ลักษณะเฉพาะการอบแห้งและคุณภาพของมะละกออบแห้งที่ผ่านการปรับสภาพเบื้องต้นด้วยสารละลายออสโมติกแบบไบนารีและเทอร์นารี

นายซูกิฮาร์โต พูนามาซิดิ

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DRYING CHARACTERISTICS AND QUALITY OF DRIED PAPAYA PRETREATED WITH BINARY AND TERNARY OSMOTIC SOLUTIONS

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In this study, the effect of using binary (sucrose - water) and ternary solution (sucrose - salt - water) on mass transfer, drying characteristics, and final quality of dried papaya was investigated. Papaya pieces were immersed in three different sucrose solutions (50, 55, and 60 °Brix) with three different levels of sodium chloride (0, 3, and 5 % w/v) for five hours. Every hour, water loss, solid gain, and weight reduction of papaya in each treatment were calculated. It was found that the addition of sodium chloride led to a significant increase in both water loss and solid gain. The osmosed papaya chunks were then dried in a hot air dryer at 60 °C. Results obtained from drying curve showed that the samples soaked in ternary solution had a higher drying rate, leading to shorter drying time. In general, the modified Henderson & Pabis appeared to be the best model to predict the drying curve of osmosed papaya from all treatments. For the final product quality, the use of ternary solution has an effect on water activity, water mobility, color, and texture properties. From the microstructure analysis, the disruption of the shape and deformation of the cell structure of papaya was likely to be seen in the sample pretreated with ternary solution compared to the sample pretreated with binary solution. Based on sensory analysis, the use of ternary solution led to better quality in color and appearance, with the overall acceptance can be considered as acceptable.

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ซูกิฮาร์โต พูนามาซิดิ: ลักษณะเฉพาะการอบแห้งและคุณภาพของมะละกออบแห้งที่ปรับสภาพเบื้องต้นด้วยสารละลายออสโมติกแบบไบนารีและเทอร์นารี(QUALITY AND DRYING CHARACTERISTICS OF DRIED PAPAYA PRETREATED WITH BINARY AND TERNARY OSMOTIC SOLUTIONS) อ. ที่ปรึกษาวิทยานิพนธ์หลัก : ผศ.ดร. เกียรติศักดิ์ ดวงมาลย์, อ. ที่ปรึกษาวิทยานิพนธ์ร่วม อ.ดร. ธนจันทร์ มหาวนิช, 94 หน้า.

งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาผลของการปรับสภาพเบื้องต้นด้วยสารละลายออสโมติกแบบไบนารี (ซูโครส-น้ำ) และเทอร์นารี (ซูโครส-เกลือ-น้ำ) ต่อการถ่ายเทมวลสาร ลักษณะการอบแห้ง และคุณภาพสุดท้ายของผลิตภัณฑ์มะละกออบแห้ง โดยแช่ชิ้นมะละกอที่ผ่านการตัดแต่งแล้วในสารละลายซูโครสที่มีความเข้มข้นแตกต่างกัน 3 ระดับ (50 55 และ 60 องศาบริกซ์) ซึ่งมีโซเดียมคลอไรด์อยู่แตกต่างกัน 3 ระดับ (0 3 และ 5% w/v) เป็นเวลา 5 ชั่วโมง คำนวณค่าการสูญเสียน้ำ ค่าการเพิ่มขึ้นของของแข็ง ค่าการลดลงของน้ำหนักทุกชั่วโมง ผลการทดลองที่ได้พบว่าการเติมโซเดียมคลอไรด์ทำให้ค่าการสูญเสียน้ำ และค่าการเพิ่มขึ้นของของแข็งเพิ่มขึ้นอย่างมีนัยสำคัญ จากนั้นนำชิ้นมะละกอที่ผ่านการปรับสภาพเบื้องต้นแล้วไปอบแห้งที่อุณหภูมิ 60 องศาเซลเซียส จากกราฟการอบแห้งแสดงให้เห็นว่าตัวอย่างที่แช่ในสารละลายออสโมติกแบบเทอร์นารีมีอัตราการอบแห้งที่สูงกว่า ส่งผลให้มีระยะเวลาในการอบแห้งลดลง นอกจากนี้ยังพบว่าแบบจำลอง modified Henderson and Pabis มีความเหมาะสมมากที่สุดในการทำนายพฤติกรรมการอบแห้งของชิ้นมะละกอในทุกชุดการทดลอง เมื่อพิจารณาคุณภาพของผลิตภัณฑ์สุดท้ายที่ได้ พบว่าการปรับสภาพเบื้องต้นด้วยสารละลายเทอร์นารีมีผลต่อวอเตอร์แอคทิวิตี ความสามารถในการเคลื่อนที่ของน้ำ สี และเนื้อสัมผัส จากการศึกษาลักษณะทางสัณฐานวิทยาของเซลล์ พบว่าตัวอย่างที่ผ่านการปรับสภาพเบื้องต้นด้วยสารละลายเทอร์นารีเกิดการสูญเสียรูปร่าง และโครงสร้างของเซลล์มะละกอสูงกว่า เมื่อเทียบกับตัวอย่างที่ผ่านการปรับสภาพเบื้องต้นด้วยสารละลายไบนารี ในด้านการประเมินผลทางประสาทสัมผัส พบว่าผลิตภัณฑ์ที่ผ่านการปรับสภาพเบื้องต้นด้วยสารละลายเทอร์นารีมีคุณภาพทางด้านสี และลักษณะปรากฏที่ดีกว่า โดยได้รับการยอมรับจากผู้ทดสอบเมื่อพิจารณาจากคะแนนด้านการยอมรับโดยรวม

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NOMENCLATURE

a* = Redness

ANOVA = Analysis of variance

a_w = Water activity

b* = Yellowness

CRD = Completely randomized design

ΔE = Distance (difference) between two colors in a color space

L* = Lightness

M_0 = Initial moisture content (% wet basis) of the sample

M_f = Weight of the cylinder,

MR = Moisture ratio

$MR_{exp,i}$ = ith experimentally observed moisture ratio

$MR_{pre,i}$ = ith predicted moisture ratio

MRS = Mean residual least square

M_t = Final moisture content (% wet basis) of the sample after osmotic dehydration

M_{t+s} = Weight of the cylinder plus the sample and the solvent

N = number of observations

NMR = Nuclear magnetic resonance

r = correlation coefficient

RMSE = Root mean square error

S_0 = Initial soluble solid content of the sample (%)

SG = Solid gain

S_t = Final soluble solid content of the sample after osmotic dehydration (%)

T_1 = Longitudinal relaxation time

T_2 = Transverse relaxation time

TPA = Texture profile analysis

V = Volume of sample

V_d = Volume of the sample after drying

V_f = Volume of the cylinder

V_o = Volume of the sample before drying

%(w/v) = Percent weight per volume

W_0 = Initial weight of the sample (g)

WL = Water loss

WL/SG ratio = Water loss to solid gain ratio

WR = Weight reduction

W_t = Final weight of the sample after osmotic dehydration (g)

ρ_s = Density of n-heptane.

CHAPTER I

INTRODUCTION

Papaya (*Carica papaya*) is an important fruit crop grown widely in tropical and subtropical lowland regions. The fruit is nutritive, rich in vitamins A, C and presents good sensory characteristics. However, papaya is perishable fruit. The total post-harvest loss of papaya is estimated from 10% to 40% of total production (Fernandes *et al*., 2006). This loss could be reduced if they are processed. Papaya can be processed into various products such as jam, dried fruit, fruit juice and pickle. One of the most popular processing is drying, which is considered as a reasonable process due to the increase in shelf life, reduction of packaging and transportation costs, and obtaining new product.

Drying is a unit operation with high energy consumption and there is often a decrease in the quality of the dried product because of high temperature used and long drying time. Because of this problem, osmotic dehydration is advisable as a pretreatment. Osmotic dehydration is a water removal process which can be done by placing fruits and vegetables in a hypertonic solution, which can be either in a binary (usually sucrose - water) or ternary solution (usually sucrose - salt - water). From the study done by previous researchers, the advantage of using the osmotic dehydration with ternary solution are (1) the water loss is higher compared to the osmotic dehydration with binary solution (Mayor *et al*., 2007), (2) energy consumption can be reduced by reducing the drying time (Tsamo *et al*., 2005), (3) the storage stability of dried fruit is increased due to the lower water activity (Alves *et al*., 2005), (4) and also due to the various types of solid gain from the ternary solution, the ternary system leads to the new product development in terms of the product formulation. Thus, the objective of this study was to study the effect of using binary and ternary osmotic solution on mass transfer, drying characteristics and dried papaya quality.

CHAPTER II

LITERATURE REVIEW

2.1 Papaya fruit description and composition

Papaya (*Carica papaya*) is a popular and important fruit crop grown widely in tropical and subtropical lowland regions. The fruit has been regarded as one of the most valuable tropical fruits that contain vitamin C, β-carotene, and presents good sensory characteristics. It is a climacteric fruit and exhibits a characteristic rise in ethylene production during ripening, along with softening, changes in color, and a development of aroma (Fernandes *et al*., 2006). According to USDA (2012), the content and composition of nutrients per 100 g papaya can be seen in Table 2.1.

