EFFECTS OF HOT WATER TREATMENT AND MODIFIED POLYPROPYLENE PACKAGING ON POSTHARVEST QUALITY AND SHELF LIFE OF LIME *Citrus aurantifolia* Swingle

Miss Mallika Boonrith

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Botany
Department of Botany
Faculty of Science
Chulalongkorn University
Academic Year 2011

ผลของการจุ่มน้ำร้อนและบรรจุภัณฑ์โพลีโพรพิลีนดัดแปรต่อคุณภาพหลังการเก็บเกี่ยวและอายุการเก็บรักษาของมะนาว *Citrus aurantifolia* Swingle

นางสาวมัลลิกา บุญฤทธิ์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตร
ปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาพฤกษศาสตร์
ภาควิชาพฤกษศาสตร์
คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2554

Thesis Title	EFFECTS OF HOT WATER TREATMENT AND MODIFIED POLYPROPYLENE PACKAGING ON POSTHARVEST QUALITY AND SHELF LIFE OF LIME *Citrus aurantifolia* Swingle
By	Miss Mallika Boonrith
Field of Study	Botany
Thesis Advisor	Teerada Wangsomboondee, Ph.D.
Thesis Co-Advisor	Assistant Professor Kanogwan Seraypheap, Ph.D.

Accepted by the Faculty of Science, Chulalongkorn University in Partial Fulfillment of Requirements for the Master Degree

……. …….. Dean of the Faculty of Science
(Professor Supot Hannongbua, Dr.rer.nat)

THESIS COMMITTEE

…….. . Chairman
(Assistant Professor Chumpol Khunwasi, Ph.D.)

……. Thesis Advisor
(Teerada Wangsomboondee, Ph.D.)

……. Thesis Co-Advisor
(Assistant Professor Kanogwan Seraypheap, Ph.D.)

……. Examiner
(Anchalee Chaidee, Ph.D.)

…..……... Examiner
(Associate Professor Rathanawan Magaraphan, Ph.D.)

……. External Examiner
(Associate Professor Nantana Angkinand)

มัลลิกา บุญฤทธิ์ : ผลของการจุ่มน้ำร้อนและบรรจุภัณฑ์พอลิโพรพิลีนดัดแปรต่อคุณภาพหลังการเก็บเกี่ยวและอายุการเก็บรักษาของมะนาว *Citrus aurantifolia* Swingle. (EFFECTS OF HOT WATER TREATMENT AND MODIFIED POLYPROPYLENE PACKAGING ON POSTHARVEST QUALITY AND SHELF LIFE OF LIME *Citrus aurantifolia* Swingle) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ดร.ธีรดา หวังสมบูรณ์ดี, อ.ที่ปรึกษาวิทยานิพนธ์ร่วม: ผศ. ดร.กนกวรรณ เสรีภาพ, 124 หน้า.

การจุ่มน้ำร้อนเป็นวิธีการที่มีประสิทธิภาพวิธีการหนึ่งในการยืดอายุการเก็บรักษาผลผลิตทางการเกษตร ซึ่งวิธีการนี้มีผลต่อการเปลี่ยนแปลงทางสรีรวิทยาบางประการ รวมถึงสามารถควบคุมการเกิดโรคได้ ในการทดลองนี้ทำการจุ่มมะนาวในน้ำร้อนที่อุณหภูมิ 40 45 50 และ 55 ºC เป็นเวลา 2 และ 5 นาที จากนั้นนำไปเก็บที่อุณหภูมิ 10 และ 25 ºC นาน 6 และ 4 สัปดาห์ ตามลำดับ ผลการทดลองแสดงให้เห็นว่า การจุ่มมะนาวในน้ำร้อนที่อุณหภูมิ 40 ºC เป็นเวลา 5 นาที เหมาะสมที่สุดในการยืดอายุการเก็บรักษาผลมะนาวทั้งการเก็บรักษาที่อุณหภูมิ 10 และ 25 ºC ซึ่งวิธีนี้สามารถชะลอการเปลี่ยนสีของเปลือก ลดการสูญเสียน้ำหนักสดและการเกิดโรคได้ดีกว่าผลมะนาวที่ไม่จุ่มน้ำร้อน (ชุดควบคุม) ในขณะที่การใช้อุณหภูมิที่สูงเกินไป จะทำให้เกิดความเสียหายแก่ผลผลิตได้ เมื่อทดลองใช้การจุ่มน้ำร้อนอุณหภูมิ 40 ºC นาน 5 นาที ร่วมกับบรรจุภัณฑ์โพรพิลีนดัดแปร (HPCH และ MPPCH) และถุงพอลิโพรพิลีน (PP) เป็นชุดควบคุม ในการเก็บรักษามะนาวหลังการเก็บเกี่ยว พบว่า มะนาวที่จุ่มน้ำร้อนร่วมกับการใช้บรรจุภัณฑ์พอลิโพร- พิลีนดัดแปร และเก็บรักษาที่อุณหภูมิ 25 ºC นาน 4 สัปดาห์ สามารถชะลอการเปลี่ยนแปลงสีของผิวเปลือกโดยมีค่า L เพิ่มขึ้นน้อยกว่าชุดควบคุม ส่วนค่า Hue ลดลงช้ากว่าชุดควบคุม ซึ่งมะนาวที่จุ่มในน้ำร้อนร่วมกับบรรจุภัณฑ์ พอลิโพรพิลีนชนิด HPCH มีความแตกต่างจากชุดควบคุมอย่างมีนัยสำคัญ นอกจากนี้มะนาวที่จุ่มในน้ำร้อนร่วมกับบรรจุภัณฑ์พอลิโพรพิลีนชนิด MPPCH สามารถเพิ่มปริมาณฟีนอลิก (total phenolic content) ในสัปดาห์สุดท้ายของการเก็บรักษา ในขณะที่ HPCH จะเพิ่มการทำงานของเอนไซม์ catalase (CAT) นอกจากนั้น HPCH ยังสามารถลดอัตราการหายใจและการเกิดโรคหลังการเก็บรักษา แต่การจุ่มน้ำร้อนร่วมกับบรรจุภัณฑ์พอลิโพรพิลีนดัดแปรไม่มีผลต่อคุณภาพหลังการเก็บเกี่ยว เช่น เปอร์เซ็นการสูญเสียน้ำหนักสด ปริมาณวิตามินซี ปริมาณของแข็งที่ละลายน้ำได้ และการทำงานของเอนไซม์ ascorbate peroxidase (APX) ส่วนการเก็บรักษามะนาวที่อุณหภูมิ10 ºC เป็นเวลา 6 สัปดาห์ พบว่า มะนาวที่ได้รับการจุ่มน้ำร้อนร่วมกับบรรจุภัณฑ์พอลิโพรพิลีนดัดแปรไม่มีผลต่อคุณภาพหลังการเก็บรักษา ยกเว้นการทำงานของเอนไซม์ APX และการเกิดโรค โดยมะนาวที่จุ่มในน้ำร้อนร่วมกับบรรจุภัณฑ์พอลิโพรพิลีนดัดแปรทั้ง 2 ชนิด สามารถเพิ่มการทำงานของเอนไซม์ APX และยังยั้งการเกิดโรคหลังจากเก็บรักษาเป็นเวลา 6 สัปดาห์ ดังนั้นการจุ่มน้ำร้อนร่วมกับบรรจุภัณฑ์พอลิโพรพิลีนดัดแปรสามารถรักษาคุณภาพหลังการเก็บเกี่ยวของผลมะนาวระหว่างการเก็บรักษาที่อุณหภูมิ 25 ºC เป็นเวลา 4 สัปดาห์ แต่ไม่พบความแตกต่างอย่างมีนัยสำคัญหลังเก็บรักษาที่อุณหภูมิ 10 ºC

ภาควิชา...พฤกษศาสตร์..... ลายมือชื่อนิสิต.....

สาขาวิชา...พฤกษศาสตร์..... ลายมือชื่อ อ.ที่ปรึกษาหลักวิทยานิพนธ์หลัก.....

ปีการศึกษา.....2554..... ลายมือชื่ออ.ที่ปรึกษาหลักวิทยานิพนธ์ร่วม.....

5272495423 : MAJOR BOTANY
KEYWORS : LIME / HOT WATER TREATMENT / POSTHARVEST QUALITY / MODIFIED POLYPROPYLENE PACKAGING

MALLIKA BOONRITH : EFFECTS OF HOT WATER TREATMENT AND MODIFIED POLYPROPYLENE PACKAGING ON POSTHARVEST QUALITY AND SHELF LIFE OF LIME *Citrus aurantifolia* Swingle. ADVISOR: TEERADA WANGSOMBOONDEE, Ph.D., CO-ADVISOR: ASST. PROF. KANOGWAN SERAYPHEAP, Ph.D., 124 pp.

Hot water treatment is an effective method for prolonging shelf life of agricultural products. This method affects some physiological changes of the products and can also control diseases. In this experiment, hot water dipping of lime at 40, 45, 50 and 55 ºC for 2 and 5 min and stored at 10 and 25 ºC for 6 and 4 weeks, respectively, was conducted. The results showed that hot water treatment at 40 ºC for 5 min was the best temperature and duration for prolonging shelf life of limes in both 10 and 25 ºC storage temperatures. This condition could delay change of peel color, decrease percentage of weight loss and percentage of disease incidence compared with fruits dipped in distilled water at room temperature (control treatment) whereas treated fruits with too high temperatures resulted in hot water damage. Appropriate temperature and period of time (40 ºC for 5 min) with modified polypropylene packaging (HPCH and MPPCH) and normal polypropylene (PP) used as control was selected to test postharvest storage of lime. After four weeks storage at 25 ºC, hot water treatment with modified polypropylene packaging efficiently delayed the increase of L value and the decrease of Hue value more than controls which were significant difference in HPCH packaging compared with control. The combination of MPPCH and hot water treatment significantly increased total phenolic content, while HPCH significantly increased catalase (CAT) activity. In addition, HPCH packaging with hot water treatment could decrease respiration rate and percentage of disease incidence at the end of storage. However, hot water treatments with modified polypropylene packaging did not affect other postharvest qualities such as percentage of weight loss, ascorbic acid, total soluble solids and ascorbate peroxidase (APX) activity. For 10 ºC storage, hot water treatment with modified polypropylene packaging had no effect on postharvest qualities after storage except APX activity and percentage of disease incidence. Lime dipped in hot water treatment combined with HPCH and MPPCH could increase APX activity and reduced disease incidence after storage for 6 weeks. These results suggested that hot water with modified polypropylene packaging can maintain postharvest quality of lime fruits during storage at 25 ºC for 4 weeks, while no significantly affect was observed for the quality of lime stored at 10 ºC.

Department…..Botany……..... Student's Signature…….....

Field of study :..Botany…….. Advisor's Signature…….

Academic Year : …2011……... Co- advisor's Signature…….

Acknowledgements

I would like to express my special thanks to my thesis advisor Dr. Teerada Wangsomboondee and co-advisor Assistant Professor Dr. Kanogwan Seraypheap, who always give me the helpful suggestions, knowledges and encouragement.

I would like to express my sincere thanks to Assistant Professor Dr. Chumpol Khunwasi, Dr. Anchalee Chaidee, Associate Professor Dr. Rathanawan Magaraphan, Associate Professor Nantana Angkinand for serving on my thesis committee, their help and valuable suggestions to complete my thesis.

I would like to thank you the Thai government budget 2011 under the Research Program on Conservation and Utilization of Biodiversity and the Center of Excellence in Biodiversity, Faculty of Science, Chulalongkorn University for supporting some budge of this thesis. And I would like to special thanks the higher Education Research Promotion and National Research University Project of Thailand, Office of the Higher Education Commision (FW 0649) Partial Funding was received from the Polymer Processing and Polymer Nanomaterials Research Unit, The Petroleum and and Petrochemical College, Chulalongkorn University and the Center of Excellence for Petroleum, Petrochemical and Advanced Materials, Thailand.

Sincere thanks are also extended to all members of Environment and Plant Physiology Research Unit, Department of Botany, Faculty of Science, Chulalongkorn University, for the great friendship throughout my study. They always make me cheerful, give a big help in my hard work and share the great memory ever.

Finally, I would like to express my special thanks to my parents and my sister who always give me the special support and wonderful spirit whenever I needed, without them I would not able to keep working hard throughout my study.

Content

Page

Page

LIST OF TABLES

Table Page

LISTS OF FIGURES

Figure Page

Figure Page

CHAPTER I
INTRODUCTION

Lime (*Citrus aurantifolia* Swingle) is one of an important economic plant of Thailand which has high demand throughtout the years. Mature green lime is a preferred stage for the consumer due to the fruit's aromatic compounds and exotic flavors. The degradation of chlorophyll process continues after harvest and is relatively rapid at ambient temperature during marketing. Yellowing of lime is an effect of the physiological and biochemical processes occurring in the tissue of the peel. In addition, disease of limes, caused by *Penicillium* sp. is the most economically important postharvest disease of limes. Wounds on the fruit and injury during harvest can be infection sites of spores of this pathogen.

In the past, there were many researches tried to control the yellowing of lime fruits during postharvest storage including coating, modified atmosphere packaging and heat treatment. Heat treatment in postharvest can be done by using hot water, vapor heat and hot air. These methods are used for preventing insect pests and fungal rots or delay ripening. Also, it can modify fruit responses to other stresses and maintain fruit quality during storage and this kind of treatment doesn't injure the fruit. When citrus fruits treated with hot water (53-60 ºC) and stored at low temperature, citrus fruits showed decrease decay, fruits rot and chilling injury. In addition, hot water treatment could increase peroxidase (POX), catalase (CAT) and ascorbate peroxidase (APX) activities as shown in Satsuma mandarins, broccoli and tomato (Ghasemnezhad et al., 2008; Hong et al., 2007; Porat et al., 2000; Rodov et al., 1994; Zhang et al., 2009).

Packagings are one of methods used for horticultural products because they can prolong shelf life of the products. Use of modified packaging (MAP) is a method for prolonging shelf life of fruits and vegetables. Xtend ® films (XF) were used for citrus fruits to reduce the development of chilling injury after 5 weeks of storage at 6 ºC (Porat et al., 2004). In addition, limes packed in the composite packaging film

could maintain quality and prolong shelf life more than control treatment (Lamo et al., 2008).

Several studies have investigated the effect of hot water treatments of citrus fruits. However, the effect of hot water treatment to prolong shelf life of lime is still not known. Therefore, this research aimed to investigate use of hot water treatment and application of packagings in limes and determine the qualities and shelf life of limes during 10 and 25 ºC storage.

Objectives:

1. To select an appropriate temperature and period of time of hot water treatment to prolong postharvest qualities of limes stored at 10 and 25 ºC.

2. To investigate the effect of hot water treatment in combination with modified polypropylene packaging on postharvest qualities of limes stored at 10 ºC for 6 weeks and 25 ºC for 4 weeks.

CHAPTER II
LITERATURE REVEIWS

1. Lime

Lime (*Citrus aurantifolia* Swingle) is a non climacteric fruit which has high economical importance because it has high demand throughout the year. Lime consumption is roughly calculated around 1 million fruits per day all over the country as lime juice for cooking and beverage. Due to the increase of population and expansion of industries, the demand for lime in the market is increasing. So lime has an important role in term of trade nowadays. Growers can get a good price of lime in dry season because lime has low production in dry season around March and April of each year (Keadtanom, 1997).

1.1 The benefits of lime

Lime is widely used for many applications such as cooking, beverage mixer and in several kinds of traditional medicines. Thai people are familiar with using lime as an ingredient for cooking for long time. In addition, lime juice can also be used in major industries as well.

The Nutritional value

Lime is high in nutritional value as we can see from the analysis of the value of a lime. The nutritional value of average consumption of 100 grams of lime is as follows: (Department of Health, 1987).

water	88.70 - 93.50 g	thiamine (Vitamin B-1)	0.019 - 0.068 mg
fatty	0.040 - 0.170 g	riboflavin (Vitamin B-2)	0.011 - 0.023 mg
fiber	0.100 - 0.500 g	ascorbic acid	30.00 - 48.70 mg
protein	0.070 - 0.112 g	niacin	0.014 - 0.25 mg
carbohydrate	6.3 g	calories	40 unit
calcium	4.500 - 33.30 mg	phosphorus	9.300 - 21.00 mg
Iron	0.190 - 0.330 mg		

In addition, lime essential oil has a refreshing scent due to the chemical composition of citronellal, citronellyl acetate, limonene, linalool, terpeneol, etc., as well as citric acid, malic acid and a fruit acid (AHA: Alpha Hydroxy Acids) group. Lime has particularly high concentrations of these acids, which can constitute as much as 8% of the dry weight of these fruits (Keadtanom, 1997).

Industrial value

Limes have been used in many major industries which are continuing to expand such as citric acid industries which require lime as a raw material. Soft drink industry uses lime as a flavoring for flavor and aroma. The cosmetic, soap, detergents, hair oil, and other industries also require lime as a raw material. In the near future, the demand of using lime in the manufactures is expected to be double (Keadtanom, 1997).

Additionally, lime has the potential to compete for the export demands in international markets including China and Japan. A report of the importation of lime from Thailand to China in 2001 was worth 101,093 USD, while import value from Taiwan and Vietnam was only 6,669 and 387 USD, respectively. Moreover, export volume of lime to Japan during the years 1995-2001 had average 2,105 tons per year and export volume to the domestic market in Europe was slightly. Expected demand for future international markets of lime will be increased (Pongsomboon, 2004).

1.2 Harvesting of lime

When limes are 3 years old, they will begin to produce fruit. The harvest of lime should be performed in the beginning of mature stage. The top of the fruit should be slightly yellow and show smooth, thin and light green peel (Keadtanom, 1997).

2. Postharvest storage of lime

2.1 The characteristics of lime after harvest period

Lime is a non climacteric fruit which has a stable respiration rate and ethylene synthesis during maturation to ripening. For example, Euraka lime has a respiration

rate around 5 ml of oxygen per kg per hour and the concentration of ethylene inside the fruit around 0.1-0.2 ppm at temperature 20 °C. Generally, lime has low respiration rate and ethylene synthesis. However, keeping lime for 2 weeks at room temperature can make peel color change from green to yellow and then brown. When lime is storage in a dry condition, it can increase respiration rate and ethylene synthesis. Ethylene will accelerate the reaction of enzymes that involve ripening and degradation of fruit such as chloropyllase in degrading chlorophyll, and pectin methylesterase in fruit softening. Moreover, total soluble solids content and tritratable acidity will be increased, but vitamin C will decrease after harvest period. So storage period of lime will depend on the metabolism of lime as well as the external environment following harvesting (Kunsongkiat, 1988).

2.2 Postharvest storage of lime

Before a long period of storage, lime should be prepared by selecting a good lime without diseases and insects, then triming lime stem and washing them with 100-200 ppm sodium hypochlorite. Lime needs to be air-dry after the cleaning process. There are many approaches that can be used to extend the storage of lime as followings: (Kunsongkiat, 1988).

2.2.1 Low temperature storage

Low temperature storage can slow down metabolism rate of lime and inhibit growth of microbes. Lime produced in tropical zone should keep at 10-15 °C storage. However, the storage temperature also depends on type and age of physiology of production. If lime is kept in temperature that is too low, chilling injury can be occurred.

2.2.2 Embed in wet sand or wet husk

Lime can be buried in wet sand or wet husk and placed at room temperature. This method can extend the storage period of lime for 21 days. However, rotten fruit can be found on day 14, but storage at 10-12 °C can extend the storage period. Embed in wet sand or wet husk can help decrease transpiration rate of lime thus slowing down wilting and losing chlorophyll of peel.

2.2. 3 Waxing

Coating lime peel with wax can slow down transpiration rate and decrease infection from microbes. Moreover, some types of wax can make peel glossy. Waxing lime peel stored at room temperature can prolong shelf life for 18.3 days while lime peel without coating can be stored for 8 days. Coating lime peel with 50-70 % of star fresh 360© wax can prolong the shelf life for 21 days.

2.2.4 Gibberellins treatment

Gibberellins are plant hormones that are used to slow down the ripening and plant deterioration for some fresh products after harvesting period. Gibberellins can slow down the changing of color skin from green to yellow. Gibberellins that widely use in agriculture are gibberellic acid (GA_3). This type of gibberellins is used with edible products. Soaking lime in GA_3 at 200 and 400 ppm can slow down the change of color of lime peel from green to yellow for 4 weeks. Using gibberellins with others preserving solution can also enhance effectiveness of the chemicals.

2.2.5 Controlled atmosphere storage

Controlled atmosphere storage is the way to keep products in controlled gas atmosphere that is different from the normal atmosphere. Generally, this method will emphasize at the decrease of O_2 concentration during storage. The storage life will also depend on age of produces and storage temperature. Controlled atmosphere storage can slow down respiration rate, ethylene synthesis, infection from microbes and physiological disorders of fruits.

Study on controlled atmosphere (5 and 10% oxygen) with low temperature at 10 °C on quality and storage life of lime showed that at low concentration of 5% and 10% O_2, storage life of limes were 8 weeks while under air condition at 10 °C and 25 °C, storage life of limes were 5 and 2 weeks, respectively. (Boonyaritthongchai et al., 2009). However, this method is not applicable in Thailand because of high investment and there is no need to preserve lime for a very long period.

2.2.6 Packaging of the produce

Packaging lime in sealed plastic bag and perforated plastic bag can help to decrease transpiration rate and exchange gas inside and outside of the fruit. This can

slow down respiration rate and ethylene synthesis. However, after packaging, lime should be kept in the suitable temperature (low), otherwise, it will transpired without using CO_2 and lead to rotten fruit. Lime that was kept in perforated plastic bag at room temperature resulted in 28 days shelf life but some effects such as shrunken fruit and changes of color to yellow could be found. At 10 °C, lime sealed in plastic bag showed a longer storage period for 13 weeks (Kunsongkiat, 1988).

Packaging of the produce is a necessary component for marketing. Packaging is done to delay physiological and pathological deteriorative changes. Because fruit is a living entity, the biological factors that are involved in the deteriorative changes are: (1) physiological factors: during respiration, CO_2 and several other volatiles are released. The commodity also emits ethylene. Water loss takes place by transpiration, (2) pathological factors: disease pathogens, mostly fungi that infected fruit, (3) biochemical/metabolic changes: compositional changes take place in sugars, acids, ascorbic acid, pigments and volatiles (Ladaniya, 2008).

The materials used for retail or small unit packaging vary in different locations depending on demand, availability and economics. However, they can be categorized as film, boxes, trays and mesh bags. Films are made of different materials such as cellophane, polyethylene (HDPE, LDPE), polyvinyl chloride (PVC), polypropylene (PP), cellulose acetate and polystyrene. Ventilation is necessary in plastic film packaging otherwise very high humidity and water accumulation can lead to decay. Important characteristics of these materials are as follows: (Ladaniya, 2008)

Polyethylene (PE): It is usually low density and easily heat-sealed. It is the most widely used film for bagging applications and excellent for film products such as oranges and grapefruits.

Polyvinyl chloride (PVC): This stretch film is widely use. It is non-fogging and does not rip or tear unless punctured. It is an excellent film for consumer packaging.

Cellulose acetate film: It is highly transparent and sparkling in appearance, making an attractive package. It is relatively high in permeability to O_2 and CO_2.

Polystyrene: This material is similar to cellulose acetate film. It is extensively use for packaging in form of trays or backings. Trays that are used to hold produce in conjunction with a film over-wrap or sleeve are called backings.

Plastic film and mesh bags: These packages are designed mainly for providing a handy consumer package to carry and also for sales promotions (Ladaniya, 2008).

Combinations of various heat treatments with individual fruit sealing, packaging in polyethylene liners or waxing were tested as means to control pathological and physiological spoilage of fruit. The experiment showed that polyethylene liners were more efficient for weight loss control than waxing. However, the liner packaging enhanced the risk of postharvest disease development, if not accompanied by appropriate decay-controlling measures (Rodov et al., 2000).

Porat et al. (2004) studied modified atmosphere packaging (MAP) using Xtend® films (XF) which effectively reduced the development of chilling injury (CI) as well as other types of rind disorders that are not related to chilling, such as rind breakdown, stem-end rind breakdown (SERB) and shriveling and collapse of the button tissue (aging) of oranges. In all cases, microperforated films (0.002% perforated area) that maintained CO_2 and O_2 concentrations of 2–3 and 17–18%, respectively, inside the package were much more effective in reducing the development of rind disorders than macroperforated films (0.06% perforated area), which maintained CO_2 and O_2 concentrations of 0.2–0.4 and 19–20%, respectively. In both types of package, the relative humidity was about 95%. No major difference was found between the effectiveness of polyethylene (PE) and XF packages, despite the fact that XF prevents water condensation inside the bags.

2.2.7 UV treatment

UV-B can be used to delay the yellowing of Tahiti lime during storage at 25 °C. From the study, high amount of UV-B at 13.2 kJ/m^2 induced more water loss than control. Moreover, UV-B at 13.2 kJ/m^2 enhanced the chlorophyll degradation in the flavedo tissue of the lime fruit, while UV-B at 8.8 kJ/m^2 delayed the chlorophyll a and chlorophyll b content breakdown (Srilaong et al., 2011). Mature green lime fruit were

irradiated with or without UV-B doses at 19.0 kJ/m^2 and then stored at 25 °C in darkness efficiently delayed the decrease of hue angle values and chlorophyll a contents. The activities of the chlorophyll-degrading enzymes, chlorophyllase, chlorophyll-degrading peroxidase and pheophytinase in the fruit with UV-B treatment were suppressed and Mg-dechelation activity was also retarded by the treatment. UV-B treatment induced a gradual increase in citric acid and suppressed the increase of sugar contents during storage. In addition, the ascorbic acid content with or without UV-B treatment decreased during storage, but the decrease in the control was faster than that with UV-B treatment (Kaewsuksaeng et al., 2011).

2.2.8 1-Methylcyclopropene (1-MCP) treatment

Fruit treated with 250 or 500 nl/l 1-MCP effectively retarded yellowing for 21 days at ambient conditions (24–31°C and 73–81% RH). Chlorophyllase and chlorophyll degrading peroxidase activities in flavedo tissue of lime peel were delayed in 1-MCP treated fruit at concentrations of 250 and 500 nl/l. In addition, 1-MCP at low concentrations (250 or 500 nl/l) effectively suppressed endogenous ethylene production (Win et al., 2006).

2.2.9 Low temperature storage

Lime fruits are susceptible to chilling injury (CI) development during cold storage. Storage at low temperature could prolong shelf life and maintain fruit quality by decreasing the rate of metabolism, delaying ripening and controlling growth of microorganisms. Chilling injury is a physiological disorder induced by low temperatures (below 10 °C) but above their freezing. Fruits storage at 5 °C for at 60 days was observed CI symptoms. However, fruits kept continuously at 12 °C did not show CI during storage. In addition, no visible symptoms of CI were observed on fruits until the last week of storage (Harhash and Obeed, 2006). The effectiveness of a cold-conditioning treatment (13 °C for 48 h) to prevent CI was evaluated in Mexican limes stored at 4, 10 and 25 °C, and 90% relative humidity. Cold conditioning reduced 1.6 fold CI symptoms, induced a significant increase of 2.2 fold peroxidase activity and maintained the activity of superoxide dismutase in limes kept at 4 °C (Rivera et al., 2007).

2.2.10 Heat treatment

Postharvest heat treatments have been used for preventing insect pests, fungal rots and delay ripening. Also, it can modify fruit responses to other stresses and maintain fruit quality during storage (Lurie, 1998). These effects change according to the type of heat treatment applied and duration of fruits exposed to heat (Gonzalez-Aguilara et al., 2010) and also including species and varieties of fruits (Lurie, 1998). It is possible to apply a moderate treatment at non-lethal temperatures resulting in both a reversible suspension of ripening and reduction of fungal decay without noticeable in fruit quality. Heat treatment affects several aspects of fruit ripening, such as ethylene production and cell wall degradation, probably through changes in gene expression and protein synthesis (Lurie, 1998). Some postharvest heat treatments can activate an antioxidant system as a response to stress, resulting in improving the antioxidant activity of fruits (Gonzalez-Aguilara et al., 2010).

3. Effect of heat treatment on postharvest quality

Postharvest heat treatments have three methods to heat commodities; hot water, vapor heat and hot air. Hot water dips are effective for fungal pathogen control, because fungal spores infect on the surface or in the first few cell layers under the peel of the fruit or vegetable. Hot water dips to control decay are often applied for only a few minutes at high temperatures for killing insect pests located at the interior of a commodity because only the surface of the commodity requires heating (Lurie, 1998). Many fruits and vegetables tolerate exposure to water temperatures of 50–60 °C for up to 10 min, but shorter exposure at these temperatures can control many postharvest plant pathogens (Barkai-Golan and Phillips, 1991). For example, Roses dipped at 50 °C for 30 s could prevent *Botrytis cinerea* development (Elad and Volpin, 1991). Hot water dipping for 15 min at 35, 45 or 55 °C could control decay of strawberries (Garcia et al., 1995). Nam Dok Mai' mango dipped in hot water at 55 °C for 5 min showed the most effectiveness for delaying firmness and TSS/TA content losses and maintaining the highest score of acceptance at day 8 of storage period (Sapayasarn et al., 2008). Rodriguez et al. (2005) found that *Opuntia ficus* Indica dipped in hot

water treatment was very useful in reducing chilling injury, fungal development and improving quality when store at 2 °C. The effects of heat-treatments of olive fruits were increase in contents of lutein, b-carotene, chlorophylls a and b and pheophytins a and b (Luaces et al., 2005). Mature-green tomato fruit treated in water for 1h at 42 °C and stored at 20 °C can reduced decay by 60% (McDonald et al., 1998). Volatiles production can also be affected by hot water dipping at 42 °C for 60 min (McDonald et al., 1996). Recently, interest has been focused on short-duration hot water rinsing and brushing of fresh fruits and vegetables (Fallik et al., 1997). In this method, hot water is sprayed over the produce as it moves along a set of brush rollers, thus, simultaneously cleaning and disinfecting the produce (Porat et al., 2000). Hot water brushing at 55-64 °C for 10-30 s has been commercially used with bell peppers, mangoes, kumquat, citrus and several other crops to reduce postharvest decay. (Ben-Yehoshua et al., 2000; Fallik et al., 1999; Porat et al., 2000; Prusky et al., 1999).

Vapor heat was developed specifically for insect control. Heat transfer is by condensation of water vapor on the cooler fruit surface (Lurie, 1998). This method was used to kill Mediterranean (*Ceratitis apitata* Wiedemann) and Mexican (*Anastrepha ludens* Loew) fruit fly. (Baker, 1952; Hawkins, 1932). Vapor heat can also be used to control insects on tropical cut flowers, although in many cases the vase life is reduced by the length of time required for full insect mortality (Hansen et al., 1992). Vapor heat treated mangoes had higher skin colour ratings, reflectance and chroma values, and lower hue angles than control (Jacobi and Giles, 1997).

Hot air has been used for both fungal and insect control. One reason is that the high humidity in vapor heat can damage the fruit being treated, sometimes while the slower heating time and lower humidity of forced hot air can cause less damage (Lurie, 1998). A high temperature forced air quarantine treatment to kill Mediterranean fruit fly, melon fly and oriental fruit fly on papayas has been developed (Armstrong et al., 1989; Hansen et al., 1990). The inhibition of ripening by heat may caused by the effect of the ripening hormone. Hot air treatment at 35–40 °C within hours can inhibits ethylene synthesis in both apples and tomatoes (Biggs et al., 1988; Klein, 1989). Fruits such as plums, pears, avocados and tomatoes subjected to hot air treatments at 30-

40 °C were often soften more slowly than non-heated fruits (Maxie et al., 1974; Shellie and Mangan, 1994; Tsuji et al., 1984). In contrast, disinfestation procedures for mangos and papaya by hot forced air for 4 h at 50 °C led to faster softening after the treatment (Biggs et al., 1988; Eaks, 1978). In addition, hot air treatment at 38–46°C was used for insect disinfestation in nectarines, tomatoes and grapefruit (Lay-Yee and Rose, 1994; Lurie and Klein, 1991; 1992; Lurie and Sabehat, 1997; Miller and McDonald, 1992). Apples treated by hot air could enhance volatiles production (Fallik et al., 1997). When a heat treatment of 2–3 days in 38 °C air was applied to tomato fruit their sensitivity to low temperature was reduced and they could be stored for up to a month at 2 °C without developing chilling injury (Lurie and Sabehat, 1997). Strawberries at white ripening stage treated at 45 °C for 3 h and then stored at 20 °C for 72 h resulted in decrease firmness, activity of enzymes associated to cell wall degradation, and expression of related genes decreased during the storage (Martínez and Civello, 2008).

4. Effect of heat treatment on postharvest quality of citrus fruits

Nowadays, heat treatment has been tested and applied to fruit and vegetable commodities as a non-chemical method to reduce postharvest diseases, insects, and physiological disorders. In citrus, the increasing demand for fruit with less or no synthetic fungicide residues has led to the development and increase the use of hot water treatments. The important species of citrus are *Citrus sinensis* (sweet orange), *C. paradisi* (grapefruit), *C. reticulata* (mandarin), *C. aurantifolia* (sour lime) and *C. grandis* (pummelo) (Karuppiah, 2004).

The most effective result of hot water treatment on citrus is to reduce decay from *Penicillium* molds which are the most important causing agent of citrus postharvest decay worldwide (Eckert and Brown, 1986). Hot water dip at 52-53 °C for 2 min can prevented decay in lemon fruit inoculated with *Penicillium digitatum*. The hot water dip had a transient inhibitory effect on the pathogen by continuously accumulating lignin a week after treatment (Nafussi et al., 2001). Lignin is one factor in the defense mechanism which against fungal infection (Tian et al., 2007). In

addition, the synthesis of pathogenesis related (PR) protein is thought to be another important mechanism of resistance to various diseases. ß-1,3-Glucanase is the most fully characterized PR protein. An increasing amount of evidence suggests that it can act directly by degrading a pathogen's cell wall or indirectly by releasing oligosaccharide, elicitors of defense reactions, both of which are potential defense mechanisms against fungal infection (Saltveit, 2000). Hot water dips at 52 °C for 3 min have been shown to reduce green mold in organic lemon inoculated with the spores of *Penicillium digitatum* (Lanza et al., 2000). Heat treatment at 44 °C for 100 min or 46 °C for 50 min decreased decay incidence in 'Olinda' oranges and 'Campbell' oranges when stored at 6 °C for 2 week and then stored 20 °C (Schirra et al., 2005). Satsuma mandarins treated by hot water dipping at 52 °C for 2 min, 55 °C for 1 min, and 60 °C for 20 s, and then stored at 5 °C for 3 weeks and subsequently at 18 °C for 1 week could lower the development of stem-end rots, mold decay, and black rots than in untreated controls (Hong et al., 2007).

For reducing physiological changes, postharvest heat treatments lead to delay fruit ripening include fruit softening, membrane and flavor changes, respiration rate, ethylene production, and volatile production. The amount of sensitivity or tolerance to heat stress of a commodity is related to the level of heat protective proteins at harvest and the postharvest production of heat shock proteins (Zhang et al., 2009). There are two types of heat responses; the first is a normal cellular response (<42 °C) that can lead to reduce chilling sensitivity, delay ripening and a modification of quality and second by occurs near the threshold for damage (>45 °C) (Paull and Chen, 2000).

