Efficiency on extending the shelf-life of ripened mango (cv. Golden Nam Dokmai) using bioplastic bags from laboratory scale and industrial scale

Mr. Tanudkid Butweangphant

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Engineering in Chemical Engineering
Department of Chemical Engineering
Faculty of Engineering
Chulalongkorn University
Academic Year 2019

ประสิทธิภาพในการยืดอายุการเก็บรักษามะม่วงสุก (พันธุ์น้ำดอกไม้สีทอง) โดยใช้ถุงพลาสติกชีวภาพจากระดับห้องปฏิบัติการและระดับอุตสาหกรรม

นายฉนัดกิจ บุตรเวียงพันธ์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
สาขาวิชาวิศวกรรมเคมี ภาควิชาวิศวกรรมเคมี
คณะวิศวกรรมศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2562

Thesis Title	Efficiency on extending the shelf-life of ripened mango (cv. Golden Nam Dokmai) using bioplastic bags from laboratory scale and industrial scale
By	Mr. Tanudkid Butweangphant
Field of Study	Chemical Engineering
Thesis Advisor	Associate Professor ANONGNAT SOMWANGTHANAROJ, Ph.D.
Thesis Co Advisor	Dr. Apita Bunsiri, Ph.D.

Accepted by the Faculty of Engineering, Chulalongkorn University in Partial Fulfillment of the Requirement for the Master of Engineering

..... Dean of the Faculty of Engineering
(Professor SUPOT TEACHAVORASINSKUN, D.Eng.)

THESIS COMMITTEE

..... Chairman
(Assistant Professor Sorada Kanokpanont, Ph.D.)

..... Thesis Advisor
(Associate Professor ANONGNAT SOMWANGTHANAROJ, Ph.D.)

..... Thesis Co-Advisor
(Dr. Apita Bunsiri, Ph.D.)

..... Examiner
(Chutimon Satirapipathkul, Ph.D.)

..... External Examiner
(Assistant Professor Supakij Suttiruengwong, Dr.Ing.)

ถนัดกิจ บุตรเวียงพันธ์ : ประสิทธิภาพในการยืดอายุการเก็บรักษามะม่วงสุก (พันธุ์น้ำดอกไม้สีทอง) โดยใช้ถุงพลาสติกชีวภาพ จากระดับห้องปฏิบัติการและระดับอุตสาหกรรม. (Efficiency on extending the shelf-life of ripened mango (cv. Golden Nam Dokmai) using bioplastic bags from laboratory scale and industrial scale) อ.ที่ปรึกษาหลัก : รศ. ดร.อนงค์นาฏ สมหวังธนโรจน์, อ.ที่ปรึกษาร่วม : ดร.อภิตา บุญศิริ

การทดสอบประสิทธิภาพในการยืดอายุมะม่วงสุกน้ำดอกไม้สีทองบ่มสุก โดยการใช้ถุงพลาสติกชีวภาพที่ผลิตในระดับห้องปฏิบัติการ และระดับอุตสาหกรรม เม็ดพลาสติกชีวภาพ พอลีแลคติก แอซิด (PLA) และสารตัวเติมจะถูกผสมด้วยเครื่องอัดรีดแบบสกรูคู่ ก่อนทำการเป่าเป็นฟิล์มด้วยเครื่องเป่าฟิล์ม ด้วยเครื่องจักรในระดับห้องปฏิบัติการ และระดับอุตสาหกรรม ถุงพลาสติกชีวภาพทั้งสองชนิด จะถูกทดสอบสมบัติการซึมผ่านของก๊าซออกซิเจน และไอน้ำ เพื่อใช้เป็นบรรจุภัณฑ์ดัดแปลงบรรยากาศ สำหรับยืดอายุมะม่วงสุก ทั้งนี้พบว่าค่าความสามารถในการซึมผ่านของก๊าซออกซิเจนอยู่ที่ 1,635.59±87.75 และ 1,250.64±96.42 cc/m^2-day ความสามารถในการซึมผ่านของไอน้ำอยู่ที่ 165.26±5.74 และ 240.45±57.76 g/m^2-day สำหรับถุงพลาสติกชีวภาพ ในระดับห้องปฏิบัติการ และระดับอุตสาหกรรมตามลำดับ มะม่วงน้ำดอกไม้ ที่ผ่านการทำความสะอาดและบ่มให้สุก จะถูกบรรจุลงในถุงทั้งสองชนิด จากนั้นจึงเก็บรักษาที่อุณหภูมิ 12 °C และ 25 °C เปรียบเทียบคุณภาพกับมะม่วงที่ไม่ได้บรรจุลงในบรรจุภัณฑ์ (มะม่วงชุดควบคุม) ทุกๆ 3 วัน ผลการทดลองพบว่า มะม่วงน้ำดอกไม้สุกเก็บรักษาที่อุณหภูมิ 12 °C ได้นาน 12 วัน และ 9 วัน ในถุงพลาสติกชีวภาพจากระดับห้องปฏิบัติการและระดับอุตสาหกรรมตามลำดับ มะม่วงชุดควบคุมมีอายุการเก็บรักษา 6 วัน สำหรับมะม่วงในถุงพลาสติกชีวภาพทั้งสองชนิด มีอายุการเก็บรักษาที่อุณหภูมิ 25 °C นาน 6 วัน ขณะที่มะม่วงชุดควบคุม ที่มีอายุการเก็บรักษา 3 วัน

สาขาวิชา วิศวกรรมเคมี ลายมือชื่อนิสิต .....

ปีการศึกษา 2562 ลายมือชื่อ อ.ที่ปรึกษาหลัก .....

ลายมือชื่อ อ.ที่ปรึกษาร่วม .....

6070405721 : MAJOR CHEMICAL ENGINEERING

KEYWORD: Bioplastic, Extended shelf-life, Nam Dokmai mangoes

Tanudkid Butweangphant : Efficiency on extending the shelf-life of ripened mango (cv. Golden Nam Dokmai) using bioplastic bags from laboratory scale and industrial scale. Advisor: Assoc. Prof. ANONGNAT SOMWANGTHANAROJ, Ph.D. Co-advisor: Dr. Apita Bunsiri, Ph.D.

Efficiency in extending the shelf-life of ripened Golden Nam Dokmai by using bioplastic bags from laboratory scale and industrial scale production was tested. Polylactic acid (PLA) pellets and various fillers were mixed via twin screw extruder before being blown into film via extruder attached to blown film die in laboratory scale and industrial scale equipment. Oxygen and water vapor permeability of both kinds of bioplastic bags were evaluated for used as modified atmosphere packaging, for extend shelf-life of ripened mango. The oxygen permeability of films was 1,635.59±87.75 and 1,250.64±96.42 cc/m^2-day and their water vapor permeability was 165.26±5.74 and 240.45±57.76 g/m^2-day for bioplastic bags in laboratory scale and industrial scale production, respectively. Nam Dokmai mangoes, after cleaning and ripening process would be packed in both bioplastic bags before being stored at 12 ℃ and 25 ℃ compared with mango without packaging (control mangoes) in term of qualities every 3 days. Mango which stored at 12 ℃, could be stored for 12 days and 9 days in laboratory and industrial bags, respectively. Control mango could be stored for 6 days. Mango in both bioplastic bags could be stored for 6 days at 25 ℃, while control mango could be stored for 3 days.

Field of Study: Chemical Engineering Student's Signature .....

Academic Year: 2019 Advisor's Signature .....

Co-advisor's Signature .....

ACKNOWLEDGEMENTS

First of all, I would like to thank my thesis advisor, Assoc. Prof. Anongnat Somwangthanaroj and my thesis co-advisor, Dr. Apita Bunsiri for her guidance, kindness advice and suggestions.

Furthermore, I would also like to thank my thesis committee members: Asst. Prof. Sorada Kanokpanont, Dr. Chutimon Satirapipathkul and Asst. Prof. Supakij Suttiruengwong for serving as my committee members and giving the comments and suggestions on early works and drafts of the research.

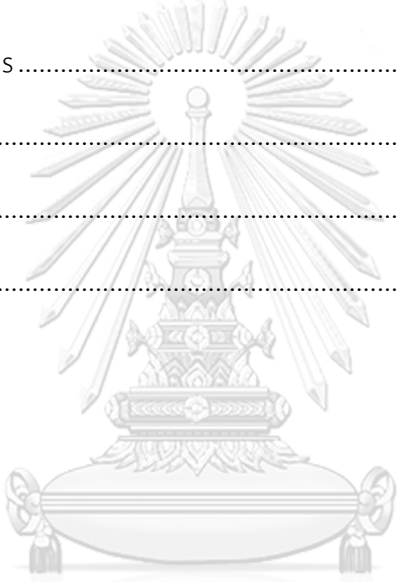
Moreover, I would like to thank Polymer laboratory at faculty of engineering Chulalongkorn university, Postharvest technology center Kasetsart university Kamphaeng saen campus for the courtesy of the operational location.

Finally, I would like to thank all those who had helped directly or indirectly towards the completion of this thesis.

Tanudkid Butweangphant

TABLE OF CONTENTS

Page



LIST OF TABLES

Page

LIST OF FIGURES

Page

CHAPTER I

INTRODUCTION

1.1 Introduction

Nowadays, Thailand has exported many agricultural fresh produces to not only domestic sector, but also overseas countries. However, these fresh produces can be degraded by their own nature, and damaged by surrounding environments (i.e., insects, impact during shipment). Normally, fruits and vegetables have different postharvest behaviors which can affect the quality of these fresh produces during transportation. One of the most popular fruit in Thailand is Nam Dokmai mango which is delicious and well-known among tourists. Ripened Nam Dokmai mango (cv. Number 4 and Golden Nam Dokmai) has delicate yellow pulp and sweet taste.

To transport and storage, mangoes are packed in the corrugated boxes and kept in refrigerator to maintain their quality until reaching the customers. After the postharvest process, mangoes still breathe, consume oxygen and release carbon dioxide, ethylene, and water vapor; this means that using a normal plastic bag eventually lead to a lack of oxygen and a high accumulation of carbon dioxide and ethylene inside the plastic bag. Finally, mangoes may get damages from carbon dioxide injury, abnormally ripen and become fermentation. Additionally, normal plastic bags are petroleum-based which cannot be biodegraded in short time. Therefore, packing mango fruit in bioplastic bags may be an option to maintain the quality, extend the shelf life and reduce plastic waste problem.

1.2 Objectives of the research

To investigate the properties of bioplastic bags that effect on shelf life extension and qualities of ripened Nam Dokmai mango at different storage condition.

To compare shelf life extending efficiency of ripened Nam Dokmai mango by using bioplastic bags from laboratory and industrial scales.

1.3 Scopes of the research

Bioplastic bags were manufactured in laboratory and industrial scales equipment. Polylactic acid (PLA) was used as main polymer.

Mechanical properties and gas permeabilities of bioplastic bags were evaluated.

Golden Nam Dokmai mango, with fully ripening state, were packed in both scales of bioplastic bags and without packing in plastic bags (control). Qualities of mango were investigated.

Storage temperature at 12 ℃ and 25 ℃ with relative humidity of 80 - 90% were used.

CHAPTER II

THEORY AND LITERATURE REVIEWS

2.1 Physiology of fresh produces

Fresh produces harvested in appropriate mature period, can be ripen, over ripen, senescent and become death in final step. On the other hand, produces were harvested in immature period, will degrade before ripe [1]. After harvest, internal stress will appear inside of produces, because postharvest produces are still alive, but they were cut off from food and water source. Storage foods and water will be changed into energy, that are used in many activities such as growth, nutrient movement or reproduction. Storage foods of produces, that comes from photosynthesis, will converse into flour, sugar or fat. When storage food is used up, produces can be regenerated with photosynthesis. On the other hand, postharvest produces cannot create food by photosynthesis. When storage food is used up, postharvest produces will degrade and reach to death period. Many literatures, reported that shelf life and qualities of fruit also depends on respiration process [2].

Fresh produces after harvest still have an active biological system. They use oxygen (O_2) to respire, release carbon dioxide (CO_2), water and energy according to **Equation 2.1**. From this equation, respiration rate can be determined by measuring oxygen and carbon dioxide content while fruits are still alive. Produces having high respiration rate will be deteriorated and ripened faster. Some fresh produces could be classified by respiration rate as shown in **Table 2.1**.

Equation 2.1 $C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{Energy}$

Base on respiration behavior, fruits can be divided into two categories. Firstly, climacteric fruits are defined as fruits that enter ‘climacteric phase’ after harvest i.e. they continue to ripe. During the respiration process, climacteric fruit will synthesize ethylene to enhance produce ripening and/or senescence. The examples of climacteric fruits are mango, banana, papaya and passion fruit. The other type is non-climacteric fruits, such as orange, grape, cherry and pomegranate, in which they

release small amount of ethylene while respire until deterioration. Climacteric and non-climacteric pattern of respiration in fruit were shown in **Figure 2.1**.

Table 2.1 Classified fresh produces by respiration rate

Levels	**Respiration rate at 5 °C (mg CO_2/kg hr)**	**Types of produces**
Lowest	< 5	Watermelon, honey dew, nut
Low	5 - 10	orange, grape, tomato, cucumber, pepper, apple, kiwi fruit, cantaloupe, squash
Medium	10 - 20	banana, eggplant, fig, guava, peach, pear, apricot, cherry, nectar, plum
High	20 - 40	passion fruit
Highest	> 40	pea, sweet corn

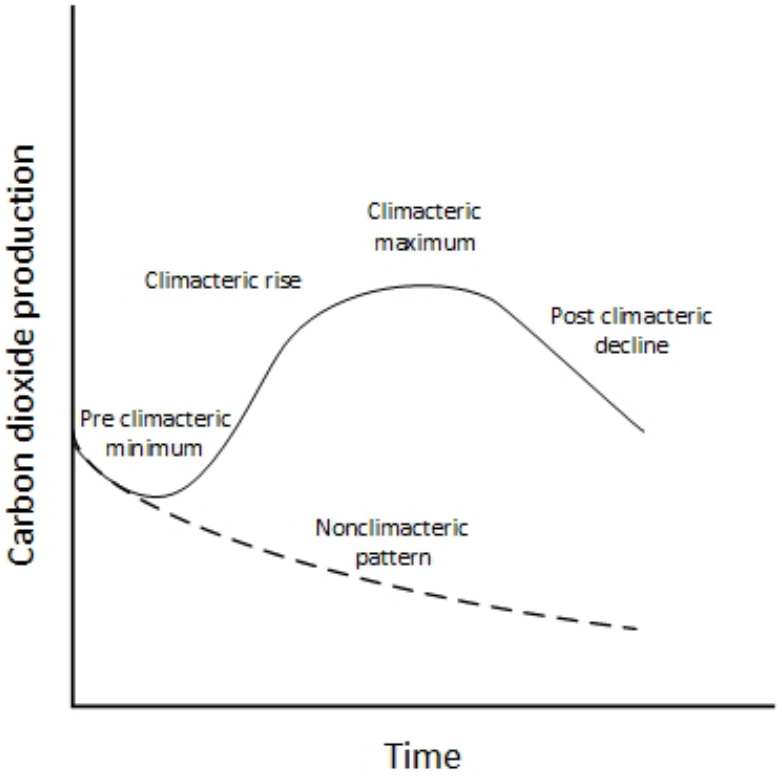


Figure 2.1 Climacteric and non-climacteric patterns of respiration of climacteric and non-climacteric fruits [3]

2.2 Mango fruit

The mango is native to the southern Asia, especially Myanmar and eastern India. It spreads early on to Malaya, eastern Asia and eastern Africa [4]. Golden Nam Dokmai is the queen of mango in Thailand which is popular among Thai and foreigners [5]. Unriped mango, the peel is green and the pulp is white. When it is completely ripe, the peel becomes light yellow, and the pulp is beautifully golden with the sweet taste as its name implies (**Figure 2.2**).

Figure 2.2 Ripened Nam Dokmai mango [5]

Degradation of mango depends on many factors which are, respiration, transpiration, cell deformation and chemical changes. ***Bhaumik B. Patel et al.*** [6] studied the respiration behavior of mango (cv. Langdo), placed in air tight multi-chambers under temperature and RH control system at the pre-set temperatures of 10, 15, 20, 25 and 35 °C, and chambers were closed with air tight lids as shown in **Figure 2.3**. Gas concentrations were observed by gas chromatographic (GC) analysis, using 1% CO_2 + 20% O_2 + balance N_2 as a standard gas. Respiration rate (RR_{CO2}) was calculated every hour from carbon dioxide concentration changed in chamber following **Equation 2.2**. Respiration rate was found to be accelerated with the increase of storage temperature. Thus, higher storage temperature enhances greater fruit respiration due to the breakdown of carbohydrates and other complex organic compounds by various chemicals and enzymatic activities [7]. Respiration rate was decreased when the storage time was longer. This was due to the increase in carbon dioxide concentrations and then decrease in oxygen in storage chambers, and the loss of substrates of respiration process. Respiration rates as a function of storage time at different temperatures were shown in **Figure 2.4.**

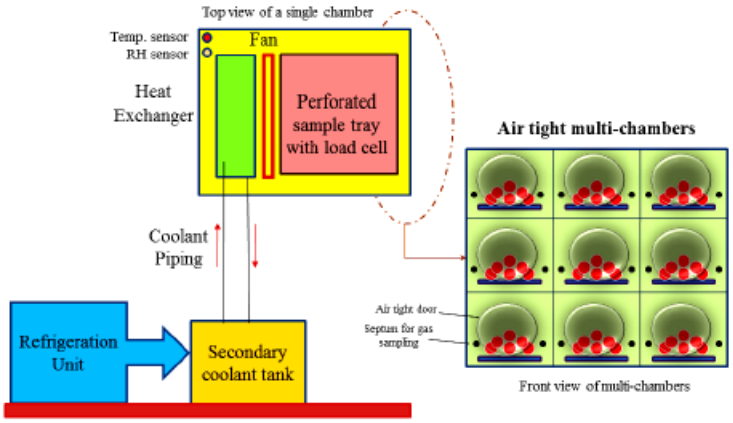


Figure 2.3 Air tight multi-chamber temperature and RH control system [6]

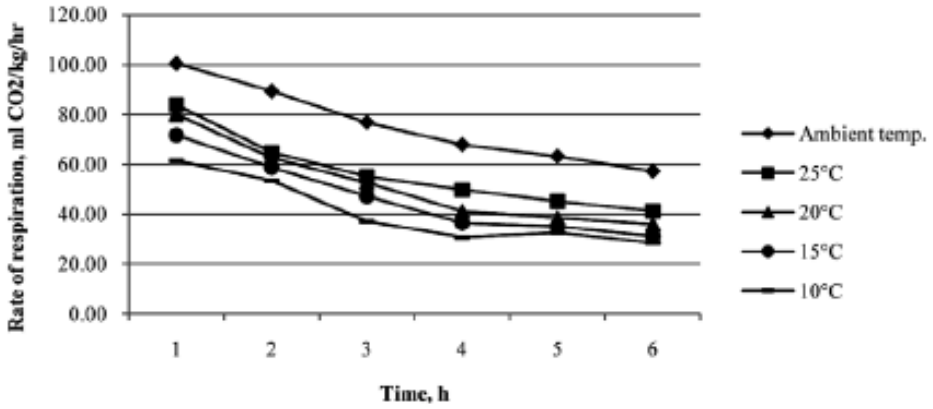


Figure 2.4 Rate of respiration of mango fruits at different temperatures under steady state storage condition

Equation 2.2

$$RR_{CO2}\left(\text{ml } CO_2/\text{kg -hr}\right) = \frac{(C^{F}_{CO_2} - C^{I}_{CO_2}) \times P_V}{W_s \times \Delta t}$$

Where; CO^{I}_{2} = Initial concentration of CO_2 (ml)

CO^{F}_{2} = Final concentration of CO_2 (ml)

P_V = Partial volume in headspace (ml)

W_S = Weight of sample (kg)

Δt = Enclosed time interval (hour)

Duangjai Noiwan et al. [5], studied the kinetics and respiration of mango during storage at various temperature. Kinetic study of fresh produces are important because the quality of fresh produces are strongly dependent on their temperature

exposure history, from production through distribution and storage to consumption [8]. The Arrhenius relation is a model widely used to describe quality loss and the effect of temperature on different physicochemical properties [9]. Mango fruit samples were stored at 13, 20, 27 and 34 °C in which the respiration rate of mango was investigated by gas chromatographic analysis. Respiration rate of mango which were stored under different temperature was shown in **Figure 2.5**. Mango showed characteristic pattern of climacteric fruit, climacteric peak was the end of mango maturation and was the onset of fruit senescence. Low storage temperature can delay pre-climacteric period, indicating that mango which is stored at low temperature has low respiration rate and become sensescence slower than that stored at high temperature.

Qualities of mango were checked, by weight loss, fruit firmness, soluble solid content (SSC), titratable acidity (TA) and color measurement, every four days for 13 °C, every two days for 20 °C and 27 °C, as well as every day for 34 °C until the fruit started showing signs of decay. The value of firmness, SSC and TA was varied according to storage temperature, this values were selected to study the kinetics of mango ripening. Values of TA, firmness and SCC were fitted by first-order kinetic model (**Equation 2.4**), second-order kinetic model (**Equation 2.5**) and Gaussian kinetic model (**Equation 2.6**), respectively.

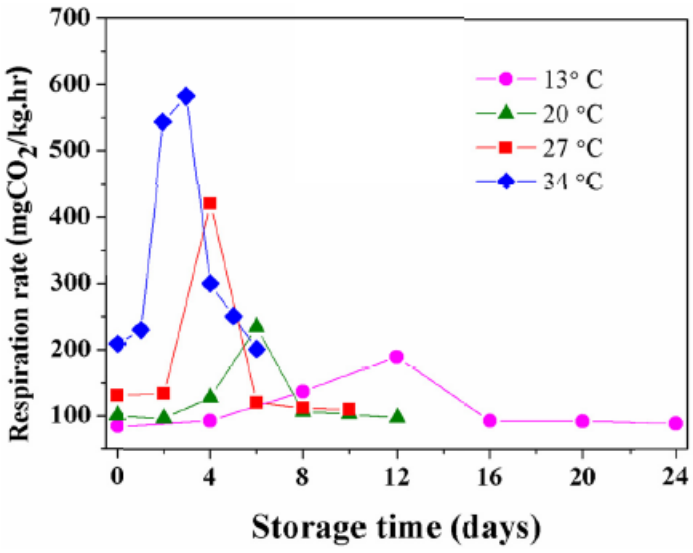


Figure 2.5 Effect of storage temperature on respiration rate of mango [5]

Equation 2.3 $F(x) = [X_0] - [X_t]$

Equation 2.4 $F(x) = \ln[X_0 - X_t]$

Equation 2.5 $F(x) = \frac{1}{X_0} - \frac{1}{X_t}$

Equation 2.6 $F(x) = \sqrt{\ln(\frac{1}{1-X})}$

Where, $[X_t]$ is the values of firmness, TSS and TA for a fixed storage time and temperature; $[X_0]$ is the initial values of firmness, TSS and TA. The firmness, TSS, and TA were measured in which the corresponding value X was used as the dynamic parameter, and the relation can be expressed in terms of the response function as shown in **Equation 2.7**.