Table 2.1 Nutrition content of ripe papaya per 100 g

Constituent	Amount
Calories (kcal)	43
Water (%)	88.06
Protein (g)	0.47
Fat (g)	0.26
Carbohydrate (g)	10.82
Calcium (mg)	20
Iron (mg)	0.25
Phosphorous (mg)	10
Potassium (mg)	182
Magnesium (g)	21
Sodium (mg)	8
Vitamin A (IU)	950
Vitamin C (mg)	60.9
Vitamin E (mg)	0.30

(Source: USDA, 2012: online).

However due to its high moisture content, papaya is highly perishable, resulting in a significant post-harvest loss. This limits large-scale exportation to countries in temperate regions. The total post-harvest loss of papaya is estimated from 10% to 40% of total production. This loss could be reduced if papaya is processed. One of the examples of the papaya processing is drying, which is a reasonable process due to improved shelf life, reduction of packaging costs, and enhanced appearance (Fernandes *et al*., 2006).

2.2 Precondition of fruit

2.2.1 Blanching

Although drying of food prevents microbial growth, certain chemical reactions caused by enzymes still occur which result in spoilage and deterioration of the product. Fresh produce contains many different enzymes that cause loss of color, loss of nutrients, and flavor changes in the dried product. These enzymes must be inactivated to prevent such reactions from taking place (Fellows, 1990).

Various pretreatment methods may be used in conjunction with the drying process to maintain or improve quality of the dried product. Blanching is one of the most common pretreatment methods. Blanching is the pretreatment which is done by heating the fruit with steam or hot water for a short period of time with the purpose of inactivating enzymatic activity in fruits, prior to further processing. One of the examples of the use of blanching as a pretreatment was reported by Ndiaye *et al*. (2009). The authors studied the steam blanching effect on polyphenol oxidase, peroxidase and color of mango. They found that blanching as a pretreatment helped inactivate polyphenol oxidase and peroxidase, the enzymes responsible for the formation of unacceptable color changes. Blanching also has an additional advantage of modifying the product texture. Moreover, blanching can help increase the drying rate, hence reducing the drying time (Chiewchan *et al*., 2010).

2.2.2 Soaking in chemical solution

Dipping or soaking of fruit in organic acids such as citric acid is an alternative method to reduce the number of microorganisms. Moreover, Jiang and Fu (1998) found that dipping litchi fruit in citric acid solution could inhibit the activity of polyphenol oxidase due to pH-lowering effect

Calcium chloride has been widely used as preservative and firming agent for whole and fresh-cut fruits and vegetables. Luna-Guzman and Barrett (2000) reported that dipping fresh-cut cantaloupes in calcium chloride solution resulted in tissue firming effect. This finding was later confirmed by Rastogi *et al*. (2008), who found that calcium chloride pretreatment resulted in an increase in hardness of carrot. The firming effect provided by calcium chloride can be explained by the action of calcium ion in maintaining the cell wall structure in fruit by interacting with pectin in the cell wall to form calcium pectate which assists molecular bonding between constituents of the cell wall. Calcium ion also increases cell turgor pressure, thus stabilizing the cell membrane. Moreover, calcium chloride also improves the resistance to fungal attack.

2.3 Osmotic dehydration

2.3.1 Definition and principle

Osmotic dehydration is a water removal process that involves soaking of foods (mostly fruits and vegetables) in a hypertonic sugar, salt, or combined solution, for reducing the water content while increasing the soluble solid content (Falade and Igbeka, 2007). During osmotic dehydration process, the driving force for water removal occurs as a result of the difference in osmotic pressure between the food and its surrounding solution with the complex cellular structure of food acts as a semi-permeable membrane (Fernandes *et al*., 2006).

According to Torreggiani and Bertolo (2004), as shown in Figure 2.1, there are three mass transfer processes that are established during osmotic dehydration process, water diffusion from the food material to the surrounding osmotic medium due to the concentration gradient between them, solute diffusion from the osmotic solution to the food, and leaching of natural solutes such as sugars, organic acids, mineral, and salts from the food into the solution.

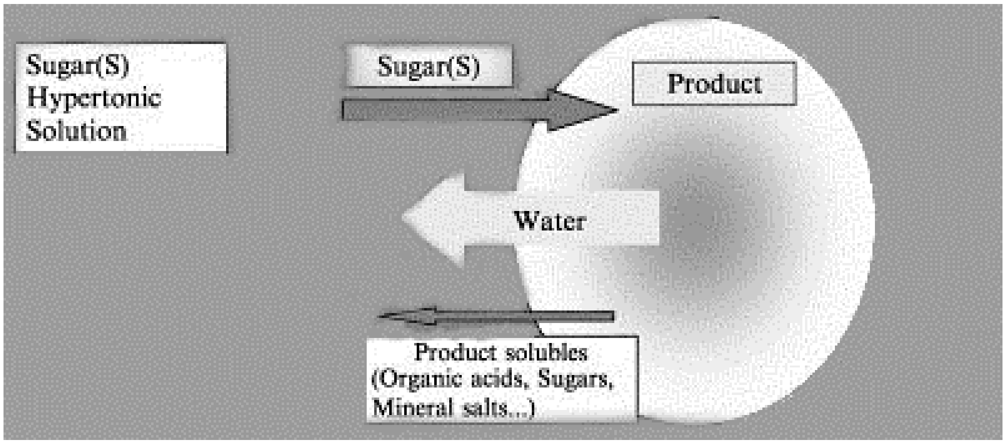


Figure 2.1 Mass transport processes during osmotic dehydration.

Source : Modified from Torreggiani and Bertolo (2004)

Osmotic dehydration is used as a pretreatment to the processes which mainly related to the improvement of some nutritional, organoleptic and functional properties of the product. As osmotic dehydration is effective at ambient temperature, heat damage to the color and flavor is minimized and the high concentration of the sugar surrounding the fruit and vegetable pieces will help preventing discoloration. Furthermore, through the selective enrichment in soluble solids, high quality fruits and vegetables are obtained with relevant properties. This process makes them applicable in different food systems (Torregiani, 1993).

However, osmotic dehydration also has some disadvantages which associate with the extensive uptake of the solute with smaller molecular size such as salt and the leaching of valuable product constituents such as organic acids and minerals. This mass transfer process may lead to substantial modification of the original product composition, which may result in a negative impact on sensory characteristics and nutritional profile, and also the large solute uptake causes additional resistance to the mass transfer of water and leads to a lower dehydration rate in complementary drying (Falade and Igbeka, 2007).

Osmotic dehydration removes water from the food up to a certain level, which is still too high for preservation purpose, so this process must be followed by another process such as drying, frying, freezing and other techniques in order to lower water content of food even more. Knowledge of the changes that occurs during the osmotic dehydration should enable a better design of the combined preservation procedures to maintain quality characteristics, such as color, texture, and nutritional properties. The applications of the osmotic dehydration as a unit operation in the fruit and vegetable processing can be seen in Figure 2.2.

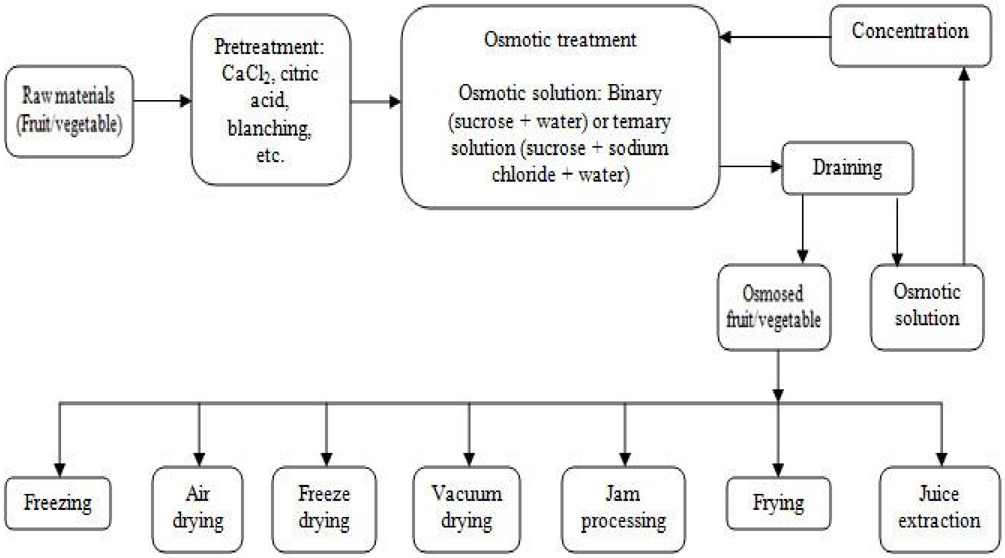


Figure 2.2 Applications of osmotic dehydration in fruit and vegetable processing.

Source : Modified from Torregiani (1993).