The major reduction in chilling injury (CI) incidence and level of damage were observed in hot water dipped at 50 °C for 2 min then stored at 2 °C for 8 weeks. The treatment could reduce CI, ethylene evolution and respiration and suppress anaerobic products. CI occurred along with higher ethylene production and respiration rate in affected fruit, and an increase in the amount of ethanol. During storage, a decline in catalase (CAT) activity was observed, while peroxidase (POX) activity increased. This rapid increase in POX activity was associated with increase peel damage due to both chilling injury and heat damage. Decreasing CI in hot water dipping was correlated

with decreased POX activity and maintenance of CAT activity during storage. Temperatures higher than 50 °C increased fruit peel damage (Ghasemnezhad et al., 2008).

The effect of postharvest hot water treatments on chilling tolerance and polyamine (PA) induction in flavedo tissue of mandarin (*Citrus reticulata*, Blanco, cv. 'Fortune') was investigated by Gonzalez-Aguilar et al. (1997). After 45 days at 2 °C, the major reduction in CI was found in fruits dipped for 6 min at 47 °C or 3 min at 53°C. The researchers concluded that the pattern of change in PA content was not related to HWT-induced cold tolerance. While heat treatment at 45 °C and then stored at 15 °C for 3 weeks could increase fruit firmness and levels of free putrescine and spermidine in the skin of treated lemons (Valero et al., 1998).

The increase in antioxidant activities of citrus peel (CP) extracts was reported in heat treated fruits reducing total phenol contents, radical scavenging activity. These results indicated that the antioxidant activity of CP extracts was significantly affected by heating temperature and duration of treatment on CP and that the heating process can be used as a tool for increasing the antioxidant activity of CP (Jeong et al., 2004).

Effects of hot water dipping at 41 °C for 20 min or at 50 °C for 5 min, and pre-storage conditioning (6 days at 16–18 ˚C and 45–65% RH) treatments to control CI in W. Navel and Valencia Late oranges then stored at 1 °C and 85–90% RH for 20 days, subsequent storage at 10 °C and 85–90% RH for 20 days (as a transit period) and an additional 20 days of simulated marketing period at 20 °C and 40–65% RH were investigated. Hot water treatments could reduce percentage of chilling injury in both cultivars, especially at 41 °C for 20 min that could also enhance peroxidase (POX) and catalase (CAT) activities in both fruit peel and juice, and the level of free phenols in juice compared with control and other treatments (Bassal and Hamahmy, 2011).

5. Green mold rot of lime

Green mold is caused by the fungus *Penicillium* sp. which is pervasive to all citrus growing regions. Spores of this organism are airborne and large numbers are produced by the fungus on the surface of infected fruit. The fungus can contaminate

the packinghouse and its equipment, storage room, transit containers and even the retail marketplace. (Barkai-Golan, 2001; Timmer et al., 2003). During harvesting and handling, the spores can germinate and infect injured fruit. Even injuries that involve only a few oil glands are sufficient to induce infection. The fungus can also attack fruit through certain physiologically induced injuries, such as injuries associated with chilling injury and stem-end rind breakdown. Fruit decaying with green mold produces relatively large amounts of ethylene gas which is a natural plant hormone that promotes respiration, senescence, and premature color development. The infection and sporulation cycle can be repeated many times in a packinghouse and in storage rooms during extended storage. This prolific spore production ability of *Penicillium* sp. enables it to eventually develop strains with resistance to chemical fungicide treatments (Whiteside et al., 1988).

5.1 Symptomatology

Initial symptoms of green mold are similar to those of sour rot and blue mold. The small decayed area appears as a soft watery spot that is more firm than comparable stages of sour rot. White mycelium is produced on the lesion surface, and when the lesion enlarges to approximately one inch in diameter, olive green spores are produced in the center. The sporulating area is surrounded by a broad zone of white mycelium and an outer zone of softened peel. The entire fruit is soon encompassed by a mass of olive green spores, which are easily dispersed by any physical motion or air currents (Timmer et al., 2000 and 2003; Brown, 2008) (Figure 1).

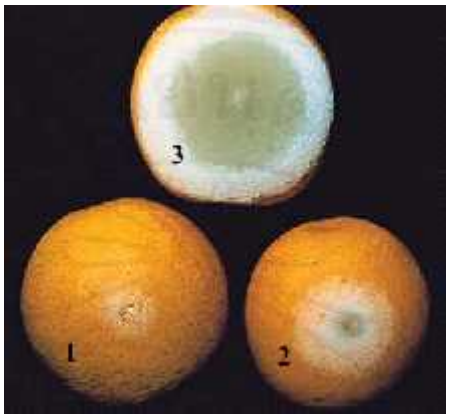

Figure 1. Three stages of green mold rot on sweet oranges (Brown, 2008).

5.2 Control

Careful harvesting and handling are needed to minimize injuries to the rind and the risk of green mold. High populations of spores must not be allowed to accumulate in the packinghouse or storage rooms. Aqueous solutions in drenchers and soak tanks should be treated continuously with a sanitizer, such as chlorine, to prevent the accumulation of green mold inoculums. The chemical treatments are used for the control of green mold but *Penicillium* sp. can develop resistance to postharvest fungicides. Resistance problems can be minimized with the use of thorough sanitation procedures, and treatments with two or more chemically unrelated fungicides. The packinghouse should be checked periodically, particularly during the cooler part of the packing season when green mold is predominant for the presence of fungicide resistant strains of green mold (Whiteside et al., 1988).

The susceptibility of fresh horticultural commodities to postharvest diseases increases during prolonged storage as a result of physiological changes in the fruits and vegetables that enable pathogens to develop (Eckert and Ogawa, 1988). Postharvest chemical treatments are very effective in controlling decay and are widely used on citrus. Recently, there has been an increased demand for fresh horticultural commodities with less or no chemical residues. A number of fungicides are no longer registered for use on fresh citrus, including those that were effectively used to control postharvest diseases. Fungicides in heated solutions (50-60 °C) are more effective at

controlling decay than non-heated solutions (Karuppiah, 2004). Heated solutions of thiabendazole (TBZ), imazalil generally recognized as safe (GRAS) like sulfur dioxide, ethanol, and sodium carbonate that are more effective at controlling postharvest decay in citrus than non-heated solutions (McDonald et al., 1991; Schirra and Mulas, 1995a and 1995b; Smilanick et al., 1995 and 1997; Wild, 1993). The incidence of green mold of navel oranges was reduced from 98.8 to 17.4% by treatment in 410 µg/m imazalil at 40.6 °C for 90 s. (Smilanick et al., 1997). In addition to use fungicides to control green mold, biological control has been introduced to control fruit decay. Aspire, a formulation of the yeast (*Candida oleophila*) registered for postharvest application to citrus, is used to control green mold by competition with the pathogen for nutrients to prevent infection (Brown et al., 2000). The concentrations 1, 3 and 5% of garlic extracts were more effective than the water control in inhibiting the growth and development of blue mold and green mold when treated fruits were stored at 10 °C and 90–95% relative humidity for 30 days (Obagwu and Korsten, 2003). Crude extracts of curcumin from methanol extract applied on citrus fruit showed the reduction of green mold rot. The combination of crude extract from curcumin and chitosan could decrease disease incidence to 26.8% whereas untreated fruit was 32.2% (Sangchot et al., 2008).

CHAPTER III
MATERIALS AND METHODS

Experiment 1. To select an appropriate temperature and period of time of hot water treatments to prolong postharvest qualities of limes during storage

1. Plant materials

The experiment was carried out by using lime (*Citrus aurantifolia* Swingle) harvested from a commercial orchard in Phetchaburi Province, Thailand. Fruits were selected with no disease wound or bruise and had uniformity in peel color and size. After transport to the laboratory, the fruits were selected again for the uniformity in size, shape and then wash with tab water for 1-2 minutes and treated with hot water.

2. Hot water treatment

In this experiment, limes were divided into 10 treatments. For control treatment, limes were dipped in distilled water at room temperature (26-27 ºC).

Treatment 1: control for 5 min

Treatment 2: control for 2 min

Treatment 3: 40 ºC for 5 min

Treatment 4: 40 ºC for 2 min

Treatment 5: 45 ºC for 5 min

Treatment 6: 45 ºC for 2 min

Treatment 7: 50 ºC for 5 min

Treatment 8: 50 ºC for 2 min

Treatment 9: 55 ºC for 5 min

Treatment 10: 55 ºC for 2 min

Then, limes were kept in the plastic bag (polypropylene) with 4 replicates (3 fruits/replicate) for each treatment. Afterward, limes were stored at 10 ºC for 6 weeks and 25 ºC for 4 weeks and measurements were done every 7 days with following parameters.

3. Measurement of some physiological changes

3.1 Percentages of weight loss

Fruit were weighed on the 1st day after treatment and then measurements were done every 7 days after treatment. Weight loss was calculated as follows:

$$\text{Weight loss (\%)} = \frac{\text{Initial weight (g)} - \text{Final weight (g)} * 100}{\text{Initial weight (g)}}$$

3.2 Peel color change

Peel color of lime was determined by measuring parameters L*, a* and b* values with a colorimeter (Color Reader CR-10, Konica Minota Sensing, INC., Japan). Color values of each fruit were computed as means of three equidistant locations on each fruit along the equator of the fruit. The hue was calculated from a* and b* values using the following formula:

$$\text{Hue} = \text{arc tangent } (a^*/b^*)$$

3.3 Disease incidence

The disease incidence was measure by counting diseased limes in east week and calculated to percentage as follows:

$$\text{Percentage of disease incidence} = \frac{\text{Number of disease fruits} * 100}{\text{Number of total fruits}}$$

4. Data analysis

All data were analyzed by ANOVA. When differences were significant ($P<0.05$), individual treatment means were compared using Duncan's Multiple Range Test ($P=0.05$).

Experiment 2: To investigate the effect of hot water and modified polypropylene packaging on postharvest qualities of limes after storage at 25 °C for 4 weeks.

1. Plant materials

Limes were selected according to Experiment 1.

2. Modified polypropylene packaging

Two modified polypropylene packagings were used in this experiment and a commercial polypropylene packaging (PP) was used as a control treatment. The

mesoporous clay was modified by organic-inorganic hybrid material through the co-condensation reaction of tetraethoxysilane (TEOS) with the functional groups (methyl and thiol) designated as HPCH and MPPCH, respectively. The HPCH packaging have a higher efficiency in adsorbing ethylene gas than the others because the methyl groups in packaging that incorporate in the porous clay heterostructure lead to a non polar surface, which causes the best ethylene adsorption. Otherwise, the thiol groups of the MPPCH packaging that incorporates in the porous clay heterostructure exhibits the best ethylene sensing by its higher sensitivity due to the largest drop of the electrical conductivity when it binds to the ethylene gas by the dipole-dipole interaction.

3. Hot water treatment

Limes were inoculated by dipping in spore suspension of *Penicillium* sp. (10^6 spore/ml) for 5 min and kept in room temperature for 24 hr. After inoculation fruits were treated with hot water at 40 ºC for 5 min (from Experiment 1). Following treatment, fruits were air dried and then packed in HPCH, MPPCH and PP, respectively. Dipping fruits in distilled water were used as a control treatment.

Treatment 1: control with PP

Treatment 2: control with HPCH

Treatment 3: control with MPPCH

Treatment 4: *Penicillium* sp. with 40 ºC for 5 min and PP

Treatment 5: *Penicillium* sp. with 40 ºC for 5 min and HPCH

Treatment 6: *Penicillium* sp. with 40 ºC for 5 min and MPPCH

Treatment 7: 40 ºC for 5 with PP

Treatment 8: 40 ºC for 5 with HPCH

Treatment 9: 40 ºC for 5 with MPPCH

Then stored at 25 ºC for 4 weeks and the measurements were done every 7 days with following parameters.

3. Measurement of some physiological changes

3.1 Percentages of weight loss

Fruits were weighed on the 1st day after treatment and then measurements were done every 7 days after treatment. Weight loss was calculated as follows:

$$\text{Weight loss (\%)} = \frac{\text{Initial weight (g)} - \text{Final weight (g)} * 100}{\text{Initial weight (g)}}$$

3.2 Peel color change

Peel color of lime was determined by measuring parameters L*, a* and b* values with a colorimeter (Color Reader CR-10, Konica Minota Sensing, INC., Japan). Color values of each fruit were computed as means of three equidistant locations on each fruit along the equator of the fruit. The hue was calculated from a* and b* values using the following formula:

$$\text{Hue} = \text{arc tangent } (a^*/b^*)$$

3.3 Total phenolic content

Phenolic compounds were extracted according to the method of Nittaya Umrat, (2010) with some modifications. Lime peel 0.1 g was ground with liquid nitrogen to fine powder, and then 1.5 ml of 80% methanol was added. The homogenate were vortexed for 1 min and centrifuged at 13,000 rpm for 15 min at 4 ºC. Then, the supernatants were collected for extract analysis.

The Folin–Ciocalteu assay, adapted from Ramful et al. (2010) was used for the determination of total phenolics presented in the lime extracts. To 200 µl extract, 3.55 ml of distilled water was added followed by 0.25 ml of Folin–Ciocalteu reagent. A blank was prepared using 0.25 ml of 80% methanol instead of plant extract. After 3 min, 1 ml of 20% sodium carbonate was added. Tube contents were vortexed before being incubated for 40 min in a water bath set at 40 ºC. The absorbance of the blue coloration formed was read at 685 nm against the blank standard. Total phenolics were calculated with respect to gallic acid standard curve (concentration range: 0–12 µg/ml). Results are expressed in µg of gallic acid/g fresh weight of plant material.

3.4 Ascorbic acid (AA)

Total ascorbic acid (AA) content was determined using the dinitrophenylhydrazine (DNPH) method with some modifications followed by Shin et al. (2007). Lime peel 0.1 g was extract with 10 ml of 6% metaphosphoric acid in 2 M

acetic acid. The mixture was centrifuged at 9000×g for 15 minutes at 4 ºC. After that, 1 ml of supernatant and was mixed with 0.05 ml of 0.2% 2,6-dichlorophenolindolphenol (DCIP) and the solution was incubated at room temperature for 1 h. Then, 1 ml of 2% thiourea in 5% metaphosphoric acid and 0.5 ml of 2% DNPH in 4.5 M sulfuric acid were added to the solution, and then incubated at 60 ºC for 3 h. The reaction was stopped by placing the tubes in an ice bath and slowly adding 2.5 ml of ice cold 90% sulfuric acid. Total AA was measured by absorbance at 540 nm using a standard curve. The concentrations were expressed as ascorbic acid on a fresh weight basis, mg/g.

3.5 Total Soluble Solids (TSS)

Total soluble solids were measured by Hand Refractometer (Model N–1E, Atago, INC., Japan) using 200 µl of lime juice and the values expressed as °Brix.

3.6 Measurement of respiration rate

After 7 days of storage at 25 ºC, five fruits per replication (overall 20 fruits per treatment) were placed into individual 0.7 L jars at 10 ºC which were quickly purged with air and sealed. After 3 hr, a 10 ml gas sample was withdrawn by the tube and syringe and replace into Saline solution 50 ml in bottle. Then, gas samples were analyzed using a gas chromatograph (Model GC -8A, Shimadzu Co., Japan).

3.7 Antioxidant activity (Nittaya Umrat, 2005)

Lime peel (0.1 g) was homogenized in 1 ml of ice-cold extraction buffer and 1% (w/v) polyvinyl polypyrrolidone (PVPP), 1 mg/ml dithiothreitol (DTT),100 mM phenylmethylsulfonyl fluoride (PMSF) with 50 mM sodium phosphate (pH 7.0) were used as extraction buffer. The homogenate was centrifuged at 13,000 g for 15 min at 4 ºC and the resulting supernatants were used directly for assay.

3.7.1 Catalase activity (CAT)

CAT activity measured by the decline in absorbance at 240 nm caused by the decomposition of H_2O_2 (Beers and Sizer, 1952) with slight modifications. The reaction mixture consisted of 1.78 ml sodium phosphate buffer (50 mM, pH 7.0), 0.2 ml H_2O_2 (100 mM) and 40 µl extract enzyme. The specific activity was expressed as U/mg protein, CAT activity was calculated as follows:

$$\text{Units/mg protein} = \frac{(\Delta \text{ A240/min})(1000)}{(43.6)(\mu\text{l plant extract})(\text{mg protein/ } \mu\text{l plant extract})}$$

3.7.2 Ascorbate peroxidase activity (APX)

APX activity was assayed by determining the oxidised ascorbate by the method of Nakano and Asada (1989). The reaction mixture consisted of 1.58 ml sodium phosphate buffer (50 mM, pH 7.0), 0.2 ml H_2O_2 (100 mM), 20 µl EDTA (500mM, pH 8.0), 0.2 ml ascorbate (2mM) and 20 µl extracted enzyme. The reaction rate was monitored by the decrease in absorbance at 290 nm. The rate constant was calculated as follows:

$$\text{Units/mg protein} = \frac{(\Delta \text{ A290/min})(1000)}{(2.8)\ )(\mu\text{l plant extract})(\text{mg protein/ } \mu\text{l plant extract})}$$

3.7.3 Total protein assay

The method was used to determine the protein content of the samples (Nittaya Umrat, 2005). Bradford dye reagent (BioRad) 50 µl was added to test tubes containing 50 µl enzyme extract samples and distilled water 100 µl and the tubes were incubated at room temperature for 5 min. The samples were then thoroughly mixed and read at a wavelength of 595 nm in a spectrophotometer. Protein content was using bovine serum albumin (BSA) as the standard protein.

3.8 Disease incidence

Disease incidence was measure according to Experiment 1.

4. Data analysis

All data were analyzed by ANOVA. When differences were significant ($P<0.05$), individual treatment means were compared using Duncan's Multiple Range Test ($P=0.05$).

Experiment 3: To investigate the effect of hot water treatment and modified polypropylene packagings on postharvest qualities of limes after storage at 10 °C for 6 weeks

The methods as in Experiment 2 were followed and a measurement of chilling injury was added.

Chilling injury (CI)

The fruit were visually scored to estimate degree of CI. CI is characterized by development of dark colored irregular shaped pitting in the fruit surface which is completely different from the water soaked areas characteristic of heat damage. It was easy to separate the symptoms when the symptoms were not severe, but there was some overlap during high levels of damage. Skin damage was assessed in a manner similar to Ghasemnezhad et al. (2008) every 7 day after storage. The extent of CI was scored from 1 to 4, where, 1 = no occurrence; 2 = 1–25%; 3 = 26–50%; 4 = more than 50% fruit surface affected.

CHAPTER IV
RESULTS

1. Selection of an appropriate temperature and period of time of hot water treatment to prolong postharvest qualities of limes during storage

1.1 Percentage of weight loss

At 25 ºC storage, limes dipped in hot water at 40 ºC for 5 min, 45 ºC for 2 min and 55 ºC for 2 min had significantly lower percentage of weight loss (2.51, 2.55 and 2.45%, respectively) than control dipped in distilled water at room temperature for 2 min (2.97%) in the fourth week (Table 1). Duration of storage effects loss of fruit weight. Limes dipped in hot water at 40 ºC for 5 min and stored at 10 ºC for 6 weeks resulted in the lowest percentage of weight loss (3.23%) which was significantly different from the control dipped in distilled water at room temperature for 5 min (4.00%) (Table 5).

1.2 Peel color change

Color change of lime peel was determined by the lightness (L value) and the color (hue value) which tended to change from green to yellow during storage. After storage at 25 ºC for 4 week, limes dipped in hot water treatments did not show significant difference in L value comparing with control except at 55 ºC for 5 min. The hue value of limes dipped in hot water at 40 ºC for 5 min changed less than other treatments (Table 2 and 3 and Figure 2). However, limes dipped in hot water at 55 ºC for 2 min after stored at 10 ºC for 6 weeks slightly increased L value which was significantly different from control. In addition, limes dipped in hot water at 40 ºC for 5 min showed slowly decreased hue value (Table 6 and 7 and Figure 3).

1.3 Disease incidence

In storage temperature at 25 ºC, rot of limes was found at the second week of storage and the fruit rot increased through the last week. Disease incidence was

highest in limes dipped in hot water at 45 ºC for 5 min and limes dipped in hot water at 50 ºC for 5 min did not showed any fruit rot during the storage times (Table 4). While storage of limes at low temperatures can effect post-harvest disease control. In this experiment, disease incidence was not detected in all treatments when stored at 10 ºC for 6 weeks (Data not shown)

Table 1. Percentage of weight loss of limes after hot water treatments and then stored at 25 ºC for 4 weeks.

Treatment	Percentages of weight loss			
	w.1	w.2	w.3	w.4
control + 2 min.	1.90±0.21^{b}	2.34±0.05^{b}	2.69±0.06^{b}	2.97±0.08^{b}
control + 5 min.	1.72±0.07^{ab}	2.33±0.09^{b}	2.65±0.09^{b}	2.84±0.12^{ab}
40 ºC 2 min.	1.62±0.09^{ab}	2.25±0.11^{ab}	2.64±0.16^{b}	2.78±0.19^{ab}
40 ºC 5 min.	1.43±0.06^{a}	2.00±0.08^{ab}	2.37±0.08^{ab}	2.51±0.11^{a}
45 ºC 2 min.	1.51±0.07^{a}	1.92±0.09^{a}	2.32±0.10^{ab}	2.55±0.10^{a}
45 ºC 5 min.	1.68±0.13^{ab}	2.19±0.22^{ab}	2.31±0.15^{ab}	-
50 ºC 2 min.	1.59±0.06^{ab}	2.17±0.10^{ab}	2.48±0.11^{ab}	2.69±0.10^{ab}
50 ºC 5 min.	1.59±0.09^{ab}	2.19±0.13^{ab}	2.52±0.12^{ab}	2.74±0.12^{ab}
55 ºC 2 min.	1.43±0.06^{a}	1.96±0.07^{a}	2.26±0.08^{a}	2.45±0.09^{a}
55 ºC 5 min.	1.74±0.10^{ab}	2.33±0.15^{b}	2.53±0.13^{b}	2.75±0.16^{ab}

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$. Data are mean values ±SE.

Table 2. L value of limes after hot water treatments and then stored at 25 ºC for 4 weeks.

Treatment	L value				
	w.0	w.1	w.2	w.3	w.4
control + 2 min.	56.16±1.6 [b]	66.00±1.84 [cd]	69.86±1.26 [c]	69.58±2.03 [b]	72.01±0.83 [b]
control + 5 min.	52.21±1.44 [a]	61.30±2.36 [abc]	67.17±2.01 [bc]	70.55±1.36 [b]	70.80±1.43 [b]
40 ºC 2 min.	48.98±0.60 [a]	62.52±1.66 [bcd]	69.11±1.31 [bc]	69.97±1.47 [b]	69.69±1.86 [b]
40 ºC 5 min.	50.71±1.17 [a]	57.89±1.80 [ab]	66.84±1.75 [bc]	69.84±1.18 [b]	71.81±0.94 [b]
45 ºC 2 min.	50.01±0.89 [a]	65.03 ±1.02 [cd]	70.15±0.76 [c]	72.34±0.48 [b]	72.14±0.39 [b]
45 ºC 5 min.	51.53±1.32 [a]	64.64±1.93 [cd]	69.46±1.43 [c]	70.03±0.80 [b]	-
50 ºC 2 min.	52.66±1.00 [a]	67.89±0.88 [d]	71.34±0.41 [c]	71.65±0.51 [b]	71.55±0.62 [b]
50 ºC 5 min.	51.49±0.88 [a]	65.32±1.56 [cd]	68.67±1.48 [bc]	69.32±1.63 [b]	68.80±1.45 [b]
55 ºC 2 min.	49.41±1.13 [a]	60.57±1.63 [abc]	64.72±1.30 [b]	68.29±1.19 [b]	69.52±1.01 [b]
55 ºC 5 min.	49.60±1.19 [a]	56.44±1.95 [a]	59.83±1.99 [a]	63.85±1.04 [a]	65.27±0.91 [a]

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$.

Data are mean values ±SE.

Table 3. Hue value of limes after hot water treatments and then stored at 25 ºC for 4 weeks.

Treatment	Hue value				
	w.0	w.1	w.2	w.3	w.4
control + 2 min.	104.1±81.08^{a}	94.54±1.75^{abc}	91.41±1.14^{abc}	89.44±0.93^{ab}	88.24±0.84^{ab}
control + 5 min.	106.53±1.20^{abc}	98.00±2.28^{bcd}	92.36±1.78^{bc}	89.85±1.28^{ab}	89.56±1.48^{b}
40 ºC 2 min.	108.77±0.32^{d}	97.56±1.53^{bcd}	90.89±1.41^{abc}	90.11±1.46^{ab}	89.33±1.50^{ab}
40 ºC 5 min.	108.56±0.45^{cd}	102.05±1.37^{d}	94.51±1.79^{c}	91.78±1.57^{b}	90.41±0.87^{ab}
45 ºC 2 min.	108.58±0.50^{cd}	94.51±0.94^{abc}	88.93±1.03^{ab}	87.98±0.69^{ab}	87.70±0.68^{ab}
45 ºC 5 min.	106.75±0.89^{cd}	94.96±2.13^{abc}	89.35±1.73^{ab}	88.63±1.42^{ab}	-
50 ºC 2 min.	106.04±0.75^{ab}	92.35±0.91^{a}	87.75±0.58^{a}	87.04±0.45^{a}	86.79±0.56^{ab}
50 ºC 5 min.	106.83±0.71^{cd}	94.85±1.52^{abc}	91.31±1.59^{abc}	90.84±1.63^{ab}	90.26±1.37^{ab}
55 ºC 2 min.	108.12±0.80^{cd}	98.55±1.20^{cd}	94.35±1.14^{c}	90.92±1.08^{ab}	89.32±0.89^{ab}
55 ºC 5 min.	107.47±0.87^{cd}	93.18±1.46^{ab}	90.74±0.72^{abc}	89.22±1.11^{ab}	86.68±1.04^{a}

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$.

Data are mean values ±SE.

Table 4. Percentage of disease incidence of limes after hot water treatments and then stored at 25 ºC for 4 weeks.

Treatment	Percentage of disease incidence			
	w.1	w.2	w.3	w.4
control + 2 min.	0.00	0.00	8.33	25.00
control + 5 min.	0.00	0.00	0.00	25.00
40 ºC 2 min.	0.00	0.00	8.33	33.33
40 ºC 5 min.	0.00	0.00	0.00	25.00
45 ºC 2 min.	0.00	25.00	33.33	33.33
45 ºC 5 min.	0.00	16.67	58.33	100.00
50 ºC 2 min.	0.00	0.00	8.33	33.33
50 ºC 5 min.	0.00	0.00	0.00	0.00
55 ºC 2 min.	0.00	0.00	0.00	8.33
55 ºC 5 min.	0.00	8.33	8.33	16.67

Table 5. Percentage of weight loss of limes after hot water treatments and then stored at 10 ºC for 6 weeks.

Treatment	Percentages of loss weight					
	w.1	w.2	w.3	w.4	w.5	w.6
control + 2 min.	1.20±0.05^{a}	1.56±0.06^{a}	2.06±0.07^{a}	2.49±0.07^{a}	3.05±0.09^{ab}	3.47±0.11^{ab}
control + 5 min.	1.23±0.06^{a}	1.68±0.08^{a}	2.19±0.11^{ab}	2.66±0.13^{a}	3.38±0.18^{bc}	4.00±0.23^{c}
40 ºC 2 min.	1.33±0.06^{a}	1.78±0.06^{a}	2.26±0.07^{ab}	2.74±0.08^{a}	3.16±0.09^{abc}	3.52±0.11^{abc}
40 ºC 5 min.	1.41±0.15^{a}	1.70±0.04^{a}	2.06±0.06^{a}	2.52±0.09^{a}	2.87±0.09^{a}	3.23±0.11^{a}
45 ºC 2 min.	1.19±0.05^{a}	1.58±0.07^{a}	2.09±0.08^{ab}	2.62±0.10^{a}	3.01±0.12^{ab}	3.47±0.15^{ab}
45 ºC 5 min.	1.25±0.06^{a}	1.64±0.07^{a}	2.06±0.07^{a}	2.44±0.15^{a}	3.11±0.10^{ab}	3.59±0.11^{abc}
50 ºC 2 min.	1.29±0.06^{a}	1.80±0.09^{a}	2.37±0.12^{b}	2.84±0.16^{ab}	3.58±0.20^{c}	3.76±0.17^{bc}
50 ºC 5 min.	1.15±0.06^{a}	1.71±0.16^{a}	2.08±0.13^{ab}	2.57±0.14^{a}	3.08±0.23^{ab}	3.51±0.22^{abc}
55 ºC 2 min.	1.21±0.12^{a}	1.80±0.06^{a}	2.32±0.08^{ab}	3.16±0.21^{b}	3.59±0.10^{c}	3.85±0.14^{bc}

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at P $\leq$ 0.05.

Data are mean values ±SE.

Table 6. L value of limes after hot water treatments and then stored at 10 ºC for 6 weeks.

Treatment	L value						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
control + 2 min.	51.02±1.11^{abcd}	54.96±1.78^{abc}	61.73± 1.94^{c}	65.04±1.82^{cd}	68.067±1.28^{cd}	70.14±0.90^{c}	69.91±0.83^{bc}
control + 5 min.	52.75±0.61^{cd}	55.76±0.78^{bc}	62.88±1.07^{c}	66.45±0.96^{d}	68.46±0.82^{d}	69.38±0.74^{c}	70.24±0.70^{bc}
40 ºC 2 min.	52.16±1.14^{ab}	55.95±1.42^{bc}	62.32±1.52^{c}	66.25±1.27^{d}	67.85±1.11^{cd}	67.69±1.33^{bc}	69.43±0.95^{bc}
40 ºC 5 min.	48.38±1.00^{a}	51.21±1.28^{a}	56.52±1.55^{ab}	61.37±1.72^{bc}	64.21±1.61^{bc}	66.76±1.60^{bc}	67.7±1.45^{b}
45 ºC 2 min.	48.72±0.69^{ab}	53.3±0.71^{abc}	58.41±1.21^{abc}	61.84±1.61^{bc}	65.23±2.07^{bcd}	67.05±1.55^{bc}	67.13±1.21^{b}
45 ºC 5 min.	51.36±1.67^{abcd}	55.22±1.66^{abc}	60.63±1.60^{bc}	65.12±1.32^{cd}	66.66±1.14^{bcd}	68.57±1.01^{bc}	69.66±0.61^{bc}
50 ºC 2 min.	52.54±1.26^{bcd}	57.27±1.39^{c}	62.04±1.14^{c}	66.28±1.11^{d}	69.14±0.76^{d}	69.69±0.76^{c}	70.9±0.50^{c}
50 ºC 5 min.	48.92±1.87^{abc}	51.99±1.94^{ab}	56.27±1.72^{ab}	59.54±1.58^{ab}	63.64±1.66^{b}	65.46±1.06^{b}	68.15±0.97^{bc}
55 ºC 2 min.	53.03±1.07^{d}	54.77±1.24^{abc}	55.43±1.08^{a}	57.01±1.04^{a}	57.79±0.96^{a}	58.35±0.95^{a}	58.97±1.19^{a}

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$.

Data are mean values ±SE.

Table 7. Hue value of limes after hot water treatments and then stored at 10 ºC for 6 weeks.

Treatment	Hue value						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
control + 2 min.	107.78±0.70^{abc}	104.36±1.37^{ab}	100.07±1.60^{abc}	97.02±1.58^{abc}	94.91±1.27^{abc}	92.44±1.12^{ab}	92.04±1.51^{abc}
control + 5 min.	105.85±0.63^{a}	102.08±0.72^{a}	97.40±0.91^{a}	93.67±0.80^{a}	91.59±0.59^{a}	90.20±0.46^{a}	90.69±0.40^{ab}
40 ºC 2 min.	106.39±0.91^{ab}	102.46±1.22^{a}	98.03±1.54^{ab}	94.58±1.31^{ab}	92.60±1.17^{ab}	91.56±0.92^{ab}	92.12±0.77^{abc}
40 ºC 5 min.	109.59±0.75^{c}	106.39±1.05^{b}	103.74±1.30^{c}	99.43±1.54^{c}	97.36±1.70^{c}	94.88±1.57^{b}	94.90±1.57^{c}
45 ºC 2 min.	109.00±0.61^{bc}	105.51±0.71^{ab}	101.77±0.92^{bc}	97.98±1.35^{abc}	96.13±1.56^{bc}	93.93±1.35^{ab}	93.90±1.24^{bc}
45 ºC 5 min.	106.96±1.24^{abc}	103.56±1.21^{ab}	99.72±1.58^{abc}	95.76±1.48^{abc}	93.84±1.43^{abc}	91.72±1.11^{ab}	91.53±1.13^{abc}
50 ºC 2 min.	106.61±0.76^{ab}	102.44±0.79^{a}	99.38±0.87^{ab}	94.24±2.13^{a}	91.89±1.92^{ab}	90.46±1.71^{a}	90.08±1.74^{a}
50 ºC 5 min.	108.00±1.25^{abc}	104.48±1.39^{ab}	101.41±1.08^{abc}	98.86±1.03^{bc}	95.04±0.87^{abc}	93.14±0.80^{ab}	92.61±0.54^{abc}
55 ºC 2 min.	106.08±0.86^{a}	102.00±0.98^{a}	97.99±1.58^{ab}	96.50±1.01^{abc}	94.80±0.92^{abc}	93.93±0.83^{ab}	94.70±0.76^{c}

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at P $\leq$ 0.05.

Data are mean values ±SE.

