective of 1-MCP treatment, TSS increased over the 1st pick from day 5 to 20 of storage before it reached a plateau or declined towards in the end of storage period. The same trend is observed in sapodilla fruits after treatment with 40 and 80 nL·L^{-1} 1-MCP for 24 h, which have an increase in TSS concentration during first 15 - 18 days after storage (Quiping et al., 2006). It was reported that depending on produces, 1-

MCP could bind to receptors to inhibit ethylene responses for about 5 - 10 days (Blankenship and Dole, 2003). Wang et al (2006) found that the shelf-life of mango cv. 'Guifei' could be extended from 8 to 12 days after treated with 5000 $nL \cdot L^{-1}$ 1-MCP for 6 h at 20ºC. Consequently, our results for 'Hoi' and 'Tron' indicate an effect of 1-MCP within 10 days after storage which corresponds well with other studies. Hence, it is recommended to repeat of 1-MCP application can enhance 1-MCP effectiveness (Blankenship and Dole, 2003).

5.2.2. Impact of 1-MCP concentration on ripening

1-MCP delayed ripening of 'Tron' and 'Hoi' fruits. However, ripening parameters of mangoes were influenced in a different way depending on concentration of 1-MCP.

Flesh firmness in relation to 1-MCP concentration: In fact, flesh firmness of both cultivars decreased with storage time. In between 1-MCP treatments of 1st pick for 5 days of storage, the higher concentration of 1-MCP showed substantially greater firmness conservation but for 10 days of storage these effect was inconsiderable. In addition, there was large variation in flesh firmness between 1-MCP and control treatments but the significant difference did not exist after 15 days or longer (Fig. 6B). Similarly, for other fruits e.g. apples, 1-MCP treated 'Pink Lady' fruit at 625 $nL \cdot L^{-1}$ for 24h at 20ºC, flesh is 7-16 N firmer than that of non-treated fruit (Wilkinson, et al., 2008). 'Gala' apples exposed to 500 $nL \cdot L^{-1}$ 1-MCP indicates higher firmness than control after being stored at either 20ºC for 3 weeks or 0ºC for 8 weeks (Fan and Mattheis, 2001).

Impact of 1-MCP concentration on color change: A similar trend appeared in skin and flesh color represented by the hue angle of 'Tron' that dropped greatly with storage duration. However, variation in the dosage of 1-MCP did not show any considerable effect. Indeed, 'Tommy Atkins' mango treated with 1-MCP and kept at 11ºC and 84% RH showed increased chroma and a reduced hue angle of skin (Lima et al., 2007). However, for other fruits such as avocado, 1-MCP treatments delayed skin color change (Feng et al., 2000, Jeong et al., 2002). It is known that the decrease of hue angle is correlated with the increase of carotenoid. Lower carotenoid content of 1-MCP treated fruit indicated that ripening of both cultivars was inhibited by 1-MCP, in which 500 $nL \cdot L^{-1}$ 1-MCP has been demonstrated to be the most effective on 'Tron'. 250 $nL \cdot L^{-1}$ 1-MCP retarded peel yellowing of mature 'Nam Dokmai' mango fruit during ripening at 8ºC and 13ºC and it also reduced the magnitude of respiratory climacteric and that of ethylene production.

Influence of 1-MCP concentration on TA: Theoretically, higher TA content of fruits implies that fruits are less ripe (Mizrach et al., 1997). In the 1st pick, treatments with 250 and 500 $nL \cdot L^{-1}$ 1-MCP for 'Tron' and 250 $nL \cdot L^{-1}$ 1-MCP for 'Hoi' showed greater effect on maintaining higher TA than other treatments. Conversely, 1-MCP concentration of 1000 $nL \cdot L^{-1}$ leads to great variation in results. Furthermore, at the 2nd pick, treatment with 250 $nL \cdot L^{-1}$ of 1-MCP showed a lesser effect, but treatment with 1000 $nL \cdot L^{-1}$ of 1-MCP kept TA higher than other treatments for both cultivars. This indicated that the lower concentrations of 1-MCP were more efficient in the 1st pick of both cultivars. In fact, 'Tron' and 'Hoi' displayed a cultivar specific sensitivity to 1-MCP treatment. Cultivar can affect product responses to 1-MCP which was mentioned by Botondi et al. (2003) and Watkins et al. (2000). The effect of 1-MCP on TA was reported to depend on kind of fruits. Concentrations of 250, 500, and 750 $nL \cdot L^{-1}$ 1-MCP delayed TA loss in plum (Domingo et al., 2003) but did not show any affect on TA in apricots (Dong et al., 2002).