2.3.2 Factors affecting osmotic dehydration

The major factors that affect the osmotic dehydration process of food material include the type of osmotic agent, concentration and temperature of the osmotic solution, ratio of the solution to the food material, and the physical and chemical properties of food materials. For fruits, properties of the raw material (such as cultivar, variety, degree of ripeness, and the tissue microstructure), and precondition (such as peeling, coating, blanching, etc) also affect the osmotic dehydration process (Falade and Igbeka, 2007).

Normally the solutions used in osmotic dehydration have high osmotic pressure and low water activity. The most commonly used osmotic agents for the osmotic solution are sucrose and sodium chloride. Sucrose and sodium chloride have been found to be the best osmotic agent because of their effectiveness, convenience, and desirable flavor (Falade and Igbeka, 2007). Other osmotic agents such as lactose, maltodextrin, ethanol, glucose, glycerine, and corn syrups have also been used. The type of osmotic agent used and its molecular weight or ionic behavior strongly affects the kinetics of water removal, solid gain, and equilibrium water content. According to El-Aouar *et al*. (2006), on their study about the influence of the osmotic agent on the osmotic dehydration of papaya, the treatments containing sucrose as the osmotic agent showed higher weight reduction, water loss, and solids gain than the treatments containing corn syrup as the osmotic agent. Moreover, Taiwo *et al*. (2003) which used strawberry as their sample and Mayor *et al*. (2007) which used pumpkin as their sample also reported that the osmotic dehydration using salt–sucrose solution gave the higher water loss and solid gain compared to the osmotic dehydration using sucrose solution.

Immersion time is one of the most important variables during osmotic dehydration process, especially on solid gain and water loss. The increase in immersion time during osmotic dehydration process will increase the weight loss of osmostically dehydrated fruit, but the increase in immersion time during osmotic process will decrease the rate of mass transfer during further process such as drying (Falade and Igbeka, 2007).

The rate of osmosis during osmotic dehydration process is affected by temperature of solution. The high temperature causes a reduction in viscosity and an increase in osmotic pressure of the osmotic solution. Although the rate of mass transfer increases with temperature, there is a limit, of perhaps 49 °C, above which enzymatic browning and flavor deterioration begin (Falade and Igbeka, 2007).

The effect of concentration of solution, immersion time and temperature of solution on the osmotic dehydration process is confirmed by the study done by El-Aouar *et al*. (2006). Upon their study about the influence of the osmotic agent on the osmotic dehydration of papaya, the authors reported that treatments with higher solution concentration, longer immersion time and higher solution temperature apparently showed higher water loss, solid gain, and weight reduction compared to the treatments with lower solution concentration, shorter immersion time and lower solution temperature.

2.3.3 Osmotic dehydration as a pretreatment for drying

Drying is one of the most important unit operations in food processing. Many food products are dried to improve their shelf life, reduce packaging costs, and enhance appearance. However, drying process may result in some undesirable quality of the food product such as, shrinkage, browning, and the loss of volatiles and aroma. Drying also is an energy intensive operation, which in order to reduce energy consumption for drying process, it is necessary to improve the energy efficiency of the drying equipment, reducing the processing time, or use in combination with an alternative process with less energy consumption, such as osmotic dehydration (Fernandes *et al*., 2006).

The use of an osmotic treatment before conventional drying has received considerable attention. Osmotic treatment has been studied mainly as a pretreatment to different drying operations, such as air drying, freeze drying, vacuum drying, and microwave drying. Osmotic dehydration pretreatment can be used in order to reduce the initial water content, which, in turn, reduces total processing and drying time, and therefore helps reducing total energy consumption (Torregiani, 1993). Besides reducing the drying time, osmotic dehydration pretreatment can also improve the product quality by improving textural quality, vitamin retention, flavor enhancement and color stabilization (Sagar and Kumar, 2010).

The advantages of using osmotic dehydration as a pretreatment for air drying process of fruit are as follows:

1. Reduce the initial moisture content of fruit before drying process, as the study done by Sunjka and Raghavan (2004), in which they found out that the osmotic dehydration as a pretreatment reduced the moisture content of cranberries from 88% to 43.5%.
2. Reduce the energy cost by reducing the total processing time of the drying papaya process, as the study done by Fernandes *et al*. (2006), in which they found out that the osmotic dehydration as a pretreatment reduced total processing time in drying process of papaya from 1130 to 450 minutes.
3. Maintain the natural color of fruit, as the study done by Lemus-Mondaca *et al*. (2009), in which they found that the dried papaya with osmotic dehydration pretreatment had better color compared to the dried papaya without osmotic dehydration pretreatment.
4. Maintain the texture (firmness) of fruit, as the study done by Lemus-Mondaca *et al*. (2009), in which they found that the dried papaya with osmotic dehydration pretreatment had better texture in terms of firmness compared to the dried papaya without osmotic dehydration pretreatment.
5. Maintain flavor and nutrient of the fruit, due to the reduction of drying time.

2.3.4 Ternary system in osmotic dehydration

In osmotic dehydration, the binary system is a process that the osmotic solution is composed of one solute with a solvent while the ternary system is a process that the osmotic solution is composed of two solutes with a solvent. In ternary system, solutes commonly used are sucrose and sodium chloride. The use of ternary osmotic solution leads to a higher water loss during osmotic dehydration compared to binary sucrose solution. The addition of sodium chloride to sucrose solution helps lower water activity, due to the dissociation of sodium chloride into two ionic species, thus producing higher osmotic pressure compared to solution containing only sucrose. This, in turn, lead to a higher water loss. Moreover, at the cellular level, sucrose and sodium chloride can pass through the cellular membrane, while due to lower molecular weight only sodium chloride can diffuse through cytoplasmic membrane. Sodium chloride diffusion inside the cytoplasm generates concentration gradients at the vacuole level and in the cytoplasm and then allows the transfer of more water from deep inside the cell and in that way water loss is increased (Mayor *et al*., 2007). In addition, presence of sodium chloride also inhibits the formation of crust (barrier) by sucrose molecules and in that way also increases the dehydration phenomenon (Tsamo *et al*., 2005). However, sodium chloride has smaller molecular size compared to sucrose, which penetrates more into the product and leads to the higher solid gain (Taiwo *et al*., 2003).

The use of ternary system presents some advantages, such as the higher water loss with higher ratio of water loss to solid gain compared to the binary system, as reported by Mayor *et al*. (2007) on their study about osmotic dehydration of pumpkin using 45 % sucrose and 7.5% of sodium chloride and Alves *et al*. (2005) on their study about osmotic dehydration of frozen mature acerola using 50 % sucrose and 10% of sodium chloride, the ternary system can be applied as a pretreatment before further process which can reduce the processing time and save the energy, solid gained from ternary solution treatment can lead to product development in term of product formulation, and according to the study done by Tonon *et al*. (2007), they found that the ternary solution had lower viscosity compared to the binary solution. However, the use of ternary solution also presents some disadvantages, which due to the high solid gain of salt, the amount of salt to be added to the ternary system needs to be considered because using the high concentration of salt affects the taste of the product become too salty. According to the study done by Monnerat *et al*. (2010), they found that the cells of osmodehydrated apple pretreated with ternary solution were likely to undergo plasmolysis compared to the cells of osmodehydrated apple that pretreated with binary solution, in which the plasmolysis will cause a loss in the turgor pressure, deformation of cell, and shrinkage (Mayor *et al*., 2007).

2.4. Drying

2.4.1. Hot air drying

In drying process, the moisture is removed from a substance using heat with the purpose to stop or slow down the growth of spoilage microorganisms, as well as the enzymatic reactions. This process results in safe storage over an extended period. Sun drying is the most common method used to preserve agricultural products in tropical and sub-tropical countries. However, there are some drawbacks such as the control of the drying operation properly, the length of the drying time, weather dependence, high labor costs, large area requirement, and problem of contamination with foreign matter. Due to these problems, hot air drying is an alternative drying method, which by using hot air dryer, a more uniform, hygienic and attractively colored product can be produced rapidly (Doymaz, 2004).

Many food products are dried to improve their shelf life, reduce packaging costs, and enhance appearance. However, drying process may result in some undesirable quality of the food product such as shrinkage, browning, and the loss of volatiles and aroma. A combination of drying with an alternative process, such as osmotic dehydration, can solve the above problems. The example of study about the combination of osmotic dehydration and hot air drying was done by Lemus-Mondaca *et al*. (2009), which on their study about the effect of osmotic pretreatment on hot air drying kinetics and quality of papaya, they found out that the dried papaya with osmotic dehydration pretreatment has better firmness, color, and microstructure compared to the dried papaya without osmotic dehydration pretreatment.

2.4.2 The drying kinetics and modeling

Drying is an industrial preservation method widely used in which water activity of food is decreased to minimize biochemical reactions of degradation. In order to improve the control of this unit operation, it is important to predict a mathematical model to simulate the drying curves. The simulation models can play an important role in designing new or in improving existing drying systems or for the control of the drying operation. The drying kinetics of materials may be described completely using their transport properties (thermal conductivity, thermal diffusivity, moisture diffusivity, and interface heat and mass transfer coefficients) together with these of the drying medium. In the case of food drying, the drying constant K is used instead of transport properties.

The drying constant combines all the transport properties and may be defined by the thin layer mathematical drying models (Togrul and Pehlivan, 2004).