Equation 2.7 $F(x) = kt$

where, k is the rate constant of the reaction that is correlated with temperature; t is the storage time. By plotting a curve between the response function of total color difference F(X) and time, a straight line could be obtained, and the k of different storage temperatures could be calculated from the slope. Taking the natural logarithm on both sides of the Arrhenius function as shown in **Equation 2.8**.

Equation 2.8 $\ln k = \ln A + E_a/RT$

By plotting a curve between ln k and 1/T, a straight line was obtained. The activation energy could be calculated from the slope, and A from the intercept directly.

Rate constant (k) and the coefficient of determination (R^2) were obtained by slope of straight line by plotting function F(X) with storage time at different storage temperature. Activation energy (E_a) was calculated from **Equation 2.8** as shown in **Table 2.2**. These E_a indicate a moderate temperature sensitivity of the deteriorate, thus firmness, SSC and TA could be accurately modeled of the degradation

mechanism involved and used to predict the influence of storage condition on critical parameters.

Table 2.2 Response of rate constants (k), the correlation coefficient (R^2) of the fit and activation energy (E_a) obtained from the firmness, SSC and TA parameter model

Parameter (X)	$F(X)$	Temperature (°C)	k	R^2	E_a (kJ mol^{-1})
Firmness	$(1/X_0) - (1/X_t)$	13	0.0310	0.8361	46.45
		20	0.0370	0.9154	
		27	0.0646	0.9167	
		34	0.1116	0.7021	
Soluble solid contents (SSC)	$[\ln\{1/(1-X)\}]^{1/2}$	13	0.0560	0.9259	43.05
		20	0.0999	0.9192	
		27	0.1321	0.9547	
		34	0.2013	0.8717	
Titratable acidity (TA)	$\ln(X_0 - X_t)$	13	0.1073	0.8072	54.22
		20	0.2632	0.9380	
		27	0.3991	0.9458	
		34	0.5424	0.8070	

2.3 Bioplastic packaging

Plastic packaging are usually used in many commercial activities, most of plastics are by-product from petroleum production. Normally, plastics are cheaper than other materials, and the properties can be adjusted to suit the desired activity. However, elimination of petroleum-based plastics is difficult because most of petroleum-based plastics cannot decompose in a short time, it takes several hundred years to decompose. Non-decomposition plastic waste causes many pollutions, removal this plastic must use the combustion process under high temperature. But petroleum-based plastics are consisted with hydrocarbon compound, at high temperature petroleum-based plastics will be decomposed and release greenhouse gases such as carbon dioxide or methane depending on the type of plastics, and greenhouse gases are one of the causes of the global warming. Bioplastics are one of the choices to reduce the use of petroleum-based plastic. Bioplastic can be divided into two types which are plastic that is produced from biomass and plastic that can be biodegraded. Some bioplastics are derived from renewable biomass sources such as vegetable oils of plants. Biodegradable plastic can be decomposed in short time under appropriate condition, and decomposition

of bioplastics does not make pollution. In a recent year, many types of bioplastics being used such as polylactic acid (PLA) or Polyhydroxyalkanoates (PHA).

Poly (lactic acid) or PLA, is one of the popular type of biodegradable polymer, derived from renewable biomass, typically from fermented plant starch such as corn, cassava, sugarcane or sugar beet pulp [10]. PLA can be synthesized by polymerization of lactic acid as shown in **Figure 2.6** [11]. Normally, the basic mechanical properties of PLA are between those of polystyrene (PS) and polyethylene terephthalate (PET). On the other hand, PLA is poor in gas permeabilities, so many researches tried to improve the gas permeabilities of PLA to use as modified atmosphere packaging (MAP).

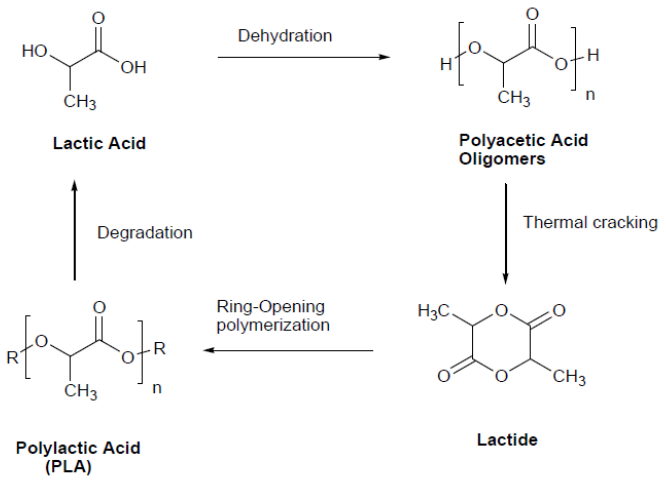


Figure 2.6 Synthesized reaction of PLA by lactic acid and lactide [11]

2.4 Modified atmosphere packaging

Modified atmosphere packaging (MAP) is one of the food protection technique, in which foods or fresh produces are packed in MAP to extend its shelf life. This package can adjust the atmosphere and gas concentration inside of the package for fresh produces to respire. Normally, MAP was used with chilled foods and fresh produces i.e. pork, meat, fruit or vegetable [12]. Normally, fresh produces use oxygen to respire and release carbon dioxide, water and energy [2]. In normal atmosphere, more oxygen concentration causes fresh produces to have higher rate

of respiration. Controlling of gas permeability across the film thickness is the main function of MAP, that can be adjusted gas concentration inside of package. A reduction of oxygen concentration and an increase of carbon dioxide concentration in MAP slows the respiration rate of fresh produces and inhibit ethylene (the plant hormone), indicating to slow down ripening process. High concentration of carbon dioxide leads to fungistatic effect, which also help to prolong shelf life of fresh produces [13].

After harvest, fresh produces can be ripened, degraded, and damaged by their own nature or surroundings (i.e. insect, impact during shipping) before reaching the customers, leading to a loss of these fresh produces during transportation. Packing fresh produces into plastic bags can reduce this loss of fresh produces, but normal plastic bags do not allow enough gas passing through the film. When oxygen inside of the package was used up, fresh produces were damaged by carbon dioxide injury. Increasing gas permeability of plastic bag packaging can adjust proper gas concentration inside plastic bags, for extending postharvest shelf life of fresh produces.

Netnapha Lamo [14] studied the effect of maleic anhydride grafted on low density polyethylene (PE-g-MA) composite with filler to extend the shelf life of fresh produces. Gas permeabilities of composite films were evaluated to investigate the shelf life extending efficiency. **Figure 2.7(a)** showed the gas permeability, i.e. oxygen, carbon dioxide and water vapor of LDPE composite films with various PE-g-MA/filler ratio and fixed filler content at 3 phr. Composite films with PE-g-MA/filler ratio of 3.0 and 3 phr of filler content showed the optimal gas permeabilities, in PE-g-MA/filler ratio at 4.0 oxygen permeability was slightly decreased. In ethylene absorption, PE-g-MA/filler ratio at 3.0 and filler content at 3 phr shown higher ethylene absorption efficiency as shown in **Figure 2.7(b)**. This composite film was used to observe in the extended shelf life of fresh produces.

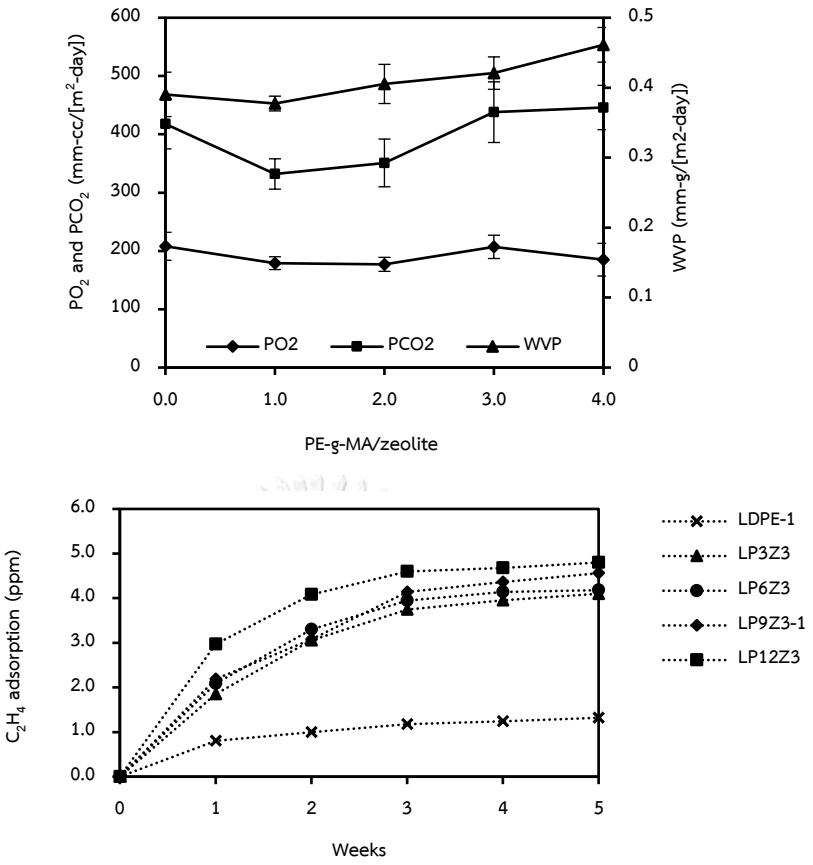


Figure 2.7 Gas permeabilities of composite films with various PE-g-MA/filler ratio and ethylene absorption of composite films [14]

Where code of samples : neat LDPE (LDPE-1), PE-g-MA/filler ratio of 1.0 and filler loading of 3 phr (LP3Z3), PE-g-MA/filler ratio of 2.0 and filler loading of 3 phr (LP6Z3), PE-g-MA/filler ratio of 3.0 and filler loading of 3 (LP9Z3-1) and PE-g-MA/filler ratio of 4.0 and filler loading of 3 phr (LP12Z3). Postharvest shelf life of Nam Dokmai mango was investigated by using composite film and neat LDPE film. Qualities of mango were observed every week as shown in **Figure 2.8**. Composite film showed higher efficiency in shelf life extending of mango compared with neat LDPE film. Mango, which was packed in the composite film, can be prolonged shelf life to 5 weeks without defect on pulp [14].

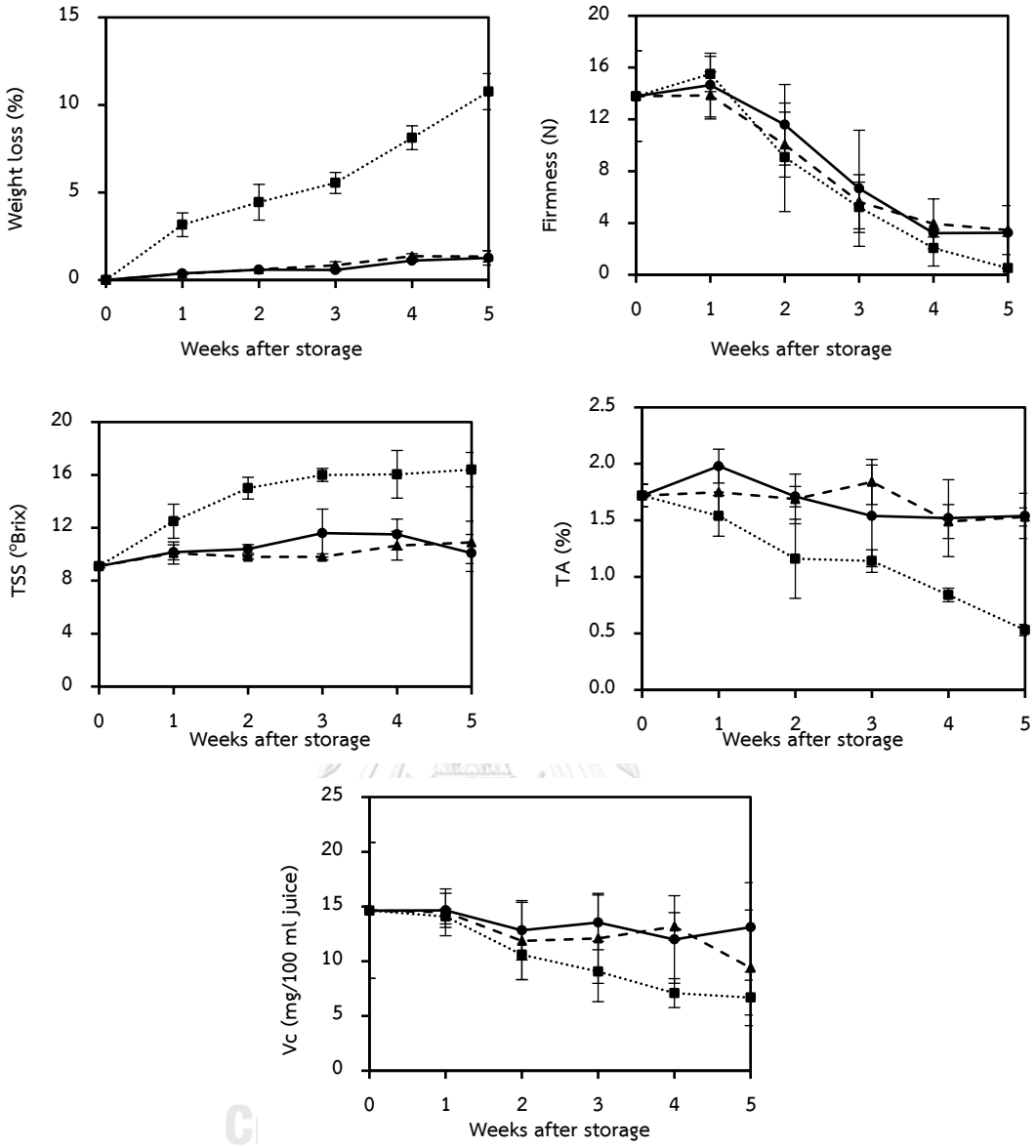


Figure 2.8 Qualities of mango; weight loss, firmness, TSS, %TA and vitamin C content of mangoes without packaging film (control, ·····■·····) and inside neat LDPE (----▲----) and composite packaging film (—●—) stored at 12°C for 5 weeks

Hai Chi [12], studied the effect of PLA nanocomposite film containing bergamot essential oil (BEO), TiO_2 nanoparticles and Ag nanoparticles on shelf life of mango. Mango was stored, in neat PLA film, PLA/BEO composite film, PLA/BEO/TiO_2 composite film and PLA/BEO/TiO_2+Ag composite film, at 20 °C for 15 days and qualities of mango were observed every 3 days. All composite films show the

efficiency in extended shelf life of mango better than neat PLA film. In addition, adding nanoparticles (TiO_2 and Ag nanoparticles) in composite film could effectively delay ripening and maintain postharvest quality of mango during the whole storage period. After harvest, mango still respire and become ripening, PLA nanocomposite film was used as MAP to extend shelf life of mango. Weight loss of mango and change of fruit firmness can be used to determine ripening process of mango after harvest are shown in **Figure 2.9**. Releasing of water vapor in respiration process was the cause of weight loss of mango [2], PLA nanocomposite films showed lower weight loss of mango than neat PLA film due to the changes in the interaction between molecules that cause the path of the water vapor molecules diffusing through the polymer matrix to become more tortuous [15]. Fruit firmness can be used to determine degradation of fresh produces pulp. Firmness of mango pulp decrease while increase of storage time. Furthermore, appropriate relative humidity within the package could reduce microbial growth and maintain texture quality [16].

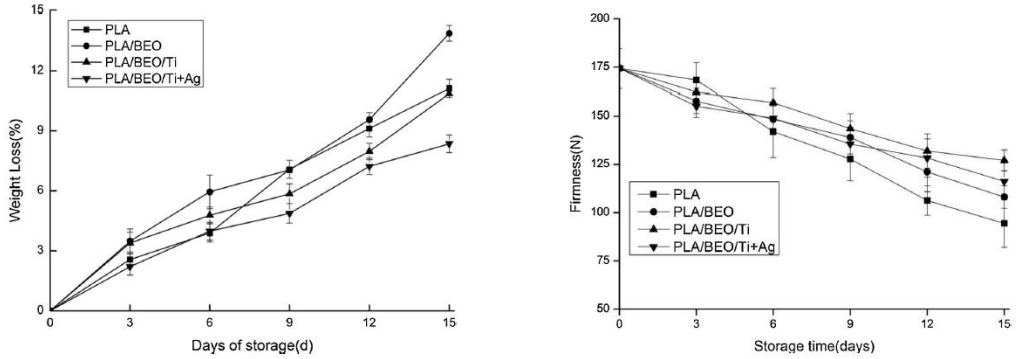


Figure 2.9 Weight loss (Right) and fruit firmness (Left) of mangoes stored at 20 ± 1 °C for 15 days [12].

Suthaphat Kamthai and Rathanawan Magaraphan [10] develop an active PLA packaging film by adding bleached bagasse carboxymethyl cellulose (CMC_B) for mango storage life extending. PLA was blended with CMC_B at 1%, 2% and 4% by weight, and compared shelf life extending effeiciency of mango with neat PLA and without packaging (control). Mangoes were kept in neat PLA, PLA/CMC_B with different ratio of CMC_B and without packaging at 13 ± 1 °C, relative humidity 90 ± 5 %,

qualities of mango were observed every 3 days untill mango degradation. PLA/CMC_B films have the ability to absorb and transmit water vapour, yielding the function of water storage in the swollen CMC_B particles, lowering the temperature inside packaging, and transmitting water vapour to keep sufficient moisture content in the packaging so that the respiration rate decreases. Increasing of CMC_B can increase the efficiency of mango shelf life extending, PLA/CMC_B film with 4% (w/w) CMC_B maintained the slowest rate of respiration in addition to ethylene production during storage in export conditions, thus illustrating the longest mango shelf life of 42 days. Adding CMC_B in PLA can improve gas permeabilities of PLA film. Gas concentration and humidity inside of composite PLA film were adjusted to reduce respiration rate of mango. Mango in PLA/CMC_B film with 4% (w/w) shows slower respiration rate than others **(Figure 2.10)**. Control mango and mango in neat PLA film, have storage time at 21 and 27 days respectively. Increasing CMC_B content in PLA, shelf life of mango was extend to 33, 36 and 42 days at CMC_B content 1%, 2% and 4% (w/w) respectively.

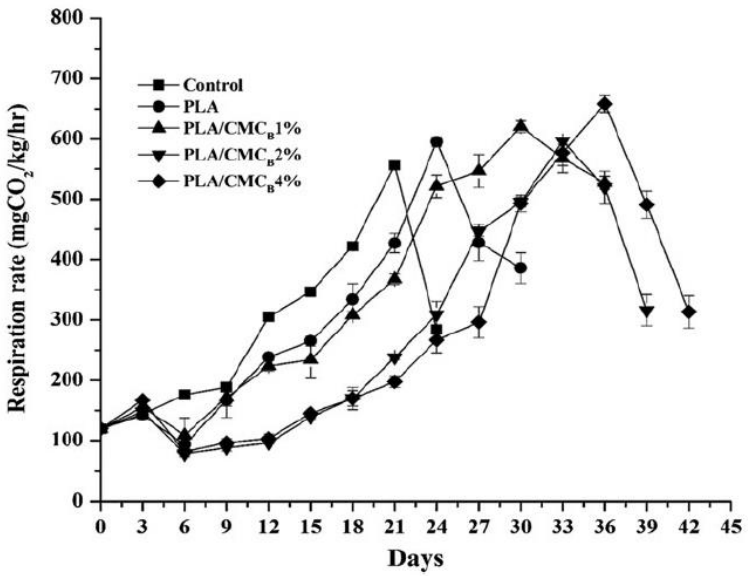


Figure 2.10 The respiration rate of mangoes in PLA/CMC_B (0 - 4% w/w) film and control mangoes during storage at 13 ± 1 °C and 90 ± 5 % RH.

CHAPTER III

METHODOLOGY

In this chapter, materials, film preparation, accelerated ripening of Nam Dokmai mango and characterization film properties and qualities of mango after store inside packaging, are described as follows.

3.1 Bioplastic bag preparation

In laboratory scale production, PLA (4043D grade) and fillers were dried at 60 ℃ to remove the absorbed moisture before being compounded via twin screw extruder (LABTECH, LTE 20-40) and blown into films via extruder attached to blown film die (COLLIN, Germany). For industrial scale production, PLA and fillers with the same formulation was blended via twin screw extruder and blown into film via extruder attached to blown film die. The thickness of films obtained from laboratory scale and industrial scale production are 32.60 and 18.73 micrometers, respectively. The films that were prepared in the laboratory and industrial scale production were designated as **Labs** and **Inds**, respectively.

3.2 Accelerated ripening of Nam Dokmai mango

To confirm the quality of Nam Dokmai mangoes, all mangoes before being kept in bioplastic packaging were disinfected by dipping in 200 ppm sodium hypochlorite (NaOCl) aqueous solution at room temperature for 3 minutes and followed by dipping in 250 ppm prochloraz aqueous solution at 52 ℃ for 5 minutes. After disinfection, all mangoes were ripened by dipping in 1,000 ppm ethephon aqueous solution at room temperature for 3 minutes. Eventually, mangoes were dried at room temperature and stored at 25 ℃ until finished the ripening process. After that, mangoes were kept at 12 ℃ and 25 ℃ with bioplastic packaging from laboratory scale, industrial scale and without packaging (control) respectively. The mangoes with each treatment are designated in **Table 3.1**.

Table 3.1 Designation of mangoes at each storage condition and temperature

Storage condition	Storage temperature (°C)	
	12	**25**
Without package	Control12	Control25
Laboratory scale bags	Labs12	Labs25
Industrial scale bags	Inds12	Inds25

3.3 Film characterizations

3.3.1 Mechanical properties

Tensile properties of films were performed by using Universal Testing Machine (Instron 5567, NY, USA) according to ASTM D 882 [17]. The initial grip separation of 100 mm and rate of grip separation of 12.5 mm/min were set for both bioplastic films.