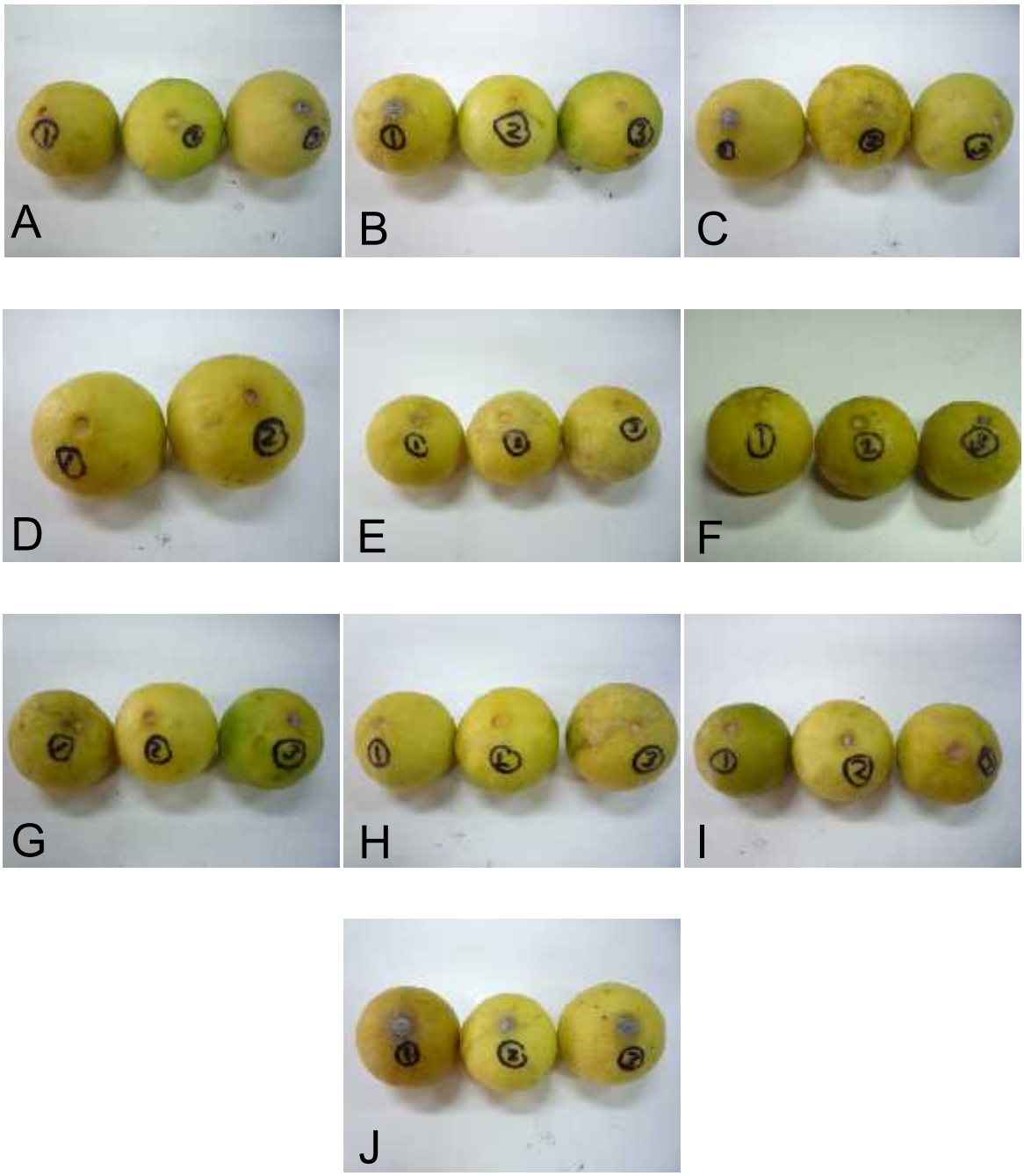

Figure 2. External appearance of lime after hot water treatments and then storage at 25 ºC for 4 weeks. A=control 2 min, B=control 5 min, C=40 ºC 2 min, D=40 ºC 5 min, E=45 ºC 2 min, F=45 ºC 5 min, G=50 ºC 2 min, H=50 ºC 5 min, I=55 ºC 2 min and J=55 ºC 5 min.

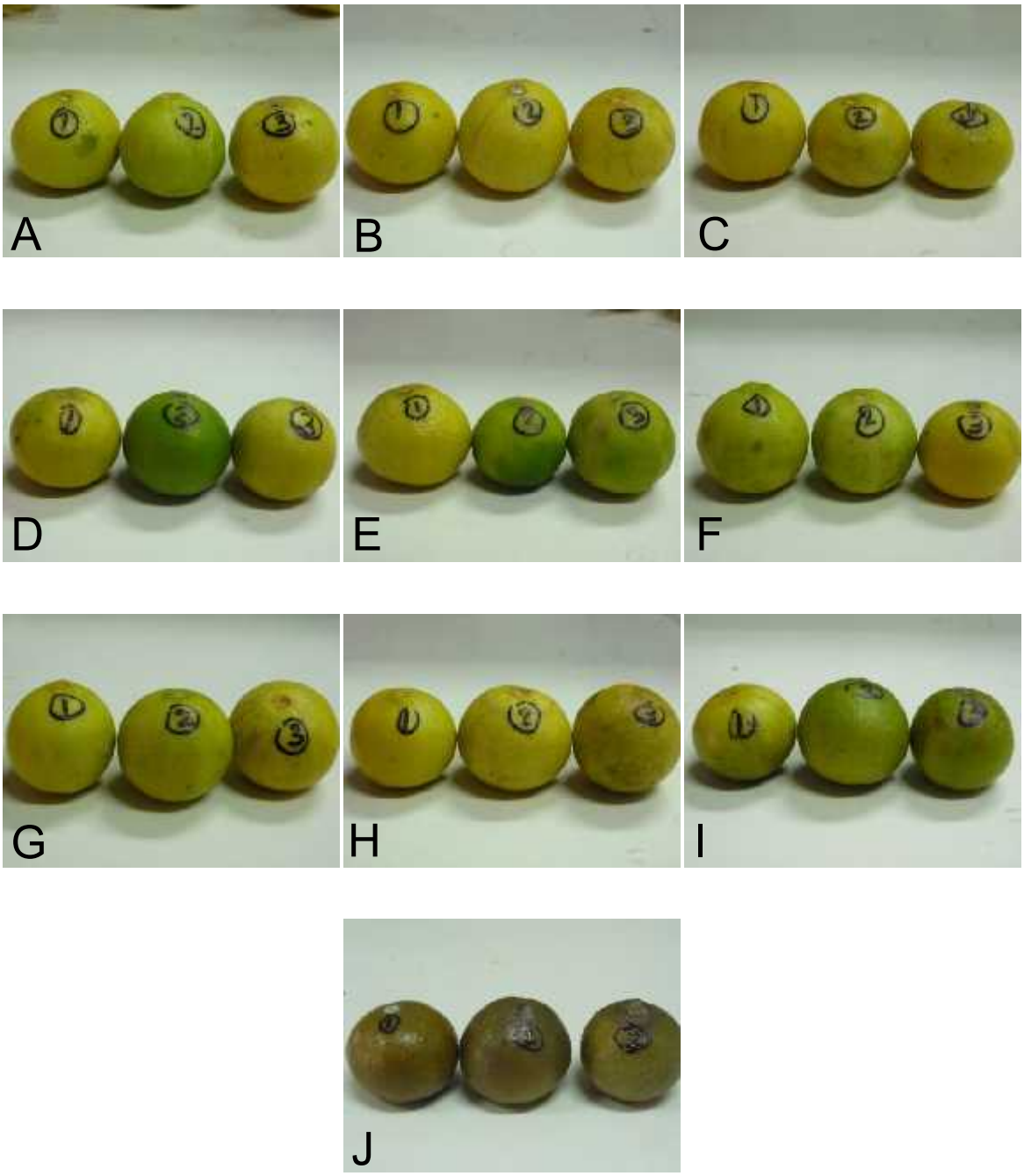

Figure 3. External appearance of lime after hot water treatments and then storage at 10 ºC for 6 weeks. A=control 2 min, B=control 5 min, C=40 ºC 2 min, D=40 ºC 5 min, E=45 ºC 2 min, F=45 ºC 5 min, G=50 ºC 2 min, H=50 ºC 5 min, I=55 ºC 2 min and J=55 ºC 5 min.

2. Effect of hot water treatment and modified polypropylene packaging on postharvest qualities of limes after storage at 25 °C for 4 weeks

2.1 Percentages of weight loss

Percentages of weight loss of limes stored at 25 ºC for 4 weeks increased during the storage time. Limes inoculated with *Penicillium* sp. then dipped in hot water and packed in PP tended to have percentage of weight loss lower than the other treatments and limes dipped in hot water and packed in PP had the highest percentages of weight loss (Table 8). When separation the treatments into sets, limes dipped in distilled water and packed in HPCH and MPPCH significantly had lower percentages of weight loss than PP packaging since the first week of storage (Figure 5A). In *Penicillium* sp. inoculation then dipped in hot water set, limes packed in PP and HPCH packaging significantly showed lower percentages of weight loss than from MPPCH packaging (Figure 5B). Percentages of weight loss of limes dipped in hot water and packed in PP, HPCH and MPPCH did not showed difference until the last week (Figure 5C).

2.2 Peel color change

2.2.1 Lightness (L value)

After storage of limes, the L value similarly increased in all treatments. The lowest L values was showed in limes inoculated with *Penicillium* sp. then dipped in hot water and packed in HPCH and the highest L values was showed in limes dipped in distilled water and packed in HPCH (Table 9 and Figure 4). Treatments that packed in PP resulted in higher L values than other packaging except in control treatments (Figure 4). In the control treatment set, the PP and MPPCH packaging decreased the L value and were significant difference from HPCH packaging (Figure 6A). Limes inoculated with *Penicillium* sp. then dipped in hot water and packed in HPCH packaging had the L value significant difference from PP packaging since the second week of storage (Figure 6B). The L value of limes dipped in hot water and packed in HPCH was significantly lower than pack in PP in the last week (Figure 6C).

2.2.2 Hue value

Hue value (hue angle) decreased during storage, indicating a change from green to yellow. Limes inoculated with *Penicillium* sp. then dipped in hot water and packed in HPCH and MPPCH and limes dipped in hot water and packed in HPCH had higher hue value than control treatments. The significant difference was found on the third and fourth weeks, indicating the delay change in peel color of limes (Table 10 and Figure 4). After 4 weeks of storage, the control treatment set did not show any significantly different between PP, HPCH and MPPCH packaging (Figure 7A). Limes inoculated with *Penicillium* sp. then dipped in hot water and packed in HPCH and MPPCH packaging significantly had higher hue value than PP packaging since the first week (Figure 7B). In addition, limes dipped in hot water and packed in HPCH showed significant difference in hue value from PP packaging since the third week (Figure 7C).

2.3 Total phenolic content

The total phenolic content of all treatments fluctuated since the first week until the last week of storage. There was no significant difference in the total phenolic content of all treatments after 4 weeks of storage (Table 11). The total phenolic content of the control treatment set increased in the first week but decreased in the second week and then fluctuated until the last week. The significant difference was found in the second week in HPCH packaging which had the highest value (Figure 8A). The treatment sets of *Penicillium* sp. inoculation with hot water and only hot water treatment showed the same pattern of the phenolic content in which gradual decrease in the amount of the phenolic content was found until the third week of storage then the phenolic content sharply increased in the last week (Figure 8B and 8C).

2.4 Ascorbic acid (AA)

The AA content of limes tended to decrease in all treatments after 4 weeks of storage except in the control treatment set. A significant increase was only observed in the control treatments (Table 12). Limed packed in PP and HPCH packaging from control treatment set showed fluctuated AA content during storage, however the AA content increased in all packaging in the last week (Figure 9A). The AA content of limes in the treatment set of *Penicillium* sp. inoculation then dipped in hot water and packed in PP, HPCH and MPPCH tended to decrease during storage until the last week (Figure 9B). Limes dipped in hot water treatment set and packed in PP, HPCH and MPPCH also showed fluctuated patterns of AA content during storage until the last week (Figure 9C).

2.5 Total Soluble Solids (TSS)

Total Soluble Solids (TSS) in limes of all treatments fluctuated since the first week until the last week except some treatments. Hot water treatments could significantly lower TSS than control treatments in the second week and then hot water treatments increased TSS until the last week (Table 13). The control treatment set had a tendency to decrease TSS of limes in all packaging with no significant difference (Figure 10A). Limes from *Penicillium* sp. inoculation then dipped in hot water and from only hot water treatment sets showed the same TSS pattern in all packaging in which the amount of TSS decreased in the first two week then increased until the last week with no significant difference (Figure 10B and 10C).

2.6 Measurement of respiration rate

The respiration rate of limes decreased in all treatments except the control treatment packed in MPPCH in the first two weeks. Then the respiration rate gradually increased until the last week for the treatments of limes treated with only hot water and the combination with *Penicillium* sp. (Table 14 and Figure 11). Slightly changes in respiration rate were observed in all treatments of the control set during storage

(Figure 11A). Limes treated with hot water and packed in MPPCH resulted in the lowest respiration rate and the control treatment packed in PP resulted in the lowest respiration rate (Table 14).

2.7 Antioxidant activities

2.7.1 Catalase activity (CAT)

After storage at 25 ºC for 4 week, almost all treatments of limes showed an increase in CAT activity from the first week until the third week and then the CAT activity decreased in the last week. However, the control treatment packed in MPPCH packaging had the highest CAT activity but there was no significant difference from the other treatments (Table 15 and Figure 12).

2.7.2 Ascorbate peroxidase activity (APX)

After four weeks of storage, limes in the control treatment packed in HPCH showed the highest APX activity which was significant difference from some treated limes treatments (Table 16). However, the pattern of APX activity of limes in all treatments tended to decrease in the first week then increased in the second and third weeks and decreased in the last week (Figure 13).

2.8 Percentage of disease incidence

The disease incidence of limes was found since the first week and increased throught out storage times. Limes inoculated with *Penicillium* sp. then dipped in hot water and packed in PP had the highest percentage of disease incidence while the control packed in HPCH did not showed disease incidence at the last week of storage (Table 17).

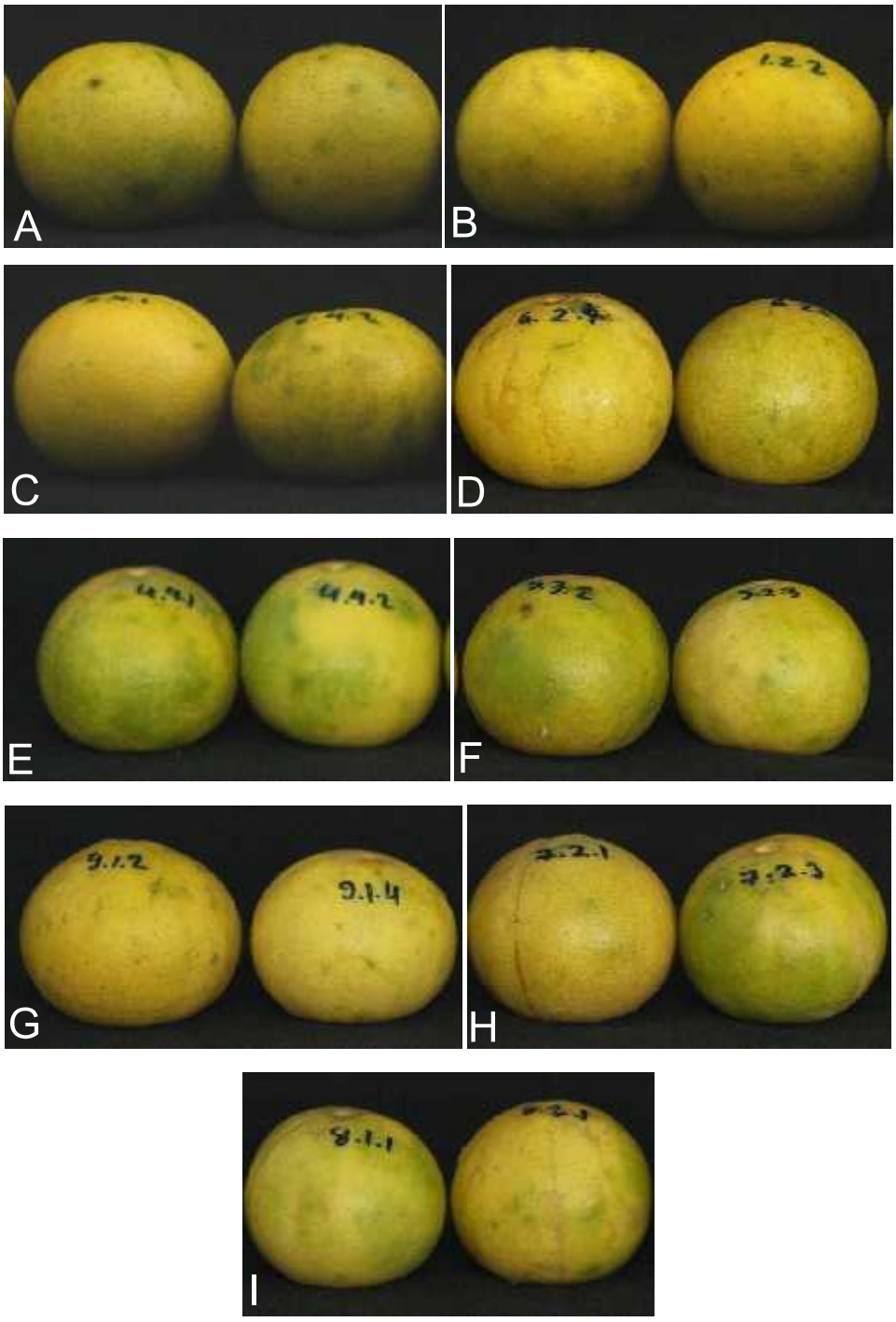

Figure 4. External appearance of lime after hot water treatments of limes after hot water treatments and packed in modified polypropylene packaging then stored at 25 ºC for 4 weeks. A=control+PP, B=control+HPCH, C=control+MPPCH, D=Pen+HWT+PP, E=Pen+HWT+HPCH, F=Pen+HWT+MPPCH, G=HWT+PP, H=HWT+HPCH, I=HWT+MPPCH.

Table 8. Percentage of weight loss of limes after hot water treatments and packed in modified polypropylene packaging then stored at 25 ºC for 4 weeks.

Treatment	Percentages of weight loss			
	w.1	w.2	w.3	w.4
control+PP	3.33±0.10^{b}	3.59±0.10^{b}	4.02±0.10^{b}	4.34±0.10^{ab}
control+HPCH	2.74±0.06^{a}	3.24±0.09^{ab}	3.60±0.09^{ab}	4.01±0.11^{ab}
control+MPPCH	2.95±0.10^{ab}	3.30±0.10^{ab}	3.62±0.11^{ab}	3.97±0.12^{ab}
Pen+HWT+PP	2.96±0.12^{ab}	3.12±0.13^{ab}	3.24±0.11^{a}	3.75±0.18^{a}
Pen+HWT+HPCH	2.83±0.12^{a}	3.03±0.12^{a}	3.37±0.14^{a}	3.99±0.20^{ab}
Pen+HWT+MPPCH	3.34±0.15^{b}	3.61± 0.13^{b}	3.96±0.14^{b}	4.61±0.20^{b}
HWT+PP	4.85±0.18^{d}	5.00±0.18^{c}	5.29±0.17^{c}	5.58±0.22^{c}
HWT+HPCH	4.44±0.12^{c}	4.71±0.14^{c}	5.06±0.15^{c}	5.48±0.22^{c}
HWT+MPPCH	4.32±0.21^{c}	4.89±0.31^{c}	5.04±0.35^{c}	5.53±0.50^{c}

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$. HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE.

Table 9. L value of limes after hot water treatments and packed in modified polypropylene packaging then stored at 25 ºC for 4 weeks.

Treatment	L value				
	w.0	w.1	w.2	w.3	w.4
control+PP	48.39±0.66^{b}	56.07±1.18^{b}	66.99±0.89^{d}	69.85±0.36^{d}	64.35±0.25^{d}
control+HPCH	47.24±0.61^{ab}	56.50±1.16^{b}	65.50±0.24^{d}	69.93±0.53^{d}	72.07±0.17^{e}
control+MPPCH	48.33±0.67^{b}	58.99±1.04^{c}	67.85±0.94^{d}	70.01±0.45^{d}	64.81±0.30^{d}
Pen+HWT+PP	47.22±0.37^{ab}	51.12±0.51^{a}	56.85±1.08^{c}	61.16±1.44^{c}	62.50±1.27^{cd}
Pen+HWT+HPCH	46.65±0.44^{ab}	49.44±0.82^{a}	51.37±0.91^{a}	54.72±1.17^{a}	56.85±1.36^{a}
Pen+HWT+MPPCH	46.63±0.61^{ab}	50.46±0.74^{a}	52.85±0.70^{ab}	57.34±1.29^{ab}	60.00±1.18^{bc}
HWT+PP	46.03±0.47^{a}	49.23±0.62^{a}	54.07±1.00^{ab}	60.611.22±^{c}	64.43±0.95^{d}
HWT+HPCH	47.19±0.51^{ab}	50.20±0.70^{a}	53.22±1.02^{ab}	56.44±1.04^{ab}	59.48±1.11^{ab}
HWT+MPPCH	47.14±0.49^{ab}	51.27±0.63^{a}	55.33±1.02^{bc}	58.45±1.29^{ab}	61.31±1.35^{bc}

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$. HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE.

Table 10. Hue value of limes after hot water treatments and packed in modified polypropylene packaging then stored at 25 ºC for 4 weeks.

	Hue value				
Treatment	w.0	w.1	w.2	w.3	w.4
control+PP	108.84±0.38^{c}	102.78±0.89^{c}	94.76±0.89^{bc}	89.60±0.41^{ab}	87.02±0.34^{ab}
control+HPCH	109.16±0.28^{c}	102.55±0.99^{c}	95.53±0.99^{bc}	90.08±0.59^{ab}	87.16±0.32^{ab}
control+MPPCH	108.61±0.31^{c}	100.64±2.33^{b}	93.73±2.33^{ab}	89.58±0.55^{ab}	86.87±2.75^{ab}
Pen+HWT+PP	104.28±0.38^{a}	97.71±4.90^{a}	92.28±4.90^{a}	88.51±1.43^{a}	85.44±1.47^{a}
Pen+HWT+HPCH	105.01±0.37^{ab}	99.40±0.58^{ab}	97.22±0.58^{c}	95.90±1.10^{d}	94.18±1.24^{d}
Pen+HWT+MPPCH	105.31±0.42^{ab}	99.42±0.50^{ab}	97.16±0.50^{c}	94.49±1.07^{cd}	91.89±1.11^{cd}
HWT+PP	105.49±0.36^{b}	99.73±0.50^{ab}	95.05±0.50^{bc}	90.87±1.04^{ab}	85.59±0.77^{a}
HWT+HPCH	104.50±0.43^{ab}	98.44±0.57^{a}	95.59±0.57^{bc}	94.19±1.03^{cd}	91.11±1.15^{c}
HWT+MPPCH	104.56±0.37^{ab}	99.12±1.24^{ab}	94.41±1.24^{ab}	92.53±1.16^{bc}	89.68±1.34^{bc}

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at P $\leq$ 0.05. HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE.

Table 11. Total phenolic content of limes after hot water treatments and packed in modified polypropylene packaging then stored at 25 ºC for 4 weeks.

Treatment	Total phenolic content (µg/g FW)				
	w.0	w.1	w.2	w.3	w.4
control+PP	6293.20±0.00 [a]	7465.94±458.59 [b]	4145.22±298.13 [a]	8471.71±653.34 [b]	6098.54±771.63 [a]
control+HPCH	6293.20±0.00 [a]	7223.85±607.68 [b]	5287.91±443.72 [b]	7553.80±384.43 [b]	5234.77±323.77 [a]
control+MPPCH	6293.20±0.00 [a]	7549.37±389.19 [b]	3971.82±184.89 [a]	8393.44±128.43 [b]	6965.02±397.98 [a]
Pen+HWT+PP	6293.20±0.00 [a]	5829.27±482.08 [ab]	4328.02± 391.88 [ab]	3807.37±545.74 [a]	7263.64±215.65 [a]
Pen+HWT+HPCH	6293.20±0.00 [a]	4605.38±85.86 [a]	4017.43±350.78 [a]	3746.99±706.90 [a]	6271.81±20.20 [a]
Pen+HWT+MPPCH	6293.20±0.00 [a]	6007.01±456.71 [ab]	3185.41±228.88 [a]	3066.91±556.82 [a]	6858.11±171.81 [a]
HWT+PP	6293.20±0.00 [a]	5946.09±990.96 [ab]	4034.32±556.83 [a]	3568.24±150.69 [a]	4925.38±133.45 [a]
HWT+HPCH	6293.20±0.00 [a]	4364.97±410.70 [a]	3597.45±415.49 [a]	2144.97±270.82 [a]	5128.98±112.73 [a]
HWT+MPPCH	6293.20±0.00 [a]	5098.55±221.26 [a]	3931.51±272.27 [a]	3871.71±468.38 [a]	7919.87±264.26 [a]

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$.

HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE.

Table 12. Ascorbic acid concentration of limes after hot water treatments and packed in modified polypropylene packaging then stored at 25 ºC for 4 weeks.

Treatment	Ascorbic acid concentration (mg/g FW)				
	w.0	w.1	w.2	w.3	w.4
control+PP	1.56±0.00 ^{a}	1.38±0.12 ^{ab}	1.81±0.08 ^{c}	1.69±0.09 ^{cd}	1.96±0.07 ^{c}
control+HPCH	1.56±0.00 ^{a}	1.77± 0.10 ^{b}	1.49±0.13 ^{bc}	1.72±0.13 ^{d}	1.97±0.28 ^{c}
control+MPPCH	1.56±0.00 ^{a}	1.44±0.20 ^{ab}	1.30±0.25 ^{abc}	1.25±0.15 ^{bcd}	1.95±0.24 ^{c}
Pen+HWT+PP	1.56±0.00 ^{a}	1.67±0.26 ^{ab}	1.09±0.29 ^{ab}	1.03±0.09 ^{ab}	0.70±0.07 ^{a}
Pen+HWT+HPCH	1.56±0.00 ^{a}	1.61±0.24 ^{ab}	0.74±0.26 ^{a}	0.97±0.24 ^{ab}	0.83±0.13 ^{ab}
Pen+HWT+MPPCH	1.56±0.00 ^{a}	1.17±0.21 ^{ab}	0.93±0.02 ^{ab}	0.74±0.28 ^{a}	0.79±0.03 ^{ab}
HWT+PP	1.56±0.00 ^{a}	1.03±0.07 ^{a}	1.17±0.01 ^{ab}	0.69±0.21 ^{a}	1.30±0.36 ^{b}
HWT+HPCH	1.56±0.00 ^{a}	1.42±0.20 ^{ab}	0.91±0.03 ^{a}	1.33±0.12 ^{bcd}	1.02±0.08 ^{ab}
HWT+MPPCH	1.56±0.00 ^{a}	1.27±0.35 ^{ab}	1.29±0.19 ^{abc}	1.22±0.05 ^{bc}	1.16±0.13 ^{ab}

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$. HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE.

Table 13. Total Soluble Solids of limes after hot water treatments and packed in modified polypropylene packaging then stored at 25 ºC for 4 weeks.

Treatment	Total Soluble Solids (°Brix)				
	w.0	w.1	w.2	w.3	w.4
control+PP	9.51±0.00 ^{a}	8.88±0.31 ^{cd}	9.13±0.13 ^{bc}	8.67±0.17 ^{a}	8.73±0.29 ^{ab}
control+HPCH	9.51±0.00 ^{a}	9.75±0.25 ^{e}	8.88±0.31 ^{b}	8.63±0.43 ^{a}	8.28±0.49 ^{a}
control+MPPCH	9.51±0.00 ^{a}	9.50±0.20 ^{de}	9.38±0.13 ^{c}	8.50±0.29 ^{a}	8.38±0.24 ^{ab}
Pen+HWT+PP	9.51±0.00 ^{a}	8.75±0.39 ^{bcd}	8.15±0.10 ^{a}	8.35±0.10 ^{a}	9.20±0.29 ^{ab}
Pen+HWT+HPCH	9.51±0.00 ^{a}	8.25±0.32 ^{abc}	7.90±0.06 ^{a}	8.20±0.08 ^{a}	9.07±0.35 ^{ab}
Pen+HWT+MPPCH	9.51±0.00 ^{a}	8.30±0.24 ^{abc}	7.90±0.10 ^{a}	8.30±0.10 ^{a}	9.45±0.61 ^{ab}
HWT+PP	9.51±0.00 ^{a}	7.75±0.15 ^{a}	8.00±0.00 ^{a}	8.60±0.40 ^{a}	9.00±0.40 ^{ab}
HWT+HPCH	9.51±0.00 ^{a}	7.85± 0.17 ^{a}	8.10±0.17 ^{a}	8.20±0.34 ^{a}	8.93±0.07 ^{ab}
HWT+MPPCH	9.51±0.00 ^{a}	8.00±0.27 ^{ab}	8.25±0.19 ^{a}	8.80±0.24 ^{a}	9.73±0.37 ^{b}

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at P $\leq$ 0.05. HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE.

Table 14. Respiration rate of limes after hot water treatments and packed in modified polypropylene packaging then stored at 25 ºC for 4 weeks.

Treatment	Respiration rate (mg CO_2/kg.hr)				
	w.0	w.1	w.2	w.3	w.4
control+PP	15.72±0.00 [a]	8.21±0.71 [ab]	12.33±0.57 [bc]	9.67±0.89 [a]	8.53±0.68 [a]
control+HPCH	15.72±0.00 [a]	10.60±0.82 [ab]	12.89±0.26 [c]	10.02±0.18 [a]	10.34±1.37 [a]
control+MPPCH	15.72±0.00 [a]	25.39±4.42 [c]	11.21±0.56 [b]	11.04±1.30 [a]	10.89±0.95 [a]
Pen+HWT+PP	15.72±0.00 [a]	7.21±0.87 [ab]	4.48±0.70 [a]	33.21±2.11 [bc]	46.95±5.47 [bc]
Pen+HWT+HPCH	15.72±0.00 [a]	5.25±0.18 [a]	5.78±0.49 [a]	23.71±2.95 [bc]	33.53±7.07 [b]
Pen+HWT+MPPCH	15.72±0.00 [a]	5.38±0.59 [a]	4.97±0.52 [a]	21.20±2.26 [ab]	40.38±3.20 [b]
HWT+PP	15.72±0.00 [a]	11.75±2.47 [b]	5.92±0.24 [a]	30.26±6.67 [bc]	56.18±6.52 [cd]
HWT+HPCH	15.72±0.00 [a]	5.87±0.37 [a]	4.79±0.61 [a]	34.82±6.26 [c]	18.03±2.70 [a]
HWT+MPPCH	15.72±0.00 [a]	7.35±0.75 [ab]	5.17±0.29 [a]	28.85±1.97 [bc]	63.16±8.94 [d]

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$. HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE.

Table 15. Catalase activity of limes after hot water treatments and packed in modified polypropylene packaging then stored at 25 ºC for 4 weeks.

Treatment	Catalase activity (units/mg protein)				
	w.0	w.1	w.2	w.3	w.4
control+PP	303.65±0.00 [a]	279.43±63.05 [ab]	445.74±135.57 [b]	537.58± 41.48 [a]	214.27± 47.31 [a]
control+HPCH	303.65±0.00 [a]	179.41±16.14 [a]	96.33±24.19 [a]	510.44±28.27 [a]	356.12±23.07 [a]
control+MPPCH	303.65±0.00 [a]	262.70±30.03 [ab]	324.70± 19.63 [ab]	751.38± 36.61 [a]	204.31±34.68 [a]
Pen+HWT+PP	303.65±0.00 [a]	328.96±53.62 [b]	541.96±27.82 [b]	500.43± 45.77 [a]	205.69±50.40 [a]
Pen+HWT+HPCH	303.65±0.00 [a]	288.64±27.06 [ab]	427.32±159.58 [b]	524.20±71.60 [a]	289.79±55.71 [a]
Pen+HWT+MPPCH	303.65±0.00 [a]	289.44±22.99 [ab]	454.19±38.83 [b]	544.08± 66.10 [a]	219.80±37.69 [a]
HWT+PP	303.65±0.00 [a]	314.26±27.95 [b]	545.99±47.73 [b]	524.80±164.85 [a]	152.95±17.06 [a]
HWT+HPCH	303.65±0.00 [a]	313.14±34.56 [ab]	513.75±19.82 [b]	590.10± 130.95 [a]	284.90±43.40 [a]
HWT+MPPCH	303.65±0.00 [a]	286.66±39.17 [ab]	476.82±149.79 [b]	592.08±74.30 [a]	197.96±44.76 [a]

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$.

HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE.

Table 16. Ascorbate peroxidase activity of limes after hot water treatments and packed in modified polypropylene packaging then stored at 25 ºC for 4 weeks.

Treatment	Ascorbate peroxidase activity (units/mg protein)				
	w.0	w.1	w.2	w.3	w.4
control+PP	3741.10±0.00 [a]	2542.58±89.68 [b]	2000.26±824.36 [a]	5153.27± 876.52 [ab]	2015.51± 51.01 [ab]
control+HPCH	3741.10±0.00 [a]	161.96±67.56 [a]	503.19±75.97 [a]	3572.34±762.16 [a]	3700.69±196.90 [b]
control+MPPCH	3741.10±0.00 [a]	974.06± 125.63 [ab]	2750.98± 403.72 [ab]	2315.55±482.46 [a]	468.26±331.83 [a]
Pen+HWT+PP	3741.10±0.00 [a]	2999.41±451.39 [b]	3297.62± 142.36 [ab]	5857.96± 455.32 [ab]	410.71±170.61 [a]
Pen+HWT+HPCH	3741.10±0.00 [a]	1763.57± 430.09 [ab]	2489.28± 81.01 [ab]	5903.39± 302.31 [ab]	1749.96± 522.53 [ab]
Pen+HWT+MPPCH	3741.10±0.00 [a]	3102.00±591.69 [b]	3125.68± 262.89 [ab]	2202.18±382.18 [a]	580.08±115.08 [a]
HWT+PP	3741.10±0.00 [a]	1654.84± 749.48 [ab]	6327.53±360.73 [b]	8147.58±414.15 [b]	803.24±64.54 [a]
HWT+HPCH	3741.10±0.00 [a]	2837.37±294.34 [b]	535.15±45.20 [a]	2761.19±129.99 [a]	757.84±100.35 [a]
HWT+MPPCH	3741.10±0.00 [a]	2397.18± 674.61 [ab]	2876.94± 114.85 [ab]	4674.76± 108.39 [ab]	491.68±150.02 [a]

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$.

HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE.

Table 17. Percentage of disease incidence of limes after hot water treatments and packed in modified polypropylene packaging then stored at 25 ºC for 4 weeks.

Treatment	percentage of disease incidence			
	w.1	w.2	w.3	w.4
control+PP	0.00	8.33	0.00	16.67
control+HPCH	0.00	0.00	0.00	0.00
control+MPPCH	0.00	8.33	0.00	16.67
Pen+HWT+PP	4.17	8.33	29.17	50.00
Pen+HWT+HPCH	0.00	4.17	12.50	20.83
Pen+HWT+MPPCH	0.00	0.00	4.17	8.33
HWT+PP	0.00	0.00	4.17	33.33
HWT+HPCH	0.00	0.00	8.33	16.67
HWT+MPPCH	0.00	0.00	8.33	29.17

HWT = hot water treatment; Pen = *Penicillium* sp.