The drying kinetics of materials can be described using an appropriate thin layer mathematical drying model, which is made up by differential equations of heat and mass transfer in the interior of the product and at its interphase with the drying agent (i.e. air). The purpose of evaluating the mathematical model was for the describing the drying behavior better, for the optimization of the drying performance and quality control. The simple exponential models that are frequently used for modeling the drying kinetics of food include the Page, Henderson and Pabis, and modified Henderson and Pabis models (Karathanos, 1999).

According to Abalone *et al*. (2006), the page model is the most adequate in describing thin layer drying kinetics of food products exhibits a decreasing drying rate. However, on the products contain considerable amounts of sugars, the moisture content determination of these products does not lead to a constant weight of solid but there is a continuous weight loss, apparently due to some sort of decomposition reaction of those sugars. From the study of Karathanos (1999), they found out that modified Henderson & Pabis Model is more suitable to describe the drying kinetics of those kind of the product with high sugar content such as raisins and currants.

2.5 Dried papaya quality

Fruits and vegetables are not only rich in nutrients but also high in moisture content. Hot air drying is a common process used for preservation by reducing the moisture content. Drying of fruits and vegetables is normally done by hot air drying process. However, there are problems associated with products achieved by hot air drying process, which high temperatures or long drying times in conventional air drying usually causes some changes in important physical properties of the products, such as loss of color, change of texture, chemical changes affecting flavor and nutrients and shrinkage.

Osmotic dehydration is normally used as a pretreatment before drying process to reduce the loss of nutrients and maintain the physicochemical characteristics of the fresh product and to optimize process energy consumption. As pretreatment, Fernandes *et al*. (2006) found out that the osmotic dehydration as a pretreatment reduced total processing time in drying process of papaya, Sunjka and Raghavan (2004) also found out that the osmotic dehydration as a pretreatment reduced the initial moisture content of cranberries before drying process. Moreover, according to Lemus-Mondaca *et al*. (2009), they found out that found that the dried papaya with osmotic dehydration pretreatment had better color and texture compared to the dried papaya without osmotic dehydration pretreatment.

Major quality characteristics associated with dried fruit products can be classified into three main groups: physical properties (such as texture, color, degree of shrinkage, and microstructure), chemical properties (such as moisture content, water activity, and water mobility), and nutritional quality (such as vitamin C and β-carotene). These parameters can affect the acceptability of dried fruit products by the consumers (Lemus-Mondaca *et al*., 2009).

2.5.1 Moisture content, water activity, and water mobility

During drying process, moisture content and water activity (a_w) are reduced to certain levels. Moisture content and a_w are among the key quality factors of dried fruits. Too high moisture content and a_w may lead to the growth of microorganism, thus shorten the shelf life of product, and also affects texture of the product. Too low moisture content and a_w may lead to excessive energy consumption and product quality damages such as color and nutrients. According to Anonymous (2002), to ensure product safety, the final moisture content of dried fruit should be less than 20% and the water activity should be about 0.6. This dried fruit has the shelf life about 6 months to 1 year depending on storage condition.

It has long been recognized that “availability”, “mobility” or “state” of water, rather than its content, plays an important role on stability, as well as properties of a food product, including texture (Sritongtae *et al*., 2011).

Nuclear magnetic resonance (NMR) is a property that magnetic nuclei have in a magnetic field and applied electromagnetic pulse or pulses, which cause the nuclei to absorb energy from the impulse and radiate this energy back out. The nuclei absorb energy at a specific resonance frequency which depends on the strength of the magnetic field and intrinsic property of the nuclei. NMR spectroscopy has been successfully used to study water mobility in various systems. The measurement of the longitudinal relaxation time (T_1) of a proton allows one to observe the degree of water binding to other chemical species (Sritongtae *et al*., 2011).

The majority of the NMR studies on water have proved the ^{1}H nucleus. In pure water, ^{1}H relaxation is dominated by intramolecular dipole-dipole mechanisms. In heterogeneous systems, there are two other mechanisms that have an effect on ^{1}H relaxation. These mechanisms are cross-relaxation and chemical exchange. Cross-relaxation is the magnetic exchange between water protons and macromolecular protons. Chemical exchange is the physical exchange between “free” water protons and the protons of water molecule “bound” to the macromolecule. Longitudinal relaxation time (T_1) is affected only by cross-relaxation, while transverse relaxation time (T_2) is affected by both cross-relaxation and chemical exchange (Mahawanich, 2000).

2.5.2 Color

Drying process results in some inevitable degradation of product’s color which usually attributed to the long drying times at high temperatures. Both enzymatic and non-enzymatic browning is the main causes of color degradation during drying process of dried fruit. If the fruits are properly pretreated, enzymatic and non-enzymatic browning can be controlled, which leads to achieve good quality of the final product (Ali *et al.* 2010). Color has a great impact on consumer acceptance of the dried fruit products. The color of the fruit may change considerably during drying process, which the main cause responsible for these changes is the degradation or loss of fruit pigments and development of browning during the process (Chiralt and Talens, 2005).

One of the advantages of using osmotic dehydration as pretreatment before drying is to minimize the heat damage to color of product. This is because the lower drying time due to some water already taken out during osmotic dehydration process, which the lower drying time means less heat exposure during drying process.

Moreover, osmotic dehydration also reduces the activity of polyphenol oxidase, which is responsible for enzymatic browning (Ali *et al*., 2010). The example of study about the effect of osmotic dehydration as the pretreatment to maintain the natural color of dried papaya was done by Lemus-Mondaca *et al*. (2009), in which they found that the dried papaya with osmotic dehydration pretreatment has better color compared to the dried papaya without osmotic dehydration pretreatment.

2.5.3 Mechanical Properties

Dried fruits have mechanical properties, such as texture, degree of shrinkage, and microstructure. The changes in these mechanical properties are important because they are related with the texture and sensory characteristics of dried fruits, and consequently with the quality and acceptance of the product by the consumer. Besides the chemical changes, the osmotic dehydration causes alteration of physical properties of fruit tissue. Shrinkage, decreased water holding capacity, changes in porosity and resistance to deformation is usually observed during osmotic dehydration process. These phenomena happen because during osmotic dehydration, there are compositional changes and mechanical stresses associated to mass transfers. Regarding to the changes in volume and porosity, high shrinkage and low porosity lead to products with poor texture quality and rehydration capability (Mayor *et al*., 2011).

According to Mayor *et al*. (2008), as shown in Figure 2.3 (a), under the normal circumstances, the internal pressure of the plant cell pushes the plasmalemma firmly against the cell wall, which is rigid enough to support fairly high hydrostatic pressure differences. This internal pressure is called turgor pressure, a hydrostatic pressure that exerted by the vacuole and the cytoplasm against the plasma membrane and cell wall which gives elastic mechanical characteristics to the plant tissue. At some point, by increasing the concentration of the osmotic solutions, the cell will lose enough liquid for its hydrostatic pressure to drop sufficiently to lead to the formation of a space between the protoplast and the cell wall. This phenomenon is called plasmolysis, which can be seen in Figure 2.3 (b).

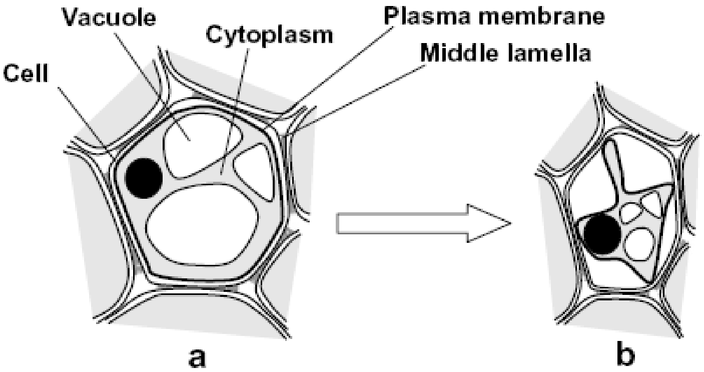


Figure 2.3. The changes of a plant cell at microstructural level during dehydration : fresh cell (a) and the cell with plasmolysis (b).

(Source : Mayor *et al*., 2008)

Normally plasmolysis occurs when the plant tissue is placed in a hypertonic solution (as in the case of osmotic dehydration process), which in this process, the plant cell loses water by osmosis. As a result of the losses of water and hence turgor pressure, the vacuole and the rest of the protoplasm will shrink and cause the plasma membrane to pull away from the cell wall. Plasmolysis is accompanied by shrinkage and deformation of cells, which these related to the shape and texture of product (Mayor *et al*., 2008). The use of sodium chloride during osmotic dehydration process enhance the plasmolysis to be occurred, which according to Monnerat *et al*. (2010) on their study about the osmotic dehydration of apples in sugar/salt solutions, they found out that the plasmolysis are likely to be happened on the sample that pretreated with the addition of 4% and 6% sodium chloride to sucrose solution. This behavior is because of the addition of the sodium chloride, which due to the greater mobility of the sodium chloride, the water diffusivity is increased, but this causes the disruption of the cellular structure.