Impact strength of films were measured using impact taster (Film Impact Taster Digital type, TOYOSEIKI) according to ASTM D3420 [18]. Both films were cut into square shape with area 100 cm^2, the pendulum head hits both films with a maximum velocity of about 74 m/minute and a maximum energy of about 5 J.

3.3.3 Thermal properties

Thermal properties of both films were investigated by differential scanning calorimetry (DSC). Film samples of 5 – 10 mg were packed and firstly heated from 30 ℃ to 220 ℃ with heating rate of 5 ℃/min, then cooled from 220 ℃ to 30 ℃ with cooling rate of 5 ℃/min, and secondly heat from 30 ℃ to 220 ℃ with heating rate of 5 ℃/min, respectively. Crystallization and enthalpy of transition are observed from this DSC thermogram. The degree of crystallinities of samples are calculated from this enthalpy using **Equation 3.1**.

Equation 3.1

$$\%\text{Crystallinity } (\%X_c) = \frac{(\Delta H_m - \Delta H_{cc})}{\emptyset \times \Delta H_m^{\circ}} \times 100$$

Where ΔH_m is enthalpy of transition at melting point.

ΔH_{cc} is enthalpy of transition at cold crystallization point.

$\Delta H°_m$ is enthalpy of transition at melting point of neat PLA with fully crystallization = 93.0 J/g [19].

$\emptyset$ is weight fraction of PLA in both of package = 0.8584

3.3.4 Oxygen permeability analysis

Oxygen permeability of both packaging films were investigated by using oxygen permeation analyzer; OX-TRAN 2/21, Mocon, USA. Area of both packaging films is 100 cm^2. Oxygen purity of 99.8% was introduced in test cell and passed through tasted films with a nitrogen (carrier gas). Passing oxygen were detected by sensor and record in unit of mm-cc/m^2-day, following the ASTM D3985

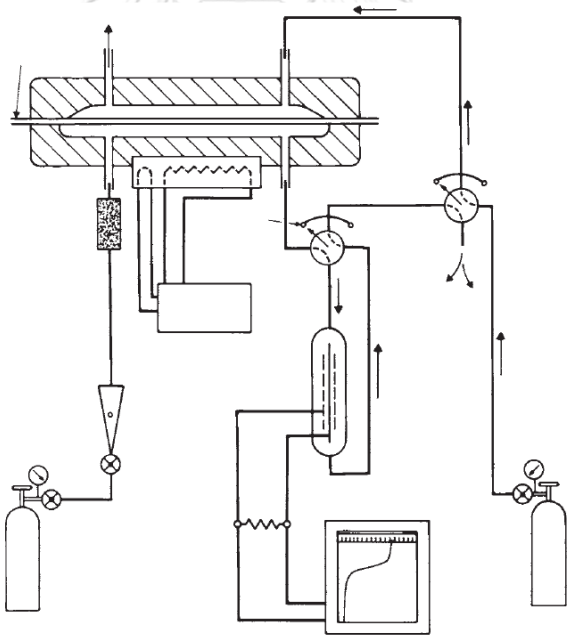


Figure 3.1 The measurement of OTR using the coulometric method

3.3.5Water vapor permeability analysis

Water vapor permeability of both packaging films were investigated by using water vapor permeation analyzer; PERMATRAN W398, Mocon, USA. Both films are required in circular shape with area of 50 cm^2. Nitrogen will be introduced into the upper half of the chamber while a moisture-free (99.99% zero grade N_2) carrier gas flow through the lower half. Molecules of water vapor diffusing through the film into the lower chamber were conveyed to the sensor by the carrier gas. The water vapor transmission rate of the test film was displayed as g/m^2/day according to ASTM E398.

3.3.6 Ethylene transmission analysis

Ethylene transmission of laboratory and industrial films were investigated. Both bioplastic films are sealed into bags with 7 x 7 cm area. The ethylene gas of 1 ppm concentration were injected into both bioplastic bags. Then the bioplastics bag filled with ethylene were kept in a closed bottle as shown in **Figure 3.2**. Ethylene concentration inside bottle was measured immediately at the beginning and every 3 days until 15 days by a gas chromatography with FID detector (model GC-8 A, Shimadzu corporation, Japan).

Figure 3.2 The equipment of ethylene transmission test

3.4 Characterization of ripened mangoes

3.4.1 Visual observations

The mangoes, which were stored with and without bioplastic bags, were investigated every 3 days for apparent physiological breakdown such as softening, blown spot, and carbon dioxide injury symptom by photograph.

3.4.2 Weight loss

The mangoes were weighed at the beginning of storage (0 day) and every 3 days of storage with electric balance. Weight loss was calculated by **Equation 3.2**.

Equation 3.2

$$\%\text{Weight loss} = \frac{(W_0 - W_f)}{W_0} \times 100$$

Where W_0 is weight at the beginning of storage (0 Day).

W_f is weight on the investigated storage day.

3.4.3 Fruit firmness

Fruit firmness of mangoes, which relates to the deformation of pulp, was tasted by using fruit firmness taster, with a 5-mm-diameter, 8-mm-diameter and 11-mm-diameter cylindrical probe which was used depending on fruit ripeness. The probe was pressed vertically against the surface of fruit samples by randomness. The firmness was expressed as kilogram so it should be multiplied with 9.81 into the unit of Newton (N).

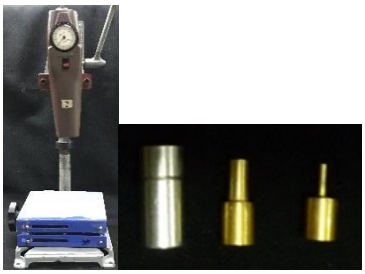


Figure 3.3 Fruit firmness taster, and various size probe

3.4.4 Color change

Color change was analyzed using color meter (Color meter: CR-400, Konica Minolta Sensing, Inc., Japan). Color measurement are made on the peel and pulp of mango. Two measurements were taken at random locations on the site of mango. The color was expressed in value of L* (lightness), a* (greenness), b* (yellowness) mode as recommended by the Commission International de l'Eclairage (CIE). The color meter was calibrated on a standard white tile before each series of measurements.

Figure 3.4 Color meter; Minolta CR-400, Konica Minolta Sensing, Japan

3.4.5 Total soluble solid (TSS) content and titratable acidity (TA)

Total soluble solid (TSS) content were determined by squeezing a few drops of juice on a refractometer (ATAGO, Japan) and the TSS value was expressed in unit of °Brix. Titratable acidity (TA) was determined by titrating of 5 mL of fruit juice with 0.1 M NaOH. The volume of NaOH was used to calculate the percentage of titratable acidity as **Equation 3.3**.

Equation 3.3

$$\%TA = \frac{\text{mL of NaOH} \times \text{conc. Of NaOH} \times \text{meq.wt.of citric acid}}{\text{mL of fruit juice}}$$

where meq.wt. of citric acid in mango was equal to 0.06404

3.4.6 The concentration of gases inside the packages

The oxygen, carbon dioxide and ethylene concentration in both packaging and control mangoes were investigated every 3 days by using gas chromatography (GC). The GC (model GC-8 A, Shimadzu corporation, Japan) equipped with stainless

steel molecular sieve 5A column (80/100) at 70 °C and thermal conductivity detector (TCD) at 150 °C and helium as carrier gas was used to determine oxygen and carbon dioxide concentration. But GC equipped with glass column (80/100) at 70 °C with TCD at150 °C and nitrogen as carrier gas was used to determine ethylene concentration. Gas sample of 1 mL collected from the bioplastic bags was injected into GC and data of gas concentration are recorder in percentage of oxygen and carbon dioxide, and ppm of ethylene.

3.4.7 Vitamin C contents

Vitamin C content, in Nam Dokmai mangoes, was determined by titration mango juice with dichloroindophenol solution. Mango juice 2 mL was mixed with 5 mL of oxalic acid – acetic acid in Erlenmeyer flask, then titrate this solution with dichloroindophenol solution until the color of juice changes into pink. In this experiment, saturated ascorbic acid solution was used as standard solution. Ascorbic acid in mango juice was calculated by **Equation 3.4**.

Equation 3.4

$$\frac{\text{mg ascorbic acid}}{\text{mL}} = \text{mL of dichloroindophenol} \times \text{mg eq.ascorbic acid} \times \text{mL of mango juice}$$

where, mg eq.ascorbic acid was calculated by volume of dichloroindophenol solution used for saturated ascorbic acid solution.

3.5 Summary of methodology

In this research, experiment was separated into 2 parts. The **part I** is preparation and characterization of bioplastic packaging from laboratory scale and industrial scale. Mechanical properties and gas permeabilities were investigated following by topic **3.3**. The **part 2** is compared the efficiency of package to extend shelf-life of Nam Dokmai mangoes. The mangoes, after accelerated ripening process, were packed in bioplastic packaging from laboratory scale and industrial scale. Qualities of ripened mangoes, which were packed in packaging, were compared with ripened mango without packaging (control) and all of samples were kept in 12 °C and

25 ℃ at 85-95 % relative humidity. Every 3 days, qualities of mango were investigated following the details in topic **3.4**.

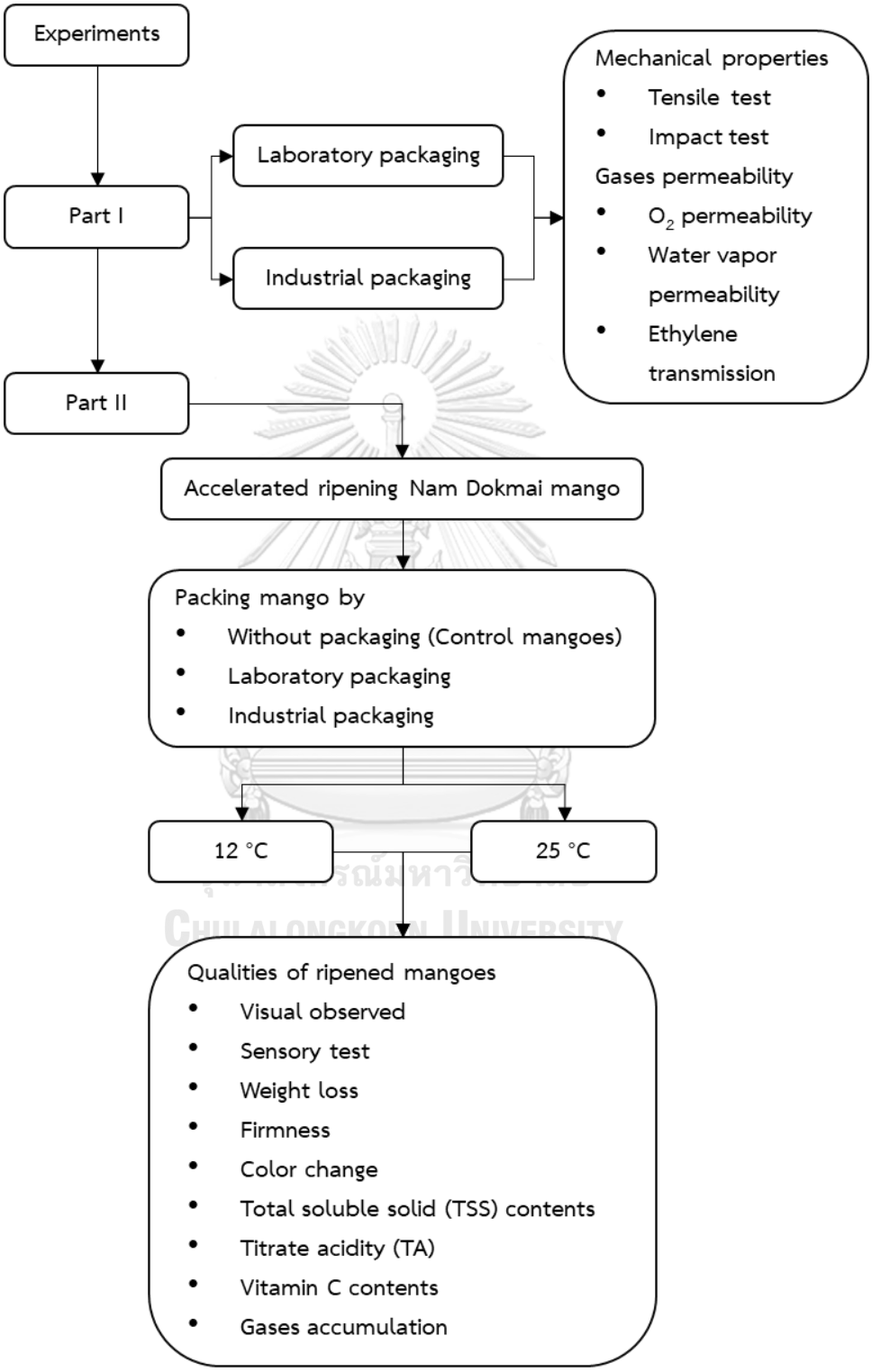


Figure 3.5 Experimental chart

CHAPTER IV
RESULT AND DISCUSSION

4.1 Characterization of plastic film packaging

4.1.1 Mechanical properties

Tensile properties of laboratory and industrial films were investigated and shown in **Figure 4.1.** Tensile strength at yield shown maximum load that films can be tolerated. In MD direction, tensile strength at yield of industrial film were lower than that of laboratory film, tensile strength of laboratory and industrial films were 52.15±8.18 MPa and 47.93±2.57 MPA, respectively. In TD direction, tensile strength of both films were insignificant differences. E-modulus of laboratory film are higher than industrial film in both of direction. However, the different of tensile strength at yield and E-modulus were insignificant differences, due to fillers were blended with PLA in the same ratio for both bioplastic films. Tensile strength at yield in MD direction was higher than that in TD direction because blown up ratio of both bioplastic films was higher than draw down ratio. Drawing the film in MD direction allows polymer chain to be orientated in MD direction, so both films have higher tensile strength in MD direction. In addition, elongation at break of industrial film in both directions were higher than that of laboratory film, because draw down and blown up ratio of machine in industrial scale production were higher than laboratory scale production [20]. **Figure 4.2** shows stress-strain curve of both bioplastic films. Industrial film shown the occurrence of necking or cold drawing, due to the orientation of polymer chain [21]. **Figure 4.3** shows the impact strength of laboratory film and industrial film which were 3.26±0.52 J/cm and 3.25±1.08 J/cm, respectively. Impact strength of both types of bioplastic films is similar.

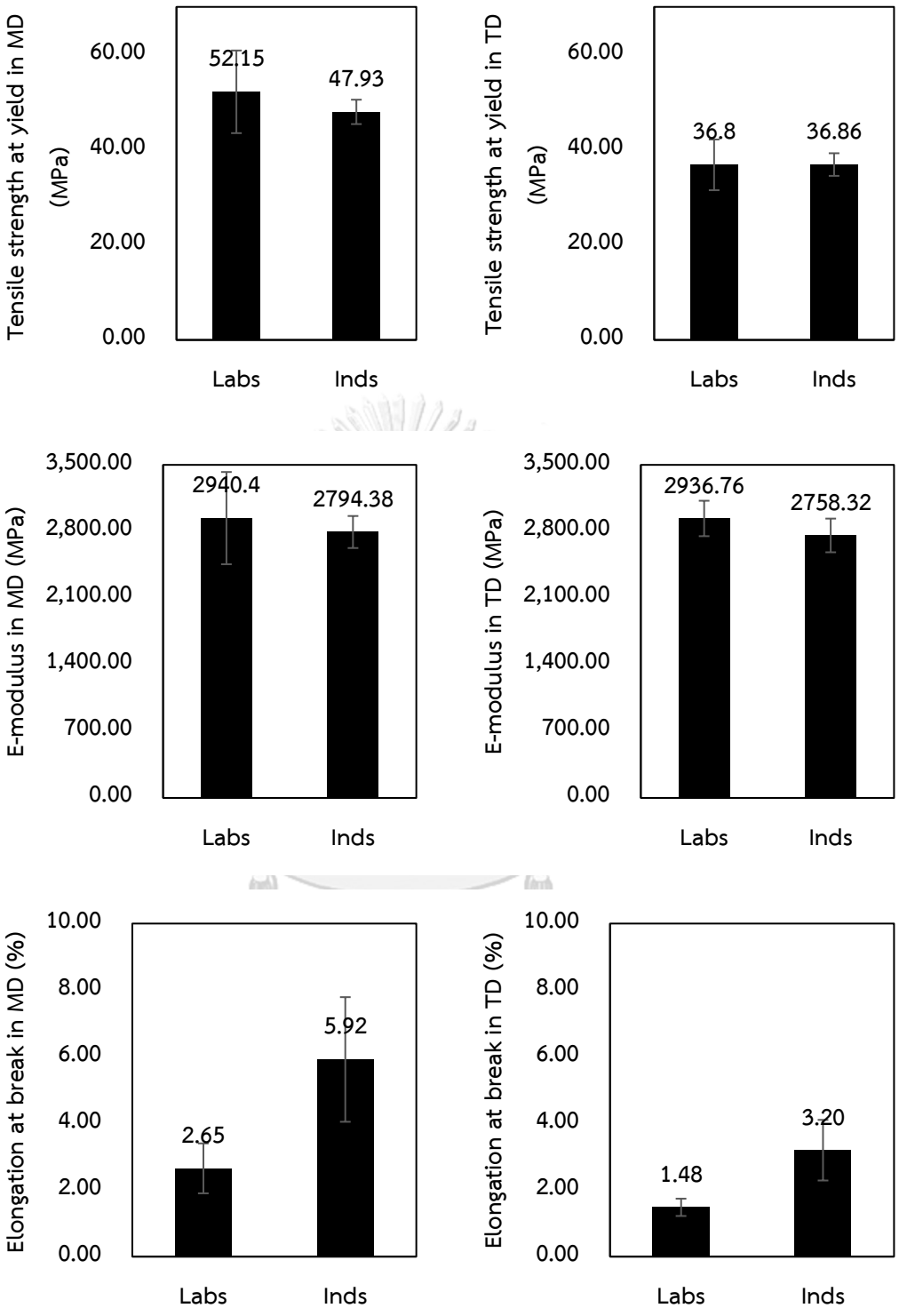


Figure 4.1 Tensile strength at yield, E-modulus and elongation at break of laboratory and industrial films

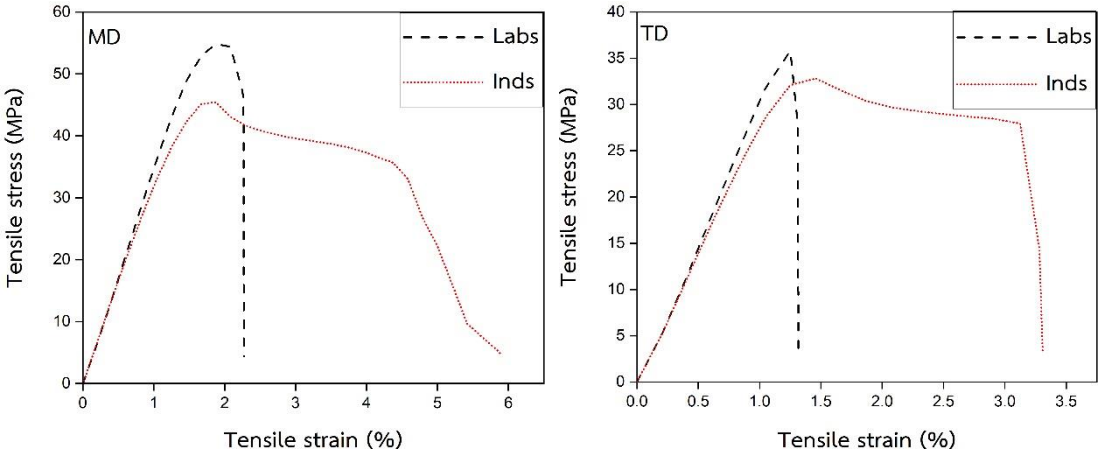


Figure 4.2 Stress-strain curves of laboratory and industrial films in MD and TD directions

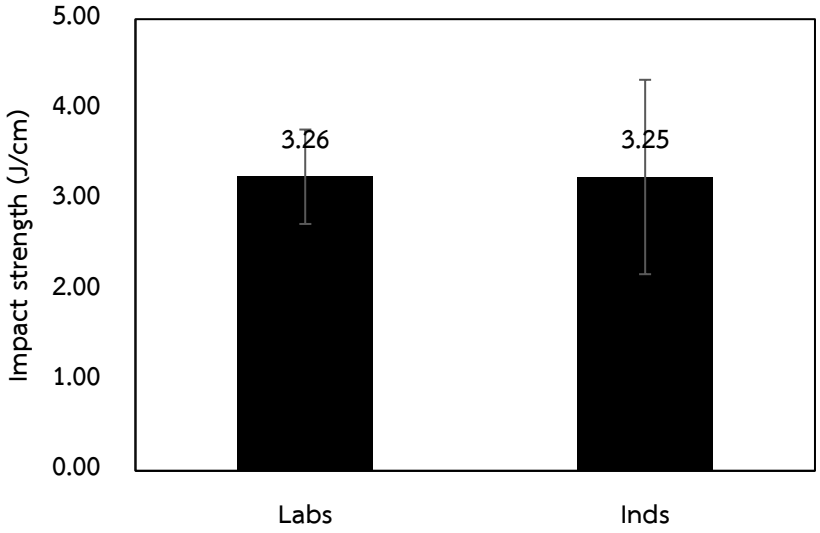


Figure 4.3 Impact strength of laboratory and industrial film

Cross section and surface of both bioplastic bags were investigated by scanning electron microscope (SEM), SEM images of neat PLA, laboratory and industrial films were shown in **Figure 4.4**. Both cross section and surface of neat PLA is smooth, SEM images of both bioplastic bags showed the distribution of fillers in PLA matrix. When considering the surface, the distribution of fillers in both bioplastic bags was similar.