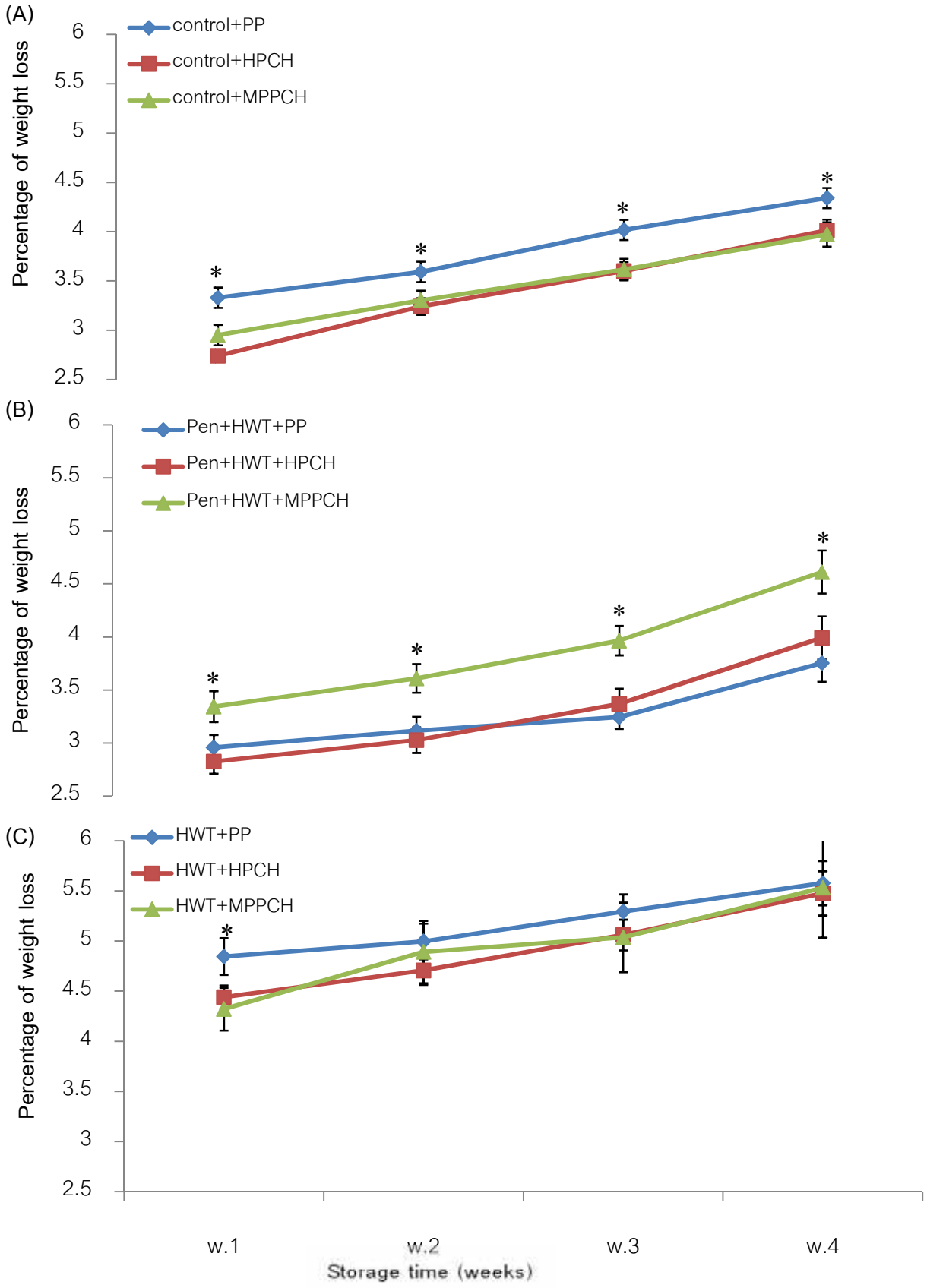

Figure 5. Percentage of weight loss of limes after hot water treatments and packed in modified polypropylene packaging then stored at 25 ºC for 4 weeks.

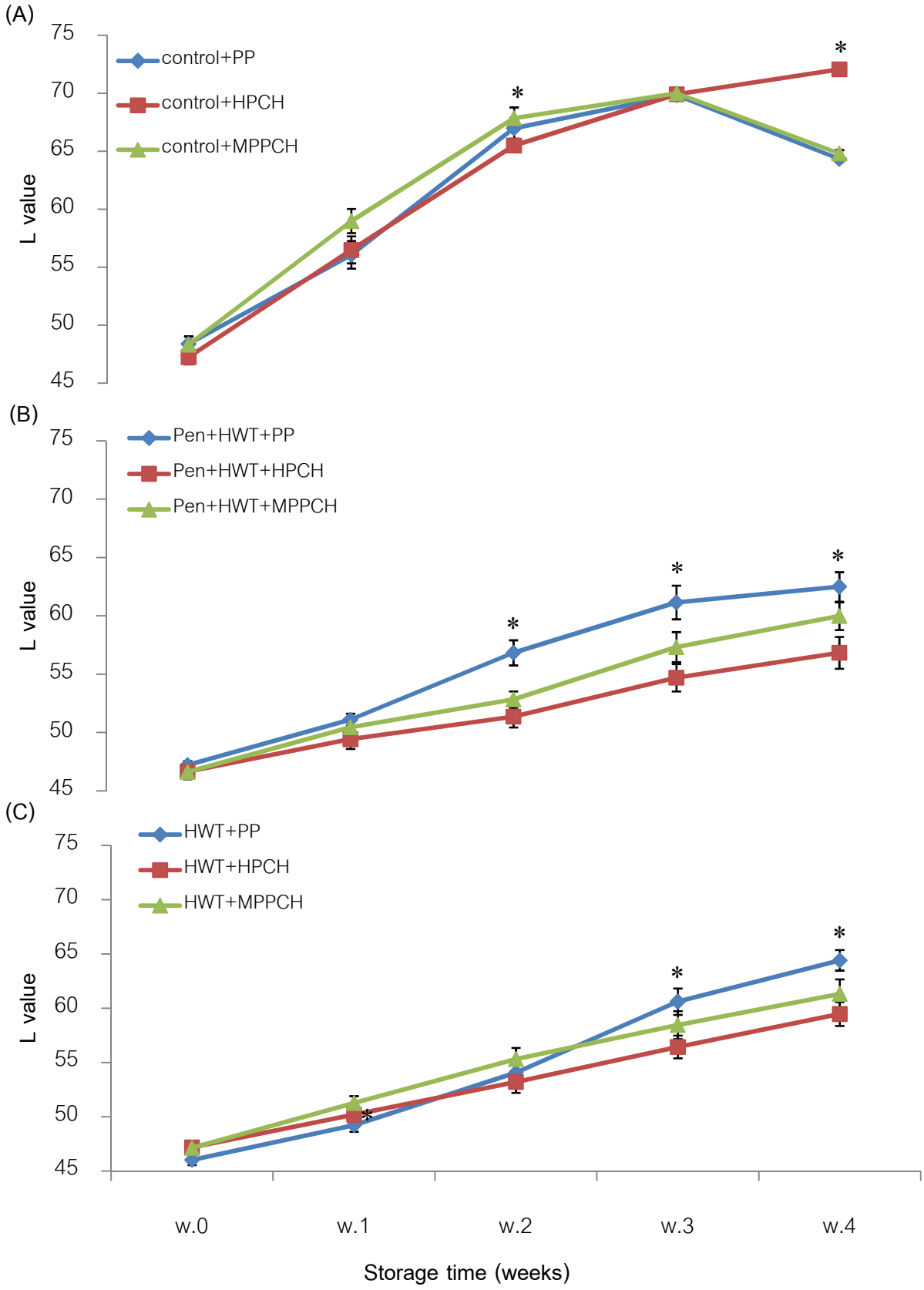

Figure 6. L value of limes after hot water treatments and packed in modified polypropylene packaging then stored at 25 ºC for 4 weeks.

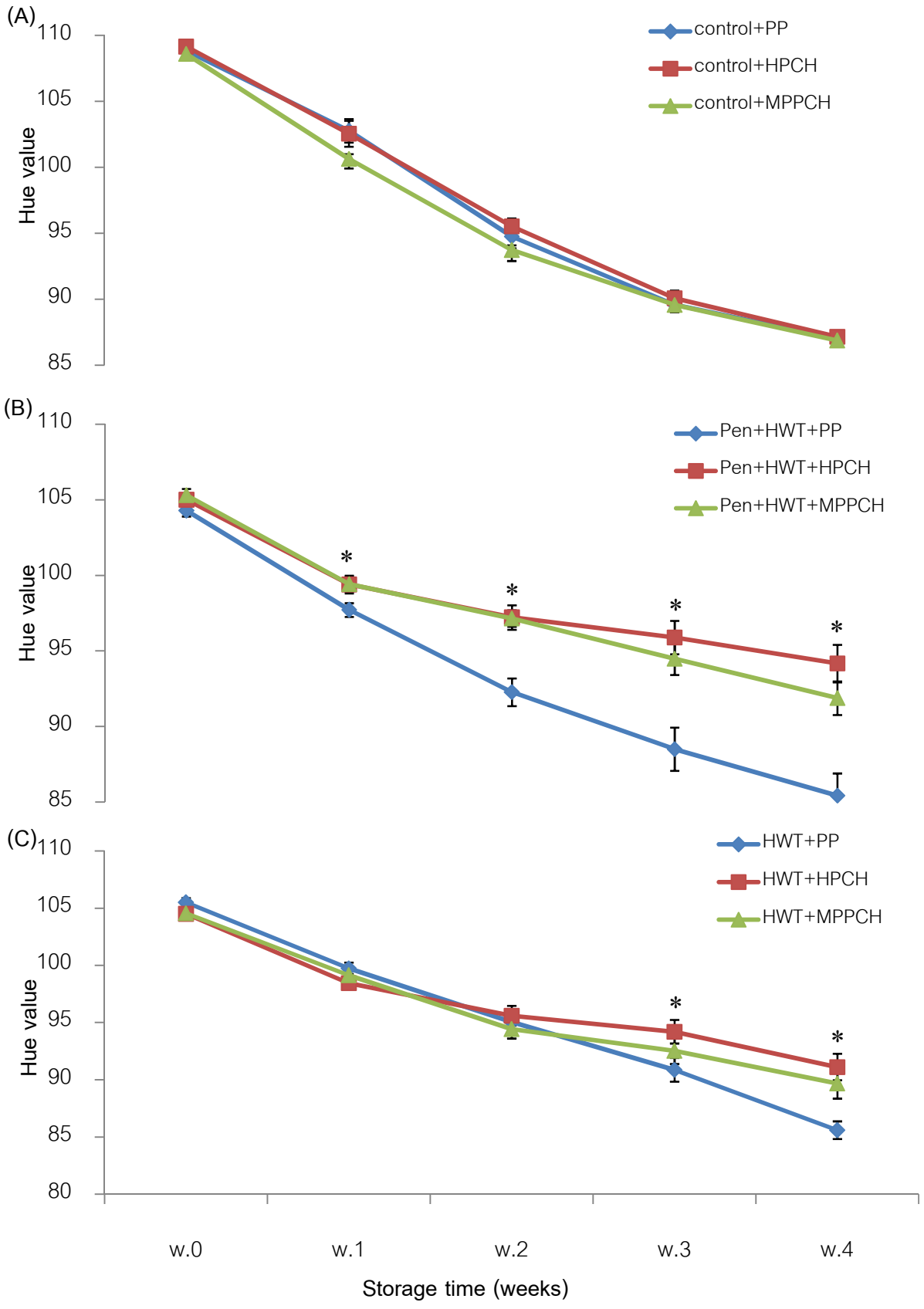

Figure 7. Hue value of limes after hot water treatments and packed in modified polypropylene packaging then stored at 25 ºC for 4 weeks.

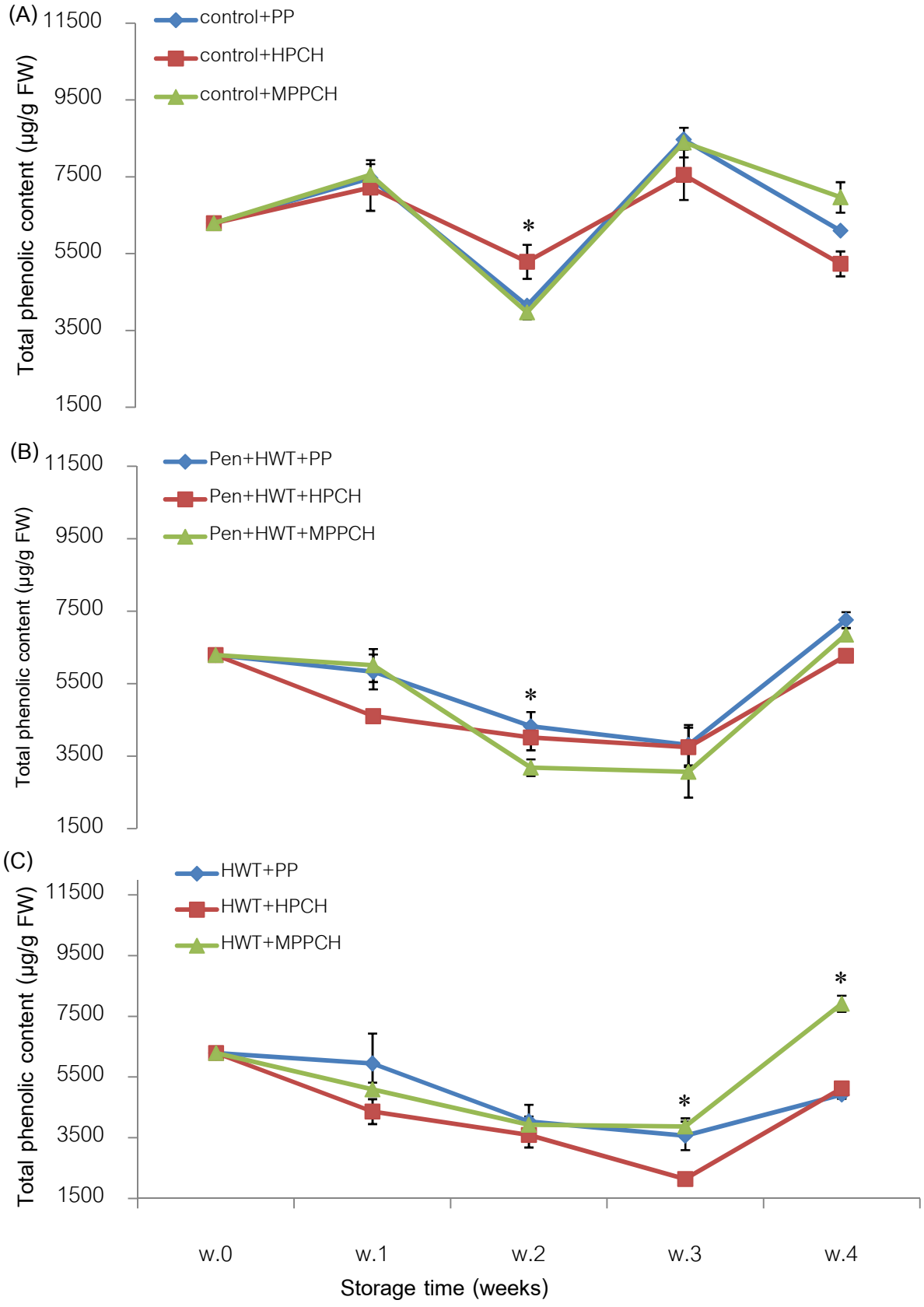

Figure 8. Total phenolic content of limes after hot water treatments and packed in modified polypropylene packaging then stored at 25 ºC for 4 weeks.

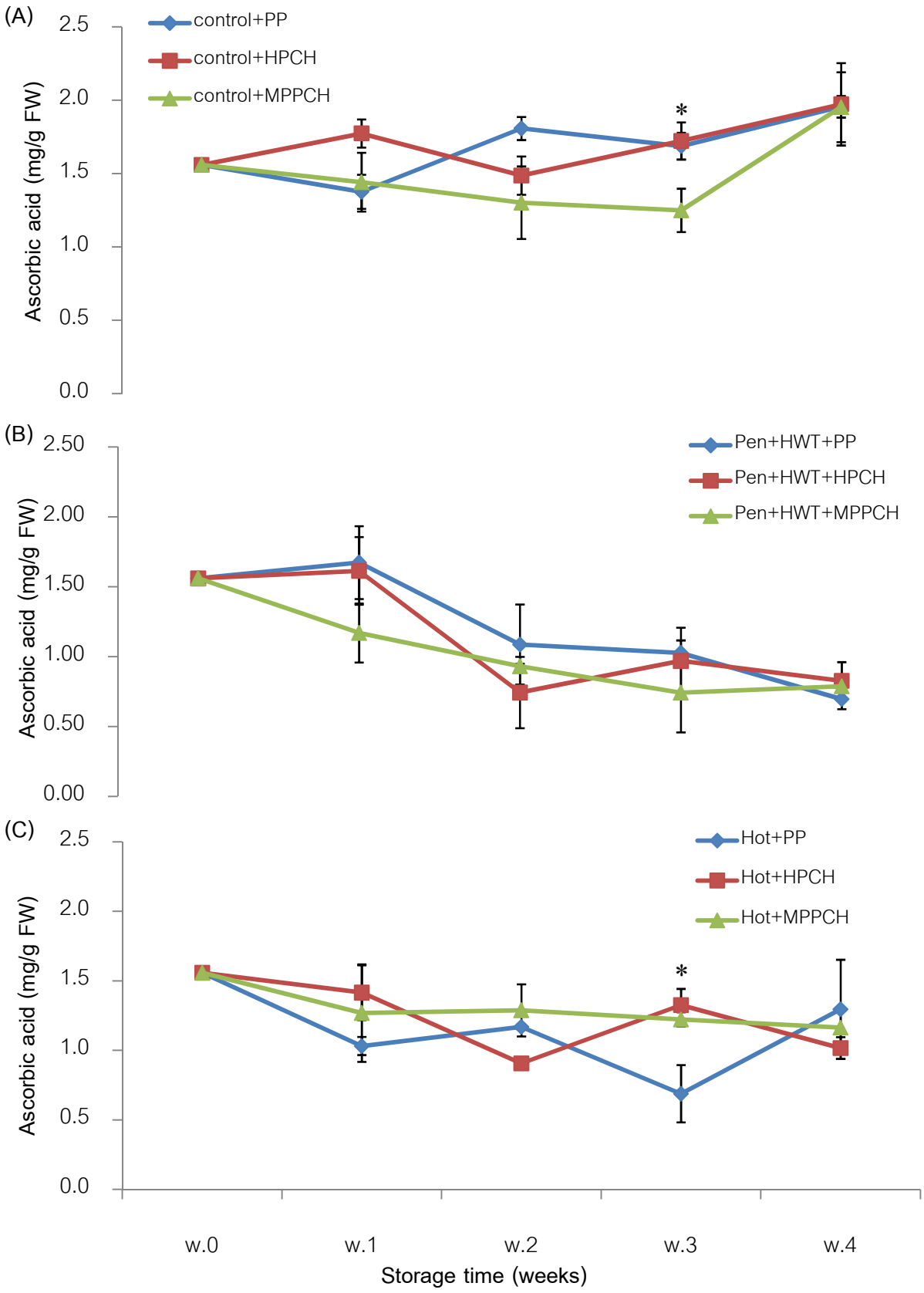

Figure 9. Ascorbic acid concentration of limes after hot water treatments and packed in modified polypropylene packaging then stored at 25 ºC for 4 weeks.

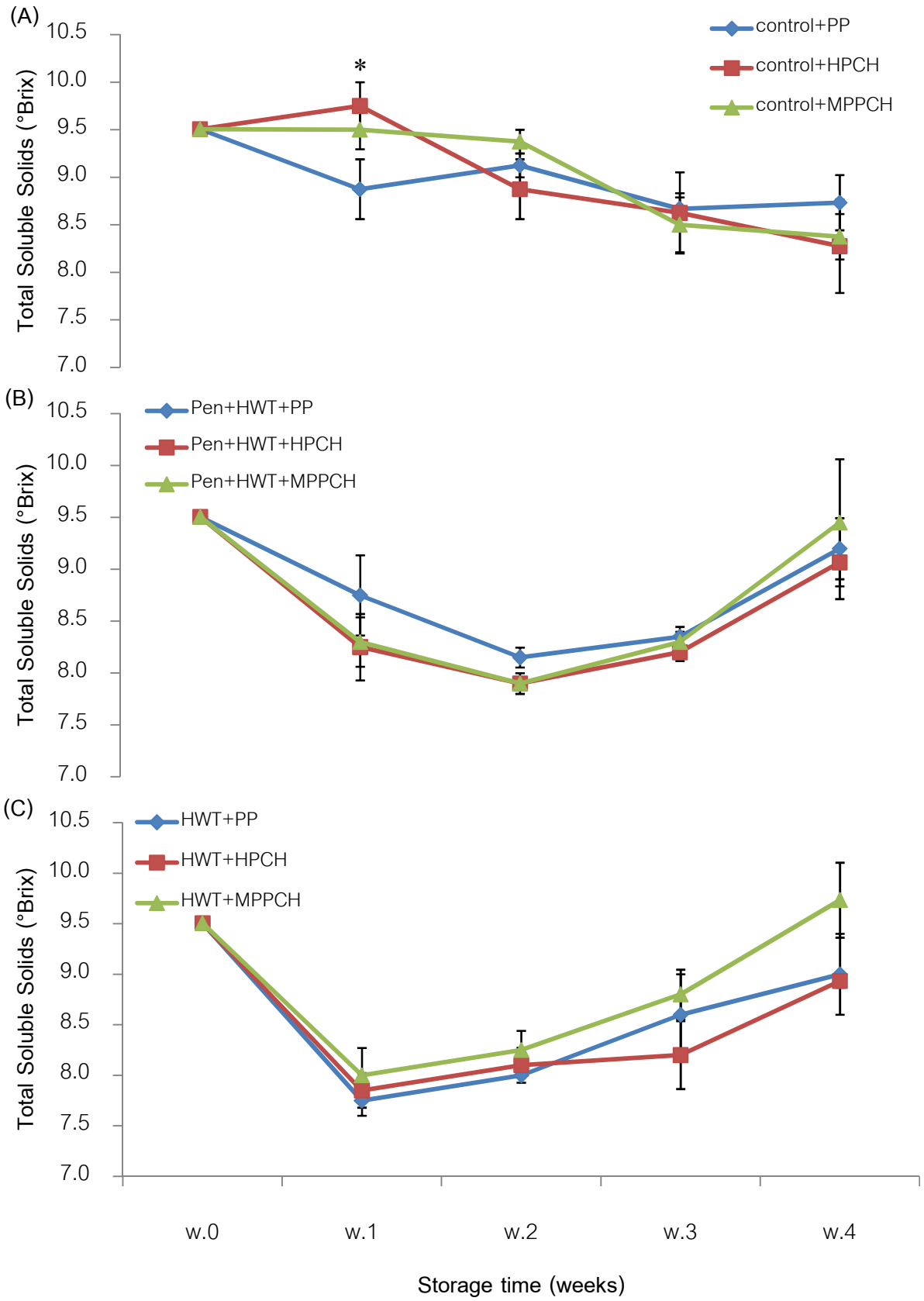

Figure 10. Total Soluble Solids of limes after hot water treatments and packed in modified polypropylene packaging then stored at 25 ºC for 4 weeks.

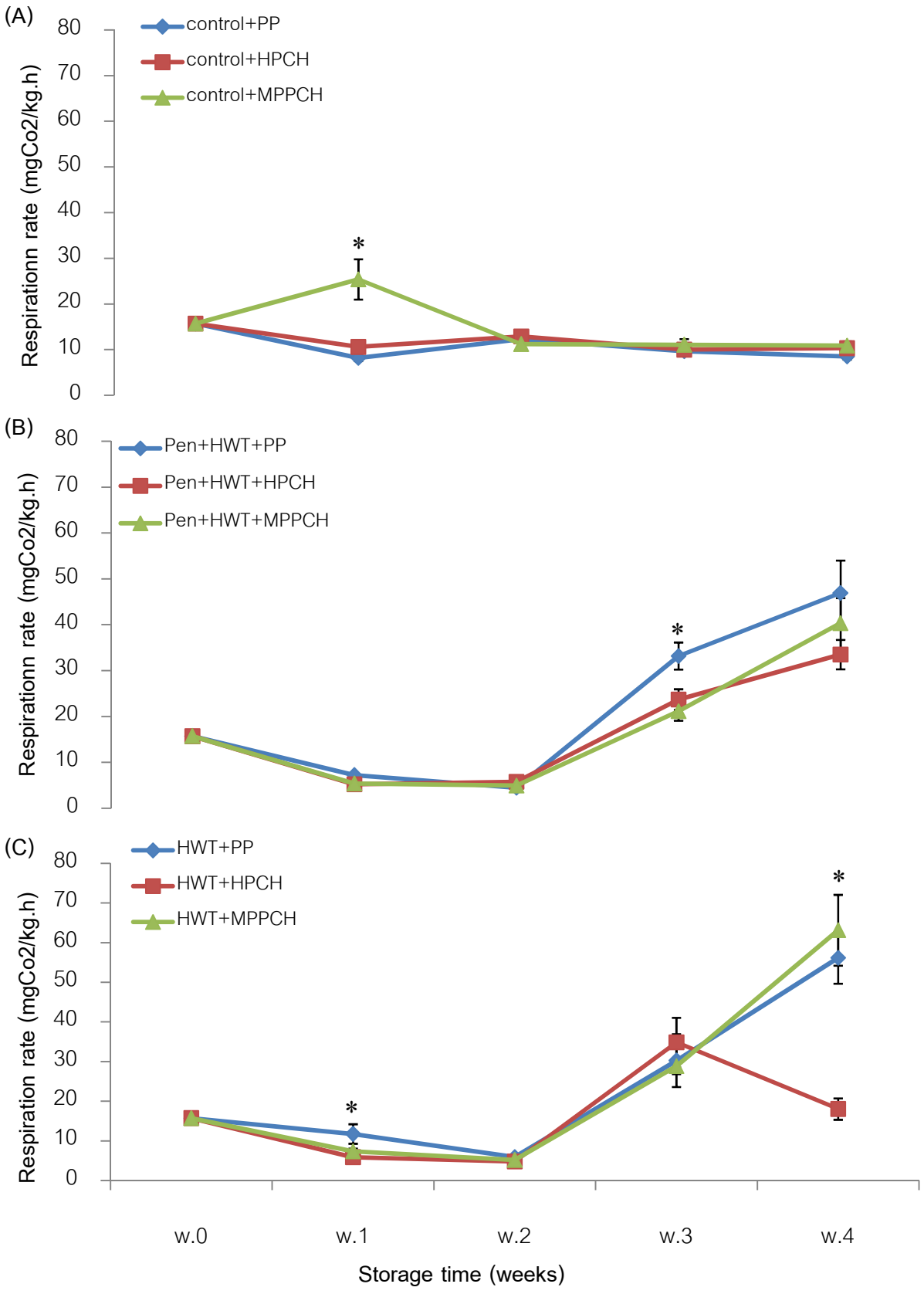

Figure 11. Respiration rate of limes after hot water treatments and packed in modified polypropylene packaging then stored at 25 ºC for 4 weeks.

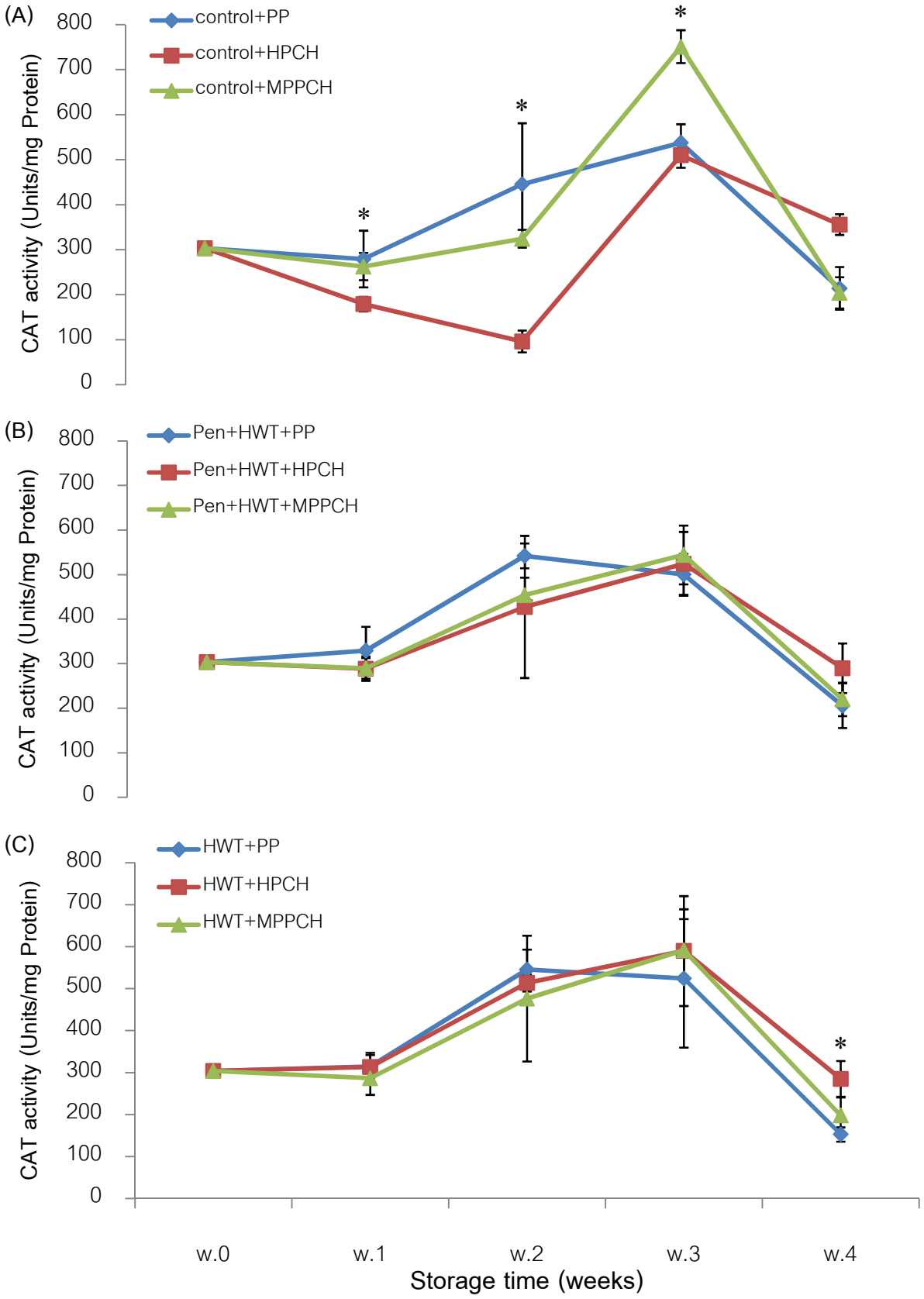

Figure 12. Catalase activity of limes after hot water treatments and packed in modified polypropylene packaging then stored at 25 ºC for 4 weeks.

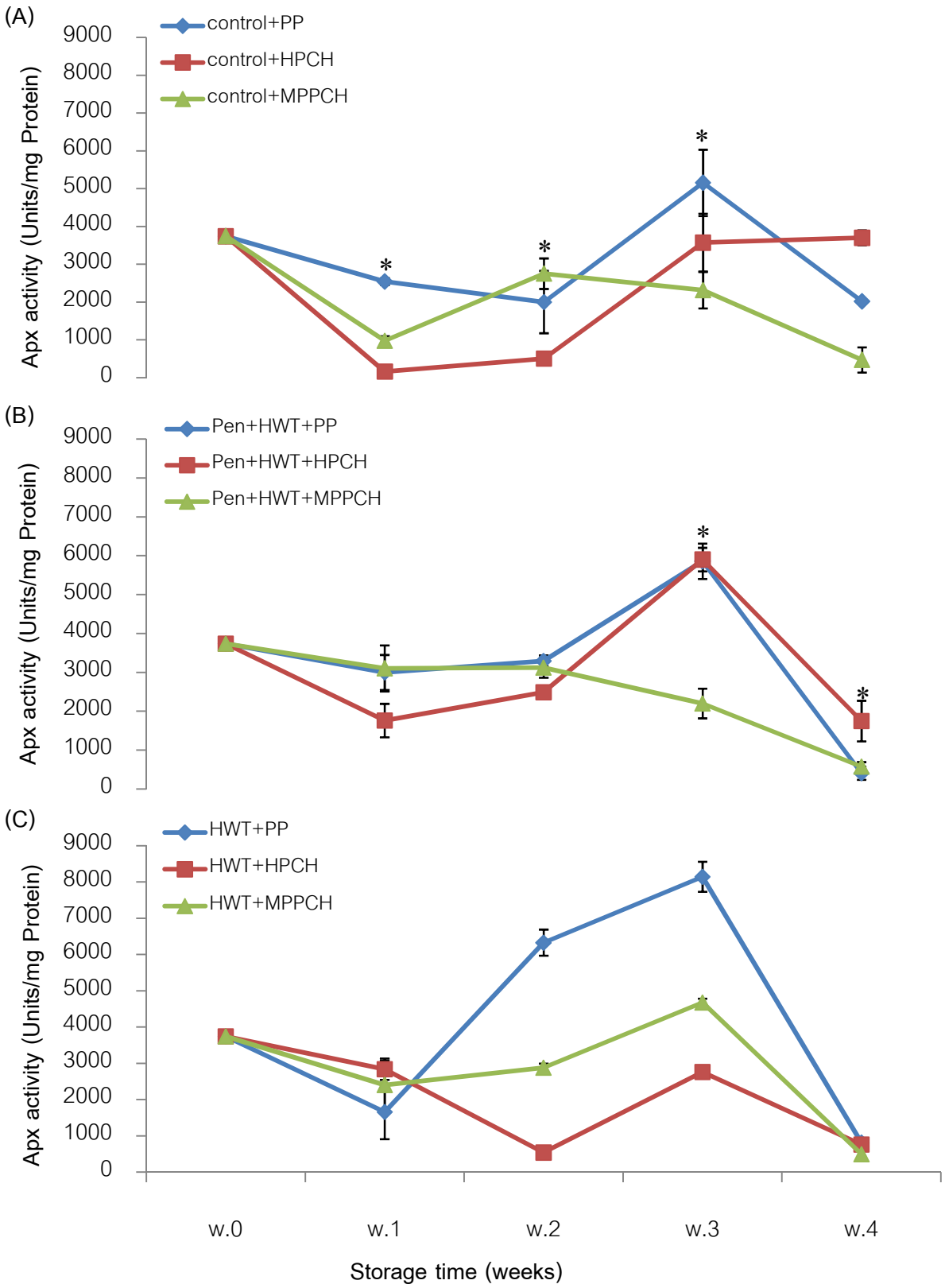

Figure 13. Ascorbate peroxidase activity of limes after hot water treatments and packed in modified polypropylene packaging then stored at 25 ºC for 4 weeks.

3. Effect of hot water and modified polypropylene packaging on postharvest qualities of limes during storage at 10 °C for 6 weeks

3.1 Percentages of weight loss

After storage at 10 ºC for 6 weeks, fruits in all treatments showed an increase in the percentage of weight loss. The lowest percentage of weight loss was found in limes inoculated with *Penicillium* sp. then dipped in hot water and packed in PP and hot water treated limes then packed in HPCH resulted in the highest percentage of weight loss (Table 18). Limes packed in PP from all treatments significantly showed lower percentage of weight loss than packed in other packaging except in hot water treatment set (Figure 15).

3.2 Peel color change

3.2.1 Lightness (L value)

In general, an increase in L value of peel may be an indicator of peel color change from green to yellower. In this study, the L value increased in all treatments during storage times. The lowest change in L value was found in limes dipped in hot water and packed in HPCH after storage for 6 weeks whereas control fruits packed in MPPCH resulted in the highest L value (Table 19 and Figure 14). However, considering the L value into sets of treatments, there was no significant difference of L value in all packaging from each treatment set (Figure 16A-C).