Starch content declined more rapidly in 1-MCP non-treated fruits. In the 1st pick, the 250 $nL \cdot L^{-1}$ 1-MCP treatment slowed starch degradation of 'Tron' and 'Hoi' fruits for 5 days. This indicates that application of low concentration as 250 $nL \cdot L^{-1}$ 1-MCP could delay ripening of 'Tron' and 'Hoi' in the 1st pick.

Appropriate 1-MCP concentration for mango application: Although the 1-MCP application to mangoes can delay ripening for several days, however, study results are inconsistent. 'Tommy Atkins' was treated with low concentrations (30 and 120 $nL \cdot L^{-1}$) of 1-MCP to delay ripening (Alves et al., 2004), while others (Hofman et al, 2001; Jiang and Joyce, 2000; and Lalel et al, 2003) required concentrations that are much higher (25,000 to 100,000 $nL \cdot L^{-1}$). Asian mango such as 'Nam Dokmai' was treated with 250 $nL \cdot L^{-1}$ 1-MCP indicating the most effective to delay firmness until the end of storage and 1-MCP treatment also prolonged the shelf-life of mango to 15 days of storage at 20ºC (Penchaiya et al., 2006). Our treatment was more effective on 'Tron' and 'Hoi' with 1000 $nL \cdot L^{-1}$ 1-MCP and this result was supported by Jiang and Joyce (2000). According to this report, concentrations between 1,000 and 100,000 $nL \cdot L^{-1}$ of 1-MCP have stronger effects on mango cv. 'Zihua' at 20ºC. Wang et al., (2006) found that 100 - 1000 $nL \cdot L^{-1}$ 1-MCP could postpone softening of mature green mango cv. 'Guifei' while being combined with vacuum infiltration at 20ºC. For other climacteric fruits such as banana, the ripening was delayed by application of 1-MCP at a concentrations as low

as 0.7 nL/L for 24 h (Sisler and Serek, 1997) or application of 1000 $nL \cdot L^{-1}$ 1-MCP for 12 - 20 h at 20ºC (Macnish et al., 2000).

5.3. The effect of ethrel treatment on fruit quality of 'Tron' and 'Hoi'

Promotion of ethrel on TSS at cool storage: Two main changes during ripening are a reduction in flesh firmness and an increase in TSS content upon ethrel treatment (Lallu et al., 1989). Higher TSS content may be explained by the activation of the metabolism and further conversion of starch into sugars (Tucker, 1993). It has been found that cool storage decelerated fruit metabolism (Kader, 1992). It was suggested that fruit stored at 12ºC was restricted in ripening. In case of 'Tron' and 'Hoi', ethrel had only limited effect on ripening of when being stored at 12ºC. Presumably, this was due to the increase of TSS content in both 'Tron' and 'Hoi', which was kept at 12ºC compared to that at 20ºC from 1 to 9 ex-storage days. At the beginning of storage, TSS of 'Hoi' was lower than 'Tron' at the same thermal regime. However, all of the treatments reached maximal total soluble solid content until the end of the storage period at each temperature level. Likewise, Montalvo et al. (2007) stated similar results for 'Ataulfo' exposed to 0, 100, 500 and 1000 ethylene $\mu L \cdot L^{-1}$ for 6 or 12 h. Moreover, 0.8% ethrel treatment of 'Tron' and 'Hoi' showed considerable higher TSS content than the control from day 1 to 3 at 12ºC. This implied the involvement of ethrel in acceleration of fruit ripening in the early phase of storage. Sergent et al. (1993) has found an increase trend in TSS of 'Kent' mango after treatment with higher ethephon concentration (at 1000, 2000 or 4000 $\mu L \cdot L^{-1}$) for 1 or 2 min. Furthermore, Centurión Yah et al. (1998) claimed that TSS of 1500 $\mu L \cdot L^{-1}$ ethrel treated mango was significantly lower than that of fruits treated with 500 and 2500 $\mu L \cdot L^{-1}$ ethrel for 3, 6 or 9 min at 27ºC. In contrast, TSS content of 'Kensington Pride' mango at immature stage was not affected, even when it was dipped in 2000 $\mu L \cdot L^{-1}$ ethrel (Kulkarni and Hamilton, 1996). This contradictory results suggest that ethrel is not applicable for quality improvement of immature mango.