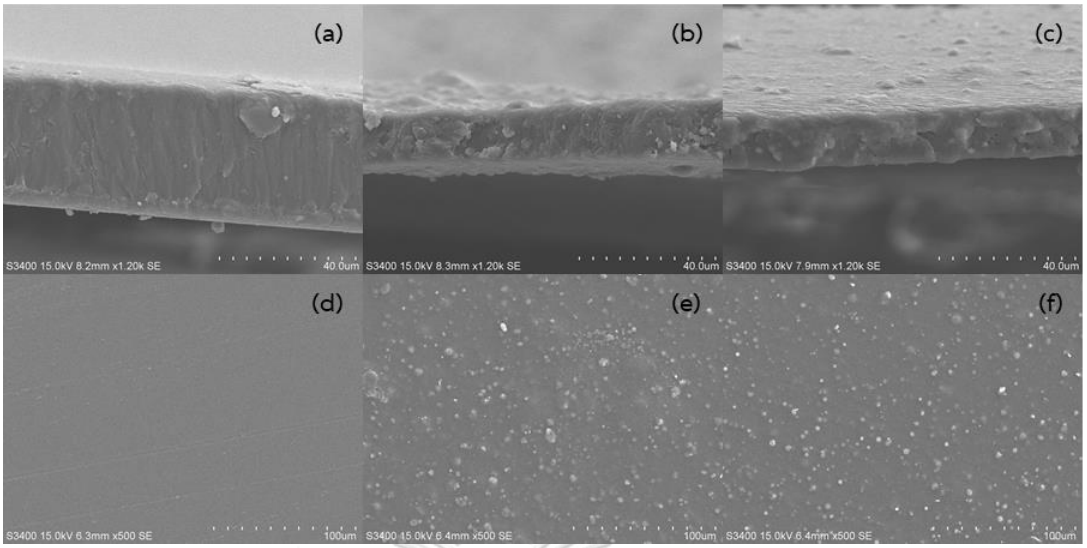


Figure 4.4 SEM images, on cross section of neat PLA (a), laboratory film (b) and industrial film (c), and on surface of neat PLA (d), laboratory film (e) and industrial film (f)

4.1.2 Crystallinity of films packaging

Crystallinity of both films were investigated by differential scanning calorimetry (DSC) technique. DSC thermogram of both films were shown in **Figure 4.5**. The thermal properties of both films were compared with that of neat PLA to investigate the crystallization of film. Cold crystallization period of both films was shifted from neat PLA indicating that adding fillers would delay the crystallization of PLA chain while heating. However, melting temperature of both bioplastic films was not shift from neat PLA, indicated that crystals in both bioplastic bags were crystal of PLA. From the result showed that PLA and fillers were physical blending [22]. From **Figure 4.5**, ΔH_m of laboratory film, industrial film and neat PLA were 26.61, 25.69 and 24.33 J/g, respectively. ΔH_{cc} of laboratory film, industrial film and neat PLA were 20.32, 20.43 and 20.80 J/g, respectively. $\Delta H°_m$ of PLA was 93.0 J/g [19], crystallinity of all samples are calculated by **Equation 3.1**. Percentage of crystals of laboratory film, industrial film and neat PLA were 7.88%, 6.59% and 3.80%, respectively.

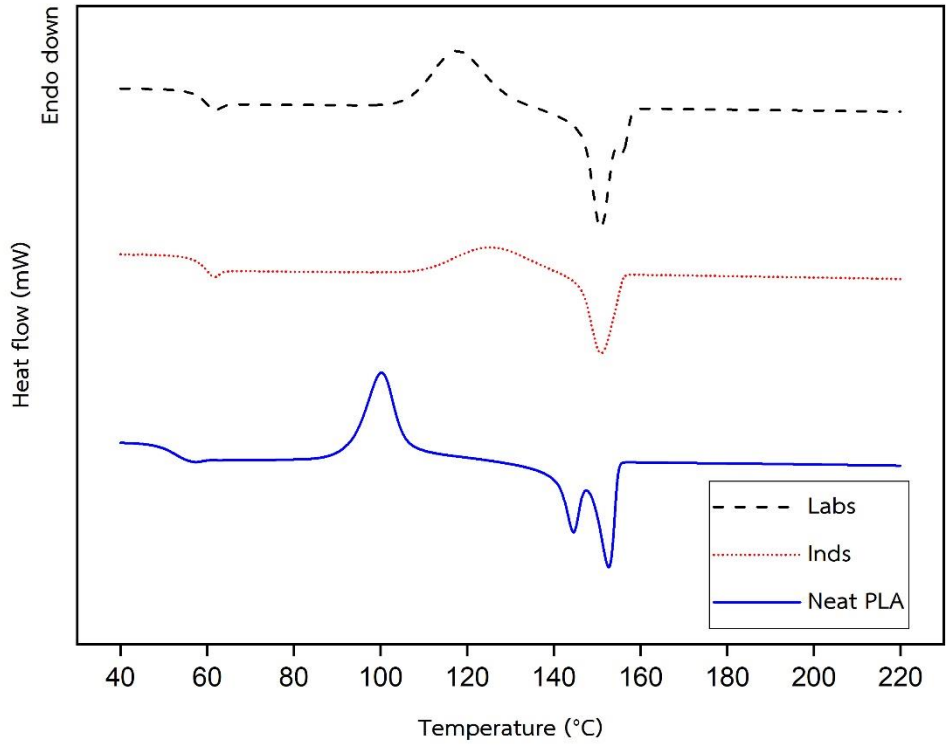


Figure 4.5 DSC thermogram of neat PLA, laboratory film and industrial films

4.1.3 Gas permeability of films

Oxygen, water vapor and ethylene permeabilities of both bioplastic films were investigated and recorded in **Table 4.1**. Oxygen and ethylene permeabilities (O_2P and C_2H_4P) of laboratory film were higher than those of industrial film because the orientation of polymer chain from blown film process would prevent gasses transfer across thickness of films [23]. O_2P, WVP and C_2H_4P were 53.32±2.86 mm-cc/m^2-day, 5.39±0.19 mm-g/m^2-day and 0.27±0.06 mm-ppm/m^2-day for laboratory film, respectively. For industrial film O_2P, WVP and C_2H_4P were 23.42±1.81 mm-cc/m^2-day, 4.50±1.08 mm-g/m^2-day and 0.17±0.04 mm-ppm/m^2-day, respectively. However, water vapor permeability of both bioplastic films was insignificant difference, due to water vapor transfer across the thickness of films by absorption and desorption process [24]. Structure of PLA and water vapor were polar, so water vapor could be interacted with PLA chain.

Table 4.1 Gasses permeability of bioplastic films

Permeabilities		Unit	Labs	Inds
			32.60 μm	18.73 μm
Oxygen	O_2 TR	cc/m^2-day	1,635.59±87.75	1,250.64±96.42
	O_2 P	mm-cc/m^2-day	53.32±2.86	23.42±1.81
Water vapor	WVTR	g/m^2-day	165.26±5.74	240.45±57.76
	WVP	mm-g/m^2-day	5.39±0.19	4.50±1.08
Ethylene	C_2H_4 TR	ppm/m^2-day	8.32±1.78	9.09±2.37
	C_2H_4 P	mm-ppm/m^2-day	0.27±0.06	0.17±0.04

** TR = Transmission rate

P = Permeation

4.2 Packing of Nam Dokmai mangoes

4.2.1 Accelerated ripening of Nam Dokmai mangoes

In this study, qualities of ripened mangoes were studied, so mangoes could be accelerated into ripened stage before starting test. 1,000 ppm ethephon aqueous solution was used to accelerate the ripeness of mangoes. Qualities of mangoes, before and after ripening process, were investigated.

Figure 4.6 The peel, pulp and core appearance of mangoes before (Unripe) and after (Ripe) ripening process

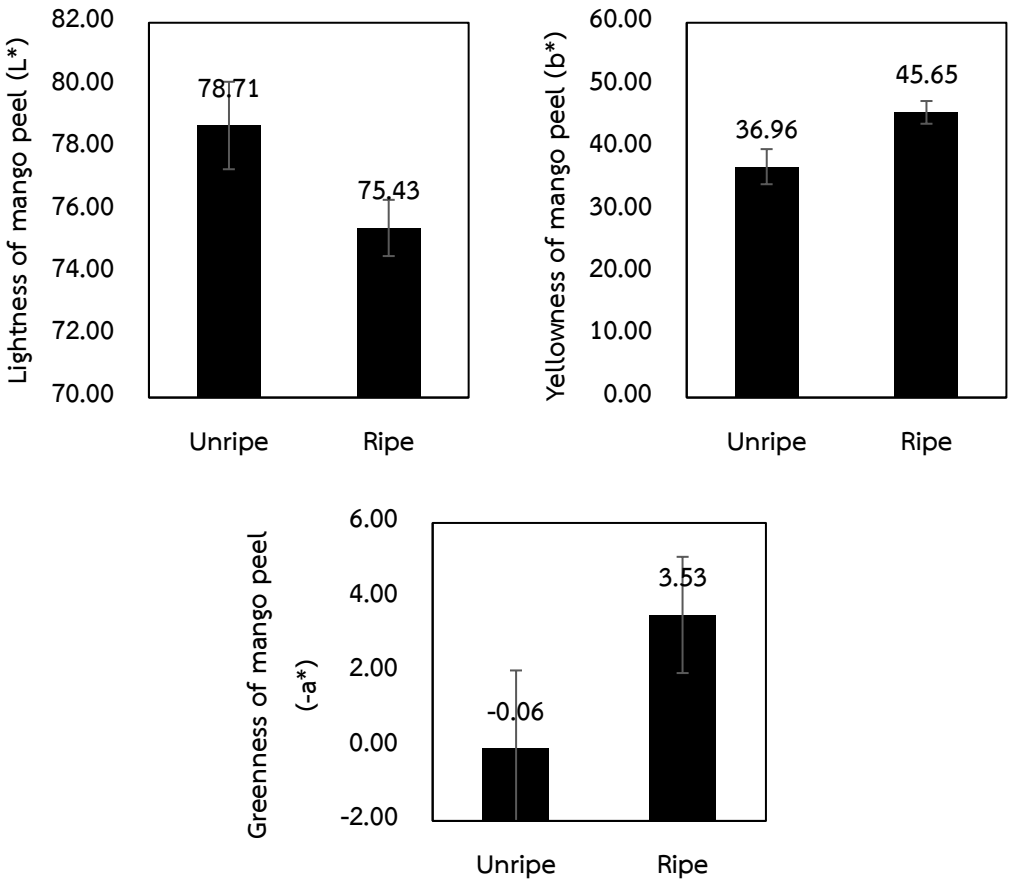


Figure 4.7 Lightness, yellowness and greenness of mango peels before (Unripe) and after (Ripe) ripening process

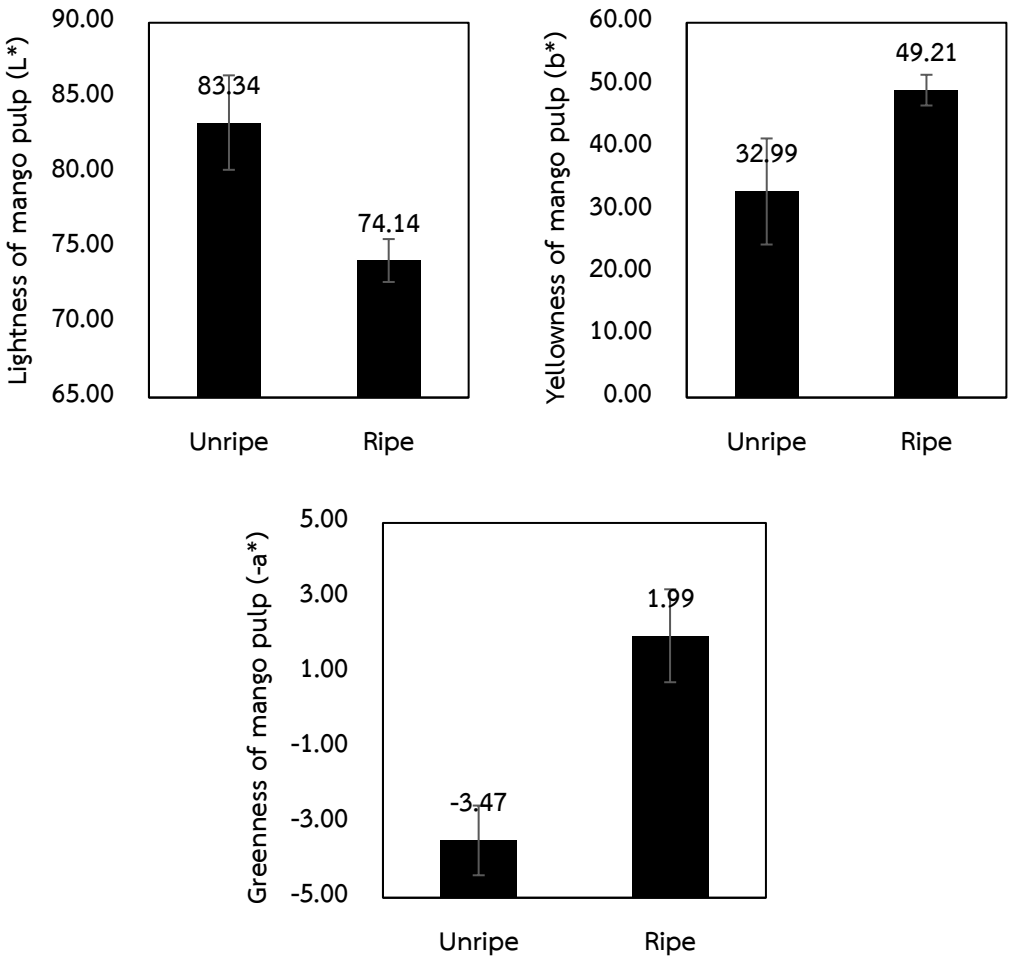


Figure 4.8 Lightness, yellowness and greenness of mango pulps before (Unripe) and after (Ripe) ripening process

Appearance, peel and pulp color change of mango after ripening process were shown in **Figure 4.6**, **Figure 4.7** and **Figure 4.8,** respectively. Before ripening process, peel of mangoes was yellow and bright but mango pulp was almost white. When mangoes ripe via ripening process, lightness and yellowness of peel and pulp decreased and increased [25], respectively.

The increase in ripeness of mangoes demonstrated increase deterioration. Mango uses stored organic compounds (from photosynthesis before harvest) in growth, when organic compounds have been used up, mango becomes degradation. Firmness of mango pulp were shown in **Figure 4.9**. After ripening process, firmness of

mango pulp decreased from 14.04±2.31 N to 3.43±0.76 N, indicating that mango pulp was deteriorated after this process. TSS of mango before and after ripening process, were insignificant differences. TA and V_C contents of ripened mangoes are significant decreased after ripening process, showing that acid and vitamin C contents were decreased after ripening [26].

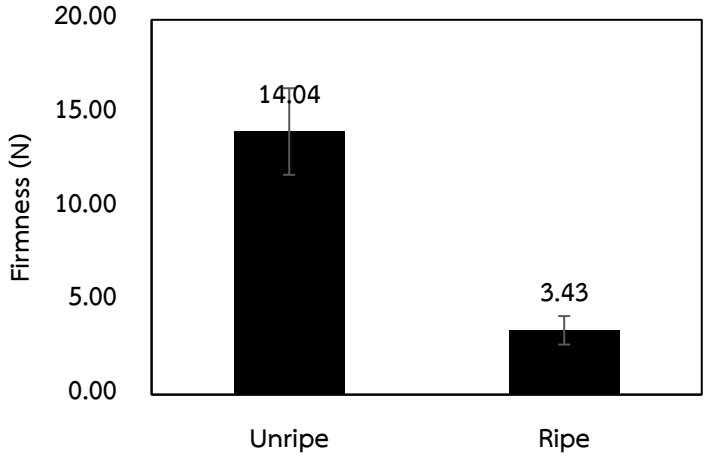


Figure 4.9 Firmness of mango pulp before (Unripe) and after (Ripe) ripening process

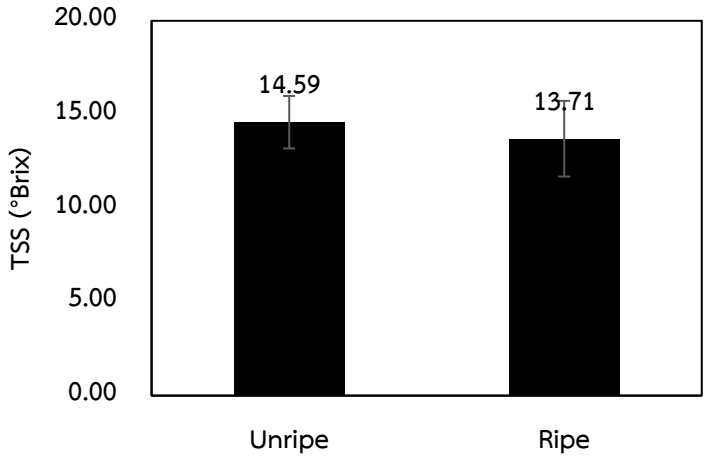


Figure 4.10 Total soluble solids (TSS) of mango juices before (Unripe) and after (Ripe) ripening process

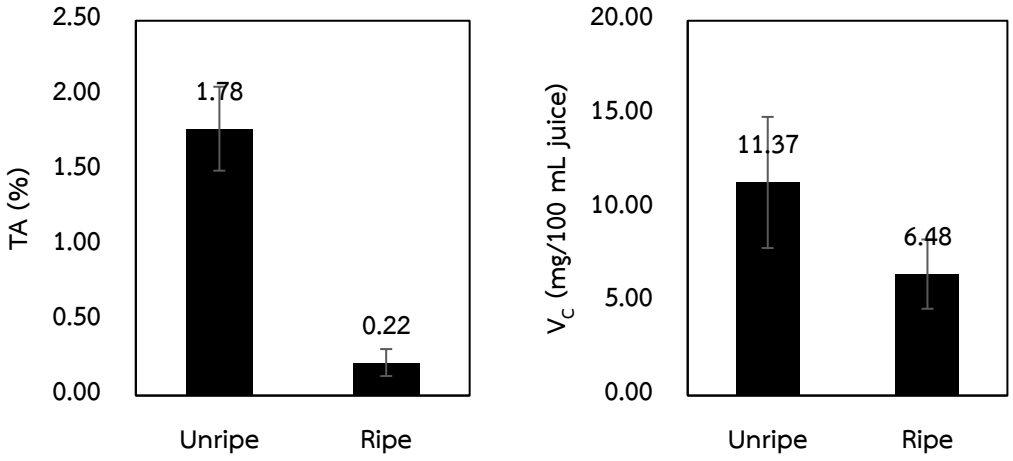


Figure 4.11 Titration acidity (TA) and Vitamin C (V_C) contents of mango juices before (Unripe) and after (Ripe) ripening process

4.2.2 Packing of Nam Dokmai mangoes in plastic packaging at 12 °C

Nam Dokmai mangoes, after ripening process, were packed in bioplastic bags from laboratory and industrial scale production. Control manogoes (without packages) and mangoes packed in bioplastic bags, were stored at 12 °C relative humidity 85-95 % and were investigated their qualities in every 3 days.

Sensory evaluation was shown in **Figure 4.12**. Yellowness of peel and pulp was insignificant differences during storage, indicating that control mangoes and mango in bioplastic bags were not deteriorated in peel and pulp after storage. Brown spot scores of control mangoes increased faster than that of mango in bioplastic bags indicating that the deterioration rate of control mangoes was higher than that of mango in bioplastic bags. Smell and taste scores of mango in bioplastic bags were decreased during storage, but control mangoes have insignificant differences in smell and taste scores. Unusual smell and taste were caused of fermentation by gas accumulation inside bioplastic bags [27].