3.2.2 Hue value

Hue value of limes tended to decrease during storage in all treatments with no significant difference in the last week of storage (Table 20 and Figure 14). However, some significant difference in Hue value were showed in some treatments during storage times (Figure 17A-C)

3.3 Total phenolic content

Total phenolic content of limes in all treatments fluctuated during storage. In the last week of storage, a tendency of decrease in total phenolic content was showed in all treatments in which limes inoculated with *Penicillium* sp. then dipped in hot water and packed in MPPCH had the lowest total phenolic content and the control treatment packed in HPCH resulted in the highest total phenolic content (Table 21). The packaging did not affect the amount of total phenolic content in an exact pattern during storage (Figture 18A-C).

3.4 Ascorbic acid (AA)

The ascorbic acid concentration of limes in all treatments fluctuated during storage. However, there was a tendency of decrease in the first three weeks then increase until the last week (Figure 19A-C). The highest AA concentration was showed in the control treatment packed in HPCH and the lowest concentration was showed in hot water treated limes packed in HPCH with significant difference (Table 22).

3.5 Total Soluble Solids (TSS)

During storage, slightly chances of TSS in limes from all treatments were observed. However, limes dipped in hot water and packed in HPCH showed the highest TSS which was significant difference from the lowest TSS of limes treated with *Penicillium* sp. then dipped in hot water and packed in PP at the last week of storage (Table 23). No significant difference in TSS were observed among all sets of packaging in all treatments except in the fifth week storage (Figure 20A-C)

3.6 Measurement of respiration rate

In the first week of storage, the respiration rate of limes decreased in all treatments then there was a tendency to increase during storage (Table 24 and Figure 21A-C). After storage, significant difference in respiration rate were found in limes inoculated with *Penicillium* sp. then dipped in hot water and packed in PP and limes in control treatment packed in HPCH (Table 24).

3.7 Antioxidant activities

3.7.1 Catalase activity (CAT)

CAT activity of limes sharply decreased in the first week of storage then the pattern of changes in CAT activity fluctuated over the storage times (Table 25 and Figure 22A-C). The increase in CAT activity was found in the control treatment set in the third week and in hot water treatment set in the fourth week while CAT activity of treated limes with *Penicillium* sp. then dipped in hot water set tended to stable during storage (Figure 22A-C). After storage, significant difference in CAT activity were found in limes inoculated with *Penicillium* sp. then dipped in hot water and packed in MPPCH and in treated limes with hot water then packed in PP (Table 25).

3.7.2 Ascorbate peroxidase activity (APX)

The APX activity of limes in all treatments was decreased at the beginning of the assay and then fluctuation of the activity was found until the last week of storage. However, high APX activity was observed in limes packed in HPCH from all treatment sets in the second and third weeks of storage (Figure 23A-C). After storage, significant difference in APX activity were found in limes inoculated with *Penicillium* sp. then dipped in hot water and packed in HPCH and the same treatment packed in PP (Table 26).

3.8 Percentage of disease incidence

Disease incidence of limes during storage at low temperature was less than storage at high temperatures in all treatments (Table 27). Low percentage of disease incidence was found since the third and the fourth week of storage in the PP packaging of hot water treated limes and the control treatment packed in HPCH packaging, respectively, while no disease incidence was observed in other treatments during storage.

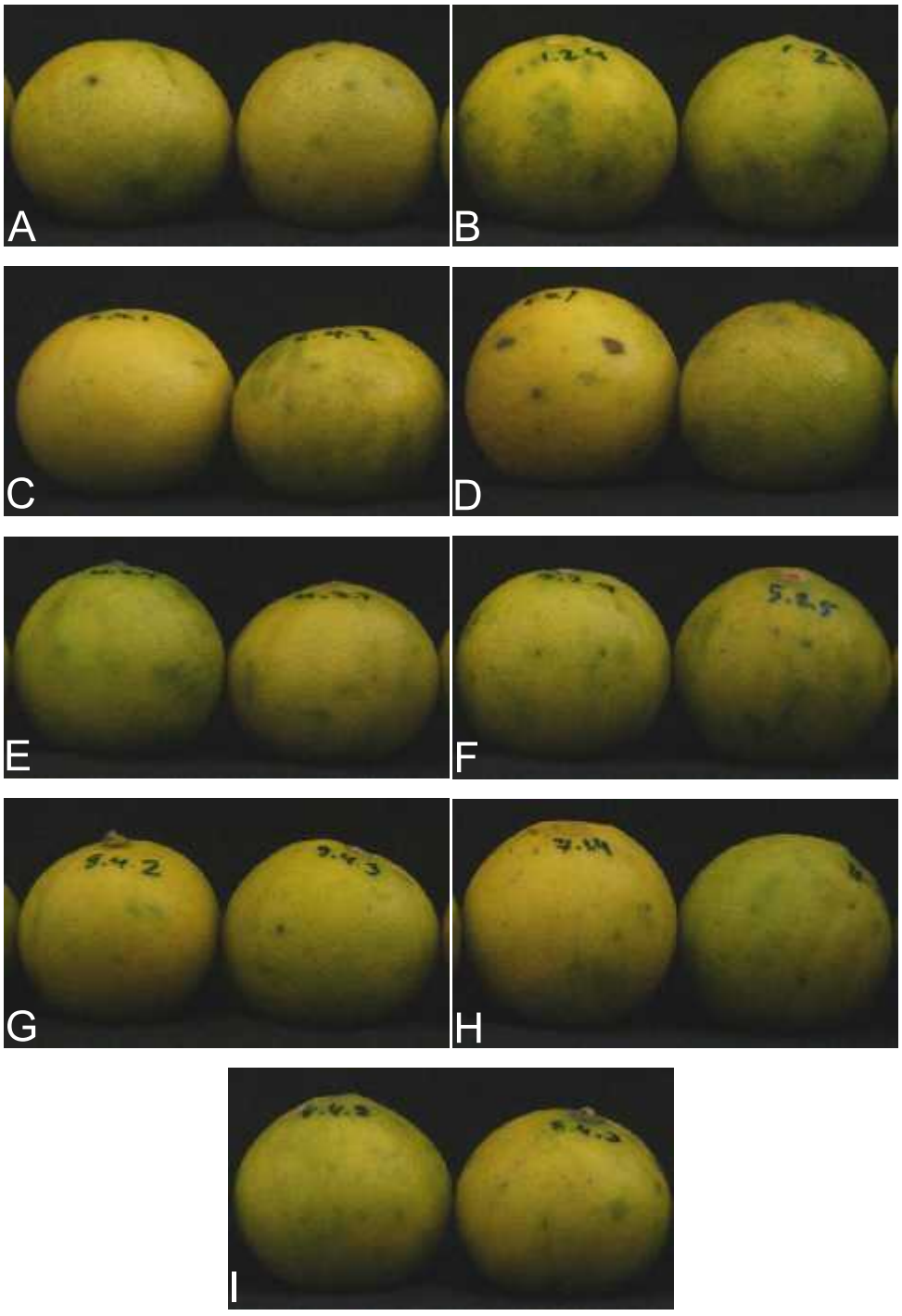

Figure 14. External appearance of lime after hot water treatments of limes after hot water treatments and packed in modified polypropylene packaging then stored at 10 °C for 6 weeks. A= control+PP, B= control+HPCH, C= control+MPPCH, D= Pen+HWT+PP, E= Pen+HWT+HPCH, F= Pen+HWT+MPPCH, G= HWT+PP, H= HWT+HPCH, I= HWT+MPPCH.

Table 18. Percentage of weight loss of limes after hot water treatments and packed in modified polypropylene packaging then stored at 10 ºC for 6 weeks.

Treatment	Percentages of weight loss					
	w.1	w.2	w.3	w.4	w.5	w.6
control+PP	0.58±0.04^{b}	0.82±0.06^{bc}	1.27±0.11^{ab}	1.55±0.15^{a}	1.81±0.15^{a}	2.08±0.17^{a}
control+HPCH	0.83±0.07^{c}	1.76±0.16^{e}	2.40±0.19^{d}	2.89±0.19^{b}	3.65±0.25^{b}	4.34±0.28^{b}
control+MPPCH	0.72±0.07^{c}	0.98±0.10^{bcd}	1.83±0.20^{c}	2.69±0.24^{b}	3.49±0.34^{b}	4.51±0.35^{b}
Pen+HWT+PP	0.55±0.04^{b}	0.74±0.04^{ab}	0.93±0.05^{a}	1.18±0.07^{a}	1.67±0.10^{a}	1.99±0.11^{a}
Pen+HWT+HPCH	0.58±0.10^{b}	1.27±0.12^{c}	1.73±0.16^{bc}	2.74±0.21^{b}	3.52±0.22^{b}	4.45±0.24^{b}
Pen+HWT+MPPCH	0.64±0.10^{bc}	1.10±0.14^{bc}	2.06±0.21^{cd}	2.64±0.21^{b}	3.45±0.20^{b}	4.24±0.25^{b}
HWT+PP	0.27±0.02^{a}	0.72±0.10^{ab}	1.00±0.11^{a}	1.51±0.24^{a}	1.76±0.27^{a}	2.01±0.27^{a}
HWT+HPCH	0.32±0.10^{a}	0.90±0.15^{bc}	1.77±0.26^{c}	2.89±0.32^{b}	3.98±0.45^{b}	4.89±0.49^{b}
HWT+MPPCH	0.23±0.02^{a}	0.47±0.05^{a}	0.92±0.11^{a}	1.28±0.12^{a}	1.85±0.13^{a}	2.12±0.13^{a}

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at P $\leq$ 0.05.

HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE.

Table 19. L value of limes after hot water treatments and packed in modified polypropylene packaging then stored at 10 ºC for 6 weeks.

Treatment	L value						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
control+PP	48.32±0.66^{ab}	52.18±0.67^{abc}	54.25±0.63^{a}	57.05± 0.67^{ab}	60.19± 0.64 ^{a}	62.65± 0.67^{ab}	64.50± 0.62^{ab}
control+HPCH	47.30±0.44 ^{ab}	51.37±0.47^{ab}	53.94±0.46^{a}	56.73± 0.59^{ab}	59.83± 0.57 ^{a}	63.07± 0.54^{ab}	64.60± 0.50^{ab}
control+MPPCH	48.94±0.77^{b}	53.11±0.86^{bc}	55.90± 0.85^{ab}	58.63±0.79^{b}	61.92± 0.69^{a}	64.42±0.60^{b}	65.58±0.52^{b}
Pen+HWT+PP	50.72±0.55^{c}	53.99±0.60^{c}	56.50±0.57^{b}	58.63± 0.65^{ab}	61.56± 0.67^{a}	63.31± 0.66^{ab}	64.54± 0.58^{ab}
Pen+HWT+HPCH	48.17±0.45^{ab}	51.69±0.58^{ab}	54.10±0.59^{a}	56.630.70± ^{ab}	59.85± 0.73^{a}	62.40± 0.69^{ab}	63.80± 0.64^{ab}
Pen+HWT+MPPCH	49.10±0.65^{b}	53.07±0.70^{bc}	55.61± 0.60^{ab}	58.06± 0.72^{ab}	61.00± 0.65^{a}	63.46± 0.67^{ab}	64.37± 0.61^{ab}
HWT+PP	47.63±0.46^{ab}	51.62±0.53^{ab}	54.69± 0.47^{ab}	56.94± 0.47^{ab}	60.88± 0.54^{a}	63.13± 0.46^{ab}	64.58± 0.46^{ab}
HWT+HPCH	46.97±0.60^{a}	50.79±0.60^{a}	53.95±0.61^{a}	56.39±0.69^{a}	59.86± 0.84^{a}	61.84±0.82^{a}	63.06±0.76^{a}
HWT+MPPCH	47.33±0.46^{ab}	51.85±0.59^{ab}	54.40±0.62^{a}	57.13± 0.65^{ab}	60.78± 0.67^{a}	63.25± 0.61^{ab}	65.08± 0.59^{ab}

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at P ≤ 0.05.

HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE.

Table 20. Hue value of limes after hot water treatments and packed in modified polypropylene packaging then stored at 10 ºC for 6 weeks.

Treatment	Hue value						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
control+PP	102.57±0.37^{abc}	101.27±0.41^{bc}	99.97±0.43^{bc}	97.88±0.48^{abc}	95.46±0.51^{ab}	92.86± 0.54^{ab}	90.62± 0.53^{a}
control+HPCH	103.25±0.27^{c}	101.24±0.32^{bc}	100.34±0.35^{bc}	98.17±0.40^{abc}	95.98±0.44^{b}	93.13± 0.43^{ab}	90.45±0.43^{a}
control+MPPCH	102.86±0.45^{bc}	100.52±0.57^{abc}	98.66±0.54^{a}	96.84±0.61^{a}	94.01±0.57^{a}	91.89±0.54^{a}	90.02± 0.51^{a}
Pen+HWT+PP	101.70±0.35^{a}	99.92±0.37^{a}	98.59±0.42^{a}	96.68±0.45^{a}	94.09±0.58^{a}	91.95±0.56^{a}	90.55±0.55^{a}
Pen+HWT+HPCH	103.35±0.27^{c}	101.71±0.37^{c}	100.52±0.44^{c}	98.39±0.53^{bc}	95.64±0.60^{ab}	93.74±0.55^{b}	91.40± 0.55^{a}
Pen+HWT+MPPCH	101.94±0.39^{ab}	100.06±0.41^{ab}	99.13±0.39^{ab}	97.01±0.48^{ab}	94.32±0.49^{ab}	92.48± 0.53^{ab}	90.50± 0.51^{a}
HWT+PP	102.60±0.30^{abc}	100.86±0.40^{abc}	99.64±0.38^{abc}	97.64±0.42^{abc}	94.67±0.47^{ab}	92.40± 0.47^{ab}	90.32±0.42^{a}
HWT+HPCH	103.46±0.31^{c}	101.75±0.36^{c}	100.46±0.40^{c}	98.520.50±^{bc}	95.23±0.60^{ab}	93.29± 0.70^{ab}	91.45±0.62^{a}
HWT+MPPCH	103.35±0.31^{c}	101.58±0.35^{c}	100.53±0.41^{c}	98.58±0.44^{c}	95.41±0.51^{ab}	92.83± 0.49^{ab}	90.39±0.46^{a}

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at P ≤ 0.05.

HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE.

Table 21. Total phenolic content of limes after hot water treatments and packed in modified polypropylene packaging then stored at 10 ºC for 6 weeks.

Treatment	Total phenolic content (mg/g FW)						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
control+PP	10.24±0.00 [a]	8.30±1.10 [ab]	11.39±1.42 [b]	7.05±1.21 [ab]	5.90±0.93 [a]	8.45±0.33 [abc]	7.72±0.84 [ab]
control+HPCH	10.24±0.00 [a]	8.70±0.58 [ab]	5.79±1.36 [a]	12.90±1.47 [d]	7.26±0.43 [abc]	6.18±0.22 [a]	10.11±0.91 [c]
control+MPPCH	10.24±0.00 [a]	8.01±1.25 [ab]	6.51±1.02 [ab]	9.09±0.87 [bc]	6.34±0.71 [ab]	9.46±0.29 [bc]	7.03±0.44 [ab]
Pen+HWT+PP	10.24±0.00 [a]	11.27±1.07 [b]	6.77±0.85 [ab]	10.24±0.95 [cd]	5.22±0.53 [a]	7.58±1.49 [abc]	8.82±0.88 [abc]
Pen+HWT+HPCH	10.24±0.00 [a]	7.64±0.14 [ab]	9.41±0.94 [ab]	6.92±0.33 [ab]	7.87±0.79 [abc]	8.29±1.10 [abc]	7.50±0.14 [ab]
Pen+HWT+MPPCH	10.24±0.00 [a]	8.25±0.62 [ab]	9.38±0.48 [ab]	10.91±1.55 [cd]	9.75±0.25 [c]	8.32±0.66 [abc]	6.89±0.21 [a]
HWT+PP	10.24±0.00 [a]	9.35±1.26 [ab]	9.97±2.01 [ab]	5.77±0.52 [a]	9.05±1.10 [bc]	10.43±1.44 [c]	9.15±0.44 [bc]
HWT+HPCH	10.24±0.00 [a]	7.11±0.52 [a]	9.15±0.39 [ab]	7.13±0.47 [ab]	7.47±0.87 [abc]	7.25±0.14 [ab]	8.27±0.36 [abc]
HWT+MPPCH	10.24±0.00 [a]	10.48±1.92 [ab]	9.92±2.48 [ab]	8.06±0.28 [abc]	8.02±1.27 [abc]	9.84±0.60 [bc]	8.04±1.01 [abc]

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$.

HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE.

Table 22. Ascorbic acid concentration of limes after hot water treatments and packed in modified polypropylene packaging then stored at 10 ºC for 6 weeks.

Treatment	Ascorbic acid concentration (mg/g FW)						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
control+PP	1.64±0.00 ^{a}	1.54± 0.17 ^{abc}	1.14±0.06 ^{a}	1.20±0.22 ^{b}	1.12±0.13 ^{a}	1.01±0.07 ^{a}	0.99±0.04 ^{ab}
control+HPCH	1.64±0.00 ^{a}	1.41± 0.14 ^{abc}	1.35±0.06 ^{a}	0.69±0.10 ^{a}	1.61±0.11 ^{b}	0.88±0.06 ^{a}	1.49±0.23 ^{c}
control+MPPCH	1.64±0.00 ^{a}	1.35± 0.06 ^{abc}	1.03±0.11 ^{a}	0.85±0.24 ^{ab}	1.04±0.22 ^{a}	1.06±0.08 ^{a}	0.82±0.17 ^{a}
Pen+HWT+PP	1.64±0.00 ^{a}	1.08±0.04 ^{a}	1.04±0.14 ^{a}	0.98± 0.15 ^{ab}	1.05±0.15 ^{a}	1.12±0.14 ^{a}	1.01± 0.09 ^{abc}
Pen+HWT+HPCH	1.64±0.00 ^{a}	1.62±0.32 ^{bc}	0.97±0.11 ^{a}	1.02±0.09 ^{ab}	0.92±0.11 ^{a}	1.04±0.05 ^{a}	1.39±0.07 ^{bc}
Pen+HWT+MPPCH	1.64±0.00 ^{a}	1.33±0.09 ^{ab}	1.07±0.17 ^{a}	0.88± 0.15 ^{ab}	1.64±0.14 ^{b}	0.95±0.11 ^{a}	1.06± 0.15 ^{abc}
HWT+PP	1.64±0.00 ^{a}	1.43± 0.14 ^{abc}	1.12±0.25 ^{a}	0.89±0.11 ^{ab}	0.87±0.07 ^{a}	1.18±0.09 ^{a}	1.34±0.25 ^{bc}
HWT+HPCH	1.64±0.00 ^{a}	1.66±0.13 ^{bc}	1.20±0.11 ^{a}	0.75±0.02 ^{ab}	1.22±0.06 ^{a}	1.26±0.19 ^{a}	0.84±0.04 ^{a}
HWT+MPPCH	1.64±0.00 ^{a}	1.82±0.06 ^{c}	1.87±0.22 ^{b}	0.90±0.08 ^{ab}	0.79±0.06 ^{a}	1.85±0.23 ^{b}	1.10± 0.09 ^{abc}

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$.

HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE.

Table 23. Total Soluble Solids of limes after hot water treatments and packed in modified polypropylene packaging then stored at 10 ºC for 6 weeks.

Treatment	Total Soluble Solids (°Brix)						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
control+PP	9.51±0.00 [a]	9.30±0.40 [a]	9.00±0.20 [a]	10.00±0.68 [a]	9.25±0.43 [a]	8.60± 0.36 [abc]	8.20± 0.64 [abc]
control+HPCH	9.51±0.00 [a]	9.10±0.45 [a]	9.50± 0.29 [ab]	8.63±0.31 [a]	9.63±0.63 [a]	9.30±0.34 [bc]	8.20± 0.32 [abc]
control+MPPCH	9.51±0.00 [a]	8.75± 0.30 [a]	9.38± 0.69 [ab]	9.25±0.14 [a]	9.00±0.00 [a]	8.25±0.26 [a]	7.85±0.32 [ab]
Pen+HWT+PP	9.51±0.00 [a]	9.30±0.39 [a]	9.63± 0.55 [ab]	9.25±0.32 [a]	9.50±0.20 [a]	9.15± 0.38 [abc]	7.70±0.17 [a]
Pen+HWT+HPCH	9.51±0.00 [a]	8.95±0.46 [a]	10.00± 0.54 [ab]	9.50±0.65 [a]	9.38±0.38 [a]	8.30±0.24 [ab]	8.35± 0.24 [abc]
Pen+HWT+MPPCH	9.51±0.00 [a]	9.60±0.65 [a]	10.63±0.55 [b]	10.00±0.54 [a]	10.25±0.95 [a]	8.15±0.15 [a]	8.00± 0.24 [abc]
HWT+PP	9.51±0.00 [a]	9.70±0.51 [a]	8.88±0.43 [a]	9.25±0.25 [a]	10.25±0.48 [a]	8.95± 0.13 [abc]	9.10±0.49 [bc]
HWT+HPCH	9.51±0.00 [a]	9.50±0.33 [a]	9.38± 0.24 [ab]	9.50±0.65 [a]	9.88±0.52 [a]	8.30±0.17 [ab]	9.30±0.60 [c]
HWT+MPPCH	9.51±0.00 [a]	9.65±0.33 [a]	9.50± 0.29 [ab]	9.38±0.38 [a]	9.13±0.52 [a]	9.50±0.53 [c]	9.10±0.45 [bc]

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at P ≤ 0.05.

HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE.

Table 24. Respiration rate of limes after hot water treatments and packed in modified polypropylene packaging then stored at 10 ºC for 6 weeks.

Tratment	Respiration rate (mg CO_2/kg.hr)						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
control+PP	8.55±0.00 [a]	4.55±0.58 [ab]	10.76±0.57 [d]	18.48±1.44 [cd]	17.58±1.73 [ab]	22.72±0.66 [b]	17.39±0.78 [b]
control+HPCH	8.55±0.00 [a]	3.26±0.04 [a]	7.31±0.23 [a]	11.59±1.30 [ab]	12.54±0.31 [a]	18.70±1.97 [ab]	13.16±1.66 [a]
control+MPPCH	8.55±0.00 [a]	3.94±0.58 [a]	12.49±0.47 [e]	14.05±1.15 [b]	22.35±2.98 [c]	15.53±3.25 [a]	14.70±0.72 [ab]
Pen+HWT+PP	8.55±0.00 [a]	3.54±0.34 [a]	9.09±0.13 [bc]	20.91±1.20 [d]	17.93±2.89 [ab]	19.66±1.53 [ab]	20.76±1.16 [c]
Pen+HWT+HPCH	8.55±0.00 [a]	3.39±0.43 [a]	8.35±0.90 [abc]	12.25±0.95 [ab]	17.54±0.87 [ab]	13.13±1.42 [a]	15.31±1.73 [ab]
Pen+HWT+MPPCH	8.55±0.00 [a]	3.15±0.35 [a]	9.83±0.23 [cd]	15.35±1.00 [bc]	14.06±0.57 [a]	14.88±1.43 [a]	14.38±0.47 [ab]
HWT+PP	8.55±0.00 [a]	5.88±0.86 [b]	9.92±0.72 [cd]	24.83±1.38 [e]	17.02±2.72 [ab]	15.57±2.38 [a]	17.09±1.45 [b]
HWT+HPCH	8.55±0.00 [a]	3.35±0.03 [a]	7.58±0.37 [ab]	12.80±1.12 [ab]	16.36±2.66 [ab]	14.34±1.44 [a]	14.70±0.83 [ab]
HWT+MPPCH	8.55±0.00 [a]	3.57±0.37 [a]	9.73±0.22 [cd]	10.06±1.02 [a]	16.17±0.68 [ab]	17.85±0.91 [ab]	13.92±0.40 [ab]

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$.

HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE.

Table 25. Catalase activity of limes after hot water treatments and packed in modified polypropylene packaging then stored at 10 ºC for 6 weeks.

Treatment	Catalase activity (units/mg protein)						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
control+PP	342.78±0.00 [a]	44.13±13.12 [a]	83.24±24.42 [c]	149.23± 24.29 [c]	31.62±5.73 [a]	38.05±4.86 [a]	30.91±2.22 [bc]
control+HPCH	342.78±0.00 [a]	40.23±12.56 [a]	48.10± 5.19 [abc]	85.96±5.78 [b]	32.37±5.55 [a]	35.35±4.15 [abc]	27.08± 1.97 [ab]
control+MPPCH	342.78±0.00 [a]	115.56±17.56 [c]	42.97±9.21 [ab]	65.19±1.30 [ab]	28.30±2.80 [a]	83.82±26.13 [b]	22.28±1.51 [ab]
Pen+HWT+PP	342.78±0.00 [a]	34.38±8.04 [a]	63.42± 7.42 [abc]	35.67±4.15 [a]	53.96±21.07 [a]	60.68± 29.79 [ab]	24.20±2.67 [ab]
Pen+HWT+HPCH	342.78±0.00 [a]	85.68±9.24 [bc]	79.79±8.37 [bc]	29.59±5.23 [a]	54.56±6.71 [a]	65.63± 10.27 [ab]	35.88±0.99 [c]
Pen+HWT+MPPCH	342.78±0.00 [a]	38.28±15.59 [a]	47.61± 13.78 [abc]	89.60±15.16 [b]	36.03±21.61 [a]	56.41± 5.44 [ab]	17.10±3.60 [a]
HWT+PP	342.78±0.00 [a]	49.66±6.20 [a]	49.57± 11.55 [abc]	87.46±20.83 [b]	235.54±65.19 [b]	45.77± 3.49 [ab]	49.11±6.48 [d]
HWT+HPCH	342.78±0.00 [a]	67.99±8.16 [ab]	55.77± 7.36 [abc]	88.11±3.13 [b]	185.79±64.10 [b]	71.44± 1.84 [ab]	24.65±4.14 [ab]
HWT+MPPCH	342.78±0.00 [a]	59.00±6.79 [ab]	36.91±1.64 [a]	40.06±7.71 [a]	69.55±8.11 [a]	27.37±9.94 [a]	17.63±2.30 [a]

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$.

HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE.

Table 26. Ascorbate peroxidase activity of limes after hot water treatments and packed in modified polypropylene packaging then stored at 10 ºC for 6 weeks.

Treatment	Ascorbate peroxidase activity (units/mg protein)						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
control+PP	6300.96±0.00 [a]	875.90±284.44 [a]	4195.80± 125.34 [ab]	5270.08±137.66 [b]	505.01±168.41 [a]	5646.46±114.42 [c]	2473.35±144.78 [b]
control+HPCH	6300.96±0.00 [a]	916.44±296.66 [a]	2986.97±233.83 [ab]	7750.37±111.77 [c]	483.09±110.28 [a]	1020.04±127.24 [ab]	1894.56± 65.67 [ab]
control+MPPCH	6300.96±0.00 [a]	1710.27±131.10 [a]	3383.65± 22.95 [ab]	5236.78±469.03 [b]	1510.20±297.30 [a]	2648.27±136.30 [abc]	2099.88± 85.45 [ab]
Pen+HWT+PP	6300.96±0.00 [a]	1899.39±112.26 [a]	3222.38±297.55 [ab]	3255.26±513.33 [ab]	1088.24±181.74 [a]	3878.41±158.53 [abc]	821.63±89.97 [a]
Pen+HWT+HPCH	6300.96±0.00 [a]	725.54±315.60 [a]	5221.79± 161.50 [b]	1396.82±267.30 [a]	606.71±15.06 [a]	4347.55±132.49 [abc]	3229.75±54.02 [b]
Pen+HWT+MPPCH	6300.96±0.00 [a]	2420.98±105.07 [a]	4040.17± 803.99 [ab]	5209.52±78.75 [b]	3406.68±245.55 [a]	3604.52±632.21 [abc]	1006.51±175.51 [a]
HWT+PP	6300.96±0.00 [a]	2257.82±674.04 [a]	3847.11± 303.05 [ab]	4448.15±797.16 [b]	1687.36±337.52 [a]	3071.87±91.26 [abc]	2153.15± 110.92 [ab]
HWT+HPCH	6300.96±0.00 [a]	1390.77±139.93 [a]	2205.97±182.42 [a]	7680.62±191.82 [bc]	846.17±534.58 [a]	830.69±206.50 [a]	2238.18± 337.47 [ab]
HWT+MPPCH	6300.96±0.00 [a]	2777.54±454.69 [a]	3328.83± 423.69 [ab]	1748.28±111.04 [a]	2366.92±117.58 [a]	5002.95±597.94 [bc]	2720.03±385.12 [b]

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$.

HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE.

Table 27. Percentage of disease incidence after hot water treatments and packed in modified polypropylene packaging then stored at 10 ºC for 6 weeks.

Treatment	Percentage of disease incidence					
	w.1	w.2	w.3	w.4	w.5	w.6
control+PP	0.00	0.00	0.00	0.00	0.00	0.00
control+HPCH	0.00	0.00	0.00	4.22	4.22	4.22
control+MPPCH	0.0	0.00	0.00	0.00	0.00	0.00
Pen+HWT+PP	0.00	0.00	0.00	0.00	0.00	0.00
Pen+HWT+HPCH	0.00	0.00	0.00	0.00	0.00	0.00
Pen+HWT+MPPCH	0.00	0.00	0.00	0.00	0.00	0.00
HWT+PP	0.00	0.00	4.22	4.22	4.22	4.22
HWT+HPCH	0.00	0.00	0.00	0.00	0.00	0.00
HWT+MPPCH	0.00	0.00	0.00	0.00	0.00	0.00

HWT = hot water treatment; Pen = *Penicillium* sp.

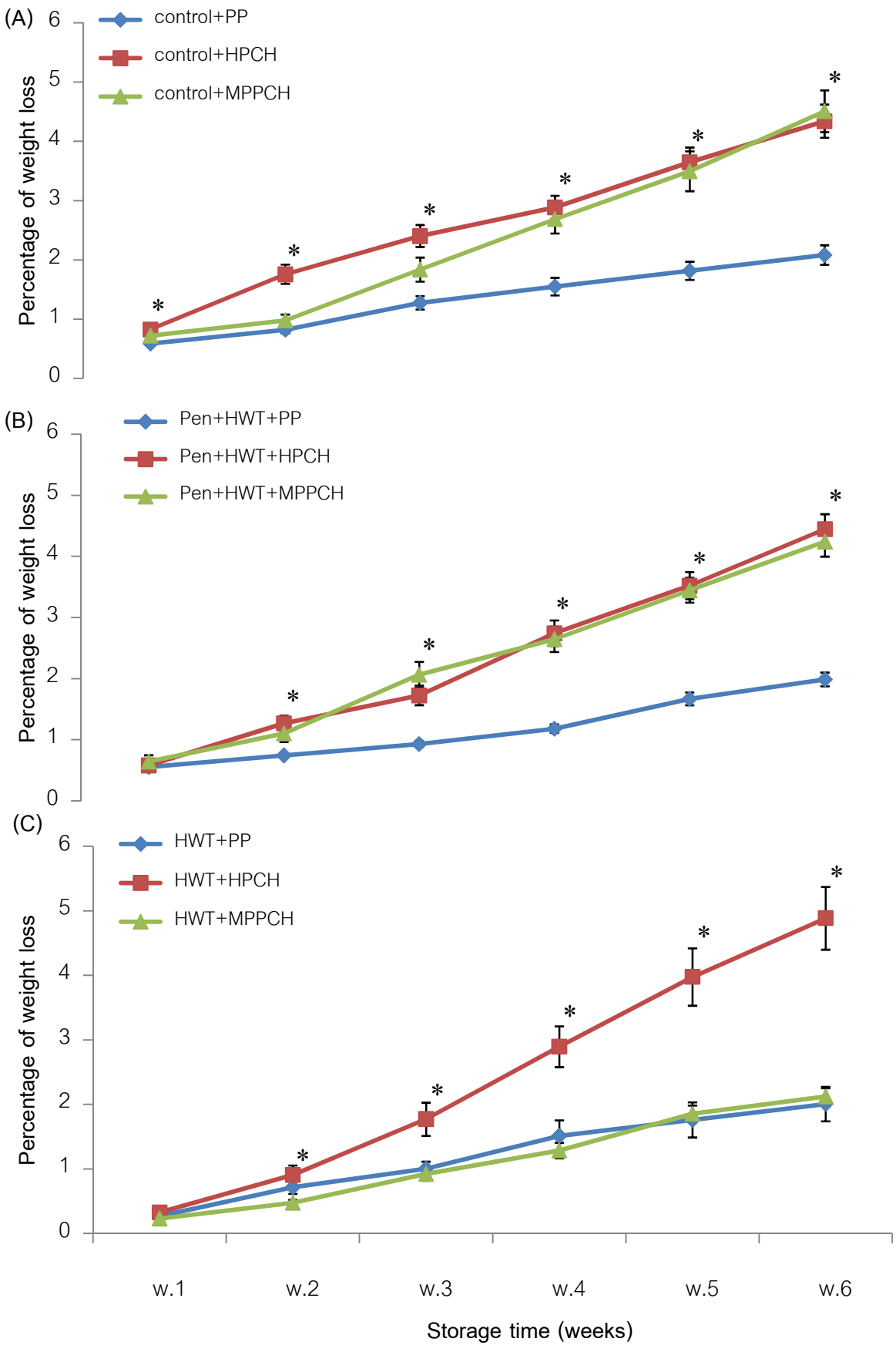

Figure 15. Percentage of weight loss of limes after hot water treatments and packed in modified polypropylene packaging then stored at 10 ºC for 6 weeks.