Support of ethrel on homogeneous color development and carotenoid synthesis: Hue angle (h) values that changed from green (120º) to yellow-orange (60º) are indicators for the ripening process of mango fruits. Hue angles of skin and flesh of both cultivars were greater at 12ºC than at 20ºC. Similar results were reported for 'Kent' and 'Ataulfo' mango (Zamora et al., 2004, Montalvo et al., 2007). Zamora et al. (2004) explained that reduction in skin hue angle is caused by enhanced carotenoid synthesis. In our experiments, 'Tron' fruit did not reduce the flesh hue angle with 0.4% ethrel at 12ºC but an increase of ethrel concentration up to 0.8%

led to such a reduction. This result implied that increase of ethrel concentration hastened the ripening of 'Tron' mangoes. Our data leads to a conclusion that ethephon has a positive effect on the color of mango skin, which is also supported by data from Centurión Yah et al. (1998). The improvement of color depended on the concentration of ethephon and the duration of treatment. Furthermore, the same concentration of 0.8% ethrel but at lower temperature as 12ºC caused slower carotenoid synthesis. Indeed, carotenoid content of 'Tron' treated with ethrel decreased at 12ºC but increased at 20ºC compared to untreated controls. In fact. mango fruits were delayed to ripen when being stored at lower temperature, but ethrel was still able to stimulate color change of skin and flesh to yellowish due to increased carotenoid synthesis. For most mango varieties, carotenoid content increases in association with the climacteric increase in respiration, that is initiated by the action of ethylene (Saltveit, 1999). 'Ataulfo' mangoes that were treated with 100, 500 and 1000 $\mu L \cdot L^{-1}$ ethylene 12 h after 4 days of storage at 13ºC has shown faster carotene synthesis in the peel together with faster and more homogenous yellow color development at low ethylene concentrations (Montalvo et al., 2007).

Ethrel and softening during storage: Softening is one of crucial ripening criteria. Softness of 'Tron' and 'Hoi' increased more steadily at 20ºC than at 12ºC as a consequence of flesh firmness loss. Additionally, 0.8% ethrel treated fruits of both cultivars increased softening at both 12ºC and 20ºC compared to control. Even 0.4% ethrel was enough to trigger softening process of 'Hoi'. 'Hoi' was firmer compared to 'Tron', but flesh firmness values of 'Hoi' were reduced steadily if increasing concentrations of ethrel were used in both temperature regimes. This depicts an essential role of exogenous ethylene on texture change after being applied. Our data is consistent with the results stated previously for mangoes cv. 'Tommy Atkins', 'Dashehari', 'Kent' and 'Ataulfo' (Kumar and Dhawan, 1995, Medlicott et al., 1990, Zamora et al., 2004, Montalvo et al., 2007).

Effect of ethrel on TA and starch reduction during storage: TA of 'Tron' and 'Hoi' at 12ºC was low compared to that at 20ºC. Low temperature caused slow ripening process with fewer breakdowns of organic acids and lower content of soluble solids. Montalvo et al. (2007) found that ACC and ACC oxidase content, the vital enzymes during climatic ripening, remained lower in mango held at 13ºC than at 25ºC. 'Hoi' showed an accelerated ripening after 0.8% ethrel treatment, reflected by the reduced TA and starch content compared to control up to day 9 at lower temperatures such as 12ºC or at higher such as 20ºC. Even 0.4% ethrel at 20ºC

caused ‘Hoi’ fruits with lesser TA than control, but this ethrel treatment did not show significant effect at 12ºC. This reduction is in contrast to results reported for cv. ‘Kent’, in which an increase in acidity was found after 1500 or 2500 $\mu L \cdot L^{-1}$ ethephon treatment at 27ºC (Centurión Yah, et al., 1998). At 20ºC, degradation of starch of ‘Tron’ was greater than control at both concentrations 0.8% and 0.4% ethrel. However, at 12ºC, this effect was not observed at 0.8% ethrel or even higher concentration as 1.6% ethrel. This suggests that ethrel is more effective at higher temperatures and thus. a lower concentration can be sufficient to get the desirable result when ethrel is applied at high storage temperatures. Montalvo et al. (2007) suggested that relatively low ethylene concentrations like 100 $\mu L \cdot L^{-1}$ were able to induce endogenous production of ethylene despite the cool storage at 13ºC, but higher concentration as 1000 $\mu L \cdot L^{-1}$ of ethylene caused inhibition of the ripening process as found in ‘Ataulfo’ mango.

Influence of ethrel concentration on fruit ripening during cool storage: Suitable concentration of substances such as ethrel, ethylen or calium carbide which are used to accelerate fruit ripening depend on form and kind of substances, stage of produces, and application methods. For hastening the ripening process in mango by calcium carbide, or ethrel/ethephone the treatment should be performed at 30 to 40ºC to obtain the optimal effect (Crane et al., 2009). The best results for ‘Ataulfo’ fruit was gained after application of 100 $\mu L \cdot L^{-1}$ ethylene for 12 h (Montalvo et al, 2007). In addition, 200 $\mu L \cdot L^{-1}$ of ethrel indicates the optimum effect on ripening of off-season ‘Neelum’ mango (Venkatesan and Tamilmani, 2010). Pre-storage ethrel (500,000 $\mu L \cdot L^{-1}$) dip treatment for 5 min not only reduced chilling injury but also improved increased TSS, TSS/acid ratio, sugars, eating quality and reduced fruit firmness even when fruit stored at 5ºC for four weeks (Nair and Singh, 2003). The present study revealed 0.8% ethrel was the appropriate concentration for ‘Tron’ and ‘Hoi’ mangoes to accelerate ripening at cool storage as 12ºC with improved quality even when both cultivars were harvested 10 days earlier than commercial harvest.