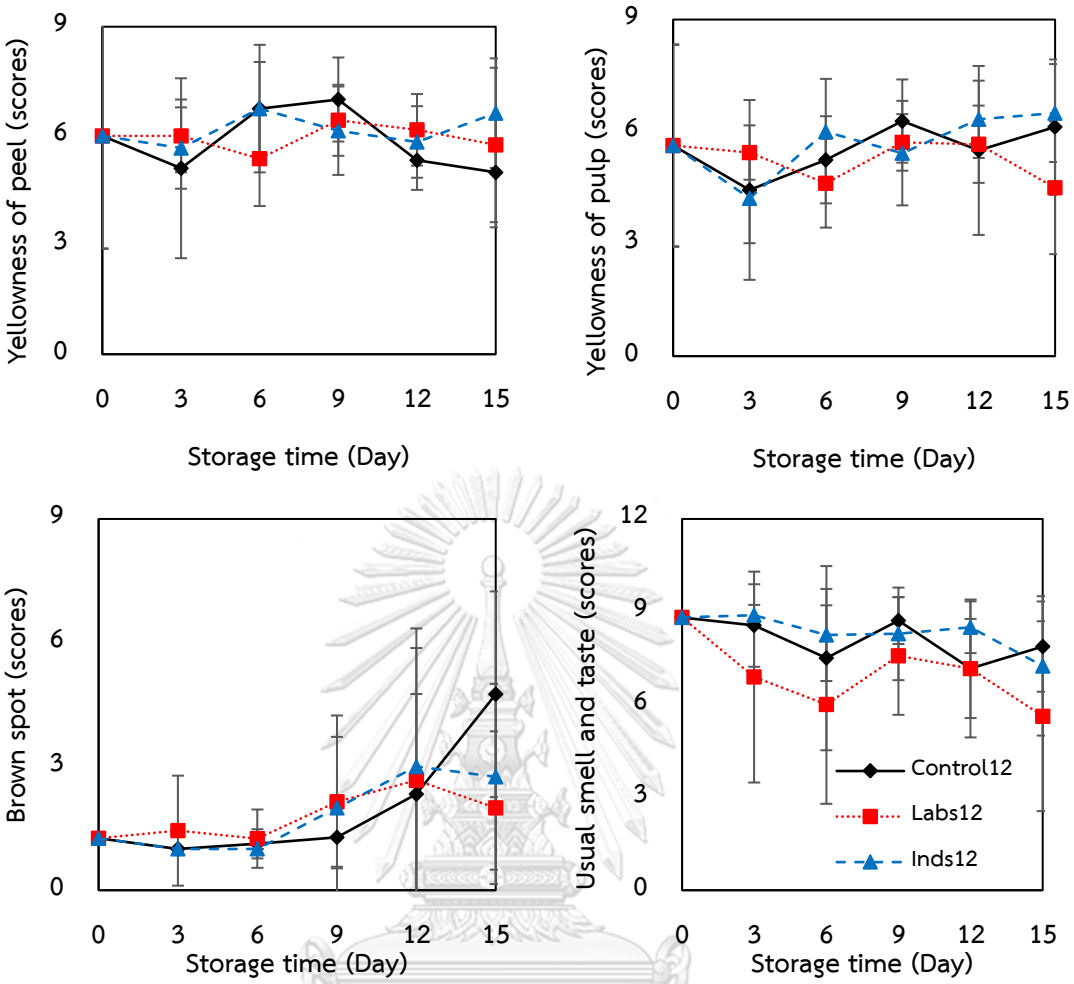


Figure 4.12 Sensory evaluation of control mangoes and mangoes packed inside laboratory and industrial bioplastic bags at 12 ℃ relative humidity 85-95 %

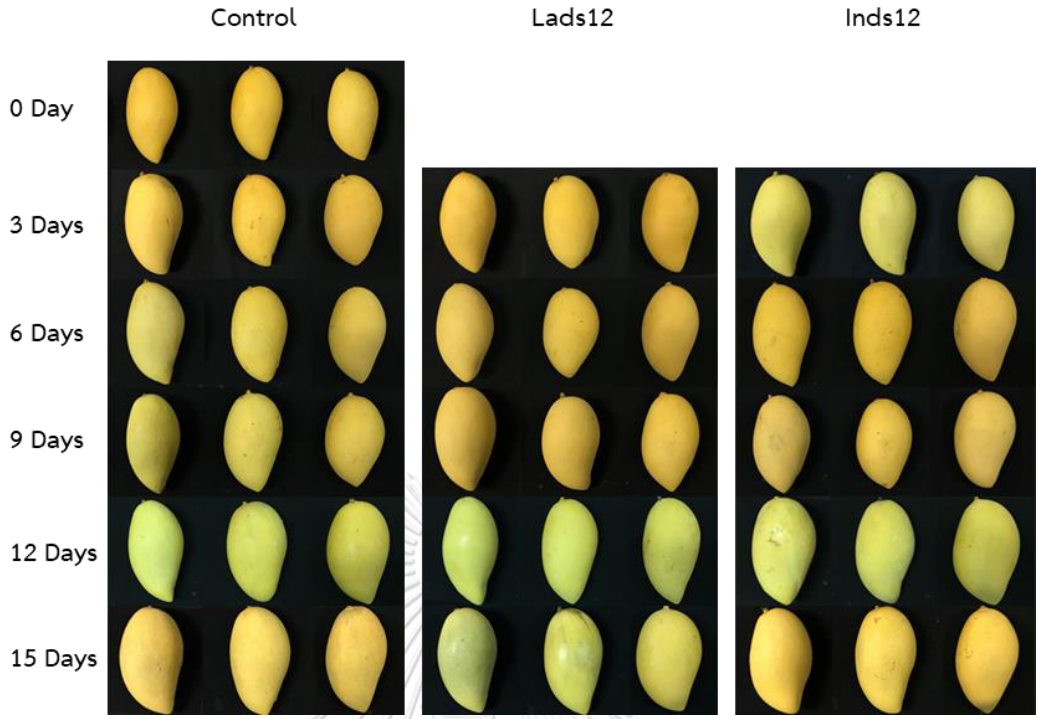


Figure 4.13 The peel appearance of control mangoes and mangoes packed inside laboratory and industrial bioplastic bags at 12 ℃ relative humidity 85-95 %

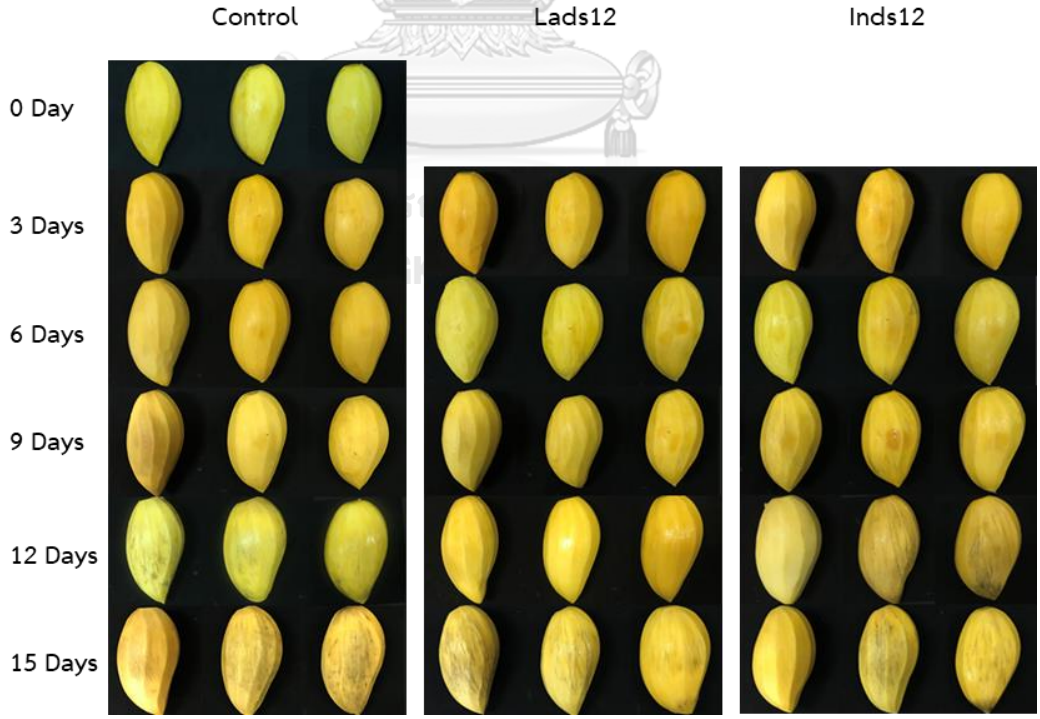


Figure 4.14 The pulp appearance of control mangoes and mangoes packed inside laboratory and industrial bioplastic bags at 12 ℃ relative humidity 85-95 %

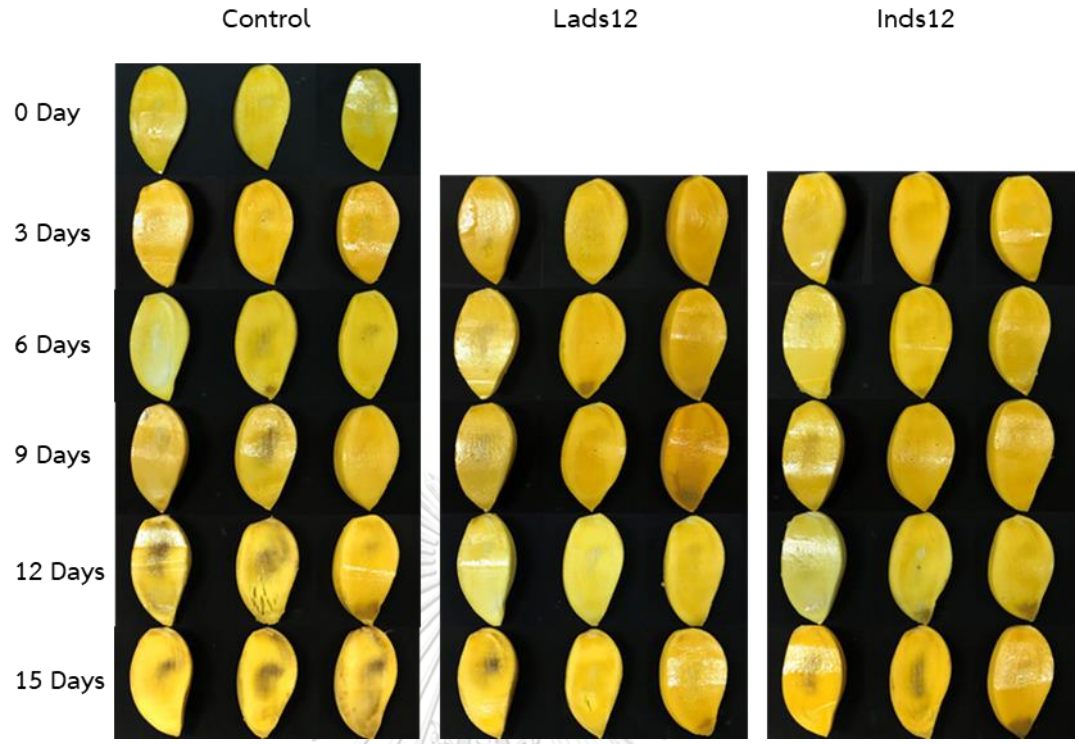


Figure 4.15 The core appearance of control mangoes and mangoes packed inside laboratory and industrial bioplastic bags at 12 ℃ relative humidity 85-95 %

The peel, pulp and core appearances of mangoes, after stored at 12 ℃ for 15 days, were shown in **Figure 4.13**, **Figure 4.14** and **Figure 4.15**, respectively. Peel and pulp of mangoes did not show the deterioration in 9 day storage for all samples. When considering on core appearance, controlled mango showed the deterioration when storage time increased to 6 days. For storage time increase to 12 days, mangoes in industrial bag showed the deterioration in pulp of mangoes but mangoes in laboratory bag were still look fresh. Because laboratory bag has higher oxygen permeability than industrial bag, so mangoes in laboratory bag have more oxygen concentration to use in respiration process. On the other hand, microbes and bacteria in mango can grow quickly under conditions with high oxygen content, resulting in mango became deterioration.

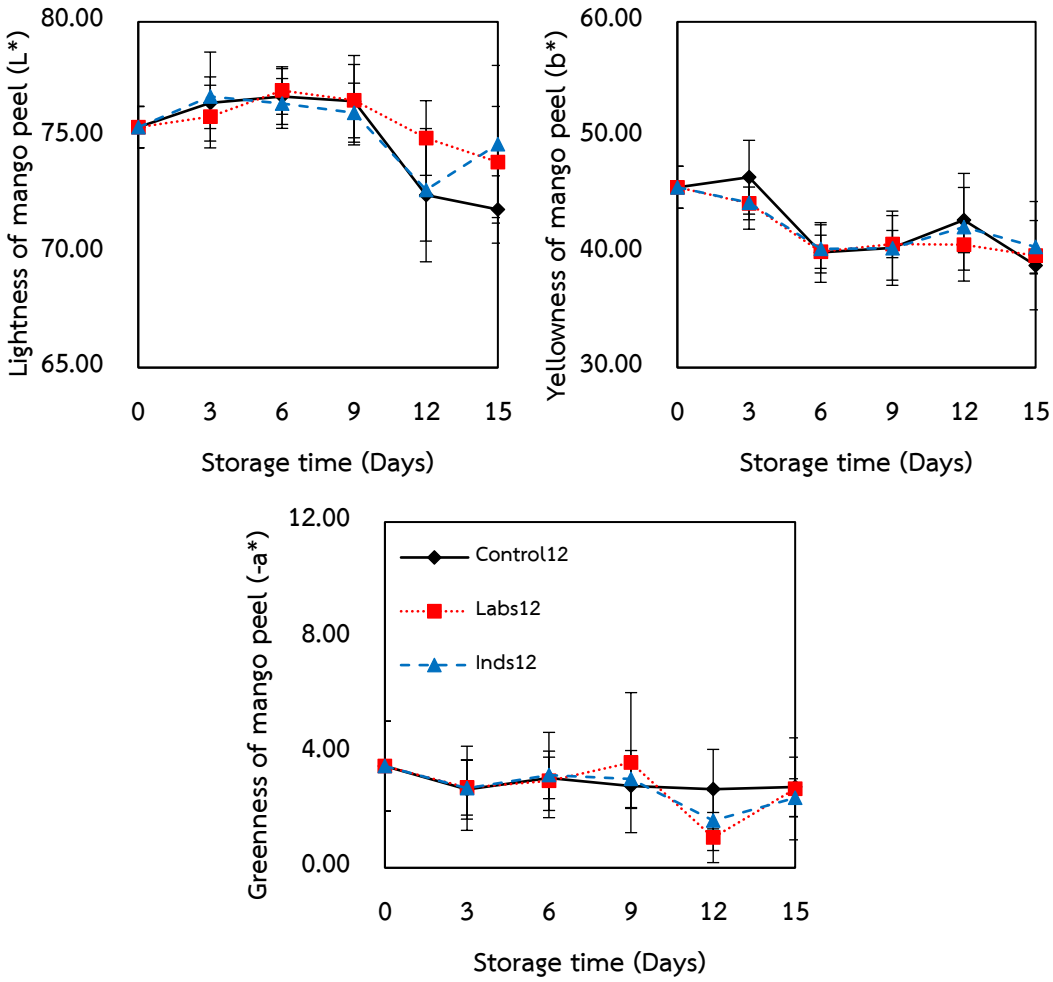


Figure 4.16 The peel lightness, yellowness and greenness of control mangoes and mangoes packed inside laboratory and industrial bioplastic bags at 12 °C relative humidity 85-95 %

Figure 4.16 and **Figure 4.17** show the color change in peel and pulp of mangoes, respectively. Peel and pulp lightness of controlled mangoes and mangoes in industrial bag were significantly decrease when storage time was 12 days showing that deterioration of controlled mangoes and mangoes in industrial bag were faster than that in laboratory bag. Yellowness of mango peel slightly decreased in 6 day storage, and 9 to 15 day storage. Yellowness of peels were insignificant difference. For 12 day storage, yellowness of mango pulp, slightly decreased indicating that the deterioration of mango pulp in 12 day storage for controlled mangoes and mangoes

in industrial bag. The greenness of mango peel and pulp, was insignificant differences in 15 day storage, due to breakdown of chlorophyll in ripening process [28].

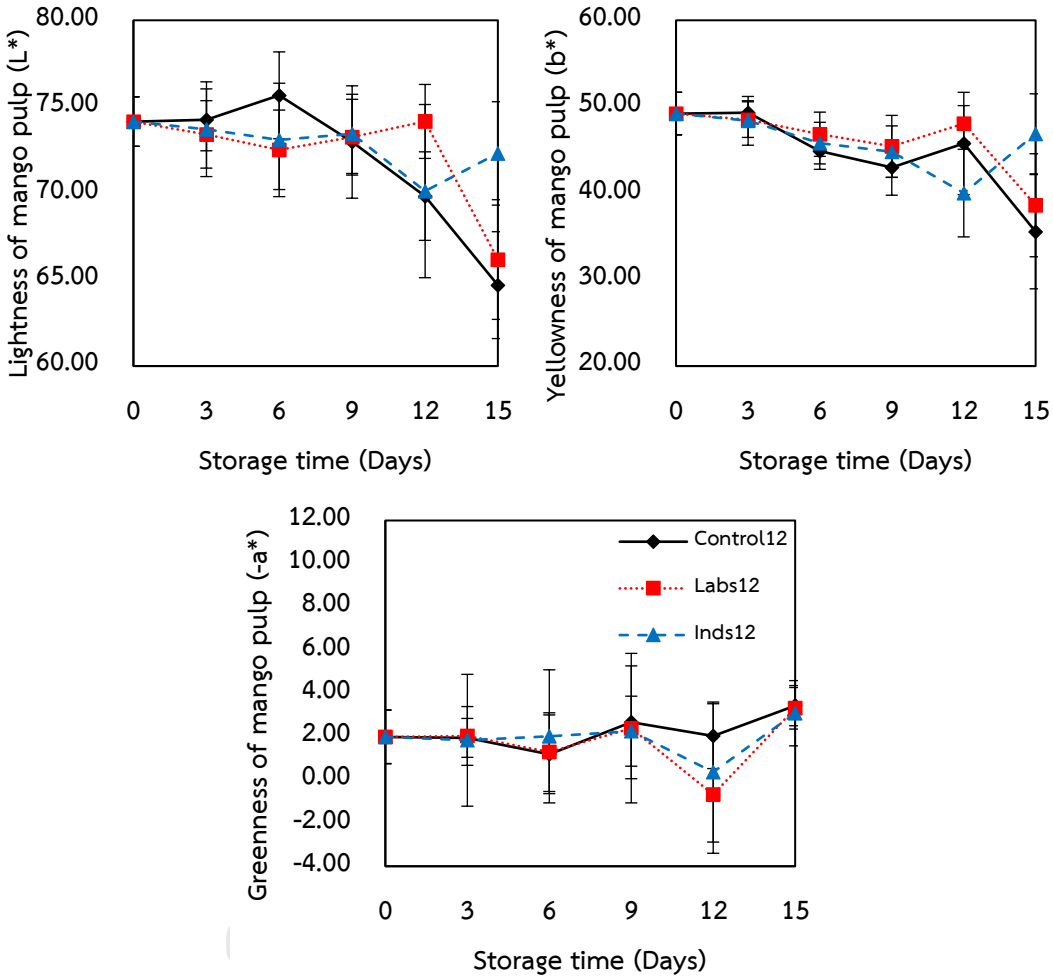


Figure 4.17 The pulp lightness, yellowness and greenness of control mangoes and mangoes packed inside laboratory and industrial bioplastic bags at 12 °C relative humidity 85-95 %

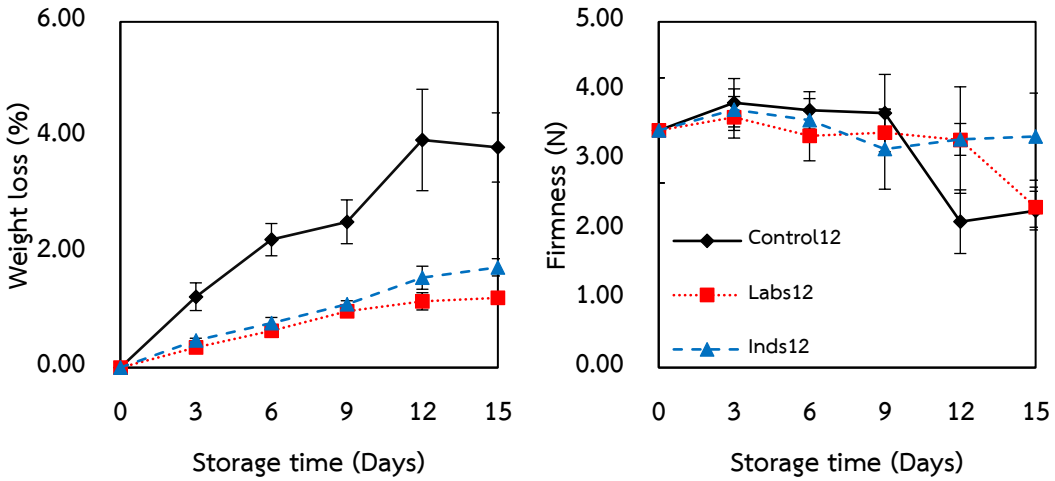


Figure 4.18 Weight loss and firmness of control mangoes and mangoes packed inside laboratory and industrial bioplastic bags at 12 ℃ relative humidity 85-95 %

Weight loss of mangoes, after storage for 15 days, were shown in **Figure 4.18**. Normally, in respiration process, mango releases carbon dioxide and water vapor. Water vapor releases from this process, are the cause of weight loss in mango. In normal atmosphere, higher oxygen concentration (around 21%), mango has high respiration rate and releases lot of water vapor [29]. Therefore, there is higher weight loss in control mangoes than mangoes in bioplastic bags. Weigh loss of control mangoes stored at 12 ℃ for 15 day storage was 3.82±0.60%. Weight loss of mangoes inside laboratory and industrial bags, at 12 ℃ for 15 day storage, were 1.21±0.05% and 1.74±0.15% respectively. Inside bioplastic bags, oxygen concentration is lower than normal atmosphere, respiration rate of mango decreased with oxygen concentration, so the weight loss of mangoes inside both of bioplastic bags are lower than that of control mangoes. Fruit firmness could indicate the deterioration of mangoes pulp [30, 31]. For storage times 12 days, firmness of control mangoes was significantly decreased but mangoes inside both of bioplastic bags were insignificant differences for 12 day storage. Firmness of control mangoes, mangoes in laboratory and industrial bags were 2.27±0.28 N, 2.32±0.29 N and 3.34±0.63 N respectively for 15 day storage. Firmness of control mango was insignificant differences with mango in

laboratory bag at 15 day storage, indicating that mango in laboratory bag deteriorated in pulp after storage time for 15 days.

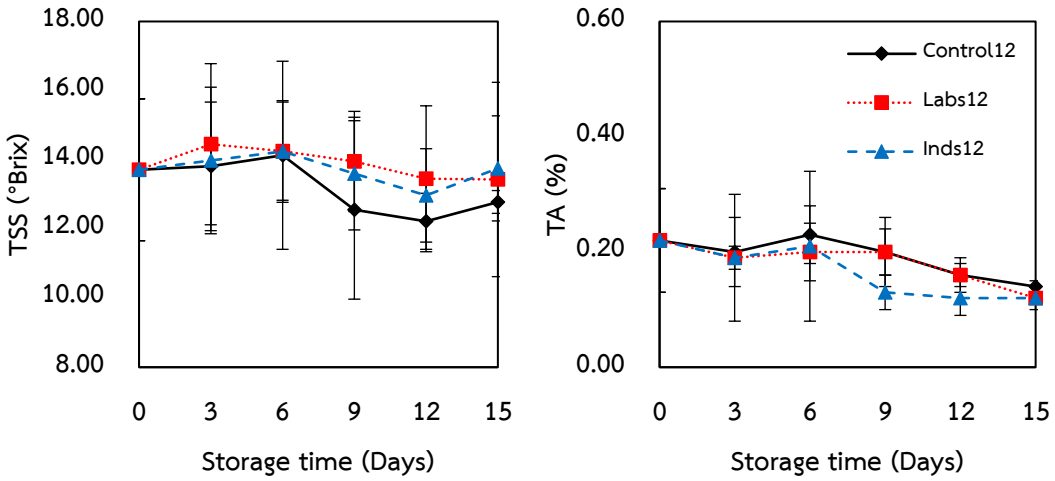


Figure 4.19 Total soluble solids (TSS) and titration acidity (TA) of control mangoes and mangoes packed inside laboratory and industrial bioplastic bags at 12 °C relative humidity 85-95 %

Total soluble solid (TSS) content, in mango that could indicate the sweetness or sugar contents. Normally, mango before harvest can be photosynthesized to produce foods that used in growth process. These foods are also stored in term of organic compound such as starch or sugar. After harvest, mango used storage foods in respiration process, so the decrease in TSS can indicate that mango still respire [32]. Control mangoes have significantly decreased in TSS more than mangoes inside both of bioplastic bags because higher respiration rate of control mangoes could accelerate the deterioration of mango. TSS value of mangoes in laboratory bag were insignificant differences to that of mangoes in industrial bag. TSS of mangoes were shown in **Figure 4.19**. %TA could indicate the acid content in mango juice. Ripened mangoes have small amount of acid contents compared to unripe mangoes. %TA of control mangoes and mangoes in both of bioplastic bags, were insignificant differences during storage. V_C content of mangoes were shown in **Figure 4.20**. V_C of all samples slightly decreased during storage time, indicating that mangoes still respire and grow after storage.