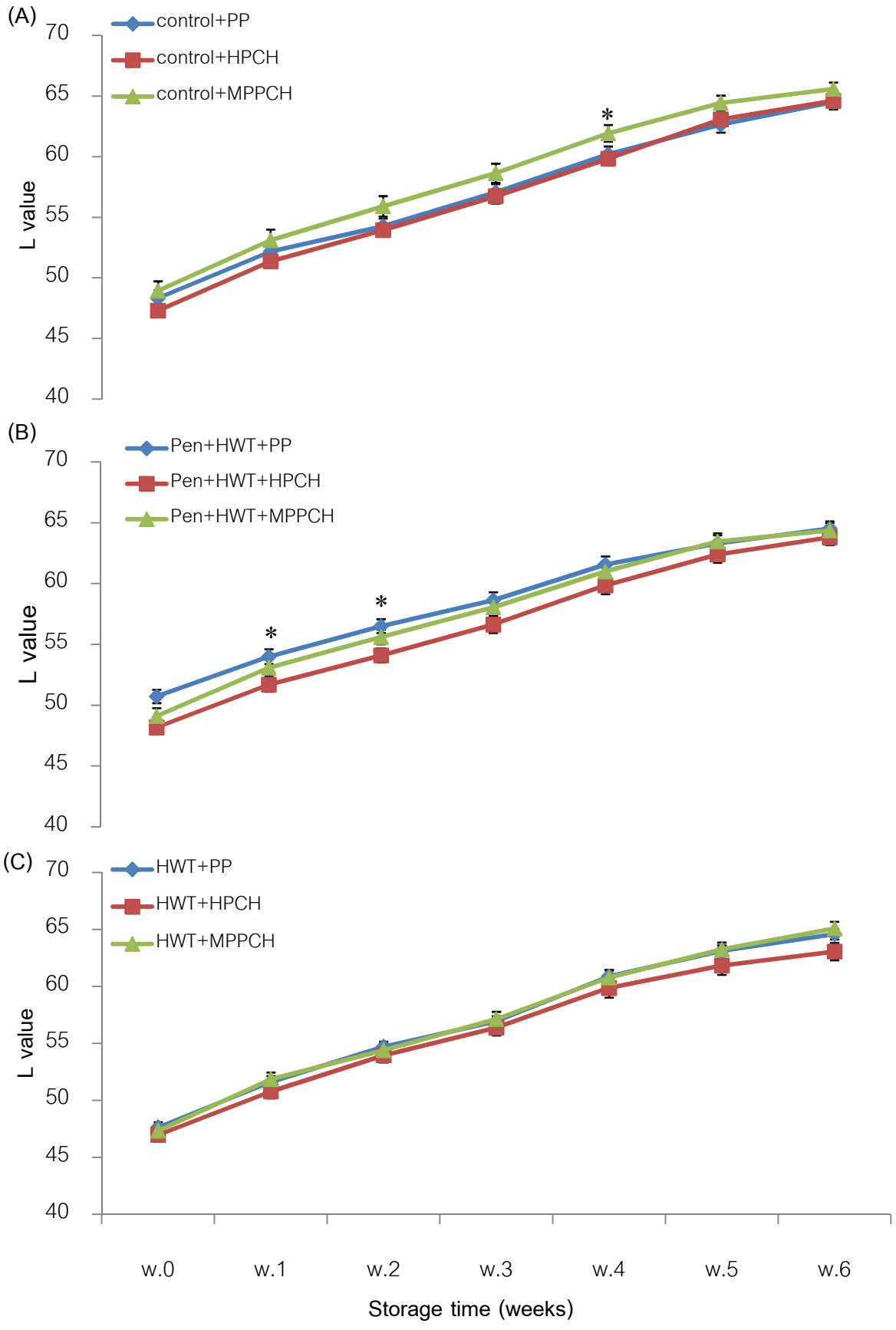

Figure 16. L value of limes after hot water treatments and packed in modified polypropylene packaging then stored at 10 ºC for 6 weeks.

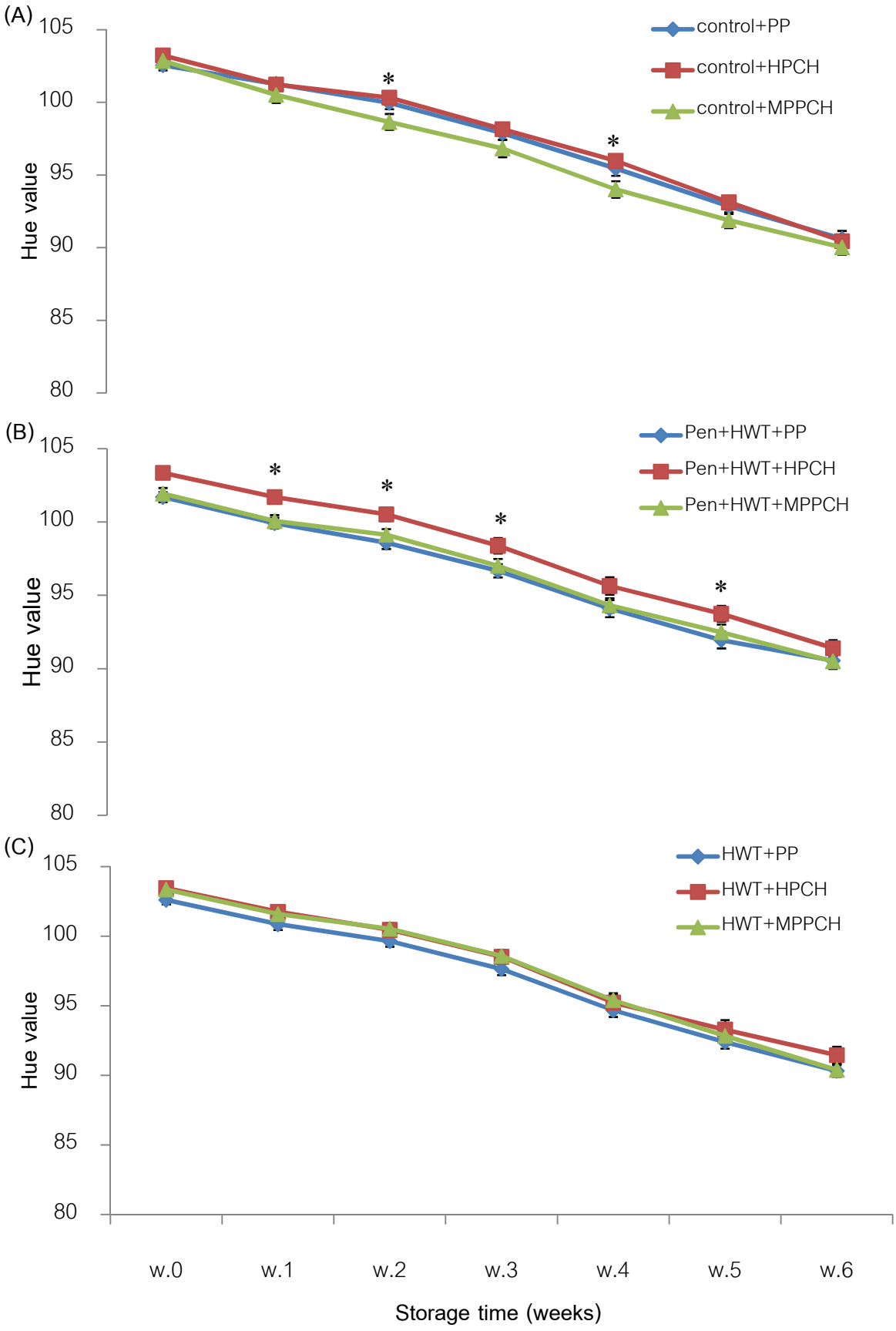

Figure 17. Hue value of limes after hot water treatments and packed in modified polypropylene packaging then stored at 10 ºC for 6 weeks.

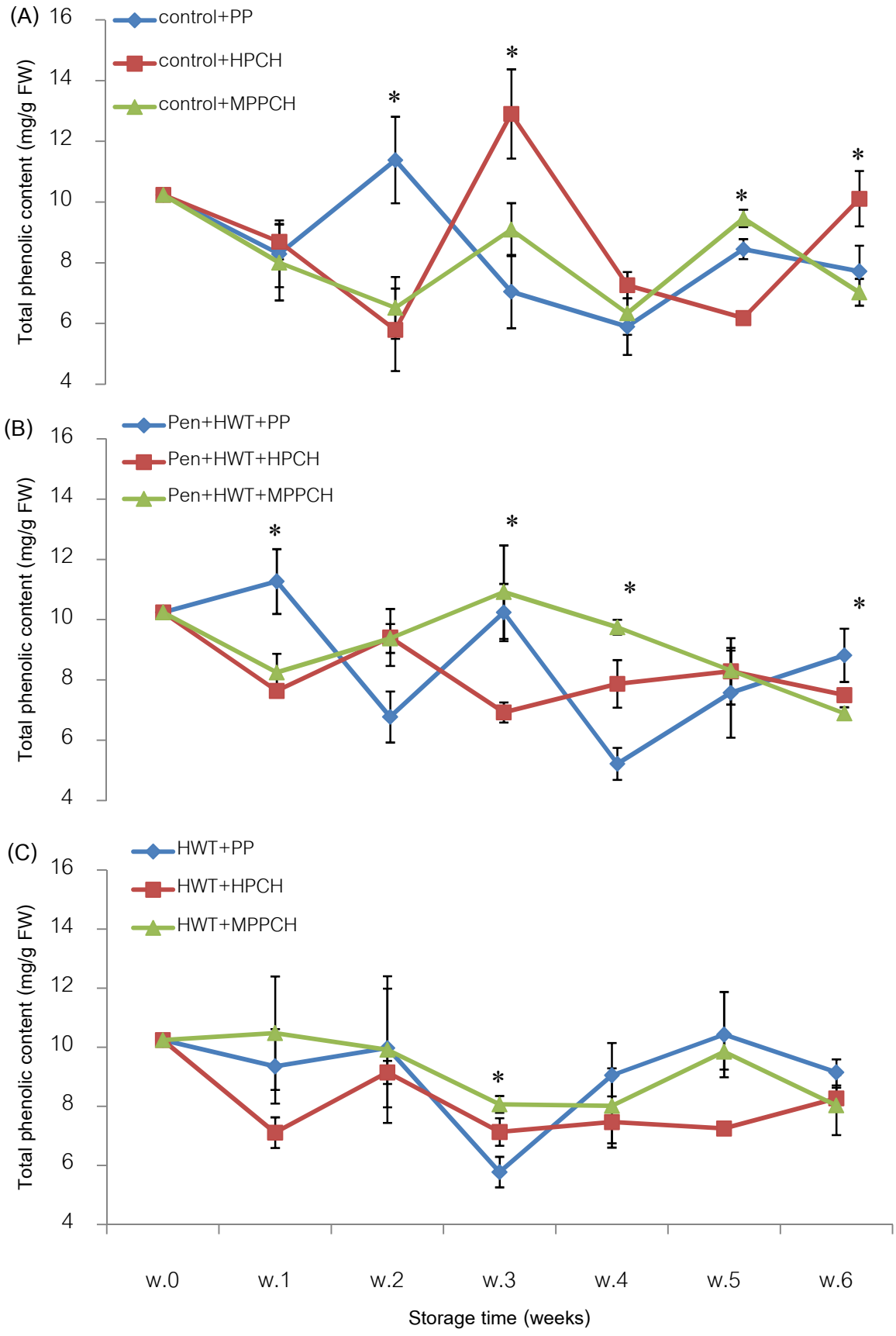

Figure 18. Total phenolic content of limes after hot water treatments and packed in modified polypropylene packaging then stored at 10 ºC for 6 weeks.

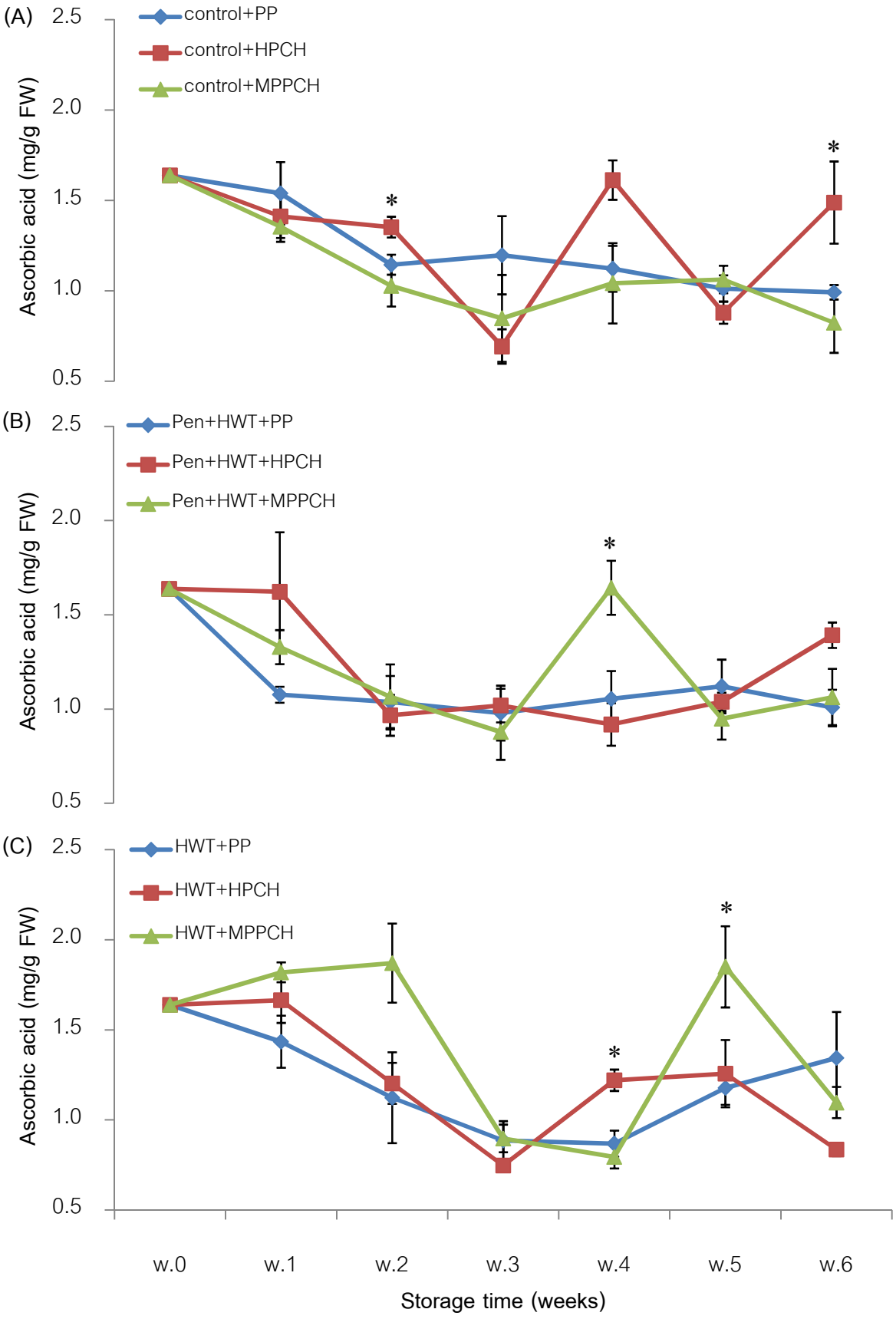

Figure 19. Ascorbic acid of limes after hot water treatments and packed in modified polypropylene packaging then stored at 10 ºC for 6 weeks.

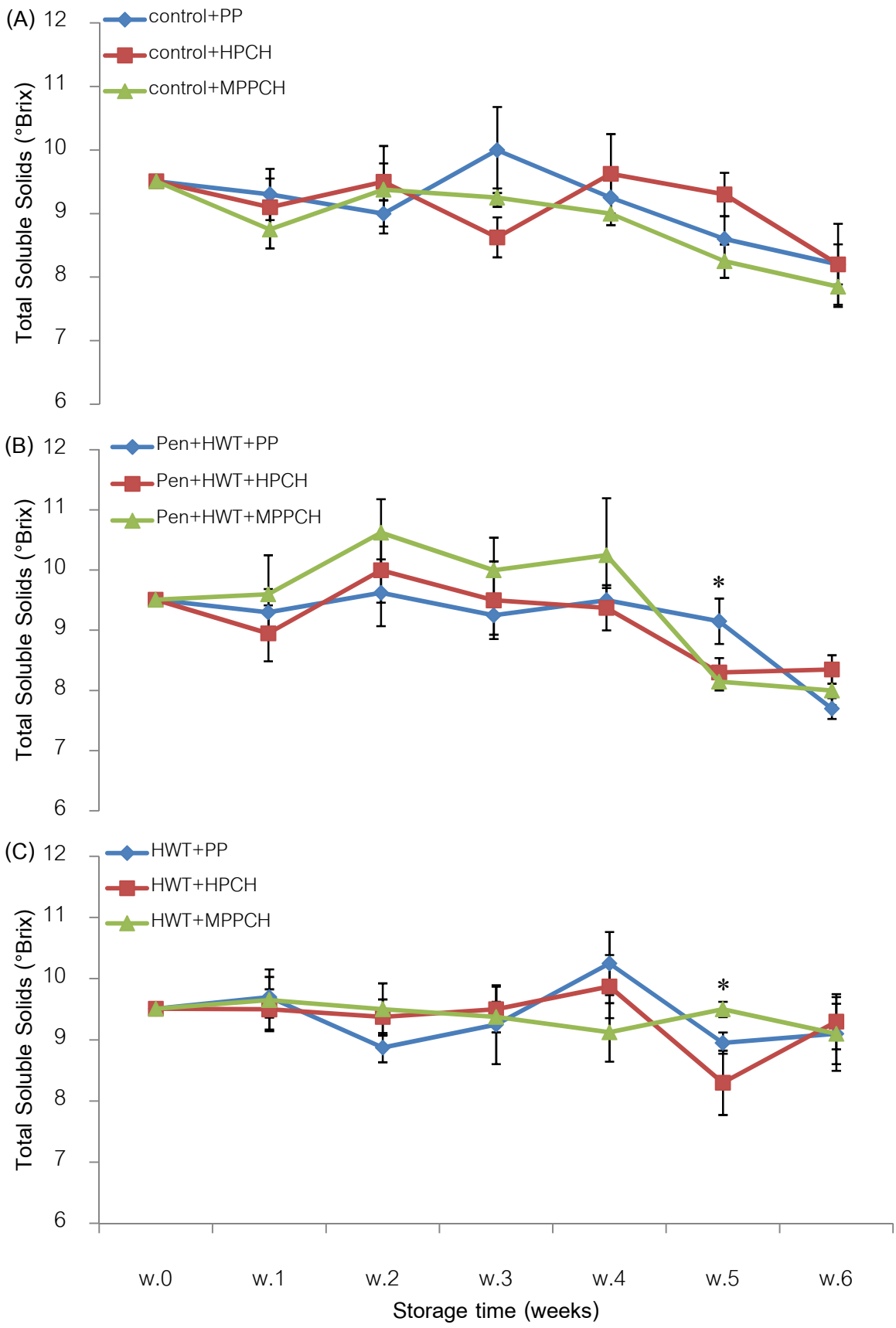

Figure 20. Total soluble solids of limes after hot water treatments and packed in modified polypropylene packaging then stored at 10 ºC for 6 weeks.

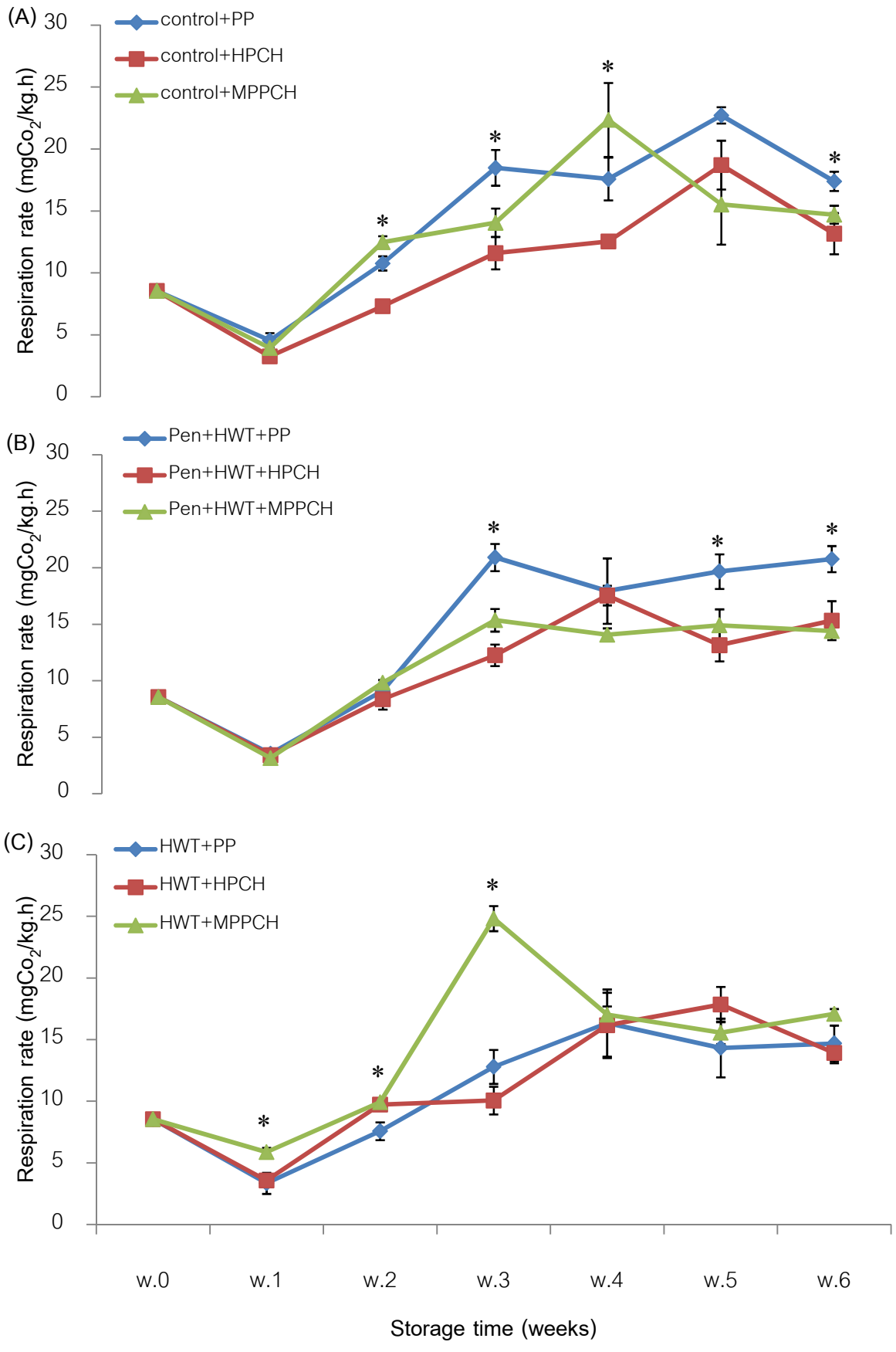

Figure 21. Respiration rate of limes after hot water treatments and packed in modified polypropylene packaging then stored at 10 ºC for 6 weeks.

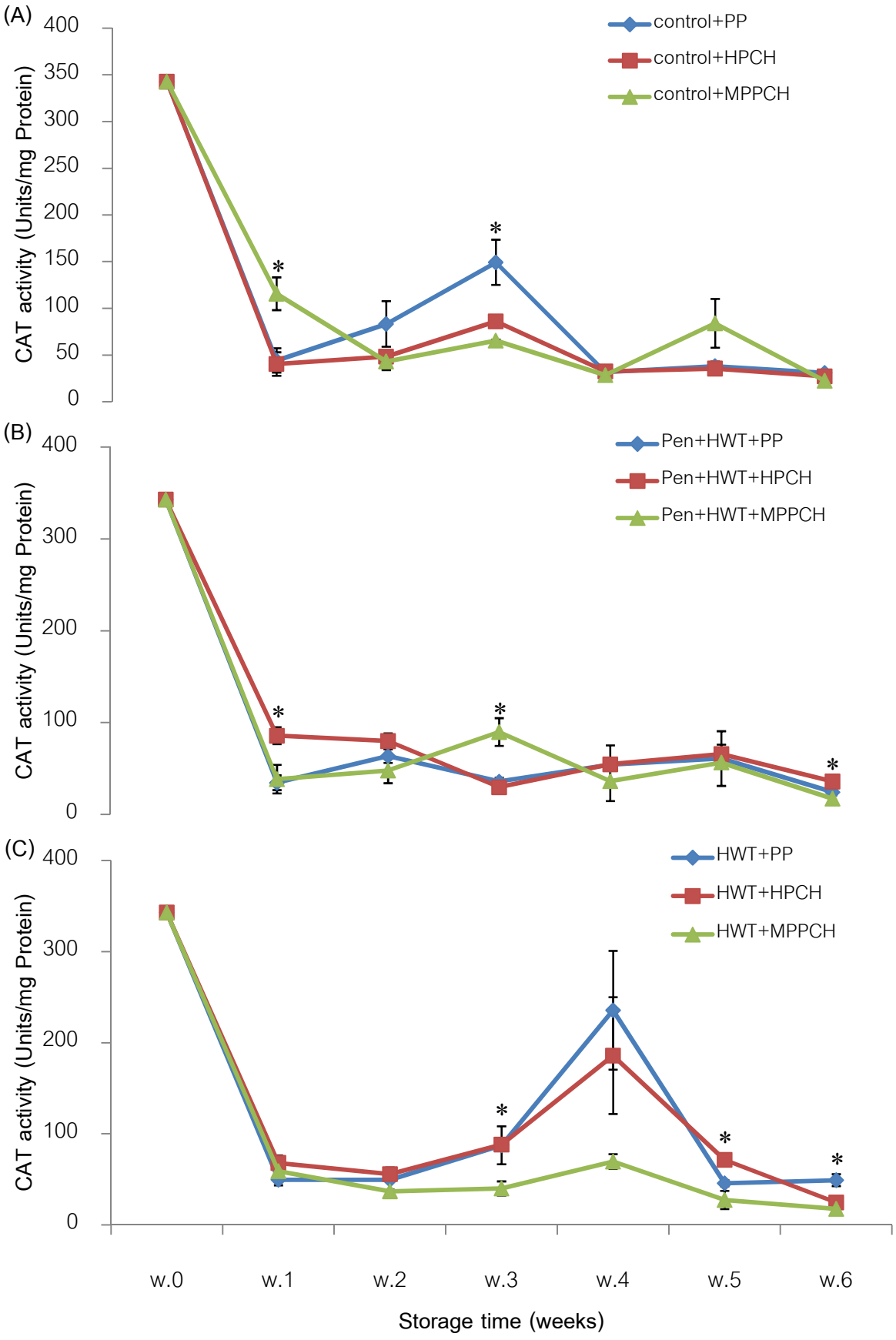

Figure 22. Catalase activity of limes after hot water treatments and packed in modified polypropylene packaging then stored at 10 ºC for 6 weeks.

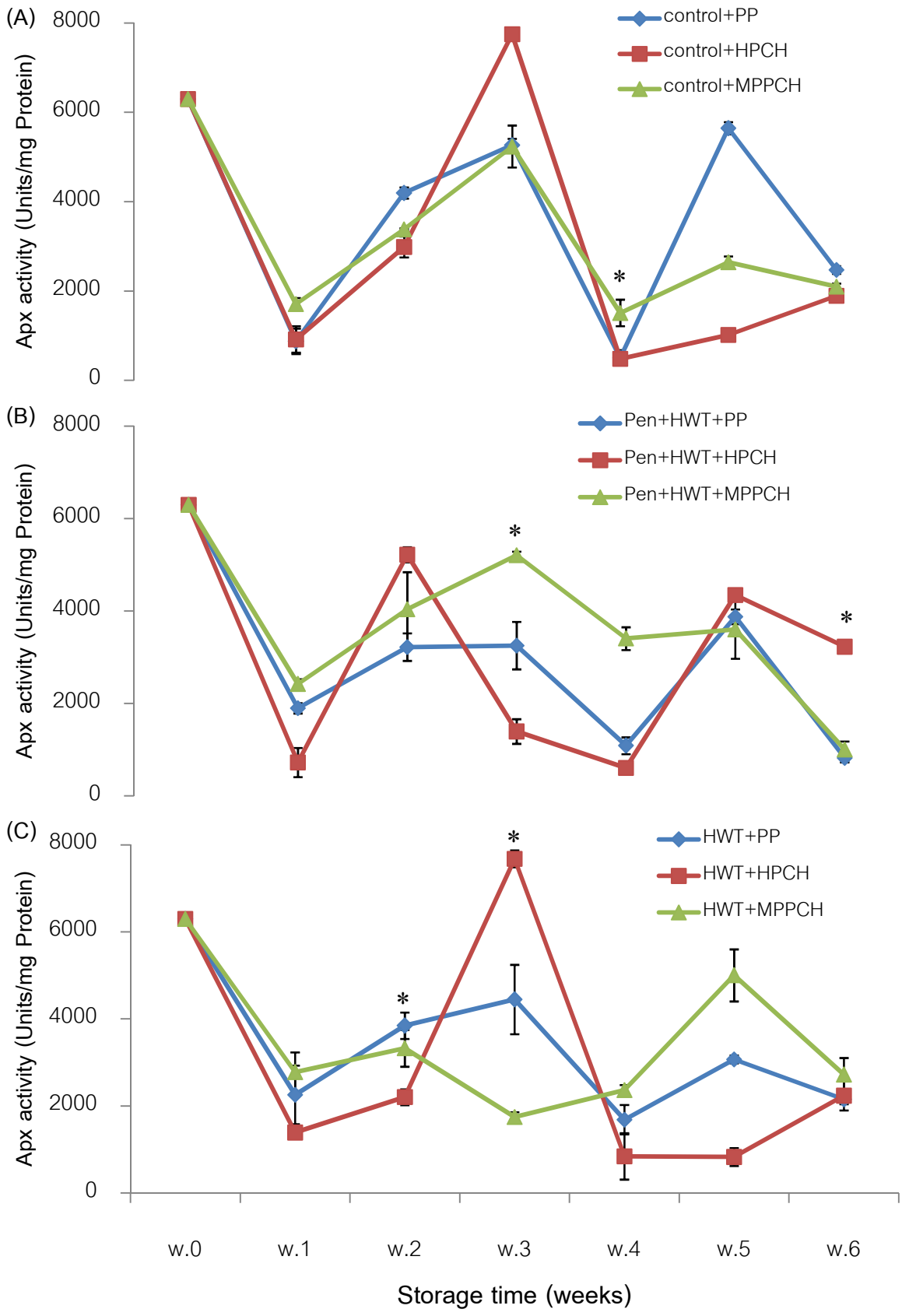

Figure 23. Ascorbate peroxidase activity of limes after hot water treatments and packed in modified polypropylene packaging then stored at 10 ºC for 6 weeks.

CHAPTER V

DISSCUSION

During storage, limes gradually loss their weights and the increase in percentages of weight loss correlated with storage times. The hot water treatment at 40 °C for 5 min could reduce weight loss when storage at 25 °C and 10 °C for 4 and 6 weeks, respectively (Table 1 and 5). However, the effect of heat treatments fluctuated in this experiment. Researchers have been reported on unstable results of heat treatments on fruits which depended on the characteristic of different fruit responses. The responses of a particular fruit involved a combination of factors such as physiological age of the commodity, time and temperature of exposure, treatment methods, and storage temperature (Cohen et al., 1994; Lydakis and Aked, 2003). Higher temperature of storage tended to increase weight loss, mainly due to the elevated transpiration rate through the microscopic cracking which occurs on the fruit surface (Cohen et al., 1994; Rodov et al., 1994). In addition, the action of the hot water decreasing weight loss was also reported by the ability of melting the fruit epicuticular waxes which could cover the fruit surface then seal the stomata and cracked surface (Obeed and Harhash, 2006).

After storage at 25 °C for 4 weeks, control limes packed in the modified polypropylene packaging tended to decrease percentage of weight loss than the combination with hot water treatment (Table 8). In general, the weight loss resulted from the difference between humidity in the fruits and the atmosphere around fruits. Modified atmosphere packaging could reduce the water loss by containing high moisture around fruits (Akbudak, 2008). We found that PP had water condensation less than modified polypropylene packaging thus, in and out flux of CO_2 and O_2 in PP was better than

modified polypropylene packaging result in higher percentage of weight loss in PP than in modified polypropylene packaging. However, the combination of hot water treatment and modified polypropylene packaging increased percentage of weight loss. This may be the effect of heat treatment on fruit which could enhance respiration, probably due to the activation of metabolic processes at high temperatures (Hong et al., 2007). The increased weight loss could be due to high respiration rate associated with accelerated ripening or increased transpiration (Jacobi et al., 2000). In the first experiment, the hot water treatment at 40 °C for 5 min could reduce the percentage of weight loss when storage at 25 °C but in the second experiment, the hot water treatment at 40 °C for 5 min increased the percentage of weight loss more than experiment 1. The observed weight loss was very similar to that reported by Siomos et al. (2011) for the combination of heat treatment and modified atmosphere packaging increased weight losses in white asparagus. However, after storage at 10 °C for 6 weeks, the hot water treatment with MPPCH packaging could reduce percentage of weight loss and was significantly difference from control packed in MPPCH (Table 18). In the contrast, Hong et al. (2007) found that the hot water dipped in Satsuma mandarin at 52 °C for 2 min, 55 °C for 1 min and 60 °C for 20 s and packed in low-density polyethylene (LDPE) showed increase in weight loss on a whole fruit after stored for 3 weeks at 5 °C (85–87% RH) and subsequently for 1 week at 18 °C. This result could be attributed to fruit transpiration enabled by the perforated packaging film bags used.

No significant difference in delaying peel color of limes were found between control and hot water treatments after storage at 25 °C and 10 °C for 4 and 6 weeks, respectively (Table 2, 3, 6, 7 and Figure 2). Similar result could be found in untreated ‘Fortune’ mandarin fruit and those treated with hot water at 50 or 54 °C for 3 min. This increase in lightness results from a loss of green color that occurred prior to a rise in

yellow-orange as indicated by an increase in a* value. Yellowing of peel is a consequence of alterations in the physiological and biochemical processes occurring in the flavedo tissue of lime peel (Tin et al., 2006). That means hot water around 40-50 °C did not affect any changes in physiological and biological processes of peel color. However, the hot water treatment at immoderate conditions of 56–58 °C for 3 min produced negative effects on peel color in 'Fortune' mandarins due to heat damage, resulting in brown and aged fruit with lowered L*a*b* values (Schirra and D'hallewin, 1997). The hot water treatment at 65 °C or higher temperatures for 2 min also caused surface browning in apple cubes, probably due to heat damage, but such discoloration was effectively prevented in the sample treated at 45 or 55 °C due to the optimum inhibition of polyphenoloxidase (Zuo et al., 2004). In this experiment, treated limes with 55 °C hot water for 5 min also caused surface browning of fruits. The darkening effect associated with decreased L values resulting from excessive treatment may have been linked to fruit dehydration (Lydakis and Aked, 2003).

After storage at 25 °C for 4 weeks, the hot water treatment with combination of HPCH and MPPCH could delay peel color change of limes (Table 9 and 10). The hot water treatment inhibited the change of peel color which may result from inhibition of chlorophyllase in peel by heat (Lurie, 1998). However, No significant difference in delay peel color change of limes were found between control and the combination treatment after storage10 °C for 6 weeks (Table 19 and 20).

In our study, the HPCH packaging was modified atmosphere packaging (MAP) which results in a reduction of O_2 and elevation of CO_2 concentrations around the fruit inside the packaging. Effects of O_2 reduction lead to CO_2 increment, reduction in respiration rate and preventing any fungal infection on fruits (Thompson, 1995). Under these atmospheric conditions, the respiration rate of the fruit decreased which delayed

compositional changes in fruits. Limes packed in the HPCH packaging showed higher ascorbic acid concentration and activities of catalase and ascorbate peroxidase than other treatment in the last week (Table 12, 15 and 16, respectively). In addition, fruits in the HPCH packaging had lower respiration rate so there was lower total soluble solid and disease incidence after storage at 25 °C for 4 weeks (Table 14, 13 and 17 respectively). However, after storage at 10 °C for 6 weeks, lime packed in HPCH showed higher total phenolic content and ascorbic acid concentration (Table 21 and 22).

After storage at 25 °C for 4 weeks, the set of limes inoculated with *Penicillium* sp. then dipped in hot water and the set of the combination with hot water and packagings increased the total phenolic content while, the set of control showed reduction in the last week of storage (Table 11). The amount of phenolic content increased when fruits were repaired themselves from injury and resistance to any fungal infection on fruits (Dixson and Paiva, 1995). Moon et al. (2011) reported that the higher level of total phenolic content in heat treatment due to increasing in amount of free phenolic acids and soluble phenolic acid esters which might resulted from enzymatic hydrolysis or from biodegradation of unextractable bound phenolic compounds over the extended storage period. While, lime after storage at 10 °C for 6 weeks showed fluctuation in total phenolic content in all treatments (Table 21).