Many aspects of cell structure are affected during osmotic dehydration of fruits, such as alteration of cell walls, splitting of the middle lamella, lysis of membranes (plasmalemma and tonoplast), tissue shrinkage, etc. These tissue changes, which strongly alter the cellular compartmentalization, wall matrix and membrane permeability, could greatly influence the mass transport properties of the product during processing.

Thus, the observation of the structural alterations in fruit tissues using microscopy would increase the scientific knowledge about modifications in fruit tissue throughout dehydration process, which allows better understanding of mass transfer process, and predict the changes that occur in the higher levels of the structure (Nieto *et al*., 2004).

CHAPTER III

METHODOLOGY

3.1 Materials

3.1.1 Fruits

- Papaya, Holland variety, horticultural maturity, was purchased from the local wholesale market (Bangkok, Thailand) during period of April 2011 to April 2012.

3.1.2 Chemicals

The following chemicals were used in this study:

- Refined sugar, Food grade (Mitr Phol Sugar Corp, Bangkok, Thailand)
- Sodium chloride, Food grade (Tokuyama, Co., Ltd., Tokyo, Japan)
- Calcium chloride, Food grade (Tokuyama, Co., Ltd., Tokyo, Japan)
- Citric acid, Food grade (Foodchem International, Co., Ltd., Shanghai, China)
- Ethyl alcohol absolute, AR grade (J.T. Baker, NJ)
- Glutaraldehyde, AR grade (UNILAB, Australia)
- n-Heptane, AR grade (Fisher, UK)
- Sodium dihydrogen phosphate, AR grade (UNILAB, Australia)
- Disodium hydrogen phosphate, AR grade (UNILAB, Australia)

3.2 Instruments

The following instruments were used in this study :

- Color meter system, ColorFlex® (Hunter Associates Laboratory, Reston, VA)
- Refractometer (Atago, Tokyo, Japan)
- Hot air oven (Heraeus Model ST5042, Postfach, Germany)
- Nuclear magnetic resonance spectrometer (Varian®, Palo Alto, CA)
- Scanning electron microscope (JEOL, Tokyo, Japan)
- Tray dryer with thermocouple (Yeo heng Model HA-100S, Bangkok, Thailand)

- Texture analyzer (Stable Micro System Model TA.XT2i, Godalming, UK)
- Water activity meter (AquaLab®, Series 3TE, Decagon Devices, Pullman, WA)

3.3 Methods

3.3.1 Precondition step

Papaya at horticultural maturity, with 5-6 % of total soluble solids was washed, peeled, and cut transversely into 1.5 cm thick slice. Each slice was then cut into four equal chunks (1.5 cm x 7.5 cm x 1.5 cm) with each chunk weight was equivalent to 15.0 g.

Precondition was done as described by Sritongtae *et al*. (2011) with a slight modification. Papaya pieces were soaked in a solution containing 1% (w/v) citric acid and 1% (w/v) calcium chloride at a fruit to solution mass ratio of 1:3 for six hours. The precondition process was done to prevent enzymatic browning and to maintain the texture of fruit. After the precondition, the samples were blanched in boiling water at 100 °C, at a fruit to solution mass ratio of 1:3, for 10 minutes.

3.3.2 Osmotic dehydration using binary osmotic solution (sucrose - water)

Four different sucrose solutions (45, 50, 55, and 60 °Brix) and isotonic solution (6 °Brix of sucrose solution) as the control were used as the binary osmotic solution. The preconditioned papaya pieces from Section 3.3.1 were immersed in those osmotic solutions for five hours at a fruit to solution mass ratio of 1:3. The temperature of the solution was initially at 55 °C but after the fruit addition, the solution was left to cool down to room temperature (30 °C) within three hours. Every hour, papaya pieces were randomly picked up, drained and blotted with absorbent paper to remove excess solution. Weight change, moisture content, and total soluble solids content were determined. Water loss (WL), solids gain (SG), weight reduction (WR), and WL/SG ratio of the sample were then calculated using Equations 3.1, 3.2, and 3.3.

Water loss (%) = $\frac{W_0 M_0 - W_t M_t}{W_0}$ (3.1)

Solid gain (%) = $\frac{W_t S_t - W_0 S_0}{W_0}$ (3.2)

Weight reduction (%) = $\frac{W_0 - W_t}{W_0} x\ 100\%$ (3.3)

where W_0 is the initial weight of the sample (g), W_t is the final weight of the sample after osmotic dehydration (g), M_0 is the initial moisture content (% wet basis) of the sample, M_t is the final moisture content (% wet basis) of the sample after osmotic dehydration, S_0 is the initial soluble solid content of the sample (%), and S_t is the final soluble solid content of the sample after osmotic dehydration (%).

The experiment was done in triplicate using completely randomized design (CRD) as the experimental design. Data were analyzed using analysis of variance (ANOVA). A Duncan's multiple range tests was used to determine the difference among sample means at p=0.05. The result of high WL and high WL/SG ratio was used as criteria to select the best three binary osmotic solutions for further study.

3.3.3 Osmotic dehydration using ternary osmotic solution (sucrose - salt - water)

The best three binary osmotic solutions selected from Section 3.3.2 were used in this study and three concentrations of NaCl (0%, 3%, and 5% (w/v)) were added into each selected binary osmotic solution to create ternary osmotic solution. There were nine conditions as shown in Table 3.1.

Table 3.1 The osmotic solutions with their symbol used in this study

Treatment	Symbol
50 °Brix Sucrose	50:0
50 °Brix Sucrose + 3% (w/v) Sodium Chloride	50:3
50 °Brix Sucrose + 5% (w/v) Sodium Chloride	50:5
55 °Brix Sucrose	55:0
55 °Brix Sucrose + 3% (w/v) Sodium Chloride	55:3
55 °Brix Sucrose + 5% (w/v) Sodium Chloride	55:5
60 °Brix Sucrose	60:0
60 °Brix Sucrose + 3% (w/v) Sodium Chloride	60:3
60 °Brix Sucrose + 5% (w/v) Sodium Chloride	60:5

The pieces of preconditioned papaya from Section 3.3.1 were immersed in the nine different ternary osmotic solutions as shown in Table 3.1 for five hours at a fruit to solution mass ratio of 1:3 as described in Section 3.3.2. Every hour, WL, SG, and WR of the sample were then calculated as details in Section 3.3.2.

The experiment was done in triplicate using factorial as the experimental design with three levels of sucrose and three levels of sodium chloride. Data were analyzed using analysis of variance (ANOVA) at p=0.05.

3.3.4 Air drying process

After five hours of pretreatment, nine osmosed samples from Section 3.3.3 were dried in a tray dryer at 60 °C with an air velocity of 1.3 m/s. Previous study showed that at 60 °C the diffusion was near maximum and the sensory characteristics of product were not much affected (Rodrigues and Fernandes, 2007). The initial weight of the samples used per tray was about 500 g. The weight of the samples was recorded up to two decimal places at designed time intervals until a constant weight was obtained. The experiment was done in duplicate. The drying curve for each condition was plotted based on the moisture ratio (MR). MR was used for the calculation of drying curve because of the differences of the initial moisture contents among the samples. MR was calculated according to Equation 3.4.

MR = $$\frac{(M_t - M_e)}{(M_0 - M_e)} \qquad (3.4)$$

where M_t is the mean moisture content of the sample at time t, M_0 is the initial moisture content of the sample, and M_e is the equilibrium moisture content of the sample. M_e was calculated from the weight of the sample after drying to constant weight.

The drying rate was calculated using Equation 3.5.

Drying rate = $$\frac{d}{d_t} MRxdrymass \qquad (3.5)$$

The drying kinetics was then predicted using the Page (Equation 3.6), Henderson and Pabis (Equation 3.7), and modified Henderson and Pabis models (Equation 3.8). The equations are as follows:

Page : MR = $\exp(-kt^n)$ (3.6) Mandala *et al*. (2005)

Henderson and Pabis : MR = $a.\exp(-kt)$ (3.7) Henderson and Pabis (1961)

Modified Henderson and Pabis :

MR = $a.\exp(-kt) + b.\exp(-gt) + c.\exp(-ht)$ (3.8) Menges and Ertekin (2006)

where MR is the moisture ratio, *t* is the drying time, and *a*, *b*, *c*, *g*, *h*, *k*, and *n* are the coefficient constants.

The correlation coefficient (r), mean residual least square (MRS), and root mean square error (RMSE) were used to find the best fitting of the three mathematical models based on the criteria of the lowest values of MRS and RMSE, and the highest value of r (Korsrilabut *et al*., 2010). These parameters can be calculated according to equations 3.9 and 3.10.

MRS = $$\frac{\sum_{i=1}^{N}\left(MR_{\exp,i} - MR_{pre,i}\right)^2}{N-1} \qquad (3.9)$$

$$\text{RMSE} = \left[\frac{1}{N} \sum_{i=1}^{N} \left(MR_{pre,i} - MR_{\exp,i} \right)^2 \right]^{1/2} \tag{3.10}$$

where $MR_{\text{exp,i}}$ is the i^{th} experimentally observed moisture ratio, $MR_{\text{pre,i}}$ is the i^{th} predicted moisture ratio, and N is the number of observations.