5.4. Hot water treatment to some external ripe parameters of ‘Tron’ and ‘Hoi’

HWT reduced the skin disorder compared to control. ‘Hoi’ should be dipped in 50ºC water for 3 - 6 min and ‘Tron’ in 48ºC water for 6 min then stored at 12ºC to achieve desired effects (Fig. 11B). Different results of HWT were reported by Lurie (1998), who recommends exposure time to HW to be 1h or more with temperature below 50ºC. However, many antifungal treatments only need some minutes at temperatures above 50ºC. Moreover,

export-quality ‘Ataulfo’ mango in Mexico are subjected during the packing process to hydrothermal treatment at 46.1ºC for 75 min followed by hydro cooling at 21ºC for 30 min (Montalvo et al., 2007).

In general, ‘Hoi’ fruit treated with 50ºC water for 3 min indicated lower skin hue angle than control and it revealed that fruit turned into yellowness more quickly. Our result is supported by other studies. First, the fact that HWT can enhance the colour intensity of peel is confirmed by Esguerra and Lizada (1990). The hue angle value of fruit skin reduces as temperature increases (from 42ºC to 49ºC), which means treatment at a higher temperature results in more intensive yellow of the fruit (Ortega and Yahia, 2000). Additionally, exposure of mangoes to high temperature (50 - 55ºC) often results in improvement of peel color intensity and increase of total carotenoid, so extending high temperature treatment may cause lack of color development (Medlicott et al., 1986). In case of ‘Ataulfo’ mango treated with 46.1ºC water for 75 min, a better color development has been observed and no effect on fruit quality has been recognizable when being stored at 13C for 2 weeks (Esquivel et al., 2006). According to published studies, it is recommended HWT of more than 6 min and temperature of around 50ºC. ‘Kensington’ mango which is treated with water at 53ºC for 5 min prior to hot vapor treatment for subsequent continuous storage at 22ºC or at 10ºC for 5 days, followed by storage at 22ºC for 5 days, shows lower hue angles, higher skin colour ratings, higher reflectance and chroma values than the untreated one (Jacobi and Gali, 1997). For cv. ‘Keitt’, dipping in HW at 50ºC for 30 min is the optimal treatment for maintaining the quality of fresh-cut mango, the yellow color and for increasing the total carotenoid content (Djioua et al., 2009).

6. Conclusions and outlook

Quality management is the most limiting factor for mango production in Northern Vietnam. Improved quality management can advance mango allocation to different markets with consistent quality. Developing quality criteria and consumer preferable profiles will help to determine the harvest time and the specific storage conditions for cv. ‘Tron’ and ‘Hoi’.

This study demonstrates that lack of proper whole chain fruit quality management systems is the key factor for the limited production of mangoes in Northern Vietnam. Improved fruit quality management can result in more consistent and higher quality particularly for distant markets. Based on the results of this work, ‘Tron’ and ‘Hoi’ fruit should be harvested using well-defined and recommended harvest quality indices and thereafter undergo appropriate postharvest management systems to attain higher fruit quality. This will help farmers to better manipulate fruit ripening processes, to deliver high quality fruit to the market and to achieve greater returns and thus livelihoods.

Basically, analyses on chemical composition of the mangoes in this study have been conducted mostly for one season so far, therefore, further research on internal quality parameters is necessary. Moreover, results of hot water treatment have just shown on some external criteria such as skin disorder, weight loss, skin color index of ‘Tron’ and ‘Hoi’. To understand further impacts of hot water treatment on postharvest quality, more detailed research on internal criteria is needed.

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Declaration of Originality

Hereby I declare that this doctoral thesis is independently written by myself. In addition, I confirm that no other sources than those specified in the thesis have been used. I assure that this thesis, in the current or similar format, has not been submitted to any other institution in order to obtain a Ph.D. or any other academic degree.

Ich erkläre hiermit, dass ich diese Dissertation selbständig angefertigt habe. Es wurden nur die im Literaturverzeichnis aufgeführten Hilfsmittel benutzt und fremdes Gedankengut als solches kenntlich gemacht. Ich versichere, dass ich diese Arbeit in gleicher oder ähnlicher Form noch keiner anderen Institution zur Prüfung vorgelegt habe.

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