The combination with hot water and modified polypropylene treatments effected reduction of ascorbic acid after stored at 25 and 10 °C for 4 and 6 weeks (Table 12 and 22). The decrease of ascorbic acid could relate with increment ascorbic acid oxidase (ASAO) activity. ASAO is a catalytic enzyme that converses ascorbic acid to dehydroascorbic acid. Bassal and Hamahmy (2011) reported that the hot water treatments decreased ASAO activity while, ascorbic acid content was generally

increased, especially in W.Navel orange. This may describe the lower ascorbic acid content of fruits because of oxidation.

After storage at 25 °C and 10 °C for 4 and 6 weeks, respectively, the hot water treatment did not affect the reduction of total soluble solids (Table 13 and 23). In general, all fruit varieties show an increase in TSS after shelf-life compared with initial values at harvest. The increase in soluble solids showed that the fruit was in ripening stage. However, lime is a non-climacteric fruit so it's ripening stage results only slightly chance in TSS (Siriphanich, 2001).

After heat treatment at 38-40 °C, an elevated respiration rate was demonstrated in apples, tomatoes and 'Kensington' mangoes (Lurie and Klein, 1990; Lurie and Klein, 1992; Jacobi et al., 2000). In our study, the increase in respiration rate was higher in the set of limes dipped in hot water treatment than in control treatment after storage at 25 °C for 4 weeks and alls treatments had no effect on respiration rate of limes when storage at 10 °C for 6 weeks. Increased respiration rate allows enhancing in metabolic rate which occurs in fruits and supports more senescence. Temperature of hot water affects the respiration rate of fruits by increasing the demand for energy to drive metabolic reactions. The respiration rate thus increases with increase in temperature of the product (Karuppiah, 2004). Increased respiration rate probably associated with microbial growth and general tissue deterioration (Silveira et al., 2011).

According to the CAT and APX activities of limes dipped in hot water and packed in HPCH and then stored at 25 °C for 4 weeks, the results showed that both CAT and APX activities increased in all treatments in the third and fourth weeks (Table 15 and 16). Limes packed in HPCH showed lower respiration rate associated with a delay in senescence so this may explain the activities of both enzymes in this experiment. Increase in the activity of natural antioxidants and antioxidant enzymes such as

superoxide dismutase (SOD), catalase (CAT), glutathione reductase (GR) and ascorbate peroxidase (APX) was reported in plants response to abiotic stress such as changes in storage temperature in order to decreased reactive oxygen species (ROS) (Bowler et al., 1992). In hot water treated limes, increase levels of CAT and APX activities was found in the third week after storage at 25 °C. This might suggest a high accumulation of H_2O_2 after hot water treatments that probably leads to an increase in catalase synthesis necessary to detoxify an excess of H_2O_2 (Lamoine et al., 2010). However, limes stored at 10 °C showed slightly increase in the activity of CAT and fluctuated level of APX activity throughout storage (Table 25 and 26). Increase in CAT activity of 'Fortune' mandarins after a hot water dipping treatment at 53 °C for 3 min was also reported (Sala and Lafuente., 2000). In this experiment, chilling injury was not observed in low temperature storage. CAT may be a major antioxidant enzyme involved in the defense mechanisms of fruit against chilling stress. Also the different effectiveness of the heat-conditioning treatments in increasing chilling tolerance of 'Fortune' mandarins may be related to induction of CAT activity during heating and its persistence during cold storage. The elevated levels of CAT in hot water treated citrus fruits showed suppressed chilling injury (Ghasemnezhad et al., 2008).

In the experiment 1, the high temperature of hot water treatment could control disease incidence of lime after storage at 25 °C for 4 weeks (Table 4). In general, the temperature of hot water treatment in citrus fruits about 50-55 °C was effective in inhibiting pathogen infection. These results suggest that the hot water had a transient inhibitory effect on the pathogen by continuously accumulating lignin a week after treatment (Nafussi et al., 2001). Lignin is one of the factors in the defense mechanism which against fungal infection (Tian et al., 2007). In addition, the hot water treatment lead to the synthesis of pathogenesis related (PR) protein which important mechanism of

resistance to various diseases. ß-1, 3-Glucanase is the most fully characterized PR protein. An increasing amount of evidences suggests that it can act directly by degrading a pathogen's cell wall or indirectly by releasing oligosaccharide, elicitors of defense reactions, both of which are potential defense mechanisms against fungal infection (Saltveit, 2000). However, the hot water at 40 °C was selected in this experiment. Hot water at 40 °C was not effective in control postharvest disease of limes, but from the previous experiment, this temperature could maintain the quality of limes. In addition, different packagings could give different results. After storage at 25 °C for 4 weeks, the percentage of disease incidence of lime inoculated with *Penicillium* sp. then dipped in hot water and packed in PP was higher than control treatment because the diseased fruit was detected very early since the first week and disease contamination within packaging could increase disease incidence (Table 17). However, effectiveness of hot water treatments on tangerine fruit using 50 and 55 °C showed reduction in the disease index and severity of green mold rot when stored at 24 °C (Inkha, 2009). Less disease incidence was found in almost all treatments when stored at 10 °C (Table 27). Thus, combination of heat treatment and low temperature storage was an effective method to reduce decay development of postharvest fruits (Porat et al., 2000; Inkha, 2009).

CHAPER VI
CONCLUSION

1. Selection of an appropriate temperature of hot water treatment and period of time to prolong postharvest qualities of limes after storage

For limes stored at 25 ºC for 4 weeks, the hot water at 40 ºC for 5 min had significantly lower percentage of weight loss than control. However, this hot water treatment condition did not have any effect on preventing color change and fruits decay.

For limes stored at 10 ºC for 6 weeks, the hot water at 40 ºC for 5 min showed lower percentage of weight loss than control. In addition, the hot water at 40 ºC for 5 min tended to delay color change by slightly increasing the L value and decrease hue value. Low temperature effectively controlled fruits decay.

2. Effect of hot water treatment and modified polypropylene packaging on postharvest qualities of limes during storage at 25 ºC for 4 weeks

The use of hot water treatment and HPCH and MPPCH packagings did not affect percentage of weight loss in the last week and weight loss significantly increased higher than control treatment. While HPCH and MPPCH packagings used with inoculated *Penicillium* sp. And hot water treated limes could delay color change of peel after storage. Total phenolic content of hot water treated fruits combined with MPPCH packaging was rapidly increased and higher than control fruits. However, ascorbic acid content, total soluble solid, respiration rate, CAT and APX activities and disease incidence of lime fruits did not show any difference among packages

3. Effect of hot water treatment and modified polypropylene packaging on postharvest qualities of limes during storage at 10 ºC for 6 weeks

The hot water treatment with HPCH and MPPCH packagings did not affect percentage of weight loss while the HPCH packaging could delay color change of peel. In addition, packagings of limes dipped in hot water treatment tended to decrease at the end of storage at 10 °C for 6 weeks, except the HPCH packaging which slightly showed

an increase in total phenolic content in the last week. The HPCH and MPPCH packagings did not affect ascorbic acid content and CAT activity but decrease total soluble solid in the last week. However, the activity of APX decreased in all treatments in the last week except HPCH packaging of hot water treated fruit which sharply increased. In addition, limes packed in HPCH and MPPCH packagings did not show any disease incidence until the end of storage.

According to the results in *Experiment 2* and *Experiment 3*, we can suggest that HPCH packaging is the most appropriate packaging to prolong shelf life of limes. Limes packed in the HPCH packaging showed higher ascorbic acid concentration and activities of catalase and ascorbate peroxidase in the last week. In addition, fruits in the HPCH packaging had less respiration rate so there was lower total soluble solid and disease incidence after storage at 25 °C for 4 weeks. However, after storage at 10 °C for 6 weeks, lime packed in HPCH showed higher total phenolic content and ascorbic acid concentration.

REFERENCES

Akbudak, B. 2008. Effect pf polypropylene and polyvinyl chloride plastic film packaging material on the quality of 'Yalova Charleston' pepper (*Capsicum annuum* L.) during storage. **Food Science and Technology Research** 14: 5-11.

Armstrong, J.W., Hansen, J.D., Hu, B.K.S. and Brown, S.A. 1989. High-temperature, forced-air quarantine treatment for papayas infested with Tephritid fruit flies (Diptera:Tephritidae). **Economic Entomology** 82: 1667-1674.

Baker, A.G. 1952. **The vapor-heat process**. U.S. Dept. Agric. Yearbook, U.S. Govt. Printing Office, Wash., DC.

Barkai-Golan, R. 2001. **Postharvest Diseases of Fruits and Vegetables**. British Library Cataloguing in Publication, Amsterdam. pp 418.

Barkai-golan, and R., Phillips, D.J. 1991. Postharvest heat treatment of fresh fruits and vegetables for decay control. **Plant disease** 75: 1085-1089.

Bashir, H.A., and Abu-goukh, A.A. 2003. Compositional changes during guava fruit ripening. **Food Chemistry** 80: 557-563.

Bassala, M. and El-Hamahmy, M. 2011. Hot water dip and preconditioning treatments to reduce chilling injury and maintain postharvest quality of Navel and Valencia oranges during cold quarantine. **Postharvest Biology and Technology** 60: 186-191.

Beers, R.F. and Sizer, I.W. 1952. A spectrophotometric method for measuring the breakdown of hydrogen peroxide by catalase. **Biological Chemistry** 195: 133-140.

Ben-Yehoshua, S., Peretz, J., Rodov, V., Nafussi, B., Yekutieli, O., Weiseblum, A. and Regev, R., 2000. Postharvest application of hot water treatment in citrus fruit:

the road from the laboratory to the packing-house. **Acta Horticulturae**. 518: 19-28.

Biggs, M.S., Woodson, W.R. and Handa, A.K. 1988. Biochemical basis of high temperature inhibition of ethylene biosynthesis in ripening tomato fruits. **Plant Physiology** 72: 572-578.

Boonyaritthongchai P., Kakaew, P., Puthmee T. and Kanlayanarat S. 2009. Effect of controlled atmosphere on prolong storage life and quality of lime. In: **Proceedings 10th International Controlled & Modified Atmosphere Research Conference**, Antalya, Turkey. pp. 80.

Bowler, C., Montagu, M.V. and Inze, D. 1992. Superoxide dismutase and stress tolerance. **Annual Review of Plant Physiology and Plant Molecular Biology.** 43: 83-116.

Brown, G.E., Davis, C. and Chambers, M. 2000. Control of citrus green mold with Aspire is impacted by the type of injury. **Postharvest Biology and Technology** 18: 57–65.

Brown, G.E. 2008. **Green Mold Rot**. [Online]. Available: http://apsnet.org/Education/K-12PlantPathways/TeachersGuide/Activities/BrownRot/text/FIGURE14.html. (November 19, 2009).

Cohen, E., Shapiro, B., Shalom, Y. and Klein, J.D. 1994. Water loss: a non-destructive indicator of enhanced cell membrane permeability of chilling-injured citrus fruit. **American Society for Horticultural Science** 119: 983-986.

Department of Health, 1987. **The table of Nutrition of Thai food 100 g edible portion**. Ministry of Public Health of Thailand. Bangkok. pp 28.

Dixon, R.A. and N.L. Paiva. 1995. Stress-induced phenylpropanoid metabolism. **Plant Cell** 7: 1079-1085.

Eaks, I.L. 1978. Ripening, respiration, and ethylene production of 'Hass' avocado fruits at 20° to 40°C. **American Society for Horticultural Science** 103: 576-578.

Eckert, J.W. and Brown, G.E. 1986. Evaluation of postharvest treatments for citrus fruits. In: K.D., Hickey. (Ed.), **Methods for Evaluating Pesticides for Control of Plant Pathogens**. American Phytopathological Society, St. Paul, Minnesota. pp. 92-97.

Eckert, J.W. and Ogawa, J.M. 1988. The chemical control of postharvest diseases: deciduous fruits, berries, vegetables and root/tuber crops. **Annual Review of Phytopathology** 26: 433-469.

Elad, Y. and Volpin, H., 1991. Heat treatment for the control of rose and carnation grey mould (*Botrytis cinerea*). **Plant pathology** 40 :278-286.

Fallik, E., Archbold, D.D., Hamilton-Kemp, T.R., Loughrin, J.H. and Collins, R.W. 1997. Heat treatment temporarily inhibits aroma volatile compound emission from Golden Delicious apples. **Agricultural and Food Chemistry** 45: 4038-4041.

Fallik, E., Grinberg, S., Alkalai, S., Yekutieli, O., Wiseblum, A., Regev, R., Beres, H. and Bar-Lev, E. 1999. A unique rapid hot water treatment to improve storage quality of sweet pepper. **Postharvest Biology and Technology** 15: 25-32.

Garcia, J.M., Aguilera, C. and Albi, M.A. 1995. Postharvest heat treatment on Spanish strawberry (Fragaria X ananassa cv Tudla). **Agricultural and Food Chemistry** 43: 1489-1492.

Ghasemnezhad, M., Marsh, K., Shilton, R., Babalar, M. and Woolf, A. 2008. Effect of hot water treatments on chilling injury and heat damage in 'satsuma' mandarins: Antioxidant enzymes and vacuolar ATPase, and pyrophosphatase. **Postharvest Biology and Technology** 48: 364-371.

Gonalez-Aguilar, G.A., Villa-Rodriguez, J.A., Ayala-Zavala, J.F. and Yhia, E.M. 2010. Improvement of the antioxidant status of tropical fruits as a secondary

response to some postharvest treatments. **Trends in Food Science and Technology** 21:475-482

Gonza´lez-Aguilar, G.A., Zacarias, L., Mulas, M. and Lafuente, M.T. 1997. Temperature and duration of water dips influence chilling injury, decay and polyamine content in 'Fortune'mandarins. **Postharvest Biology and Technology** 12: 61-69.

Hansen, J.D., Armstrong, J.W., Hu, B.K.S. and Brown, S.A. 1990. Thermal death of oriental fruit fly (Diptera: Tephriti-dae) third instars in developing quarantine treatments for papayas. **Economic Entomology** 83:160-167.

Hansen, J.D., Hara, A.H. and Tenbrink, V.L. 1992. Vapor heat: a potential treatment to disinfest tropical cut flowers and foliage. **Horticultural Science** 27: 139-143.

Harhash, M.M and Al – Obeed R.S. 2006. Intermittent warming of "mexican" lime to reduce chilling injury during cold storage. **Advanced Agricultural Research** 11: 515-531.

Hawkins, L.A. 1932. Sterilization of citrus fruit by heat. **Citri culture** 9: 21-22.

Hong, S.I., Lee, H.H. and Kim, D. 2007. Effects of hot water treatment on the storage stability of satsuma mandarin as a postharvest decay control. **Postharvest Biology and Technology** 43:271-279.

Inkha, S. 2009. **Effect of heat treatment on anatomical and biochemical changes in tangerine fruit peel during infection of green mold and chilling injury**. Docter's Thesis, Postharvest technology Chiang Mai University.

Jacobi, K.K. and Giles, J.E. 1997. Quality of `Kensington' mango (*Mangifera indica* Linn.) fruit following combined vapour heat disinfestation and hot water disease control treatments. **Postharvest Biology and Technology** 12: 285-292.

Jacobi, K.K., MacRae, E.A. and Hetherington, S.E. 2000. Effects of hot air conditioning of 'Kensington' mango fruit on the response to hot water treatment. **Postharvest Biology and Technology** 21; 39–49.

Jeong, S.M., Kim, S.Y., Kim, D.R., Jo, S.C., Nam, K.C. and Ahn, D.U. 2004. Effect of heat treatment on the antioxidant activity of extracts from citrus peels. **Agricultural and Food Chemistry** 52: 3389-3393.

Kaewsuksaenga, S., Uranob, Y., Aiamla-orc, S., Shigyo, M. and Yamauchi, N. 2011. Effect of UV-B irradiation on chlorophyll-degrading enzyme activities and postharvest quality in stored lime (*Citrus latifolia* Tan.) fruit. **Postharvest Biology and Technology** 61: 124-130.

Karuppiah, K.J.J. 2004. **Heat treatments for controlling postharvest diseases and chilling injury in florida citrus.** Master's Thesis, Faculty of science University of Florida.

Keadtanom, S. 1997. **Cultivation of lime**. Bangkok. Aksansiam Printing.

Klein, J.D. 1989. Ethylene biosynthesis in heat treated apples. In: H., Clijsters, M., de Proft, R., Marcelle and M., van Pouche. (Eds.), **Biochemical and Physiological Aspects of Ethylene Production in Lower and Higher Plants.** Kluwer, Dordrecht, The Netherlands, pp. 184–190.

Kunsongkiat, N. 1988. **Storage of lime**. [Online]. Available from: http://www.eto.ku.ac.th/neweto/e-book/plant/herb_gar/s_lamon.pdf (September 4, 2009)

Ladaniya, M.S. 2008. **Citrus fruit biology, technology and evaluation.** Academic Press, San Diego, CA, USA. pp. 558.

Lamo, N., Somwangthanaroj, A. and Bunsiri, A. 2008. **Development of packaging film from LDPE/zeolite composites for extending shelf life of lime**. Available from http://kucon.lib.ku.ac.th/Fulltext/KC4711022.pdf (September 4, 2009).

Lamoine, M.L., Chaves, A.R., and Martinez, G.A. 2010. Influence of combined hot air and UV-C treatment on antioxidant system of minimally processed broccoli (*Brassica oleracea* var. Italica). **Food Science and Technology** 43: 1313-1319.

Lanza, G., di Martino Aleppo, E., Strano, M.C., and Recupero, G.R. 2000. Evaluation of hot water treatments to control postharvest green mold in organic lemon fruit. In: **Proceedings International Society Citriculture XI CONGRESS.**, Orlando. pp. 1167-1168.

Lay-Yee, M. and Rose, K.J. 1994. Quality of 'Fantasia' nectarines following forced air heat treatments for insect disinfestation. **Horticultural Science** 29: 663-666.

Luaces, P., Perez, A.G., Garcıa, J.E.M. and Sanz, C. 2005. Effects of heat-treatments of olive fruit on pigment composition of virgin olive oil. **Food Chemistry** 90: 169-174.

Lurie, S. 1998. Postharvest heat treatment. **Postharvest Biology and Technology** 14: 257-269.

Lurie, S., Klein, J.D., 1990. Heat treatment of ripening apples differential effects on physiology and biochemistry. **Plant Physiology** 78, 181-186.

Lurie, S. and Klein, J.D. 1991. Acquisition of low temperature tolerance in tomatoes by exposure to high temperature stress. **American Society for Horticultural Science** 116: 1007-1012.

Lurie, S. and Klein, J.D. 1992. Ripening characteristics of tomatoes stored at 12°C and 2°C following a prestorage heat treatment. **Scientia Horticulturae** 51: 55-64.

Lurie, S. and Sabehat, A. 1997. Prestorage temperature manipulations to reduce chilling injury in tomatoes. **Postharvest Biology and Technology** 11: 57-62.

Lydakis, D.A.J. 2003. Vapor heat treatment of Sultanina table grapes II. Effect on postharvest quality. **Postharvest Biology and Technology** 27: 117-126.

Martínez, G.A. and Civello, P.M. 2008. Effect of heat treatments on gene expression and enzyme activities associated to cell wall degradation in strawberry fruit. **Postharvest Biology and Technology** 49: 38-45.

Maxie, E., Mitchell, G., Sommer, N., Snyder, G. and Rae, H. 1974. Effects of elevated temperatures on ripening of 'Bartlett' pear. **American Society for Horticultural Science** 99: 344-349.

McDonald, R.E., McCollum, T.G. and Baldwin, E.A. 1996. Prestorage heat treatments influence free sterols and flavor volatiles of tomatoes stored at chilling temperature. **American Society for Horticultural Science** 121: 531-536.

McDonald, R.E., MaCollum, T.G. and Baldwin, E.A. 1998. Heat treatment of mature green tomatoes: differential effects of ethylene and partial ripening. **American Society for Horticultural Science** 123: 457-462.

McDonald, R.E., Miller, W.R., McCollum, T.G. and Brown, G.E. 1991. Thiabendazole and imazalil applied at 53 °C reduce chilling injury and decay of grapefruit. **Horticultural Science** 26: 397-399.

Miller, W.R. and McDonald, R.E. 1992. Postharvest quality of early season grapefruit after forced air vapor heat treatment. **Horticultural Science** 27: 422-424.

Moon, Y.C., Chuan, C., Jeong, H.P., Johan, L., Jeongmi L. and Sung, W.K. 2011. Effects of storage period and heat treatment on phenolic compound composition in dried Citrus peels (Chenpi) and discrimination of Chenpi with different storage periods through targeted metabolomic study using HPLC-DAD analysis. **Pharmaceutical and Biomedical Analysis** 54: 638-645.

Nafussi, B., Ben-Yehoshua, B., Rodov, V., Peretz, J., Ozer, B.K. and D'Hallewin, G. 2001. Mode of action of hot-water dip in reducing decay of lemon fruit. **Agricultural and Food Chemistry** 49: 107-113.

Nakano, Y. and Asada, K. 1989. Hydrogen peroxide is scavenged by ascorbate specific peroxidase in spinach chloroplasts. **Plant and Cell Physiology** 22: 867-880.

Nittaya Ummarat. 2005. **Antioxidant enzymatic activities of hot water treated 'Hom Thong'banana during storage.** Master's Thesis, Department of Botany, Faculty of Science, Chulalongkorn University.

Nittaya Umrat. 2010. **Change in antioxidant system and expression of genes encoding antioxidant enzymes in hot water-treated 'Hom Thong' banana fruits during storage.** Docter's Thesis, Program in Biological Science, Faculty of Science, Chulalongkorn University.

Obagwu, J. and Korsten, L. 2003. Control of citrus green and blue molds with garlic extracts. **Plant Pathology** 109: 221-225.

Obeed, R.S. and Harhash, M.M. 2006. Impact of postharvest treatments on storage life and quality of "Mexican" lime. **Advanced Agricultural Research** 11: 533-549.

Payll, R.E. and Chen, N.J. 2000. Heat treatment and fruits ripening. **Postharvest Biology and Technology** 21: 31-37.

Pongsomboon, W. 2004. **Commercial production of lime**. Horticultural Research of Pichit province. Department of Agriculture. Bangkok. pp 67.

Porat, R., Daus, A., Weiss, B., Cohen, L., Fallik, E. and Droby, S. 2000. Reduction of postharvest decay in organic citrus fruit by a short hot water brushing treatment. **Postharvest Biology and Technology** 18: 151-157.

Porat, R., Weiss, B., Cohen, L., Vinokur, V., Pavoncello, D., Daus, A. and Droby, S. 2000. Induction of grapefruit resistance to *Penicillium digitatum* by chemical, physical and biological elicitors. In: **Proceedings International Society Citri Culture XI CONGRESS**: 1146-1148.

Porat, R., Weiss, B., Cohen, L., Daus, A. and Aharoni, N. 2004. Reduction of postharvest rind disorders in citrus fruit by modified atmosphere packaging. **Postharvest Biology and Technology** 33: 35-43

Prusky, D., Fuchs, Y., Kobiler, I., Roth, I., Weksler, A., Shalom, Y., Fallik, E., Zaurberman, G., Pesis, E., Akerman, M., Yekutieli, O., Wiseblum, A., Regev, R. and Artes, L. 1999. Effect of hot water brushing, prochloraz treatment and waxing on the incidence of black spot decay caused by *Alternaria alternate* in mango fruit. **Postharvest Biology and Technology** 15: 165-174.

Ramful, D., Bahorunb, T., Bourdonc, E., Tarnusc, E. and Aruoma, O.I. 2010. Bioactive phenolics and antioxidant propensity of flavedo extracts of Mauritian citrus fruits: Potential prophylactic ingredients for functional foods application. **Toxicology** 278: 75-87.

Rivera, F., Pelayo-Zaldivar, C., Leon, F.D., Buentello, B. and Castillo-Rivera, M. 2007. Cold-conditioning treatment reduces chilling injury in Mexican limes (*Citrus aurantifolia* S.) stored at different temperatures. **Food Quality** 30: 121-134.

Rodov, V., Agar, T., Peretz, J., Nafussia, B., Kim, J.J. and Ben-Yehoshua, S. 2000. Effect of combined application of heat treatments and plastic packaging on keeping quality of 'Oroblanco' fruit (*Citrus grandis* L.C. paradisi Macf.). **Postharvest Biology and Technology** 20: 287-294.

Rodov, V., Ben-Yehoshua, S., Albagli, R. and Fang, D.Q. 1994. Reducing chilling injury and decay of stored citrus fruit by hot water dips. **Postharvest Biology and Technology** 5: 119-127.

Rodriguez, S., CasÓlibaa, R.M., Questaa, A.G. and Felker, P. 2005. Hot water treatment to reduce chilling injury and fungal development and improve visual quality of two *Opuntia ficus* Indica fruit clones. **Arid Environments** 63: 366-378.

Sala, J.M. and Lafuente, M.T. 2000. Catalase enzyme activity is related to tolerance of mandarin fruits to chilling. **Postharvest Biology and Technology** 20: 81-89.

Saltveit, M.E., 2000. Wound induced changes in phenolic metabolism and tissue browning are altered by heat shock. **Postharvest Biology and Technology** 21: 61-69.

Sangchot, S., Knewhom, N. and Luxanapisuth, S. 2008. Control of green mold rot of citrus caused by *Penicillium digitatum*, with partial purified extract of curcuma and chitosan. **Agricultural Science** 39: 23-26.

Sapayasarn, P., Nimitkeatkai, H., Techavuthiporn, C. and Wongs-Aree, C. 2008. Comparative study between hot water and hot vapour treatments on ripening quality of 'Nam Dok Mai' mango. **Agricultural Science** 39: 91-94.

Schirra, M. and D'hallewin, G., 1997. Storage performance of Fortune mandarins following hot water dips. **Postharvest Biology and Technology** 10: 229-238.

Schirra, M. and Mulas, M. 1995a. Improving storability of 'Tarocco' oranges by postharvest hot-dip fungicide treatments. **Postharvest Biology and Technology** 6: 129-138.

Schirra, M. and Mulas, M. 1995b. Influence of postharvest hot-water dip and imazalil fungicide treatments on cold-stored 'Di Massa' lemons. **Advances in Horticultural Science** 1: 43-46.

Schirra, M., Mulas, M., Fadda, A., Mignani, I. and Lurie, S. 2005. Chemical and quality traits of 'Olinda' and 'Campbell' oranges after heat treatment at 44 or 46 ºC for fruit fly disinfestations. **Food Science and Technology** 38: 519-527.

Shellie, K.C. and Mangan, R.L. 1994. Disinfestation: effect of non-chemical treatments on market quality of fruit. In: B.R., Champ. (Ed.), **Postharvest Handling of Tropical Fruits. ACIAR Proceedings**. pp. 304–310.

Shin Y., Liu, R.H., Nock, J.F., Holliday, D. and Watkins, C.B. 2007. Temperature and relative humidity effects on quality, total ascorbic acid, phenolics and flavonoid concentrations, and antioxidant activity of strawberry. **Postharvest Biology and Technology** 45: 349-357.

Silveira, A.C., Aguayo, E., Escalona, V.H. and Artés, F. 2011. Hot water treatment and peracetic acid to maintain fresh-cut Galia melon quality. **Innovative Food Science and Emerging Technologies** 12: 569-576.

Siomos, A.S., Gerasopoulos, D., Tsouvaltzis, P. and Koukounaras, A. 2010. Effects of heat treatment on atmospheric composition and color of peeled white asparagus in modified atmosphere packaging. **Innovative Food Science and Emerging Technologies** 11: 118-122.

Smilanick, J.L., Mackey, B.E., Reese, R., Usall, J. and Margosan, D.A. 1997. Influence of concentration of soda ash, temperature, and immersion period on the control of postharvest green mold of oranges. **Plant disease** 81: 379-382.

Smilanick, J.L., Margosan, D.A. and Henson, D.J. 1995. Evaluation of heated solutions of sulfur dioxide, ethanol and hydrogen peroxide to control postharvest green mold of lemons. **Plant disease** 79: 742-747.

Siriphanich, J. 2001. **Physiology postharvest technology of fruits and vegetables.** Bangkok: Kasetsart university press. pp. 369.

Srilaong, V., Aiamla-or, S., Soontornwat, A., Shigyo, M. and Yamauchi, N., 2011. UV-B irradiation retards chlorophyll degradation in lime (Citrus latifolia Tan.) fruit. **Postharvest Biology and Technology** 59: 110–112.

Tian, S.P., Yao, H.J., Deng, X., Xu, X.B., Qin, G.Z. and Chan, Z.L. 2007. Characterization and expression of ß-1,3-glucanase genes in jujube fruit

induced by the microbial biocontrol agent *Cryptococcus laurentii*. **Phytopathology** 97: 260-268.

Timmer, L.W., Garnsey, S.M. and Graham, L.H. 2000. **Compendium of Citrus Diseases**. APS Press, Minnesota. pp 92.

Timmer, L.W., Garnsey, S.M. and Broadbent, P. 2003. Disease of citrus. In: R.C., Ploetz. (ED.), **Diseases of Tropical Fruit Crops**. CABI Publishing, London. pp. 163-180.

Tin, O.W., Varit, S., Julian, H., Khin , L.K., and Sirichai, K. 2006. Effects of different concentrations of 1-MCP on the yellowing of West Indian lime (*Citrus aurantifolia*, Swingle) fruit. **Postharvest Biology and Technology** 42 : 23-30.

Tsuji, M., Harakawa, H. and Komiyama, Y. 1984. Changes in shelf life and quality of plum fruit during storage at high temperatures. **Japanese Society for Horticultural Science** 52: 469-473.

Valero, D., Martínez-Romero, D., Serrano, M. and Riquelme, F. 1998. Postharvest gibberellins and heat treatment effects on polyamines, abscisic acid and firmness in lemons. **Food Science** 63: 611-615.

Wild, B.L. 1993. Reduction of chilling injury in grapefruit and oranges stored at 1°C by prestorage hot dip treatments, curing, and wax application. **Experimental Agriculture** 33: 495-498.

Win, T.O., Srilaong, V., Heyes, J., Kyu, K.L. and Kanlayanarat S. 2006. Effects of different concentrations of 1-MCP on the yellowing of West Indian lime (*Citrus aurantifolia* Swingle) fruit. **Postharvest Biology and Technology** 42: 23-30.

Whiteside, J.O., Garnsey, S.M. and Timmer, L.W. 1988. **Compendium of citrus diseases.** American Phytopathological Society, St. Paul, Minnesota. pp. 80.

Zhang, Z., Nakano, K. and Maezawa, S. 2009. Comparison of the antioxidant enzymes of broccoli after cold or heat shock treatment at different storage temperatures. **Postharvest Biology and Technology** 54: 101-105.

Zuo, L., Lee, E.J. and Lee, J.H., 2004. Effect of hot water treatment on quality of fresh-cut apple cubes. **Food Science and Biotechnology** 13: 821-825.

APPENDICE

Table A1. Percentage of weight loss of lime after hot water treatment and packed in modified polypropylene packaging then stored at 25 ºC for 4 weeks.

(A)

Treatment	Percentages of weight loss			
	w.1	w.2	w.3	w.4
control+PP	3.33±0.10[b]	3.59±0.10[b]	4.02±0.10[b]	4.34±0.10[b]
control+HPCH	2.74±0.06[a]	3.24±0.09[a]	3.60±0.09[a]	4.01±0.11[a]
control+MPPCH	2.95±0.10[a]	3.30±0.10[a]	3.62±0.11[a]	3.97±0.12[a]

(B)

Treatment	Percentages of weight loss			
	w.1	w.2	w.3	w.4
Pen+HWT+PP	2.96±0.12[a]	3.12±0.13[a]	3.24±0.11[b]	3.75±0.18[a]
Pen+HWT+HPCH	2.83±0.12[a]	3.03±0.12[a]	3.37±0.14[a]	3.99±0.20[a]
Pen+HWT+MPPCH	3.34±0.15[b]	3.61±0.13[b]	3.96±0.14[b]	4.61±0.20[b]

(C)

Treatment	Percentages of weight loss			
	w.1	w.2	w.3	w.4
HWT+PP	4.85±0.18[b]	5.00±0.18[a]	5.29±0.17[a]	5.58±0.22[a]
HWT+HPCH	4.44±0.12[ab]	4.71±0.14[a]	5.06±0.15[a]	5.48±0.22[a]
HWT+MPPCH	4.32±0.21[a]	4.89±0.31[a]	5.04±0.35[a]	5.53±0.50[a]

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$. HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE.

Table A2. L value of lime after hot water treatment and packed in modified polypropylene packaging then stored at 25 ºC for 4 weeks.

(A)

Treatment	L value				
	w.0	w.1	w.2	w.3	w.4
control+PP	48.39±066 [a]	56.07±1.18 [a]	66.99±0.89 [ab]	69.85±0.36 [a]	64.35±0.25 [a]
control+HPCH	47.24±0.61 [a]	56.50±1.16 [a]	65.50±0.24 [a]	69.93±0.53 [a]	72.07±0.17 [b]
control+MPPCH	48.33±0.67 [a]	58.99±1.04 [a]	67.85±0.94 [b]	70.01±0.45 [a]	64.81±0.30 [a]

(B)

Treatment	L value				
	w.0	w.1	w.2	w.3	w.4
Pen+HWT+PP	47.22±037 [a]	51.12±0.51 [a]	56.85±1.08 [b]	61.16±.44 [b]	62.50±1.27 [b]
Pen+HWT+HPCH	46.65±0.44 [a]	49.44±0.82 [a]	51.37±0.91 [a]	54.72±1.17 [a]	56.85±1.36 [a]
Pen+HWT+MPPCH	46.63±0.61 [a]	50.46±0.74 [a]	52.85±0.70 [a]	57.34±1.29 [a]	60.00±1.18 [ab]

(C)

Treatment	L value				
	w.0	w.1	w.2	w.3	w.4
HWT+PP	46.03±0.49 [a]	49.23±0.62 [a]	54.07±1.00 [a]	60.61±1.22 [b]	64.43±0.95 [b]
HWT+HPCH	47.19±0.51 [a]	50.20±0.70 [ab]	53.22±1.02 [a]	56.44±1.04 [a]	59.48±1.11 [a]
HWT+MPPCH	47.14±0.47 [a]	51.27±0.63 [b]	55.33±1.02 [a]	58.45±1.29 [ab]	61.31±1.35 [ab]

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$. HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE.

Table A3. Hue value of lime after hot water treatment and packed in modified polypropylene packaging then stored at 25 ºC for 4 weeks.