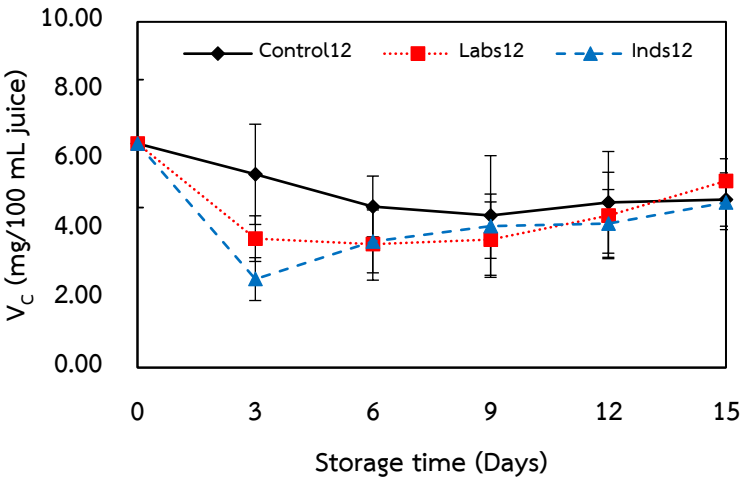


Figure 4.20 Vitamin C (V_C) contents of control mangoes and mangoes packed inside laboratory and industrial bioplastic bags at 12 ℃ relative humidity 85-95 %

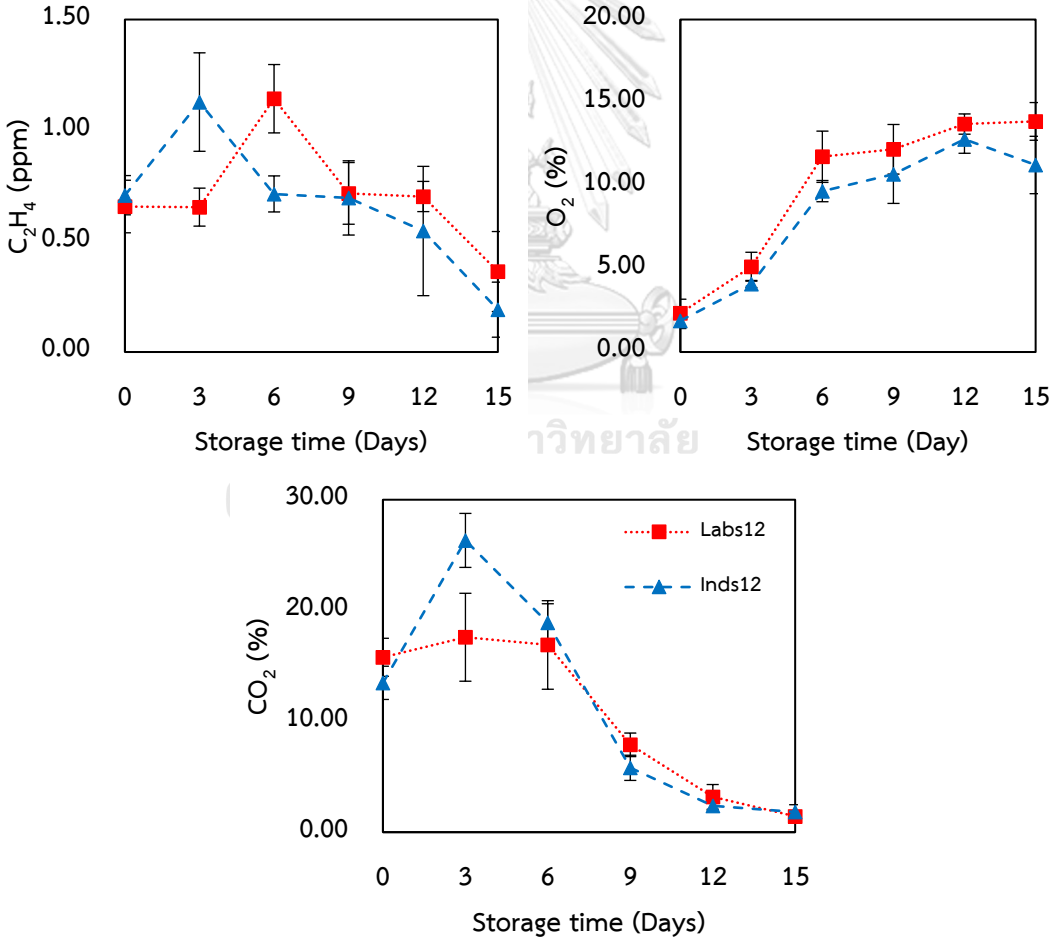


Figure 4.21 Gasses accumulation in laboratory and industrial bags at 12 ℃ relative humidity 85-95 %

Gasses accumulation in both bioplastic bags were investigated by gas chromatography technique every 3 day storage. Ethylene, oxygen and carbon dioxide concentration, for 15 day storage, were shown in **Figure 4.21**. In respiration of mango, oxygen was used in this process, carbon dioxide and ethylene were released. Carbon dioxide and ethylene accumulation in both bioplastic bags were in the same trend, concentration of carbon dioxide and ethylene increased in 6 day storage and decreased when storage time increased. Increase of carbon dioxide and ethylene was from respiration process of mango. When respiration rate decreased, carbon dioxide and ethylene accumulation in both bioplastic bags decreased together. Ethylene concentration, in both of bioplastic bags significantly increased at 6 day and 3 day storage for laboratory bag and industrial bag, respectively. Carbon dioxide concentration increased when storage time increased to 6 days, then decreased when storage time increased to 15 days respectively.

Oxygen concentration in both bioplastic bags showed similar trend during storage. Oxygen concentration slightly increased when storage time increased. When respiration of mango decreased, the amount of oxygen used was also reduced accordingly. However, increase of oxygen concentration of laboratory bag was higher than that of industrial bag because oxygen permeability of laboratory bag was higher than that of industrial bag. Oxygen accumulation in laboratory bag and industrial bag at storage time 15 days were 13.8724±1.134 % and 11.2486±1.7266 %, respectively.

4.2.3 Packing of Nam Dokmai mangoes in plastic packaging at 25 °C

Storage temperature effects on the shelf-life of mango. In this part, mangoes were stored at 25 ℃ relative humidity 85-95% without packaging (control mangoes) compared to packing in laboratory and industrial bioplastic bags. Qualities of mangoes were investigated every 3 days.

Sensory evaluation of control mangoes and mangoes in bioplastic bags were recorded and were shown in **Figure 4.22**. Peel yellowness of all treatments were insignificant differences for 9 day storage, control mangoes and mango in laboratory

bag show similar trend in yellowness of pulp. Pulp yellowness of mango in industrial bag decreased when storage time increased to 6 days, indicating that deterioration of mango in industrial bag was begun. Brown spot of all treatments were significantly increased after 3 day storage, and increased of storage time made smell and taste scores also decreased. From this result, the deterioration of all mango treatments began after 3 days of storage.

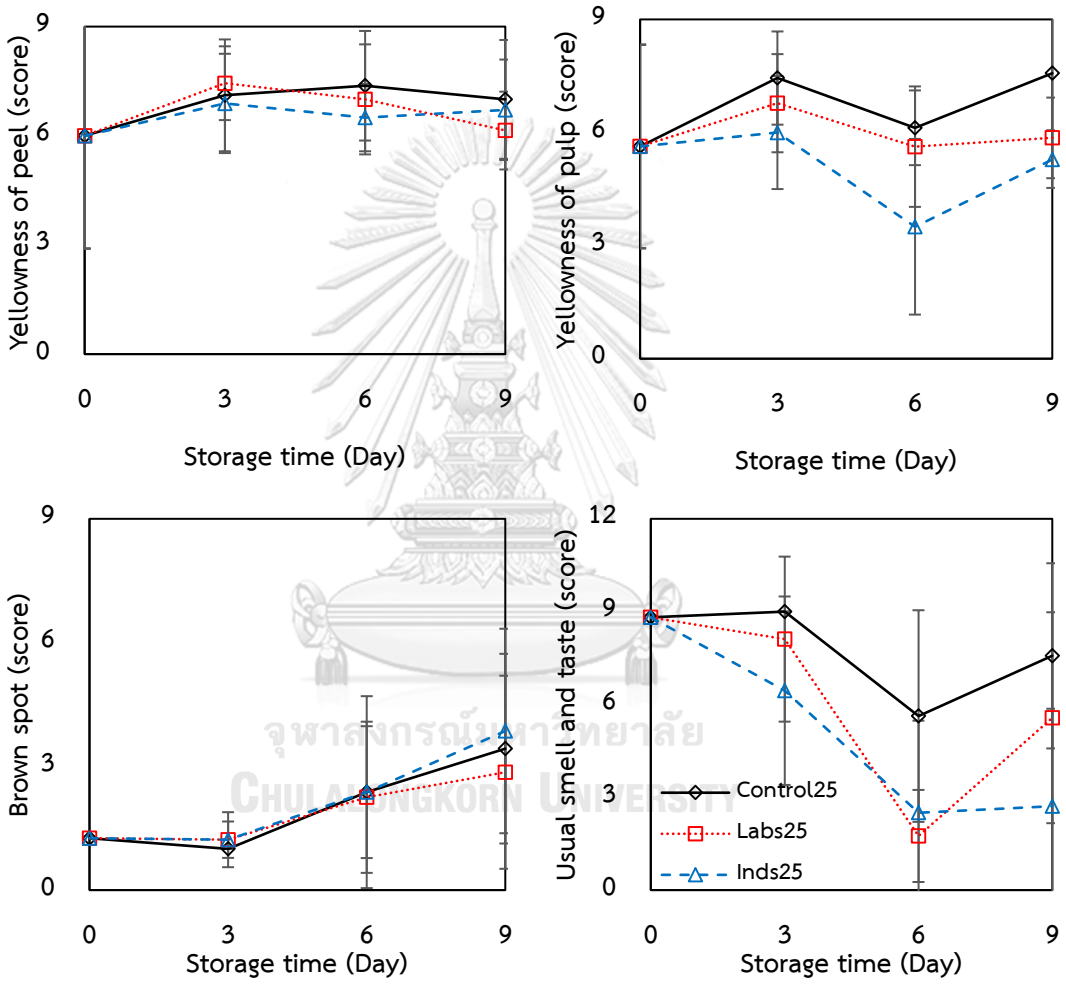


Figure 4.22 Sensory evaluation of control mangoes and mangoes packed inside laboratory and industrial bioplastic bags at 25 °C relative humidity 85-95 %

The peel, pulp and core appearances of mangoes were shown in **Figure 4.23** **Figure 4.24** and **Figure 4.25**, respectively. Deterioration of mango peel, pulp and core was showed in 6 day storage for control mangoes. Control mangoes showed

faster deterioration rate than mangoes in bioplastic bags, because the respiration rate of control mangoes was higher than mango in packaging. Peel of mangoes, packed in laboratory bag, turned to be brown in 9 day storage. Color change of mango peel and pulp were shown in **Figure 4.26** and **Figure 4.27**, respectively. Lightness and yellowness of peel and pulp were slightly decreased in 9 day storage of all treatments. Greenness of mangoes was insignificant differences for all of treatments. From this result, color change of control mangoes and packed mangoes was insignificant differences for 9 day storage at 25 ℃.

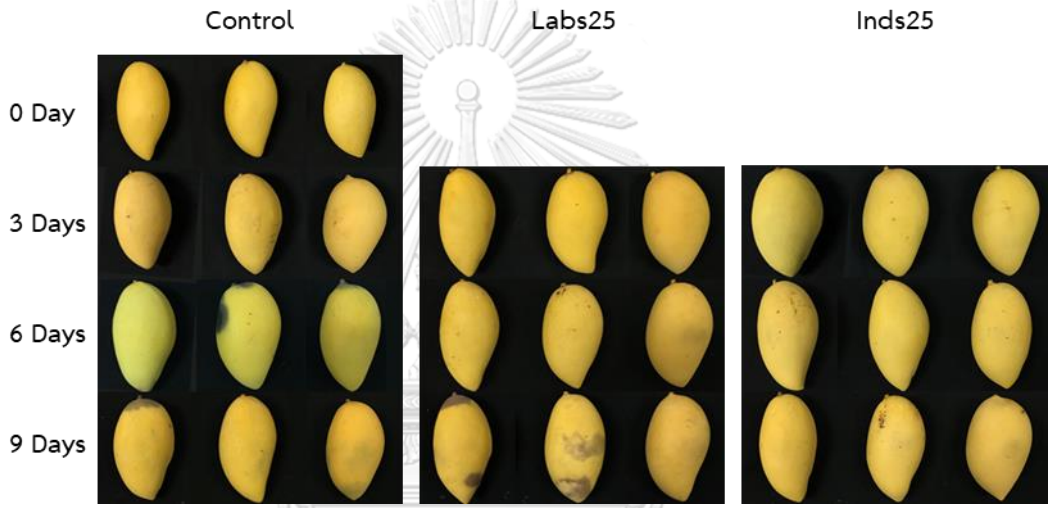


Figure 4.23 The peel appearance of control mangoes and mangoes packed inside laboratory and industrial bioplastic bags at 25 ℃ relative humidity 85-95 %

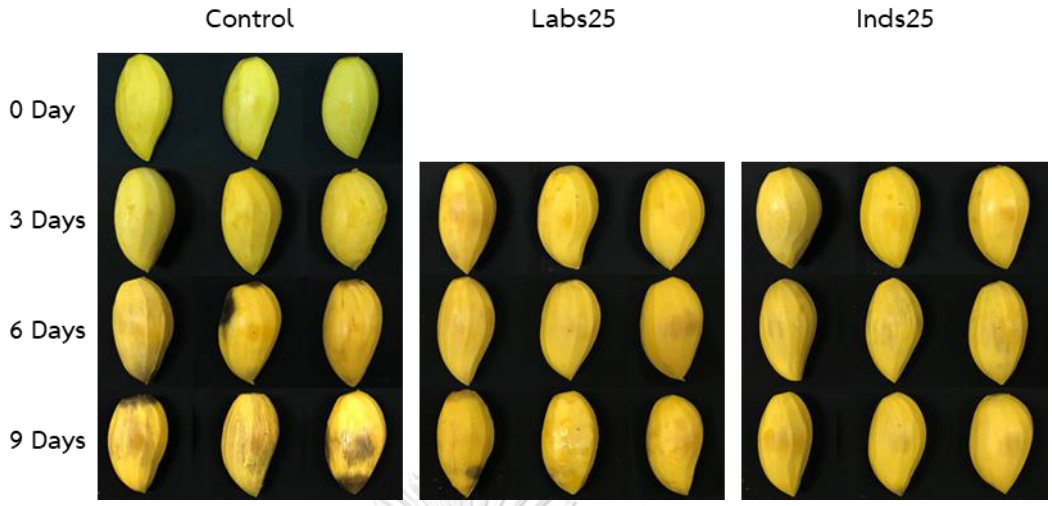


Figure 4.24 The pulp appearance of control mangoes and mangoes packed inside laboratory and industrial bioplastic bags at 25 °C relative humidity 85-95 %

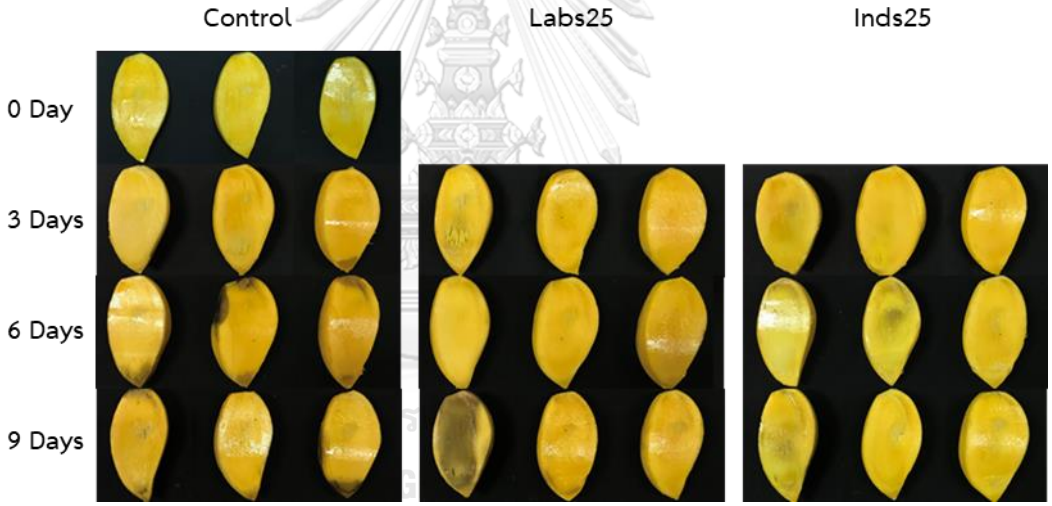


Figure 4.25 The core appearance of control mangoes and mangoes packed inside laboratory and industrial bioplastic bags at 25 °C relative humidity 85-95 %

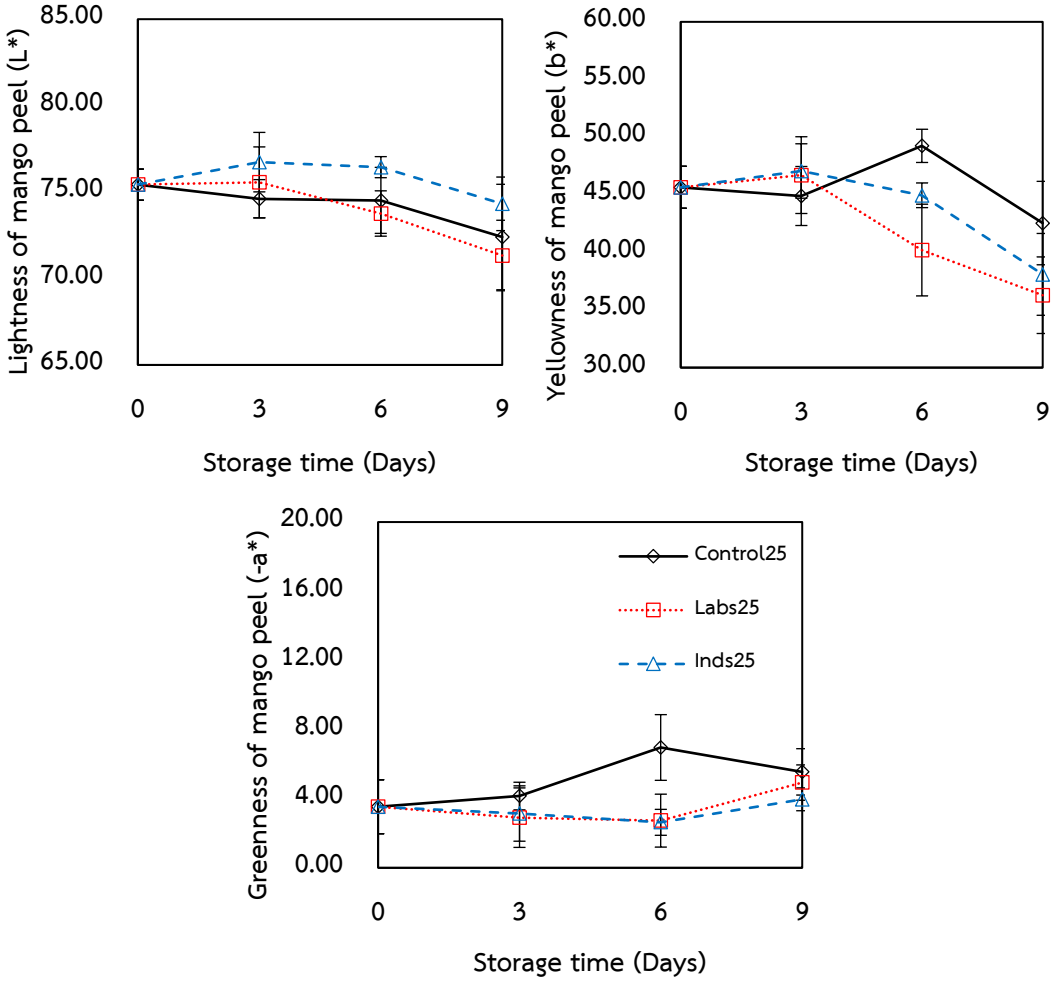


Figure 4.26 The peel lightness, yellowness and greenness of control mangoes and mangoes packed inside laboratory and industrial bioplastic bags at 25 °C relative humidity 85-95 %

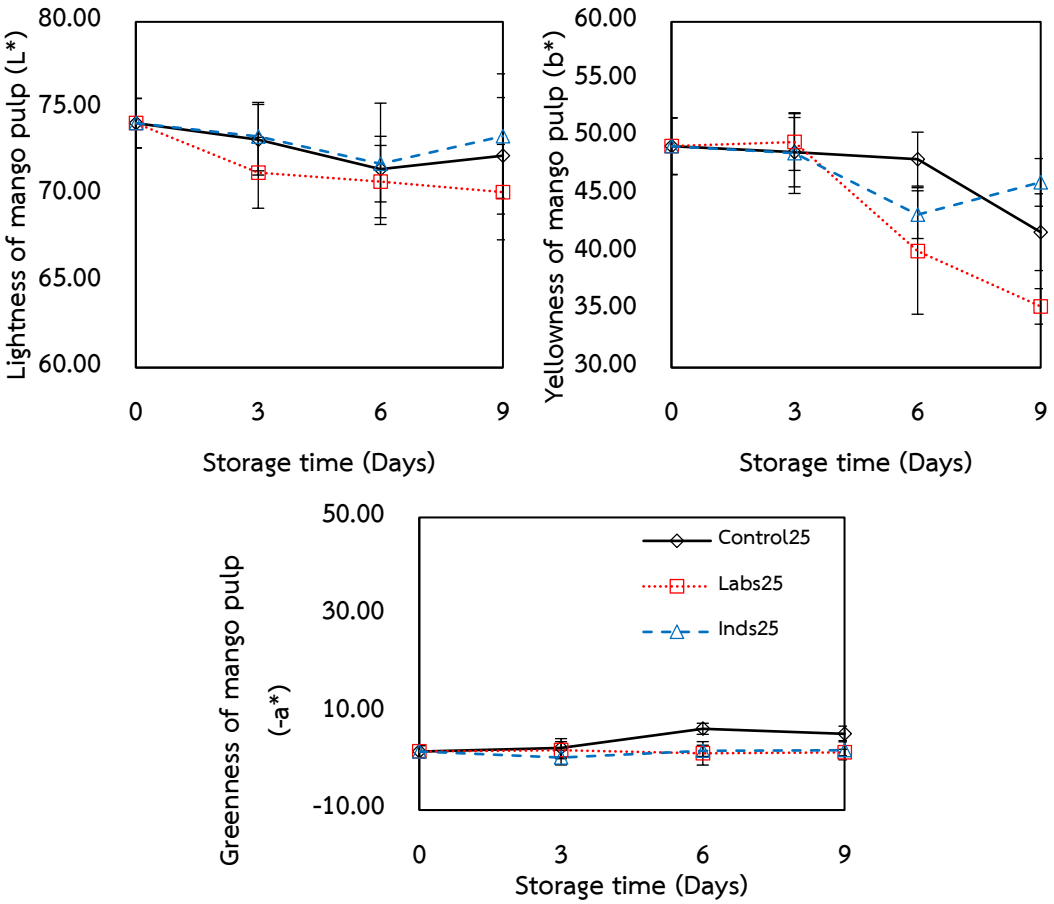


Figure 4.27 The pulp lightness, yellowness and greenness of control mangoes and mangoes packed inside laboratory and industrial bioplastic bags at 25 ℃ relative humidity 85-95 %