3.3.5 Determination of physical and chemical properties of osmosed-air dried papaya

To measure the characteristics of the samples after drying, the osmosed papaya from each treatment were dried until the moisture content reached about 16% (wet basis). The information obtained from the drying curve in Section 3.3.4 was used to determine the drying time. The physical and chemical properties of dried samples were determined as follows:

3.3.5.1 Moisture content

Moisture content of the samples was determined by drying oven method as described in AOAC (2000). This method was done by weighing 5.000 gram of sample into an aluminum pan with exact known weight. The sample was then dried in hot air oven at 105 °C for 5 hours, cooled in desiccator to obtain the constant weight, and the final weight of the sample was then determined. The moisture content of the sample was then calculated using Equation 3.11.

$$\text{Moisture content (\% wet basis)} = \frac{W_0 - W_t}{W_0} x100\% \tag{3.11}$$

where W_0 is the initial weight of sample and W_t is the weight of the sample after drying.

3.3.5.2 Water activity

Water activity was determined by using water activity meter (AquaLab®, Series 3TE, Decagon Devices, Pullman, WA). This method was done by chopping the sample into small pieces, five gram of the chopped sample was then put inside the close container, and was left for one hour to reach the equilibrium. The water activity of the chopped sample was then measured at 25 °C.

In this analysis, three measurements were done for each treatment. The experiment was done in duplicate using factorial as the experimental design with three levels of sucrose and three levels of sodium chloride. Data were analyzed using analysis of variance (ANOVA) at p=0.05.

3.3.5.3 Water mobility

Water mobility was monitored using a ^{1}H-NMR longitudinal relaxation time (T_1) obtained from nuclear magnetic resonance spectrometer (Varian®, Palo Alto, CA) operating at 500 MHz as described by Sritongtae *et al*. (2011). A multinuclear 5 mm probe was used. A cylindrical piece of osmosed-dried papaya with 5 mm diameter and 40 mm height was fitted into a 5 mm NMR tube. The experiment was carried out at a constant temperature (25 ^{o}C). The T_1 value was measured using the Inversion-Recovery method ($5T_1$-180^{o}-τ-90^{o}), with a 90^{o} pulse width of 6.30 μs and τ delay values which ranged from 0.0375 to 4.8 s.

In this analysis, three measurements were done for each treatment. The experiment was done in duplicate using factorial as the experimental design with three levels of sucrose and three levels of sodium chloride. Data were analyzed using analysis of variance (ANOVA) at p=0.05.

3.3.5.4 Texture

Compression test and texture profile analysis were used to evaluate the texture of osmosed-dried papaya. The cutting work was determined by using compression test method using BSK blade as the probe. The condition with pre-test speed of 2 mm/s, test speed of 2 mm/s, post-test speed of 10 mm/s, distance of 10 mm, and trigger force of 5 g was employed (Arganosa *et al*., 2008).

Typical cutting work curve is shown in Figure 3.1. The value of cutting force is presented by the first peak force in g_f, and the value of cutting energy is presented as the area under force-deformation curve (g_f.s).

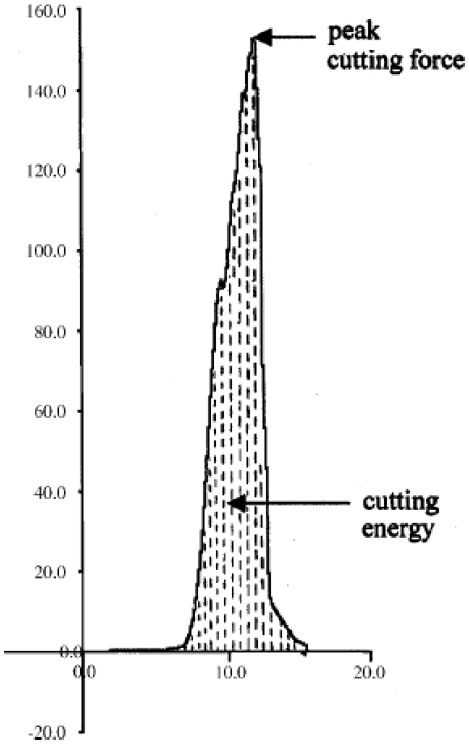


Figure 3.1 Typical force–deformation curve for cutting the samples with HDP/BSK blade cutter to determine the cutting work values.
(Source : Singh and Reddy, 2006).

The texture profile analysis method with hardness, cohesiveness, chewiness, and adhesiveness as the texture parameters was monitored by using Texture Analyzer (Stable Micro System Model TA.XT2i, Godalming, UK) with a 100 mm diameter compression plate was used as the probe. The condition with pre-test speed of 1 mm/s, test speed of 1 mm/s, post-test speed of 1 mm/s, strain of 30 %, time of 5 s and trigger force of 5 g was employed (Arganosa *et al.*, 2008).

Typical texture profile analysis (TPA) plot is presented in Figure 3.2, which the value for hardness is presented by the peak force of the first compression cycle in g_f, cohesiveness is the ratio of the positive force area during the second compression to that during the first compression (Area 2/Area 1), springiness is the ratio of the time duration of force input during the second compression to that during the first compression (Length 2/Length 1), adhesiveness is the negative area under the baseline between the compression cycles (Area 3) and chewiness is the hardness multiplied by cohesiveness multiplied by springiness in g_f.

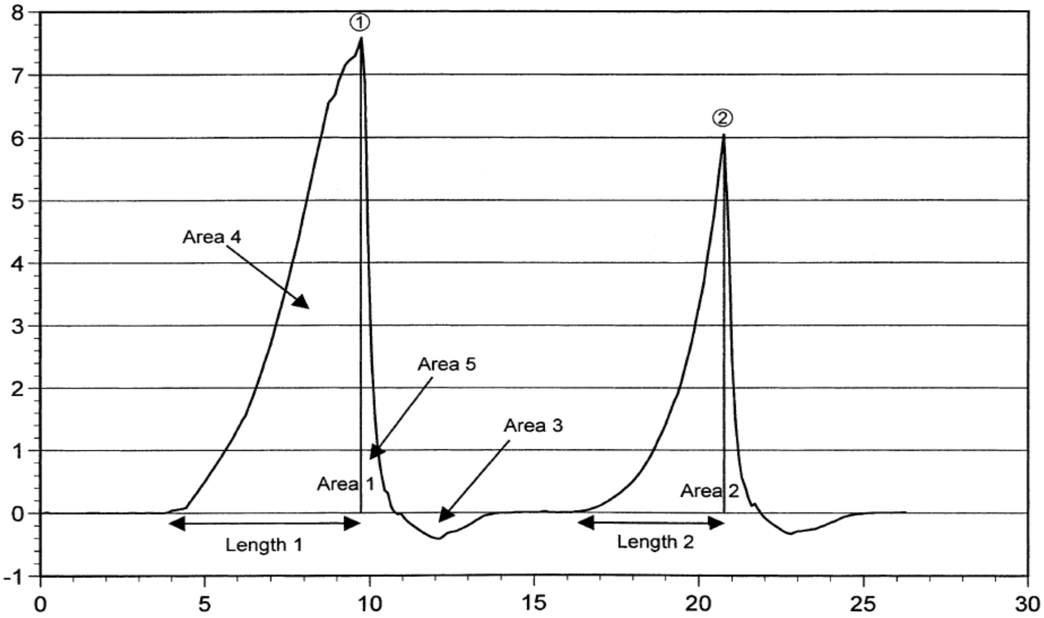


Figure 3.2 Typical force-by-time plot through two cycles of penetration of the samples to determine texture profile analysis values.

(Source : Caine *et al*., 2003).

In this analysis, 10 measurements (one measurement per each piece) were done for each treatment. The experiment was done in duplicate using factorial as the experimental design with three levels of sucrose and three levels of sodium chloride. Data were analyzed using analysis of variance (ANOVA) at p=0.05.

3.3.5.5 Color

Color measurement of osmosed-dried papaya was done by using ColorFlex® color meter system (Hunter Associates Laboratory, Reston, VA). The color was expressed in terms of the CIE L*, a*, b* uniform color space, where L* represents lightness, a* represents chromaticity on a green (-) to red (+) axis and b* represents chromaticity on a blue (-) to yellow (+) axis (Duangmal *et al*., 2008). The color difference (ΔE) was calculated using Equation 3.12.

$$\Delta E = \sqrt{(L*-L*_0)^2 + (a*-a*_0)^2 + (b*-b*_0)^2} \tag{3.12}$$

In this analysis, 24 measurements (three measurements per each piece) were done for each treatment. The experiment was done in duplicate using factorial as the experimental design with three levels of sucrose and three levels of sodium chloride. Data were analyzed using analysis of variance (ANOVA) at p=0.05.