(A)

Treatment	Hue value				
	w.0	w.1	w.2	w.3	w.4
control+PP	108.84±0.38 [a]	102.78±0.89 [a]	94.76±0.90 [a]	89.60±0.41 [a]	87.02±0.34 [a]
control+HPCH	109.16±0.28 [a]	102.55±0.99 [a]	95.53±0.60 [a]	90.08±0.59 [a]	87.16±0.32 [a]
control+MPPCH	108.61±0.31 [a]	100.64±0.73 [a]	93.73±0.83 [a]	89.58±0.55 [a]	86.87±0.36 [a]

(B)

Treatment	Hue value				
	w.0	w.1	w.2	w.3	w.4
Pen+HWT+PP	104.28±0.38 [a]	97.71±0.46 [a]	92.28±0.92 [a]	88.51±1.43 [a]	85.44±1.47 [a]
Pen+HWT+HPCH	105.01±0.37 [a]	99.40±0.58 [b]	97.22±0.81 [b]	95.90±1.10 [b]	94.18±1.24 [b]
Pen+HWT+MPPCH	105.31±0.42 [a]	99.42±0.50 [b]	97.16±0.54 [b]	94.49±1.07 [b]	91.89±1.11 [b]

(C)

Treatment	Hue value				
	w.0	w.1	w.2	w.3	w.4
HWT+PP	105.49±038 [a]	99.73±0.50 [a]	95.05±0.78 [a]	90.87±1.04 [a]	85.59±0.77 [a]
HWT+HPCH	104.50±0.43 [a]	98.44±0.57 [a]	95.59±0.86 [a]	94.19±1.03 [b]	91.11±1.15 [b]
HWT+MPPCH	104.56±0.36 [a]	99.12±0.49 [a]	94.41±0.82 [a]	92.53±1.16 [ab]	89.68±1.34 [b]

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$. HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE.

Table A4. Total phenolic content of lime after hot water treatment and packed in modified polypropylene packaging then stored at 25 ºC for 4 weeks.

(A) Treatment	Total phenolic content (µg/g FW)				
	w.0	w.1	w.2	w.3	w.4
control+PP	6293.20±0.00 [a]	7465.94±458.59 [a]	4145.22±298.13 [a]	8471.71±128.43 [a]	6098.54±771.63 [a]
control+HPCH	6293.20±0.00 [a]	7223.85±607.68 [a]	5287.91±443.72 [b]	7553.80±653.34 [a]	5234.77±323.77 [a]
control+MPPCH	6293.20±0.00 [a]	7549.37±389.19 [a]	3971.82±184.89 [a]	8393.44±384.43 [a]	6965.02±397.98 [a]

(B) Treatment	Total phenolic content (µg/g FW)				
	w.0	w.1	w.2	w.3	w.4
Pen+HWT+PP	6293.20±0.00 [a]	5829.27±482.08 [a]	4328.02±391.88 [b]	3807.37±556.82 [a]	7263.64±215.65 [a]
Pen+HWT+HPCH	6293.20±0.00 [a]	4605.38±85.86 [a]	4017.43±350.78 [ab]	3746.99±545.74 [a]	6271.81±20.20 [a]
Pen+HWT+MPPCH	6293.20±0.00 [a]	6007.01±456.71 [a]	3185.41±228.88 [a]	3066.91±706.90 [a]	6858.11±171.81 [a]

(C) Treatment	Total phenolic content (µg/g FW)				
	w.0	w.1	w.2	w.3	w.4
HWT+PP	6293.20±0.00 [a]	5946.09±990.96 [a]	4034.32±556.83 [a]	3568.24±468.38 [b]	4925.38±133.45 [a]
HWT+HPCH	6293.20±0.00 [a]	4364.97±410.70 [a]	3597.45±415.49 [a]	2144.97±150.69 [a]	5128.98±112.73 [a]
HWT+MPPCH	6293.20±0.00 [a]	5098.55±221.26 [a]	3931.51±272.27 [a]	3871.71±270.82 [b]	7919.87±264.26 [b]

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$.

HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE.

Table A5. Ascorbic acid content of lime after hot water treatment and packed in modified polypropylene packaging then stored at 25 ºC for 4 weeks.

(A)

Treatment	Ascorbic acid concentration (mg/g FW)				
	w.0	w.1	w.2	w.3	w.4
control+PP	1.56±0.00 [a]	1.38±0.12 [a]	1.81±0.08 [a]	1.69±0.09 [b]	1.96±0.07 [a]
control+HPCH	1.56±0.00 [a]	1.77±0.10 [a]	1.49±0.13 [a]	1.72±0.13 [b]	1.97±0.28 [a]
control+MPPCH	1.56±0.00 [a]	1.44±0.20 [a]	1.30±0.25 [a]	1.25±0.15 [a]	1.95±0.24 [a]

(B)

Treatment	Ascorbic acid concentration (mg/g FW)				
	w.0	w.1	w.2	w.3	w.4
Pen+HWT+PP	1.56±0.00 [a]	1.67±0.26 [a]	1.09±0.29 [a]	1.03±0.09 [a]	0.70±0.07 [a]
Pen+HWT+HPCH	1.56±0.00 [a]	1.61±0.24 [a]	0.74±0.26 [a]	0.97±0.24 [a]	0.83±0.13 [a]
Pen+HWT+MPPCH	1.56±0.00 [a]	1.17±0.21 [a]	0.93±0.02 [a]	0.74±0.28 [a]	0.79±0.03 [a]

(C)

Treatment	Ascorbic acid concentration (mg/g FW)				
	w.0	w.1	w.2	w.3	w.4
Hot+PP	1.56±0.00 [a]	1.03±0.07 [a]	1.17±0.01 [a]	0.69±0.21 [a]	1.30±0.36 [a]
Hot+HPCH	1.56±0.00 [a]	1.42±0.20 [a]	0.91±0.03 [a]	1.33±0.12 [b]	1.02±0.08 [a]
Hot+MPPCH	1.56±0.00 [a]	1.27±0.35 [a]	1.29±0.19 [a]	1.22±0.05 [b]	1.16±0.13 [a]

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$. HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE.

Table A6. Total Soluble Solids of lime after hot water treatment and packed in modified polypropylene packaging then stored at 25 ºC for 4 weeks.

(A)

Treatment	Total Soluble Solids (°Brix)				
	w.0	w.1	w.2	w.3	w.4
control+PP	9.51±0.00 [a]	8.88±031 [a]	9.13±0.13 [a]	8.67±0.17 [a]	8.73±0.29 [a]
control+HPCH	9.51±0.00 [a]	9.75±0.25 [b]	8.88±0.31 [a]	8.63±0.43 [a]	8.28±0.49 [a]
control+MPPCH	9.51±0.00 [a]	9.50±0.20 [ab]	9.38±0.13 [a]	8.50±0.29 [a]	8.38±0.24 [a]

(B)

Treatment	Total Soluble Solids (°Brix)				
	w.0	w.1	w.2	w.3	w.4
Pen+HWT+PP	9.51±0.00 [a]	8.75±0.39 [a]	8.15±0.10 [a]	8.35±0.10 [a]	9.20±0.29 [a]
Pen+HWT+HPCH	9.51±0.00 [a]	8.25±0.32 [a]	7.90±0.06 [a]	8.20±0.08 [a]	9.07±0.35 [a]
Pen+HWT+MPPCH	9.51±0.00 [a]	8.30±0.24 [a]	7.90±0.10 [a]	8.30±0.10 [a]	9.45±0.61 [a]

(C)

Treatment	Total Soluble Solids (°Brix)				
	w.0	w.1	w.2	w.3	w.4
HWT+HPCH	9.51±0.00 [a]	7.85±0.15 [a]	8.10±0.00 [a]	8.20±0.40 [a]	8.93±0.40 [a]
HWT+MPPCH	9.51±0.00 [a]	8.00±0.17 [a]	8.25±0.17 [a]	8.80±0.34 [a]	9.73±0.07 [a]
HWT+PP	9.51±0.00 [a]	7.75±0.27 [a]	8.00±0.19 [a]	8.60±0.24 [a]	9.00±0.37 [a]

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$. HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE.

Table A7. Respiration rate of lime after hot water treatment and packed in modified polypropylene packaging then stored at 25 ºC for 4 weeks.

(A)

Treatment	Respiration rate (mg CO_2/kg.hr)				
	w.0	w.1	w.2	w.3	w.4
control+PP	15.72±0.00 [a]	8.21±0.71 [a]	12.33±0.57 [a]	9.67±0.89 [a]	8.53±0.68 [a]
control+HPCH	15.72±0.00 [a]	10.60±0.82 [a]	12.89±0.26 [a]	10.02±0.18 [a]	10.34±1.37 [a]
control+MPPCH	15.72±0.00 [a]	25.39±4.42 [b]	11.21±0.56 [a]	11.04±1.30 [a]	10.89±0.95 [a]

(B)

Treatment	Respiration rate (mg CO_2/kg.hr)				
	w.0	w.1	w.2	w.3	w.4
Pen+HWT+PP	15.72±0.00 [a]	7.21±0.18 [a]	4.48±0.49 [a]	33.21±2.95 [b]	46.95±7.07 [a]
Pen+HWT+HPCH	15.72±0.00 [a]	5.25±0.59 [a]	5.78±0.52 [a]	23.71±2.26 [a]	33.53±3.20 [a]
Pen+HWT+MPPCH	15.72±0.00 [a]	5.38±0.87 [a]	4.97±0.70 [a]	21.20±2.11 [a]	40.38±5.47 [a]

(C)

Treatment	Respiration rate (mg CO_2/kg.hr)				
	w.0	w.1	w.2	w.3	w.4
HWT+PP	15.72±0.00 [a]	11.75±2.47 [b]	5.92±0.24 [a]	30.26±6.67 [a]	56.18±6.52 [b]
HWT+HPCH	15.72±0.00 [a]	5.87±0.37 [a]	4.79±0.61 [a]	34.82±6.26 [a]	18.03±2.70 [a]
HWT+MPPCH	15.72±0.00 [a]	7.35±0.75 [ab]	5.17±0.29 [a]	28.85±1.97 [a]	63.16±8.94 [b]

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$. HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE.

Table A8. Catalase activity of lime after hot water treatment and packed in modified polypropylene packaging then stored at 25 ºC for 4 weeks.

(A) Treatment	Catalase activity (units/mg protein)				
	w.0	w.1	w.2	w.3	w.4
control+PP	303.65±0.00 [a]	279.43±63.05 [b]	445.74±135.57 [b]	537.58±41.48 [a]	214.27±47.31
control+HPCH	303.65±0.00 [a]	179.41±16.14 [a]	96.33±24.19 [a]	510.44±28.27 [a]	356.12±23.07
control+MPPCH	303.65±0.00 [a]	26.27±3.03 [a]	324.70±19.63 [ab]	751.38±36.31 [b]	204.31±34.68

(B) Treatment	Catalase activity (units/mg protein)				
	w.0	w.1	w.2	w.3	w.4
Pen+HWT+PP	303.65±0.00 [a]	328.96±53.62 [a]	541.96±27.82 [a]	500.43±45.77 [a]	205.69±50.40 [a]
Pen+HWT+HPCH	303.65±0.00 [a]	288.64±27.06 [a]	427.32±159.58 [a]	524.20±71.60 [a]	289.79±55.71 [a]
Pen+HWT+MPPCH	303.65±0.00 [a]	289.44±22.99 [a]	454.19±38.83 [a]	544.08±66.10 [a]	219.80±37.69 [a]

(C) Treatment	Catalase activity (units/mg protein)				
	w.0	w.1	w.2	w.3	w.4
HWT+PP	303.65±0.00 [a]	314.26±27.95 [a]	545.99±47.73 [a]	524.80±164.85 [a]	152.95±17.06 [a]
HWT+HPCH	303.65±0.00 [a]	313.14±34.56 [a]	513.75±19.82 [a]	590.10±130.95 [a]	284.90±43.40 [b]
HWT+MPPCH	303.65±0.00 [a]	286.66±39.17 [a]	476.82±149.79 [a]	592.08±74.30 [a]	197.96±44.76 [ab]

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$

HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE.

Table A9. Ascorbate peroxidase activity of lime after hot water treatment and packed in modified polypropylene packaging then stored at 25 ºC for 4 weeks.

(A) Treatment	Ascorbate peroxidase activity (units/mg protein)				
	w.0	w.1	w.2	w.3	w.4
control+PP	3741.10±0.00 [a]	2542.58±89.68 [c]	2000.26±824.36 [ab]	5153.27±876.52 [b]	2015.51±51.01 [a]
control+HPCH	3741.10±0.00 [a]	161.96±67.56 [a]	503.19±75.97 [a]	3572.34±762.16 [ab]	3700.69±196.90 [a]
control+MPPCH	3741.10±0.00 [a]	974.06±125.63 [b]	2750.98±403.72 [b]	2315.55±482.46 [a]	468.26±331.83 [a]

(B) Treatment	Ascorbate peroxidase activity (units/mg protein)				
	w.0	w.1	w.2	w.3	w.4
Pen+HWT+PP	3741.10±0.00 [a]	2999.41±451.39 [a]	3297.62±142.36 [a]	5857.96±455.32 [b]	410.71±170.61 [b]
Pen+HWT+HPCH	3741.10±0.00 [a]	1763.57±430.09 [a]	2489.28±81.01 [a]	5903.39±302.31 [b]	1749.96±522.53 [a]
Pen+HWT+MPPCH	3741.10±0.00 [a]	3102.00±591.69 [a]	3125.68±262.89 [a]	2202.18±382.18 [a]	580.08±115.08 [a]

(C) Treatment	Ascorbate peroxidase activity (units/mg protein)				
	w.0	w.1	w.2	w.3	w.4
HWT+PP	3741.10±0.00 [a]	1654.84±749.48 [a]	6327.53±360.73 [a]	8147.58±414.15 [a]	803.24±64.54 [a]
HWT+HPCH	3741.10±0.00 [a]	2837.37±294.34 [a]	535.15±45.20 [a]	2761.19±129.99 [a]	757.84±100.35 [a]
HWT+MPPCH	3741.10±0.00 [a]	2397.18±674.61 [a]	2876.94±114.85 [a]	4674.76±108.39 [a]	491.68±150.02 [a]

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$.

HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE.

Table A10. Percentages of weight loss of lime after hot water treatment and packed in modified polypropylene packaging then stored at 10 ºC for 6 weeks.

(A) Treatment	Percentages of weight loss					
	w.1	w.2	w.3	w.4	w.5	w.6
control+PP	0.58±0.04[a]	0.82±0.06[a]	1.27±0.11[a]	1.55±0.15[a]	1.81±0.15[a]	2.08±0.17[a]
control+HPCH	0.83±0.07[b]	1.76±0.16[b]	2.40±0.19[c]	2.89±0.19[b]	3.65±0.25[b]	4.34±0.28[b]
control+MPPCH	0.72±0.07[ab]	0.98±0.10[a]	1.83±0.20[b]	2.69±0.24[b]	3.49±0.34[b]	4.51±0.35[b]

(B) Treatment	Percentages of weight loss					
	w.1	w.2	w.3	w.4	w.5	w.6
Pen+HWT+PP	0.55±0.04[a]	0.74±0.04[a]	0.93±0.05[a]	1.18±0.07[a]	1.67±0.10[a]	1.99±0.11[a]
Pen+HWT+HPCH	0.58±0.10[a]	1.27±0.12[b]	1.73±0.16[b]	2.74±0.21[b]	3.52±0.22[b]	4.45±0.24[a]
Pen+HWT+MPPCH	0.64±0.10[a]	1.10±0.14[b]	2.06±0.21[b]	2.64±0.21[b]	3.45±0.20[b]	4.24±0.25[a]

(C) Treatment	Percentages of weight loss					
	w.1	w.2	w.3	w.4	w.5	w.6
HWT+PP	0.27±0.02[a]	0.72±0.10[ab]	1.00±0.11[a]	1.51±0.24[a]	1.76±0.27[a]	2.01±0.27[a]
HWT+HPCH	0.32±0.10[a]	0.90±20.15[b]	1.77±0.26[b]	2.89±0.32[b]	3.98±0.45[b]	4.89±0.49[b]
HWT+MPPCH	0.23±0.02[a]	0.47±0.05[a]	0.92±0.11[a]	1.28±0.12[a]	1.85±0.13[a]	2.12±0.13[a]

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$.

HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE

Table A11. L value of lime after hot water treatment and packed in modified polypropylene packaging then stored at 10 ºC for 6 weeks.

(A) Treatment	L value						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
control+PP	48.32±0.66 [a]	52.18±0.67 [a]	54.25±0.63 [a]	57.05±0.67 [a]	60.19±0.64 [ab]	62.65±0.67 [a]	64.50±0.62 [a]
control+HPCH	47.30±0.44 [a]	51.37±0.47 [a]	53.94±0.46 [a]	56.73±0.59 [a]	59.83±0.57 [a]	63.07±0.54 [a]	64.60±0.50 [a]
control+MPPCH	48.94±0.77 [a]	53.11±0.86 [a]	55.90±0.85 [a]	58.63±0.79 [a]	61.92±0.69 [b]	64.42±0.60 [a]	65.58±0.52 [a]

(B) Treatment	L value						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
Pen+HWT+PP	50.72±0.55 [b]	53.99±0.60 [b]	56.50±0.57 [b]	58.63±0.65 [a]	61.56±0.67 [a]	63.31±0.66 [a]	64.54±0.58 [a]
Pen+HWT+HPCH	48.17±0.45 [a]	51.69±0.58 [a]	54.10±0.59 [a]	56.63±0.70 [a]	59.85±0.73 [a]	62.40±0.69 [a]	63.80±0.64 [a]
Pen+HWT+MPPCH	49.10±0.65 [a]	53.07±0.70 [ab]	55.61±0.60 [ab]	58.06±0.72 [a]	61.00±0.65 [a]	63.46±0.67 [a]	64.37±0.61 [a]

(C) Treatment	L value						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
HWT+PP	47.63±0.46 [a]	51.62±0.53 [a]	54.69±0.47 [a]	56.94±0.47 [a]	60.88±0.54 [a]	63.13±0.46 [a]	64.58±0.46 [a]
HWT+HPCH	46.97±0.60 [a]	50.79±0.60 [a]	53.95±0.61 [a]	56.39±0.69 [a]	59.86±0.84 [a]	61.84±0.82 [a]	63.06±0.76 [a]
HWT+MPPCH	47.33±0.46 [a]	51.85±0.59 [a]	54.40±0.62 [a]	57.13±0.65 [a]	60.78±0.67 [a]	63.25±0.61 [a]	65.08±0.59 [a]

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$.

HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE

Table A12. Hue value of lime after hot water treatment and packed in modified polypropylene packaging then stored at 10 ºC for 6 weeks.

(A) Treatment	Hue value						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
control+PP	102.57±0.37 [a]	101.27±0.41 [a]	99.97±0.43 [b]	97.88±0.48 [a]	95.46±0.51 [b]	92.86±0.54 [a]	90.62±0.53 [a]
control+HPCH	103.25±0.27 [a]	101.24±0.32 [a]	100.34±0.35 [b]	98.17±0.40 [a]	95.98±0.44 [b]	93.13±0.43 [a]	90.45±0.43 [a]
control+MPPCH	102.86±0.45 [a]	100.52±0.57 [a]	98.66±0.54 [a]	96.84±0.61 [a]	94.01±0.5 [a]	91.89±0.54 [a]	90.02±0.51 [a]

(B) Treatment	Hue value						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
Pen+HWT+PP	101.70±0.35 [a]	99.92±0.37 [a]	98.59±0.42 [a]	96.68±0.45 [a]	94.09±0.58 [a]	91.95±0.56 [a]	90.55±0.55 [a]
Pen+HWT+HPCH	103.35±0.27 [b]	101.71±0.37 [b]	100.52±0.44 [b]	98.39±0.53 [b]	95.64±0.60 [a]	93.74±0.55 [b]	91.40±0.55 [a]
Pen+HWT+MPPCH	101.94±0.39 [a]	100.06±0.41 [a]	99.13±0.39 [a]	97.01±0.48 [ab]	94.32±0.49 [a]	92.48±0.53 [ab]	90.50±0.51 [a]

(C) Treatment	Hue value						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
HWT+PP	102.60±0.30 [a]	100.86±0.40 [a]	99.64±0.38 [a]	97.64±0.42 [a]	94.67±0.47 [a]	92.40±0.47 [a]	90.32±0.42 [a]
HWT+HPCH	103.46±0.31 [a]	101.75±0.36 [a]	100.46±0.40 [a]	98.52±0.50 [a]	95.23±0.60 [a]	93.29±0.70 [a]	91.45±0.62 [a]
HWT+MPPCH	103.35±0.31 [a]	101.58±0.35 [a]	100.53±0.41 [a]	98.58±0.44 [a]	95.41±0.51 [a]	92.83±0.49 [a]	90.39±0.46 [a]

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$.

HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE

Table A13. Total phenolic content of lime after hot water treatment and packed in modified polypropylene packaging then stored at 10 ºC for 6 weeks.

(A) Treatment	Total phenolic content (mg/g FW)						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
control+PP	10.24±0.00 [a]	8.30±1.10 [a]	11.39±1.42 [b]	7.05±1.21 [a]	5.90±0.93 [a]	8.45±0.33 [b]	7.72±0.84 [ab]
control+HPCH	10.24±0.00 [a]	8.70±0.58 [a]	5.79±1.36 [a]	12.90±1.47 [b]	7.26±0.43 [a]	6.18±0.22 [a]	10.11±0.91 [b]
control+MPPCH	10.24±0.00 [a]	8.01±1.25 [a]	6.51±1.02 [a]	9.09±0.87 [ab]	6.34±0.71 [a]	9.46±0.29 [c]	7.03±0.44 [a]

(B) Treatment	Total phenolic content (mg/g FW)						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
Pen+HWT+PP	10.24±0.00 [a]	11.27±1.07 [b]	6.77±0.85 [a]	10.24±0.95 [ab]	5.22±0.53 [a]	7.58±1.49 [a]	8.82±0.88 [b]
Pen+HWT+HPCH	10.24±0.00 [a]	7.64±0.14 [a]	9.41±0.94 [a]	6.92±0.33 [a]	7.87±0.79 [b]	8.29±1.10 [a]	7.50±0.14 [ab]
Pen+HWT+MPPCH	10.24±0.00 [a]	8.25±0.62 [a]	9.38±0.48 [a]	10.91±1.55 [b]	9.75±0.25 [b]	8.32±0.66 [a]	6.89±0.21 [a]

(C) Treatment	Total phenolic content (mg/g FW)						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
HWT+PP	10.24±0.00 [a]	7.11±1.26 [a]	9.15±2.01 [a]	7.13±0.52 [a]	7.47±1.10 [a]	7.25±1.44 [a]	8.27±0.44 [a]
HWT+HPCH	10.24±0.00 [a]	10.48±0.52 [a]	9.92±0.39 [a]	8.06±0.47 [ab]	8.02±0.87 [a]	9.84±0.14 [a]	8.04±0.36 [a]
HWT+MPPCH	10.24±0.00 [a]	9.35±1.92 [a]	9.97±2.48 [a]	5.77±0.28 [b]	9.05±1.27 [a]	10.43±0.60 [a]	9.15±1.01 [a]

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$.

HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE

Table A14. Ascorbic acid content of lime after hot water treatment and packed in modified polypropylene packaging then stored at 10 ºC for 6 weeks.

(A) Treatment	Ascorbic acid concentration (mg/g FW)						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
control+PP	1.64±0.00 [a]	1.54±0.06 [a]	1.14±0.11 [ab]	1.20±0.24 [a]	1.12±0.22 [a]	1.01±0.08 [a]	0.99±0.17 [a]
control+HPCH	1.64±0.00 [a]	1.41±0.17 [a]	1.35±0.06 [b]	0.69±0.22 [a]	1.61±0.13 [a]	0.88±0.07 [a]	1.49±0.04 [a]
control+MPPCH	1.64±0.00 [a]	1.35±0.14 [a]	1.03±0.06 [a]	0.85±0.10 [a]	1.04±0.11 [a]	1.06±0.06 [a]	0.82±0.23 [a]

(B) Treatment	Ascorbic acid concentration (mg/g FW)						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
Pen+HWT+PP	1.64±0.00 [a]	1.08±0.04 [a]	1.04±0.14 [a]	0.98±0.15 [a]	1.05±0.15 [a]	1.12±0.14 [a]	1.01±0.09 [a]
Pen+HWT+HPCH	1.64±0.00 [a]	1.62±0.32 [a]	0.97±0.11 [a]	1.02±0.09 [a]	0.92±0.11 [a]	1.04±0.05 [a]	1.39±0.07 [a]
Pen+HWT+MPPCH	1.64±0.00 [a]	1.33±0.09 [a]	1.07±0.17 [a]	0.88±0.15 [a]	1.64±0.14 [b]	0.95±0.11 [a]	1.06±0.15 [a]

(C) Treatment	Ascorbic acid concentration (mg/g FW)						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
HWT+PP	1.64±0.00 [a]	1.43±0.14 [a]	1.12±0.25 [a]	0.89±0.11 [a]	0.87±0.07 [a]	1.18±0.09 [a]	1.34±0.25 [a]
HWT+HPCH	1.64±0.00 [a]	1.66±0.13 [a]	1.20±0.11 [a]	0.75±0.02 [a]	1.22±0.06 [b]	1.26±0.19 [a]	0.84±0.04 [a]
HWT+MPPCH	1.64±0.00 [a]	1.82±0.06 [a]	1.87±0.22 [a]	0.90±0.0 [a]	0.79±0.06 [a]	1.85±0.23 [b]	1.10±0.09 [a]

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$.

HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE

Table A15. Total Soluble Solids of lime after hot water treatment and packed in modified polypropylene packaging then stored at 10 ºC for 6 weeks.

(A) Treatment	Total Soluble Solids (°Brix)						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
control+PP	9.51±0.00 [a]	9.30±0.40 [a]	9.00±0.20 [a]	10.00±0.68 [a]	9.25±0.43 [a]	8.60±0.36 [a]	8.20±0.64 [a]
control+HPCH	9.51±0.00 [a]	9.10±0.45 [a]	9.50±0.29 [a]	8.63±0.31 [a]	9.63±0.63 [a]	9.30±0.34 [a]	8.20±0.32 [a]
control+MPPCH	9.51±0.00 [a]	8.75±0.30 [a]	9.38±0.69 [a]	9.25±0.14 [a]	9.00±0.00 [a]	8.25±0.26 [a]	7.85±0.32 [a]

(B) Treatment	Total Soluble Solids (°Brix)						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
Pen+HWT+PP	9.51±0.00 [a]	9.30±0.39 [a]	9.63±0.55 [a]	9.25±0.32 [a]	9.50±0.20 [a]	9.15±0.38 [b]	7.70±0.17 [a]
Pen+HWT+HPCH	9.51±0.00 [a]	8.95±0.46 [a]	10.00±0.54 [a]	9.50±0.65 [a]	9.38±0.38 [a]	8.30±0.24 [ab]	8.35±0.24 [a]
Pen+HWT+MPPCH	9.51±0.00 [a]	9.60±0.65 [a]	10.63±0.55 [a]	10.00±0.54 [a]	10.25±0.95 [a]	8.15±0.15 [a]	8.00±0.24 [a]

(C) Treatment	Total Soluble Solids (°Brix)						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
HWT+PP	9.51±0.00 [a]	9.70±0.33 [a]	8.88±0.24 [a]	9.25±0.35 [a]	10.25±0.52 [a]	8.95±0.17 [ab]	9.10±0.60 [a]
HWT+HPCH	9.51±0.00 [a]	9.50±0.33 [a]	9.38±0.29 [a]	9.50±0.38 [a]	9.88±0.52 [a]	8.30±0.53 [a]	9.30±0.45 [a]
HWT+MPPCH	9.51±0.00 [a]	9.65±0.51 [a]	9.50±0.43 [a]	9.38±0.25 [a]	9.13±0.48 [a]	9.50±0.13 [b]	9.10±0.49 [a]

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$.

HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE

Table A16. Respiration rate of lime after hot water treatment and packed in modified polypropylene packaging then stored at 10 ºC for 6 weeks.

(A) Treatment	Respiration rate (mg CO_2/kg.hr)						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
control+PP	8.55±0.00 [a]	4.55±0.58 [a]	10.76±0.57 [b]	18.48±1.44 [a]	17.58±1.73 [c]	22.72±0.66 [a]	17.39±0.78 [c]
control+HPCH	8.55±0.00 [a]	3.26±0.04 [a]	7.31±0.23 [a]	11.59±1.30 [a]	12.54±0.31 [a]	18.70±1.97 [a]	13.16±1.66 [a]
control+MPPCH	8.55±0.00 [a]	3.94±0.58 [a]	12.49±0.47 [c]	14.05±1.15 [a]	22.35±2.98 [ab]	15.53±3.25 [a]	14.70±0.72 [ab]

(B) Treatment	Respiration rate (mg CO_2/kg.hr)						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
Pen+HWT+PP	8.55±0.00 [a]	3.54±0.34 [a]	9.09±0.13 [a]	20.91±1.20 [b]	17.93±2.89 [a]	19.66±1.53 [c]	20.76±1.16 [b]
Pen+HWT+HPCH	8.55±0.00 [a]	3.39±0.43 [a]	8.35±0.90 [a]	12.25±0.95 [a]	17.54±0.87 [a]	13.13±1.42 [a]	15.31±1.73 [a]
Pen+HWT+MPPCH	8.55±0.00 [a]	3.15±0.35 [a]	9.83±0.23 [a]	15.35±1.00 [a]	14.06±0.57 [a]	14.88±1.43 [ab]	14.38±0.47 [a]

(C) Treatment	Respiration rate (mg CO_2/kg.hr)						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
HWT+PP	8.55±0.00 [a]	3.35±0.86 [b]	7.58±0.72 [b]	12.80±1.38 [b]	16.36±2.72 [a]	14.34±2.38 [a]	14.70±1.45 [a]
HWT+HPCH	8.55±0.00 [a]	3.57±0.03 [a]	9.73±0.37 [a]	10.06±1.12 [a]	16.17±2.66 [a]	17.85±1.44 [a]	13.92±0.83 [a]
HWT+MPPCH	8.55±0.00 [a]	5.88±0.37 [a]	9.92±0.22 [b]	24.83±1.02 [a]	17.02±0.68 [a]	15.57±0.91 [a]	17.09±0.40 [a]

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$.

HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE

Table A17. Catalase activity of lime after hot water treatment and packed in modified polypropylene packaging then stored at 10 ºC for 6 weeks.

(A) Treatment	Catalase activity (units/mg protein)						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
control+PP	342.78±0.00 [a]	44.13±13.12 [a]	83.24±24.42 [a]	149.23±24.29 [b]	31.62±5.73 [a]	38.05±4.86 [a]	30.91±2.22 [b]
control+HPCH	342.78±0.00 [a]	40.23±12.56 [a]	48.10±5.19 [a]	85.96±5.78 [a]	32.37±5.55 [a]	35.35±4.15 [a]	27.08±1.97 [ab]
control+MPPCH	342.78±0.00 [a]	115.56±17.56 [b]	42.97±9.21 [a]	65.19±1.30 [a]	28.30±2.80 [a]	83.82±26.13 [a]	22.28±1.51 [a]

(B) Treatment	Catalase activity (units/mg protein)						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
Pen+HWT+PP	342.78±0.00 [a]	34.38±8.04 [a]	63.42±7.42 [a]	35.67±4.15 [a]	53.96±21.07 [a]	60.68±29.79 [a]	24.20±2.67 [a]
Pen+HWT+HPCH	342.78±0.00 [a]	85.68±9.24 [b]	79.79±8.37 [a]	29.59±5.23 [a]	54.56±6.71 [a]	65.63±10.27 [a]	35.88±0.99 [b]
Pen+HWT+MPPCH	342.78±0.00 [a]	38.28±15.59 [a]	47.61±13.78 [a]	89.60±15.16 [b]	36.03±21.16 [a]	56.41±5.44 [a]	17.10±3.60 [a]

(C) Treatment	Catalase activity (units/mg protein)						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
HWT+PP	342.78±0.00 [a]	49.66±6.20 [a]	49.57±11.55 [a]	87.46±20.83 [b]	235.54±65.19 [a]	45.77±3.49 [a]	49.11±6.48 [b]
HWT+HPCH	342.78±0.00 [a]	67.99±8.16 [a]	55.77±7.36 [a]	88.11±3.13 [b]	185.79±64.10 [a]	71.44±1.84 [b]	24.65±4.14 [a]
HWT+MPPCH	342.78±0.00 [a]	59.00±6.79 [a]	36.91±1.64 [a]	40.06±7.71 [a]	69.55±8.11 [a]	27.37±9.94 [a]	17.63±2.30 [a]

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$.

HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE

Table A18. Ascorbate peroxidase activity of lime after hot water treatment and packed in modified polypropylene packaging then stored at 10 ºC for 6 weeks.

(A) Treatment	Ascorbate peroxidase activity (units/mg protein)						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
control+PP	6300.96±0.00 [a]	875.90±284.44 [a]	4195.80± 125.34 [a]	5270.08±137.66 [a]	505.01±168.41 [a]	5646.46±114.4 [b]	2473.35±144.78 [a]
control+HPCH	6300.96±0.00 [a]	916.44±296.66 [a]	2986.97±233.83 [a]	7750.37±111.77 [a]	483.09±110.28 [a]	1020.04±127.24 [a]	1894.56± 65.67 [a]
control+MPPCH	6300.96±0.00 [a]	1710.27±131.10 [a]	3383.65± 22.95 [a]	5236.78±469.03 [a]	1510.20±297.30 [b]	2648.27±136.30 [ab]	2099.88± 85.45 [a]

(B) Treatment	Ascorbate peroxidase activity (units/mg protein)						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
Pen+HWT+PP	6300.96±0.00 [a]	1899.39±112.26 [a]	3222.38±297.55 [a]	3255.26±513.33 [b]	1088.24±181.74 [a]	3878.41±158.53 [a]	821.63±89.97 [a]
Pen+HWT+HPCH	6300.96±0.00 [a]	725.54±315.60 [a]	5221.79± 161.50 [a]	1396.82±267.30 [a]	606.71±15.06 [a]	4347.55±132.49 [a]	3229.75±54.02 [b]
Pen+HWT+MPPCH	6300.96±0.00 [a]	2420.98±105.07 [a]	4040.17± 803.99 [a]	5209.52±78.75 [c]	3406.68±245.55 [a]	3604.52±632.21 [a]	1006.51±175.51 [a]

(C) Treatment	Ascorbate peroxidase activity (units/mg protein)						
	w.0	w.1	w.2	w.3	w.4	w.5	w.6
HWT+PP	6300.96±0.00 [a]	2257.82±674.04 [a]	3847.11± 303.05 [b]	4448.15±797.16 [b]	1687.36±337.52 [a]	3071.87±91.26 [a]	2153.15± 110.92 [a]
HWT+HPCH	6300.96±0.00 [a]	1390.77±139.93 [a]	2205.97±182.42 [a]	7680.62±191.82 [c]	846.17±534.58 [a]	830.69±206.50 [a]	2238.18± 337.47 [a]
HWT+MPPCH	6300.96±0.00 [a]	2777.54±454.69 [a]	3328.83± 423.69 [b]	1748.28±111.04 [a]	2366.92±117.58 [a]	5002.95±597.94 [a]	2720.03±385.12 [a]

Means followed by different letters in each column are significantly different by Duncan's multiple range tests at $P \leq 0.05$

HWT = hot water treatment; Pen = *Penicillium* sp. Data are mean values ±SE.

BIOGRAPHY

Miss Mallika Boonrith was born on March 25, 1986 in Bangkok Province. She finished the secondary school from Bodindecha (Sing Singhaseni) 2 in 2004. Then, she study in Bachelor's degree, majored in Agronomy, Faculty of agricultural Technology, at King Mongkut's Institute of Technology Ladkrabang from 2004 to 2008.