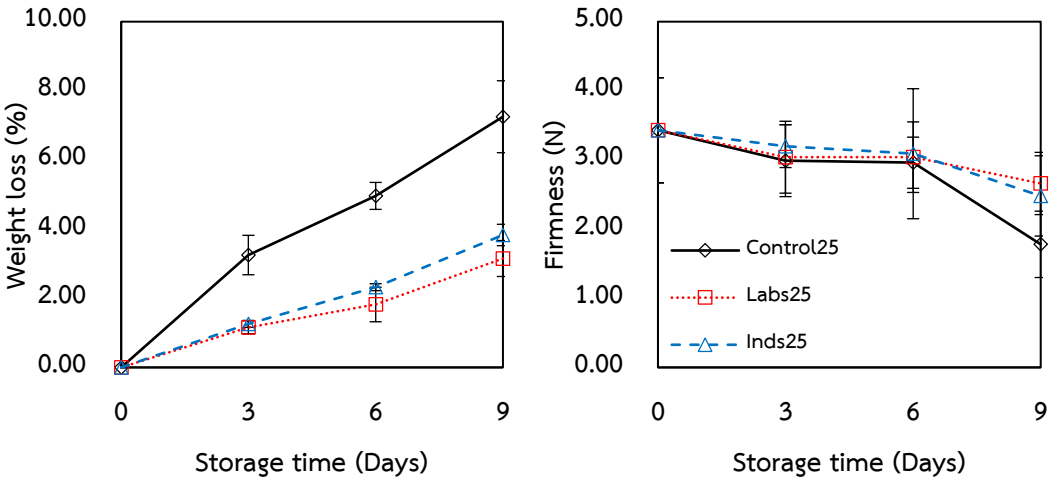


Figure 4.28 Weight loss and firmness of control mangoes and mangoes packed inside laboratory and industrial bioplastic bags at 25 ℃ relative humidity 85-95 %

Weight loss and pulp firmness of mangoes were shown in **Figure 4.28**. Weight loss of mangoes depends on water released from mango respiration. Control mangoes show higher weight loss than mangoes in bioplastic bags because control mangoes have higher rate of respiration than mangoes in bioplastic bags [33, 34]. For 9 day storage, weight loss of control mangoes, mangoes in laboratory and industrial bags were 7.25±1.04 %, 3.15±0.52 % and 3.83±0.31 %, respectively. Mangoes, with higher respiration rate, showed higher deterioration rate. Firmness of control mangoes significantly decreased faster than that of mangoes in bioplastic bags for 9 day storage. This indicated that pulp deterioration of control mango was faster than that of mangoes in bioplastic bags. For 9 day storage, pulp firmness of control mangoes, mango in laboratory and industrial bags were 1.78±0.48 N, 2.66±0.45 N and 2.48±0.58 N, respectively.

TSS, TA and V_C contents of all samples were shown in **Figure 4.29**. TSS of all samples were insignificantly different, and slightly decreased in 9 day storage. In the same way, TA of all samples slightly decreased during storage, control mangoes showed lower TA content than mangoes in bioplastic bags. V_C contents of all samples were significantly decreased in 3 day storage. This indicated that vitamin C contents were used in respiration process of mangoes in 3 day period.

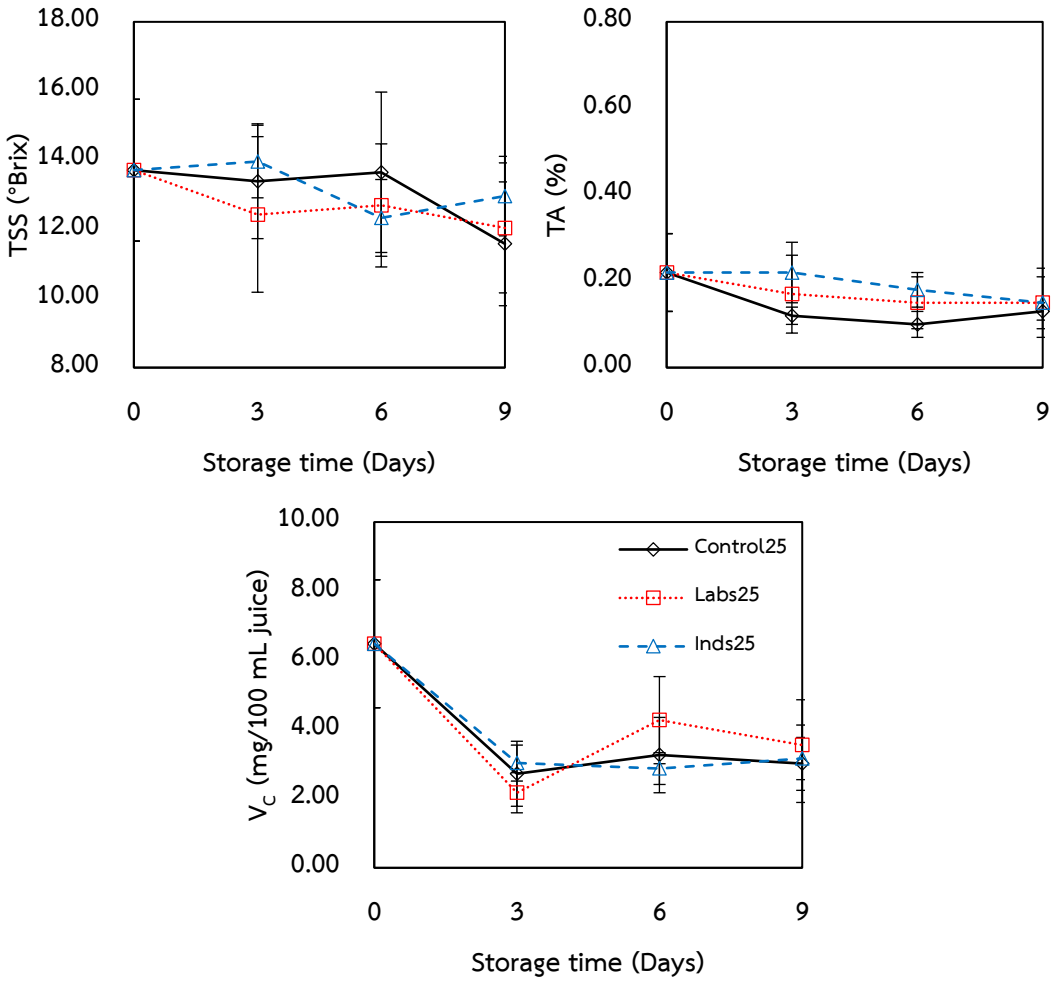


Figure 4.29 Total soluble solids (TSS), titration acidity (TA) and vitamin C (V_C) contents of control mangoes and mangoes packed inside laboratory and industrial bioplastic bags at 25 °C relative humidity 85-95 %

Although TSS, TA and V_C contents were insignificant different, mangoes still deteriorated as shown in **Figure 4.23** and **Figure 4.24.** Gasses accumulation inside packaging were shown in **Figure 4.30.** Ethylene inside both bioplastic bags slightly decreased, indicating that accumulated ethylene in bags could be transferred across the thickness of films. Carbon dioxide inside both of bioplastic bags were significant decreased during storage, indicating that respiration rate of mango inside bioplastic bag reduced during storage. Decrease of ethylene and carbon dioxide when storage time increased, was the result of reduction of respiration rate and gas permeability of

packaging. Oxygen concentration inside both bioplastic bags slightly increased when storage time increased. Oxygen permeability of both bioplastic bags was caused of increased oxygen concentration inside bioplastic bag. Gasses accumulation inside bioplastic bag at 25 ℃ were similar with that at 12 ℃, that showed the efficiency in gasses permeabilities of both bioplastic bags.

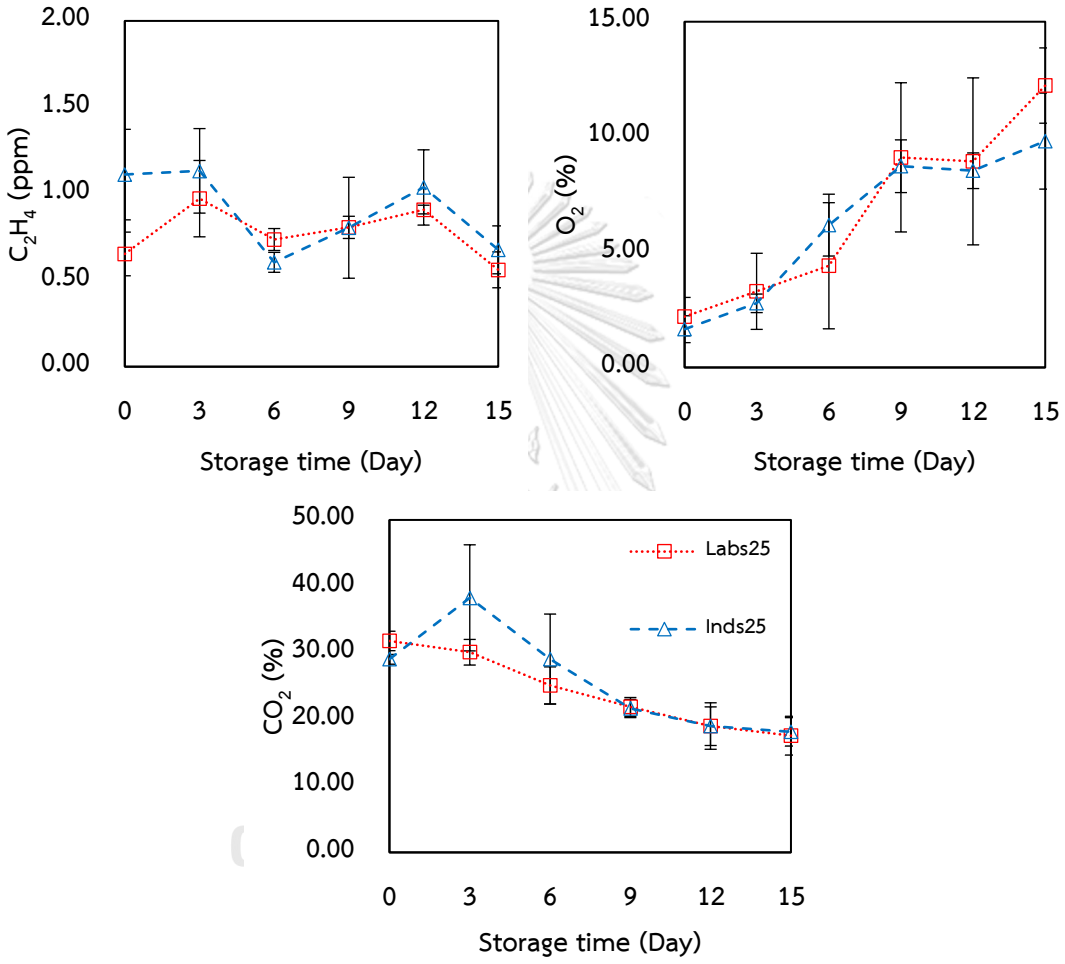


Figure 4.30 Gasses accumulation in laboratory and industrial bag at 25 ℃ relative humidity 85-95 %

CHAPTER V
CONCLUSION

5.1 Conclusions

In this study, bioplastic bags were produced in laboratory and industrial scale production. Both bioplastic bags were used to prolong shelf-life of mango (cv. Golden Nam Dokmai). Mechanical properties and gasses permeability of bags were investigated before mango was packed. Qualities of mangoes, such as visual observation, %weight loss, firmness of pulp, color change, TSS, %TA and vitamin C contents, were investigated every 3 days for 15 day storage.

For both bioplastic bags, PLA and fillers were mixed via twin screw extruder and blown into films via blown film extruder with similar fillers ratio but different scale of machine. Tensile properties and impact strength of both films were insignificant different, except the elongation at break of both films. Higher in draw down and blow up ratio of industrial blown film extruder, was the cause of polymer chain orientated in MD and TD direction. Elongation at break of laboratory film and industrial film were 2.65±0.75 % and 5.92±1.87 % in MD direction, 1.48±0.26 % and 3.20±0.91 % in TD direction. Orientation of polymer chain are blocking of gasses permeation, so laboratory film had higher oxygen permeability than industrial film Oxygen permeability of laboratory and industrial film were 53.32±2.86 and 23.42±1.81 mm-cc/m^2-day, respectively.

Nam Dokmai mangoes were kept in laboratory and industrial bags, then stored at 12 ℃ and 25 ℃, respectively. Qualities of mango in both bags, were compared with control mangoes (without packaging), to compare shelf-life extending efficiency of bioplastic bags. At 12 ℃, mango in laboratory bag could be stored for 12 days without deterioration. Control mangoes and mango in industrial bag began to deteriorate in 12 day storage. When considering on core appearances, control mango was deteriorated when storage time increased to 6 days. Respiration process of mango are cuased of deterioration, packing mango in bioplastic bags can limit oxygen content to be used in respiration process. Mango in both bioplastic bags showed

slower deterioration rate compared with control mangoes. Weight loss of control mango was higher than mango in bioplastic bags, because control mangoes have higher rate of respiration. Decrease in firmness, TSS, TA and V_C contents indicated that deterioration rate of mango had begun. In the same way, mangoes which were stored at 25 ℃ showed the same trend as those kept in 12 ℃. However, mangoes which were stored at 25 ℃ showed deterioration rate faster than those stored at 12 ℃. Deterioration was begun in 6 day storage for control mangoes and in 9 days for laboratory and industrial bags. Nam Dokmai mango could be stored at 25 ℃ for 6 days in both bioplastic bags, while control mango could be stored for 3 days.

From all of results, packing mango in bioplastic bags could limit oxygen inside bags and limit respiration of mango, so mango in both bioplastic bags had longer shelf-life than control mangoes. Temperature was the imporatant factor to select storage condition, at high temperature mango also had high respiration rate and became deteriorate faster. However, efficiency in mango shelf-life extending of both packaging were insignificant difference.

5.2 Recommendations

Based on what has been discovered in this research, the following recommendations were suggested:

- Carbon dioxide permeability of both packaging should be measured.
- Gasses absorption in both packaging should be measured.
- Similar stage of Nam Dokmai mangoes should be used.

REFERENCES

[1] Techawongstien, S. Physiology of Fruit Ripening. in: Faculty of agriculture, Khon kaen university, 2004.

[2] Siriphanich, J. Physiology and postharvest fruit and vegetable technology. Bangkok: Kasetsart university Kamphaeng Saen campus, 2006.

[3] Watson, J.A. Postharvest Storage, Packaging and Handling of Specialty Crops: A Guide for Florida Small Farm Producers. Food and Agricultural Sciences (2016).

[4] CRFG. Mango fruit facts [Online]. 1996. Available from: http://www.crfg.org/pubs/ff/mango.html

[5] Noiwan, D., Suppakul, P., Joomwong, A., Uthaibutra, J., and Rachtanapun, P. Kinetics of Mango Fruits (Mangifera indica cv. 'Nam Dok Mai Si Thong') Quality Changes during Storage at Various Temperatures. Journal of Agricultural Science 9(6) (2017): 199-212.

[6] Patel, B.B., Roy, F.S., Saiyad, M.J.S., and Joshi, D.C. Respiration behaviour and heat of respiration of mango (cv. Langdo) under different storage conditions. International Journal of Agriculture, Environment and Biotechnology 9(5) (2016): 855-859.

[7] Rani, T.S. Studies on Respiration Rates in Coccinia grandis (Ivy Gourd) at Different Temperatures. Journal of Food Processing & Technology 04(04) (2013): 1-5.

[8] Bobelyn, E., Hertog, M.L.A.T.M., and Nicolaï, B.M. Applicability of an enzymatic time temperature integrator as a quality indicator for mushrooms in the distribution chain. Postharvest Biology and Technology 42(1) (2006): 104-114.

[9] Olivera, D.F. and Salvadori, V.O. Kinetic modeling of quality changes of chilled ready to serve lasagna. Journal of Food Engineering 110(3) (2012): 487-492.

[10] Kamthai, S. and Magaraphan, R. Development of an active polylactic acid (PLA) packaging film by adding bleached bagasse carboxymethyl cellulose (CMCB) for mango storage life extension. Packaging Technology and Science 32(2) (2019): 103-116.

[11] Wootthikanokkhan, J. Research and patents related to the development of

packaging from PLA bio-plastics. in: King mongkut's university of technology Thonburi.

[12] Chi, H., Song, S., Luo, M., and Zhang, C. Effect of PLA nanocomposite films containing bergamot essential oil, TiO2 nanoparticles, and Ag nanoparticles on shelf life of mangoes. Scientia Horticulturae 249 (2019): 192-198.

[13] Ward, G. Modified Atmosphere Packaging for Extending Storage Life of Fresh Fruits and Vegetables. in Reference Module in Food Science, 2016.

[14] Lamo, N. Development of packaging film from LDPE/zeolite composites for extending shelf life of fresh produces. Master's thesis, Chulalongkorn University, 2009.

[15] Liu, Y., Wang, S., Lan, W., and Qin, W. Fabrication and Testing of PVA/Chitosan Bilayer Films for Strawberry Packaging. Coatings 7(8) (2017): 109-124.

[16] Antmann, G., Ares, G., Lema, P., and Lareo, C. Influence of modified atmosphere packaging on sensory quality of shiitake mushrooms. Postharvest Biology and Technology 49(1) (2008): 164-170.

[17] Standard Test Method for Tensile Properties of Thin Plastic Sheeting. ASTM International (2002): 1-9.

[18] Standard Test Method for Pendulum Impact Resistance of Plastic Film. ASTM International (2002): 2-7.

[19] Backes, E.H., Pires, L.d.N., Costa, L.C., Passador, F.R., and Pessan, L.A. Analysis of the Degradation During Melt Processing of PLA/Biosilicate® Composites. Journal of Composites Science 3(2) (2019): 52-63.

[20] Auksornkul, S., Soontaranon, S., Kaewhan, C., and Prasassarakich, P. Effect of the blow-up ratio on morphology and engineering properties of three-layered linear low-density polyethylene blown films. Journal of Plastic Film & Sheeting 34(1) (2017): 27-42.

[21] Cicero, J.A. and Dorgan, J.R. Physical Properties and Fiber Morphology of Poly(lactic acid) Obtained from Continuous Two-Step Melt Spinning. Journal of Polymers and the Environment 9(1) (2001): 1-10.

[22] Jing, M., Sui, G., Zhao, J., Zhang, Q., and Fu, Q. Enhancing crystallization and mechanical properties of poly(lactic acid)/milled glass fiber composites via self-

assembled nanoscale interfacial structures. Composites Part A: Applied Science and Manufacturing 117 (2019): 219-229.

[23] Krohn, J., Tate, R., and Jordy, D. Factors affecting the permeability of PE blown films. Proceedings of the SPE 55th Annual Technical Conference & Exhibits: 1654-1658.

[24] Teo, P.S. and Chow, W.S. Water Vapour Permeability of Poly(lactic acid)/Chitosan Binary and Ternary Blends. KMUTNB: IJAST 7 (2014): 23-27.

[25] Uthairatanakij, A. and Laohakunjit, N. Effect of gamma rays on physico-chemical and ripening changes of 'Nam-Dok-Mai' mangoes. International Symposium "New Frontier of Irradiated food and Non-Food Products" (2005): 2-10.

[26] Shimbhanao, W. Acceleration of 'Nam Dok Mai' Mango Ripening Effecting Physicochemical and Volatile Characteristics. Agricultural Journal 35(1) (2018): 1-11.

[27] Phanumong, P., Sangsuwan, J., and Rattanapanone, N. Effect of modified atmosphere packaging with varied gas combinations and treatment on the quality of minimally-processed litchi fruits. Songklanakarin J. Sci. Technol. 39 (2017): 715-722.

[28] Nambi, V.E., Thangavel, K., Shahir, S., and Chandrasekar, V. Color Kinetics During Ripening of Indian Mangoes. International Journal of Food Properties 19 (2016): 2147-2155.

[29] Zhu, X., Wang, Q., Cao, J., and Jiang, W. Effects of Chitosan coating on Postharvest quality of mango (Mangifera Indica L. CV. TAINONG) Fruits. Journal of Food Processing and Preservation 32 (2008): 770-784.

[30] Jha, S.N., Jaiswal, P., Narsaiah, K., Kaur, P.P., Singh, A.K., and Kumar, R. Textural properties of mango cultivars during ripening. J Food Sci Technol 50(6) (2013): 1047-57.

[31] Yashoda, H., Prabha, T., and Tharanathan, R. Mango ripening – Role of carbohydrases in tissue softening. Food Chemistry 102(3) (2007): 691-698.

[32] Tefera, A. Effects of disinfection, packaging and evaporatively cooled storage on sugar content of mango. African Journal of Biotechnology, 7 (2010): 065-072.