3.3.5.6 Volume shrinkage

Volume shrinkage was determined with liquid displacement method using n-heptane as the organic solvent as described by Yan *et al*. (2008) with a slight modification. A cylinder with the volume of 80 ml was calibrated using distilled water to determine the exact volume of the cylinder. The samples were then weighed precisely and transferred into the cylinder half filled with n-heptane. The cylinder was then filled with n-heptane, the level of solvent being carefully adjusted to ensure consistency, and weighed. The volume of sample (V) was calculated using Equation 3.13 and the volume shrinkage of the sample (S) was then determined using Equation 3.14.

$$V = V_f - \frac{M_{t+s} - M_f - M}{\rho_s} \tag{3.13}$$

where V_f is the volume of the cylinder, M_{t+s} is the weight of the cylinder plus the sample and the solvent, M_f is the weight of the cylinder, and $\boldsymbol{\rho}_s$ is the density of n-heptane.

$$S = \frac{V_0 - V_d}{V_0} x100\% \tag{3.14}$$

where V_d is the volume of the sample after drying and V_o is the volume of the sample before drying.

In this analysis, the volume shrinkage was determined in respect to fresh papaya and in respect to osmosed papaya. Eight measurements were done for each treatment. The experiment was done in duplicate using factorial as the experimental design with three levels of sucrose and three levels of sodium chloride. Data were analyzed using analysis of variance (ANOVA) at p=0.05.

3.3.5.7 Microstructure

The microstructure of the sample was analyzed using scanning electron microscope method as described by Kunawantanit (2011). The samples were cut into three slabs (5 mm x 3 mm x 3 mm). For the fresh papaya, the samples were preconditioned by soaking in 2.5 % w/w glutaraldehyde for 2 hour, and were then cleaned from glutaraldehyde by soaking it with phosphate buffer (0.2 M, pH 7.2) two times (each times 10 minutes). The fresh papaya samples were then soaked with ethanol 30 %, 50 %, 70 %, and 90 % respectively in 30 minutes for each solution. For all the dried papaya, the samples were soaked with absolute ethanol 3 times (each time for one hour).

The samples (fresh and dried) were then dehydrated with critical point dryer (Balzers Model CPD 020, Vaduz, Liechtenstein) with the temperature 31 ^{o}C and pressure 73.8 Bar. The samples were then soaked in liquid nitrogen, and were then fractured. After the samples were fractured, the sample was put on the stub, and the surface of the sample was then coated with gold by using ion sputter (Balzers Model CPD 040, Vaduz, Liechtenstein). The microstructure of the sample was then investigated using Scanning Electron Microscope (JEOL, Tokyo, Japan) with 15 kV accelerating voltage and 150x zoom level.

3.3.6 Sensory analysis of osmosed-dried papaya

In this study, four best osmosed-dried papaya samples from previous analyses in Section 3.3.5 were chosen as the samples for sensory analysis. The sensory analysis was done in descriptive test and acceptance test.

3.3.6.1 Descriptive test

The descriptive test was used for determining the intensity of the sensory qualities of osmosed-dried papaya samples. The samples were presented to the panelists on a white plate labeled with three-digit number codes. Fifteen Graduate students from the Department of Food Technology, Chulalongkorn University were used as the panelists. They were trained to make all of them have the same standard of evaluation and understand the whole idea for each sensory attribute. They were then asked to rate the intensity of sensory attributes with the scale from 0 to 10 on a 15 cm line scale, with the sensory attributes to be determined such as color (yellowness and redness), shrinkage, texture (hardness and chewiness), and taste (sweetness and saltiness). The experiment was conducted under white fluorescence light in an air-conditioned room (25 ^{o}C). Drinking water was provided to clear the palate.

In this experiment, the randomized complete block design (RCBD) was used as the experimental design. Data were analyzed using analysis of variance (ANOVA). A Duncan's multiple range tests was used to determine the difference among sample means at p=0.05.

3.3.6.2 Acceptance test

The acceptance test was used for determining the quality and consumer acceptability of osmosed-dried papaya samples, based on their color, texture, appearance, taste and overall acceptance. The samples were presented to the panelists on a white plate labeled with three-digit number codes. Fifty panelists from the Department of Food Technology, Chulalongkorn University, were each asked to rate each sensory attribute on a 7-point hedonic scale from 1 (dislike extremely) to 7 (like extremely). The experiment was conducted under white fluorescence office lighting in an air-conditioned room (25 ^{o}C). Drinking water was provided to clear the palate.

In this experiment, the randomized complete block design (RCBD) was used as the experimental design. Data were analyzed using analysis of variance (ANOVA). A Duncan's multiple range tests was used to determine the difference among sample means at p=0.05.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Osmotic dehydration using binary osmotic solution (sucrose – water)

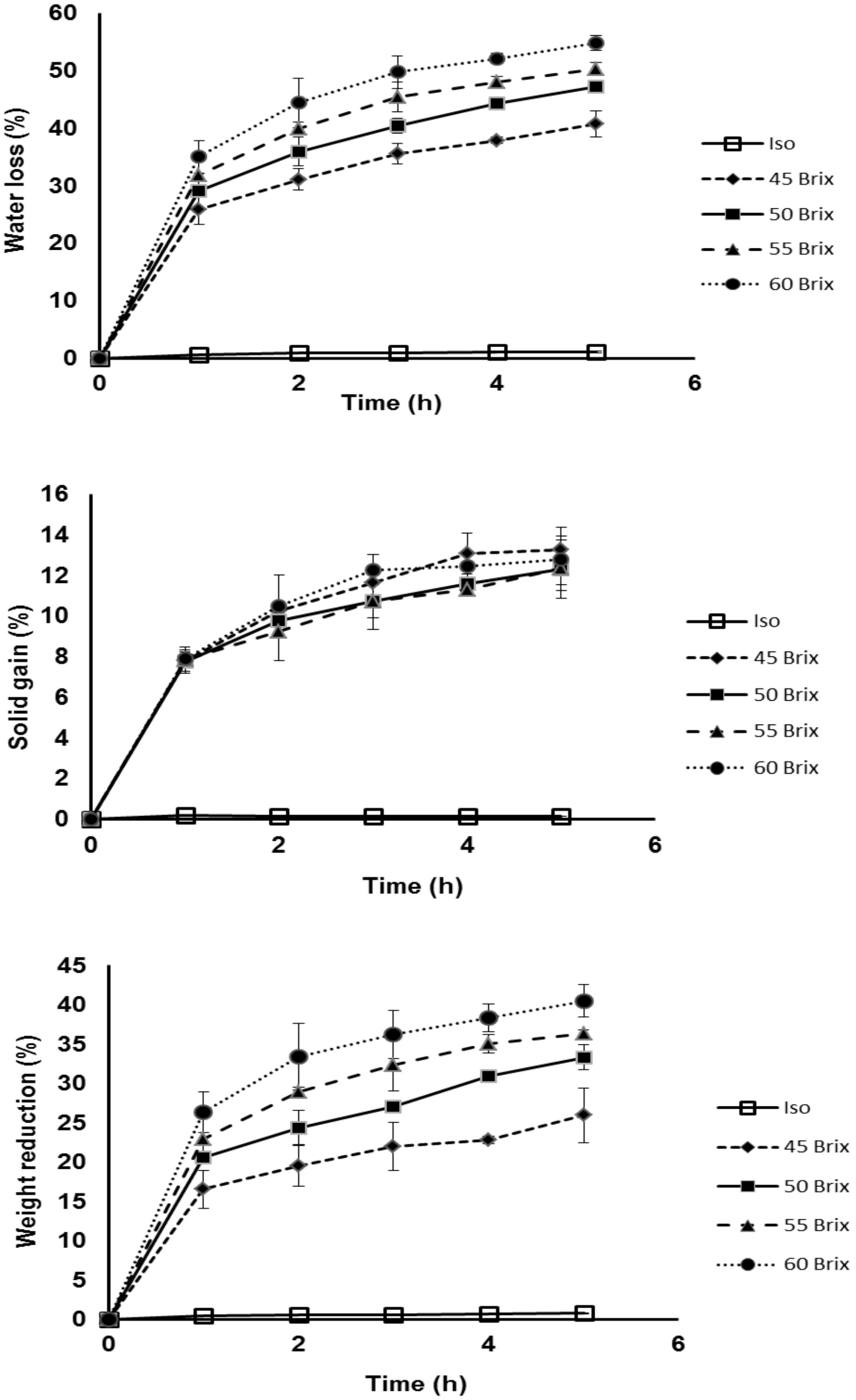
4.1.1 Water loss, solid gain, and weight reduction

During osmotic dehydration process, there are normally three mass transfer processes occurred: (a) water diffusion from the food material to the surrounding osmotic medium due to the concentration gradient between them, (b) solute diffusion from the osmotic solution to the food, and (c) leaching of natural solutes such as sugars, organic acids, mineral, and salts from the food into the solution. In this study, the mass transfer was presented in the term of water loss (WL), solid gain (SG), and weight reduction (WR). The mass transfer of osmotic dehydration using binary solution, sucrose in water, can be seen in Figure 4.1 (a), (b), and (c).