[33] Chiumarelli, M., Ferrari, C.C., Sarantópoulos, C.I.G.L., and Hubinger, M.D. Fresh

cut ‘Tommy Atkins’ mango pre-treated with citric acid and coated with cassava (Manihot esculenta Crantz) starch or sodium alginate. Innovative Food Science & Emerging Technologies 12(3) (2011): 381-387.

[34] Hoa, T.T. and Ducamp, M.-N. Effects of different coatings on biochemical changes of ‘cat Hoa loc’ mangoes in storage. Postharvest Biology and Technology 48(1) (2008): 150-152.

APPENDICES

Appendix A: DSC thermogram of both bioplastic films and neat PLA

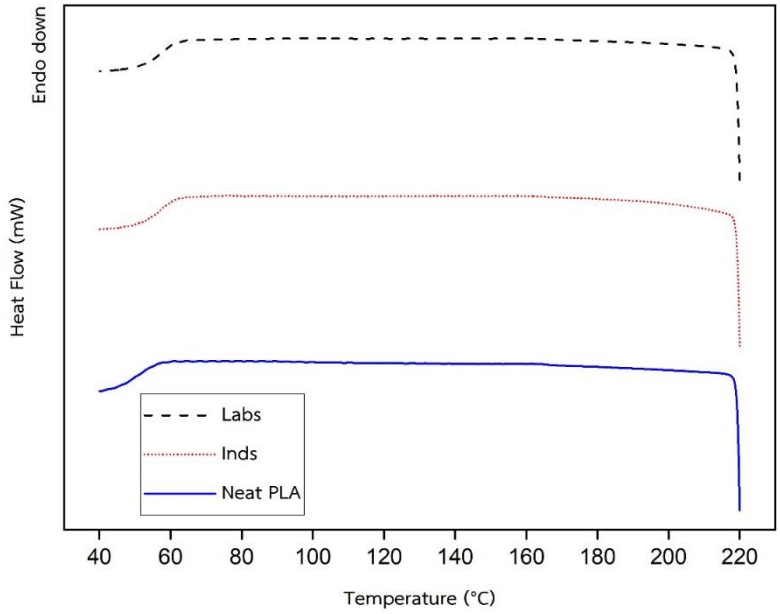


Figure A-1 DSC thermogram of both bioplastic films and neat PLA in cooling step at cooling rate 5 °C/miniute

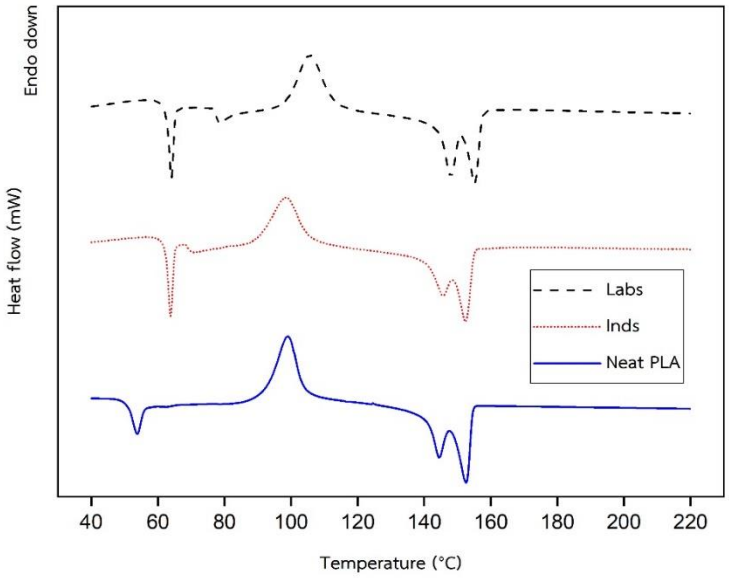


Figure A-2 DSC thermogram of both bioplastic films and neat PLA in 2nd heating step at heating rate 5 °C/miniute

Appendix B: Crystallinity's calculation of both bioplastic films and neat PLA

Crystallinity of both bioplastics films and neat PLA were calculated by enthalpy of transition in cold crystallization and melting crystallization period for heating scan, and in crystallization period for cooling scan. Enthalpy of transition was derived from integration of peak areas of each period, **Error! Reference source not found.** shows the enthalpy of cold crystallization and melting crystallization period, these values were used to calculate percentages of crystallinity by **Equation 3.1**.

Table B-1 Enthalpy of transition of both bioplastic films and neat PLA for each period.

Samples	**Enthalpy of cold crystallization, ΔH_{cc} (J/g)**	**Enthalpy of crystallization, ΔH_m (J/g)**
Neat PLA	20.80	24.33
Labs	20.32	26.61
Inds	20.43	25.69

For example, crystallinity of neat PLA was calculated. $\Delta H°_m$ is enthalpy of transition of neat PLA with fully crystallization = 93.0 J/g.

$$\text{Percentage of crystallinity } (\%X_C) = \frac{(\Delta H_m - \Delta H_{cc})}{\emptyset \times \Delta H^{\circ}_m} \times 100$$

$$= \frac{(24.33-20.80)}{1.0\times 93.0} \times 100$$

$$= 3.80\ \%$$

For laboratory and industrial films, crystallinity of both films was calculated following by **Equation 3.1** by using weight fraction of PLA was 0.8584.

$$\%X_C \text{ of laboratory film} = \frac{(\Delta H_m - \Delta H_{cc})}{\emptyset \times \Delta H^{\circ}_m} \times 100$$

$$= \frac{(26.61-20.32)}{0.8584\times93.0}\times100$$

$$= 7.88\ \%$$

Crystallinity of both bioplastic films and neat PLA was shown in **Error! Reference source not found.**.

Table B-2 Crystallinity of both bioplastic films and neat PLA

Samples	**Crystallinity (%)**
Neat PLA	3.80
Labs	7.88
Inds	6.59

Crystallinity of both bioplastic films and neat PLA in 2nd heating step was shown in **Table B-3**.

Table B-3 Crystallinity of both bioplastic films and neat PLA in 2nd heating scan.

Samples	**Enthalpy of cold crystallization, ΔH_{cc} (J/g)**	**Enthalpy of crystallization, ΔH_m (J/g)**	**Crystallinity (%)**
Neat PLA	20.79	24.71	4.22
Labs	21.83	23.45	2.03
Inds	13.49	13.87	0.48

Appendix C: Statistical analysis

In this study, analysis of variance (ANOVA) was used to test for difference of data. The total deviation of all data was compared via F-test. For example, statistical calculation of weight loss of Nam Dokmai mango after storage at 12 ℃ for 3 days was shown below.

Table C-1 Weight loss of Nam Dokmai mango after storage at 12 ℃ for 3 days

Sample No.	Weight loss of mango (%)		
	Control	Labs12	Inds12
1	1.22	0.36	0.50
2	1.55	0.36	0.51
3	1.17	0.31	0.45
4	0.98	0.36	0.42
Summation	4.91	1.39	1.87
Average	1.23	0.35	0.47

From **Table C-1**, the differences can be calculated as following:

Degree of freedom among groups (df_1) = k-1 = 3-1 =2

Degree of freedom within groups (df_2) = n-k = 12-3 = 9

Corrected of means (CM) $= \frac{(\sum\sum X_{ij})^2}{n}$

$= \frac{(4.91+1.39+1.87)^2}{12}$

$= 5.57$

Total sum of square (SS_T) $= \sum\sum X_{ij}^2 - CM$

$= (1.22^2+1.55^2+1.17^2+...+0.45^2+0.42^2)-5.57$

$= 2.00$

Between groups sum of square (SS_B) $= \sum \left(\frac{(\sum X_i)^2}{n_i} \right)$ -CM

$= \left(\frac{4.91^2}{4} + \frac{1.39^2}{4} + \frac{1.87^2}{4} \right)$ -5.57

$= 1.82$

Within group sum of square (SS_E) = SST-SSB

= 2.00-1.87

= 0.18

Mean square between groups (MS_B) $= \frac{SSB}{k-1}$

$= \frac{1.82}{3-1}$

= 0.912

Mean square within group (MS_E) $= \frac{SSE}{n-k}$

$= \frac{0.18}{12-3}$

= 0.019

F_{obs} $= \frac{MSB}{MSE}$

$= \frac{0.912}{0.019}$

= 47.02

In an ANOVA, the F-ratio was used to determine the differences between groups in an experiment. F-ratio was called F_{crit}, this value can be received by F-Table. From this example, F_{crit} values was 4.26 at $df_1 = 2$, $df_2 = 9$ and alpha = 0.05. F-ration by calculation (F_{obs}) was higher than F_{crit}, that means there were statistically significant differences in three group of data.

Appendix D: Statistic data

Table D-1 The peel lightness (L*) of mango which stored at 12 ℃

Lightness (L*)	Control12	Labs12	Inds12	F-test
3 Days	**76.49±1.12**	75.89±1.36	76.76±1.93	ns
6 Days	**76.76±1.21**	77.02±1.03	76.46±1.08	ns
9 Days	**76.56±1.59**	76.6±1.94	76.06±1.28	ns
12 Days	**72.48±2.89**	74.96±1.62	72.71±2.22	ns
15 Days	**71.86±1.46**	73.92±2.41	74.69±3.42	ns

Table D-2 The peel yellowness (b*) of mango which stored at 12 ℃

Yellowness (b*)	Control12	Labs12	Inds12	F-test
3 Days	46.52±3.2	44.25±1.42	44.3±2.29	ns
6 Days	39.99±2.59	40.05±1.44	40.3±2.09	ns
9 Days	40.39±2.8	40.72±1.18	40.36±3.22	ns
12 Days	42.8±2.83	40.66±2.2	42.18±4.67	ns
15 Days	38.87±0.74	39.71±4.7	40.48±2.28	ns

Table D-3 The peel greenness (-a*) of mango which stored at 12 ℃

Greenness (-a*)	Control12	Labs12	Inds12	F-test
3 Days	2.72±1.03	2.78±0.95	2.76±1.46	ns
6 Days	3.12±0.72	3.02±1.03	3.22±1.48	ns
9 Days	2.84±0.78	3.65±2.43	3.08±0.99	ns
12 Days	2.73±1.38	1.05±0.87	1.64±1.04	ns
15 Days	2.81±1.03	2.74±1.77	2.43±0.66	ns

Table D-4 The pulp lightness (L*) of mango which stored at 12 ℃

Lightness (L*)	Control12	Labs12	Inds12	F-test
3 Days	74.24±1.79	73.4±1.95	73.7±2.74	ns
6 Days	75.66±2.51	72.51±2.3	73.08±3.28	ns
9 Days	72.96±3.25	73.24±2.19	73.43±2.29	ns
12 Days	69.83±2.56	74.15±2.14	70.12±5.01	ns
15 Days	64.68±3.09	66.16±3.46	72.3±2.99	s

Table D-5 The pulp yellowness (b*) of mango which stored at 12 ℃

Yellowness (b*)	Control12	Labs12	Inds12	F-test
3 Days	49.31±1.38	48.51±2.06	48.37±2.82	ns
6 Days	44.88±2.12	46.82±2.56	45.79±2.41	ns
9 Days	42.96±3.19	45.42±3.58	44.8±2.98	ns
12 Days	45.75±5.92	48.04±2.09	40.01±5.07	s
15 Days	35.54±6.61	38.6±5.96	46.86±4.63	s

Table D-6 The pulp greenness (-a*) of mango which stored at 12 ℃

Greenness (-a*)	Control12	Labs12	Inds12	F-test
3 Days	1.94±0.9	2.03±1.36	1.83±3.05	ns
6 Days	1.18±1.82	1.28±1.82	2.01±3.08	ns
9 Days	2.66±2.61	2.39±3.46	2.25±1.62	ns
12 Days	2.02±1.5	-0.68±2.72	0.36±3.24	ns
15 Days	3.43±0.93	3.31±0.96	3.08±1.51	ns

Table D-7 Weight loss (%) of mango which stored at 12 ℃

Weight loss (%)	Control12	Labs12	Inds12	F-test
3 Days	1.23±0.24	0.35±0.03	0.47±0.04	s
6 Days	2.22±0.28	0.64±0.07	0.77±0.1	s
9 Days	2.53±0.38	0.98±0.08	1.1±0.06	s
12 Days	3.95±0.88	1.15±0.15	1.56±0.2	s
15 Days	3.82±0.6	1.21±0.05	1.74±0.15	s

Table D-8 Firmness (N) of mango which stored at 12 ℃

Firmness (N)	Control12	Labs12	Inds12	F-test
3 Days	3.83±0.35	3.62±0.3	3.73±0.3	ns
6 Days	3.72±0.27	3.35±0.36	3.58±0.31	ns
9 Days	3.68±0.56	3.4±0.33	3.16±0.58	ns
12 Days	2.11±0.46	3.29±0.77	3.3±0.23	s
15 Days	2.27±0.28	2.32±0.29	3.34±0.63	s

Table D-9 TSS (°Brix) of mango which stored at 12 ℃

TSS (°Brix)	Control12	Labs12	Inds12	F-test
3 Days	13.81±1.86	14.45±2.33	13.98±2.12	ns
6 Days	14.13±2.72	14.25±1.42	14.24±1.47	ns
9 Days	12.55±2.58	13.95±1.45	13.6±1.63	ns
12 Days	12.22±0.81	13.45±2.11	12.97±1.35	ns
15 Days	12.78±0.33	13.43±2.81	13.75±1.52	ns

Table D-10 TA (%) of mango which stored at 12 ℃

TA (%)	Control12	Labs12	Inds12	F-test
3 Days	0.2±0.06	0.19±0.02	0.19±0.11	ns
6 Days	0.23±0.05	0.2±0.05	0.21±0.13	ns
9 Days	0.2±0.04	0.2±0.06	0.13±0.03	s
12 Days	0.16±0.03	0.16±0.02	0.12±0.03	s
15 Days	0.14±0.01	0.12±0.02	0.12±0.01	ns

Table D-11 V_C contents (mg/100 mL juice) of mango which stored at 12 ℃

V_C (mg/100 ml juice)	Control12	Labs12	Inds12	F-test
3 Days	0.9±0.23	0.6±0.11	0.41±0.1	s
6 Days	0.75±0.14	0.58±0.17	0.59±0.15	ns
9 Days	0.71±0.28	0.6±0.18	0.66±0.15	ns
12 Days	0.78±0.24	0.71±0.2	0.68±0.16	ns
15 Days	0.79±0.12	0.88±0.1	0.78±0.13	ns

Table D-12 Carbon dioxide contents (%) inside bioplastic bags which stored at 12 ℃

CO_2 (%)	Labs12	Inds12	F-test
0 Day	15.7801±1.7158	13.4764±1.4996	s
3 Days	17.5913±3.9677	26.3289±2.4366	s
6 Days	16.8937±3.995	18.9004±1.7118	ns
9 Days	7.8843±1.0655	5.8083±1.1362	s
12 Days	3.1865±1.114	2.3869±0.3926	ns
15 Days	1.4341±0.1844	1.8241±0.6534	ns

Table D-13 Ethylene contents (ppm) inside bioplastic bags which stored at 12 ℃

C_2H_4 (ppm)	Labs12	Inds12	F-test
0 Day	0.6563±0.1186	0.7074±0.0886	ns
3 Days	0.6537±0.0857	1.1276±0.2221	s
6 Days	1.1427±0.1543	0.713±0.0813	s
9 Days	0.7156±0.1391	0.6952±0.1674	ns
12 Days	0.7015±0.0681	0.5458±0.2917	ns
15 Days	0.363±0.1805	0.1911±0.1242	ns

Table D-14 Oxygen contents (%) inside bioplastic bags which stored at 12 ℃

O_2 (%)	Labs12	Inds12	F-test
0 Day	2.3319±0.8444	1.8828±0.471	ns
3 Days	5.131±0.8683	4.0898±0.213	s
6 Days	11.746±1.5431	9.6779±0.6394	s
9 Days	12.1959±1.4904	10.6966±1.758	ns
12 Days	13.7116±0.6072	12.797±0.8422	s
15 Days	13.8724±1.134	11.2486±1.7266	s

Table D-15 The peel lightness (L*) of mango which stored at 25 ℃

Lightness (L*)	Control25	Labs25	Inds25	F-test
3 Days	74.61±1.11	75.56±2.05	76.73±1.72	ns
6 Days	74.52±1.91	73.76±1.31	76.44±0.61	s
9 Days	72.4±3.05	71.33±2.04	74.32±1.55	s

Table D-16 The peel yellowness (b*) of mango which stored at 25 ℃

Yellowness (b*)	Control25	Labs25	Inds25	F-test
3 Days	44.89±2.56	46.7±3.33	47.06±2.36	ns

6 Days	49.24±1.44	40.2±3.98	44.95±1.07	s
9 Days	42.54±3.62	36.28±3.32	38.09±3.55	s

Table D-17 The peel greenness (-a*) of mango which stored at 25 ℃

Greeness (-a*)	Control25	Labs25	Inds25	F-test
3 Days	4.15±0.8	2.9±1.72	3.14±1.6	ns
6 Days	6.96±1.9	2.73±1.53	2.63±0.75	s
9 Days	5.55±1.34	4.93±1.02	3.96±0.66	s

Table D-18 The pulp lightness (L*) of mango which stored at 25 ℃

Lightness (L*)	Control25	Labs25	Inds25	F-test
3 Days	73.18±2.04	71.27±2.05	73.36±1.98	ns
6 Days	71.48±1.9	70.76±2.09	71.79±3.51	ns
9 Days	72.25±3.37	70.15±2.76	73.39±3.6	ns

Table D-19 The pulp yellowness (b*) of mango which stored at 25 ℃

Yellowness (b*)	Control25	Labs25	Inds25	F-test
3 Days	48.69±3.01	49.57±2.46	48.61±3.5	ns
6 Days	48.09±2.34	40.12±5.49	43.27±2.07	s
9 Days	41.75±3.33	35.31±1.54	46.07±2.07	s

Table D-20 The pulp greenness (-a*) of mango which stored at 25 ℃

Greenness (-a*)	Control25	Labs25	Inds25	F-test
3 Days	2.74±1.9	2.27±1.75	0.76±1.52	ns
6 Days	6.66±1.14	1.63±2.4	2.14±1.15	s
9 Days	5.6±1.61	1.79±0.67	2.26±1.97	s

Table D-21 Weight loss (%) of mango which stored at 25 ℃

Weight loss (%)	Control25	Labs25	Inds25	F-test
3 Days	3.25±0.57	1.16±0.19	1.26±0.1	s
6 Days	4.96±0.39	1.82±0.5	2.32±0.1	s
9 Days	7.25±1.04	3.15±0.52	3.83±0.31	s

Table D-22 Firmness (N) of mango which stored at 25 ℃

Firmness (N)	Control25	Labs25	Inds25	F-test
3 Days	2.99±0.52	3.04±0.52	3.2±0.31	ns
6 Days	2.96±0.37	3.04±0.51	3.09±0.94	ns
9 Days	1.78±0.48	2.66±0.45	2.48±0.58	s

Table D-23 TSS (°Brix) of mango which stored at 25 ℃

TSS (°Brix)	Control25	Labs25	Inds25	F-test
3 Days	13.39±1.66	12.43±2.25	13.96±1.05	ns
6 Days	13.65±2.32	12.69±1.78	12.33±1.11	ns
9 Days	11.58±1.79	12.04±1.88	12.96±1.15	ns

Table D-24 TA (%) of mango which stored at 25 ℃

TA (%)	Control25	Labs25	Inds25	F-test
3 Days	0.12±0.02	0.17±0.09	0.22±0.07	s
6 Days	0.1±0.03	0.15±0.06	0.18±0.04	s
9 Days	0.13±0.02	0.15±0.06	0.15±0.08	s

Table D-25 V_C contents (mg/100 mL juice) of mango which stored at 25 ℃

V_C (mg/100 ml juice)	Control25	Labs25	Inds25	F-test
3 Days	0.44±0.15	0.35±0.09	0.49±0.08	ns
6 Days	0.53±0.18	0.69±0.2	0.46±0.07	s
9 Days	0.49±0.18	0.58±0.21	0.51±0.1	ns

Table D-26 Carbon dioxide contents (%) inside bioplastic bags which stored at 25 ℃

CO_2 (%)	Labs25	Inds25	F-test
0 Day	31.8047±1.464	29.044±0.7351	s
3 Days	30.1108±1.9244	38.2825±7.9789	s
6 Days	25.1091±2.7928	29.0881±6.7631	ns
9 Days	21.8771±1.4205	21.6444±1.3692	ns
12 Days	18.9819±2.8994	19.0076±3.4922	ns
15 Days	17.5618±2.9136	18.1342±2.1304	ns

Table D-27 Ethylene contents (ppm) inside bioplastic bags which stored at 25 ℃

C_2H_4 (ppm)	Labs25	Inds25	F-test
0 Day	0.6521±0.072	1.111±0.2619	s
3 Days	0.9719±0.3154	1.1328±0.2443	ns
6 Days	0.7355±0.3617	0.6035±0.0576	ns
9 Days	0.8058±0.2593	0.8035±0.2919	ns
12 Days	0.9088±0.0995	1.0367±0.2175	ns
15 Days	0.56±0.1657	0.6757±0.1386	ns

Table D-28 Oxygen contents (%) inside bioplastic bags which stored at 25 ℃

O_2 (%)	Labs25	Inds25	F-test
0 Day	2.2043±0.8342	1.6601±0.5826	ns
3 Days	3.3033±1.6508	2.7838±0.4033	ns
6 Days	4.4124±2.7362	6.1768±1.3412	ns
9 Days	9.1145±3.2368	8.73±1.143	ns
12 Days	8.9398±3.6221	8.5335±0.7716	ns
15 Days	12.2296±1.6321	9.8218±2.0827	s

*** s = the data were significant differences

ns = the data were insignificant differences

VITA

NAME	Tanudkid Butweangphant
DATE OF BIRTH	7 August 1993
PLACE OF BIRTH	Kalasin province
INSTITUTIONS ATTENDED	Graduated high school from Kasetsart university laboratory school Kamphaeng Sean campus education research and development center in 2012. Graduated Bachelor's Degree Faculty of Engineering and Industrial Technology in Petrochemicals and Polymeric Materials, Silpakorn University, Thailand in 2016.
HOME ADDRESS	192 Moo 8 Banglen Nakorn prothom province
PUBLICATION	Butweangphant, T., Somwangthanaroj, A., Bunsiri, A. (2019, May 30) Performance of bioplastic-based modified atmosphere packaging for extending shelf life of Nam-Dok-Mai mango. Proceedings of the Pure and Applied Chemistry International Conference 2019 (PACCON2019), Bangkok, Thailand.