As shown in Figure 4.1 (a), (b), and (c), for all conditions, the WL, SG, and WR value sharply increased during first three hours due to the high osmotic pressure gradient between sample and osmotic medium during initial hours of the process. After three hours, those values gradually increased because the osmotic pressure gradient was not as high as early step. Moreover, at the same osmotic concentration, the longer immersion time led to a higher water loss, solid gain, and weight reduction. This is because the longer immersion time facilitates the contact and diffusion between surface of fruit pieces and the osmotic solution, which led the mass transfer phenomena to occur. However, from the fourth hour of immersion time, the increase of the water loss, solid gain and weight reduction was likely to be lower than previous hour. It might be possible that the mass transfer process almost reached the equilibrium or the osmotic gradient was low. This assumption was also supported by the work done by to El-Aouar *et al*. (2006), who reported that the treatment immersed for 210 minutes in sucrose solution time are likely to have higher percentage of water loss, solid gain, and weight reduction than the treatments immersed for 120 minutes in sucrose solution during osmotic dehydration of papaya.

From Figure 4.1 (a) and (c), the treatment with higher concentration of sucrose was significantly higher ($p<0.05$) in water loss and weight reduction compared to the treatment with lower concentration of sucrose (Appendix B.1 and B.2). The result was in good agreement with the study done by El-Aouar *et al*. (2006), their study on the influence of the osmotic agent on the osmotic dehydration of papaya, also found that the treatment with 56 ^{o}Brix of sucrose showed the higher weight reduction and water loss than the treatment with 44 ^{o}Brix of sucrose at the same period of immersion time. Ispir and Togrul (2009), study on osmotic dehydration of apricot, also found that the treatment with 70 ^{o}Brix of sucrose has the higher water loss compared to the treatments with 40 ^{o}Brix of sucrose. The higher water loss was because the increase in the concentration of osmotic solution leads to the higher in the osmotic pressure of the solution, thus increasing the driving force of the process and increasing the rate of water removal. However, from Figure 4.1 (b), at the same period of immersion time, the higher in concentration of sucrose showed no significant difference ($p\geq0.05$) in the solid gain (Appendix B.1 and B.2). The result was not in good agreement with the study done by El-Aouar *et al*. (2006) and Ispir and Togrul (2009). From the study on osmotic dehydration of papaya done by El-Aouar *et al*. (2006), they found that the treatment with 56 ^{o}Brix of sucrose showed the lower solid gain than the treatment with 44 ^{o}Brix of sucrose. From the study on osmotic dehydration of apricot done by Ispir and Togrul (2009), they found that the treatment with 70 ^{o}Brix of sucrose has the higher solid gain compared to the treatments with 40 ^{o}Brix of sucrose. This might be possible that the difference in solid gain is affected by osmotic solution concentration, immersion time, and also type of fruit.

In isotonic solution, the concentration of sucrose solution was 6 ^{o}Brix. Due to the same total soluble solid between isotonic solution and papaya sample, there appeared to be no changes in water loss, solid gain, and weight reduction. This was due to the fact that there was no driving force when there was no difference in osmotic pressure.



(a)

(b)

(c)

Figure 4.1 The effect of different sucrose concentrations on water loss (a), solid gain (b), and weight reduction (c) during osmotic dehydration of papaya.

4.1.2 Water loss to solid gain ratio

The quality or goodness of the osmotic agent can be indicated by many parameters, such as WL, SG, WL/SG ratio, viscosity of solution, etc. One of the most important parameters is the ratio of water loss to solid gain (WL/SG ratio) (Mayor *et al*., 2007). The value of WL/SG ratio is related to the effectiveness of the osmotic dehydration process, which the higher value of WL/SG ratio the better the process. This is because the higher water loss means the higher amount of water is taken out from the product and the lower solid gain is desirable because the high solid gain affects the changes in quality and sensory characteristics of the product. The high level of solids that are incorporated into the fruit during osmotic dehydration process significantly affects sensory acceptance and the final product may present a taste that is totally different from the fresh fruit. The effect of different sucrose concentrations on WL/SG ratio during osmotic dehydration of papaya can be seen in Table 4.1.

As shown in Table 4.1, the increase in sucrose concentration contributes to the increase in the value of of WL/SG ratio, except for the isotonic solution. For isotonic solution, even the value of water loss and solid gain is very low, but the value of of WL/SG ratio is higher compared to other sucrose solutions.

In this study, the result of high WL and high WL/SG ratio was used as criteria to select the best three binary osmotic solutions for next step. From the results shown in Figure 4.1 (a) and Appendix B.1 the treatment with sucrose concentration of 45 ^{o}Brix has significantly lower in the value of water loss compared to other treatments. Moreover, as shown in Table 4.1, the treatment with sucrose concentration of 45 ^{o}Brix has lowest value of WL/SG ratio compared to other treatments. The isotonic solution also was not selected because even the WL/SG ratio of this solution is high, but the water loss is very low. Therefore, it can be concluded that the best three binary osmotic solutions for the next step are 50 ^{o}Brix, 55 ^{o}Brix, and 60 ^{o}Brix.

Table 4.1 The effect of different sucrose concentrations on WL/SG ratio during osmotic dehydration of papaya

Hour	Treatment	WL/SG
1	Iso	3.91 ± 0.49
	45	3.31 ± 0.39
	50	3.76 ± 0.29
	55	4.07 ± 0.66
	60	4.44 ± 0.49
2	Iso	6.01 ± 0.09
	45	3.02 ± 0.10
	50	3.68 ± 0.33
	55	4.37 ± 0.63
	60	4.33 ± 1.09
3	Iso	5.91 ± 0.37
	45	3.06 ± 0.21
	50	3.77 ± 0.26
	55	4.30 ± 0.79
	60	4.06 ± 0.39
4	Iso	7.11 ± 1.04
	45	2.91 ± 0.25
	50	3.82 ± 0.08
	55	4.25 ± 0.11
	60	4.19 ± 0.34
5	Iso	7.76 ± 0.97
	45	3.08 ± 0.33
	50	3.87 ± 0.46
	55	4.08 ± 0.27
	60	4.33 ± 0.61

4.2 Osmotic dehydration using ternary osmotic solution (sucrose - salt - water)

In this study, the mass transfer of osmotic dehydration using ternary solution was studied. The addition of sodium chloride into sucrose solution, the binary osmotic solution, was the model of ternary osmotic solution. The mass transfer was presented in the term of water loss, solid gain, and weight reduction, shown in Table 4.2.

Table 4.2 The effect of addition of sucrose and sodium chloride on WL, SG, and WR during osmotic dehydration of papaya

Hour	Sucrose	Sodium chloride	WL	SG	WR
1st	50 °Brix	0 (% w/v)	29.06 ± 0.16	7.77 ± 0.59	20.57 ± 0.44
	50 °Brix	3 (% w/v)	28.84 ± 2.33	9.64 ± 1.54	18.55 ± 3.69
	50 °Brix	5 (% w/v)	30.66 ± 1.12	10.27 ± 0.81	19.98 ± 1.12
	55 °Brix	0 (% w/v)	31.79 ± 2.85	7.89 ± 0.59	22.98 ± 2.84
	55 °Brix	3 (% w/v)	30.74 ±1.53	9.39 ± 0.21	21.46 ± 1.10
	55 °Brix	5 (% w/v)	33.61 ± 2.05	10.65 ± 0.77	23.03 ± 2.81
	60 °Brix	0 (% w/v)	35.03 ± 2.85	7.91 ± 0.34	26.38 ± 2.57
	60 °Brix	3 (% w/v)	33.48 ± 3.24	8.94 ± 0.48	23.34 ± 2.95
	60 °Brix	5 (% w/v)	36.66 ± 1.17	9.26 ± 0.74	27.17 ± 1.72
Main effect:					
Sucrose			*	NS	*
Sodium chloride			NS	*	NS
Interaction:					
Sucrose x sodium chloride			NS	NS	NS

Table 4.2 (Continued)

2nd	50 °Brix	0 (% w/v)	35.91 ± 2.49	9.79 ± 0.68	24.40 ± 2.14
	50 °Brix	3 (% w/v)	37.23 ± 2.83	11.02 ± 0.14	25.46 ± 2.42
	50 °Brix	5 (% w/v)	39.04 ± 0.50	11.59 ± 0.69	26.23 ± 0.59
	55 °Brix	0 (% w/v)	39.89 ± 1.12	9.28 ± 1.48	28.93 ± 0.56
	55 °Brix	3 (% w/v)	40.27 ± 2.67	12.01 ± 0.75	28.63 ± 1.93
	55 °Brix	5 (% w/v)	41.35 ± 1.37	12.72 ± 0.37	28.63 ± 1.28
	60 °Brix	0 (% w/v)	44.39 ± 4.30	10.49 ± 1.51	33.42 ± 4.19
	60 °Brix	3 (% w/v)	42.88 ± 1.84	11.13 ± 0.47	31.22 ± 2.84
	60 °Brix	5 (% w/v)	45.88 ± 1.46	11.24 ± 0.56	33.72 ± 1.26
Main effect:					
Sucrose			*	NS	*
Sodium chloride			NS	*	NS
Interaction:					
Sucrose x sodium chloride			NS	NS	NS
3rd	50 °Brix	0 (% w/v)	40.38 ± 1.29	10.75 ± 0.85	27.01 ± 0.53
	50 °Brix	3 (% w/v)	38.90 ± 2.97	13.16 ± 1.95	25.14 ± 3.38
	50 °Brix	5 (% w/v)	42.81 ± 1.37	14.18 ± 1.99	28.02 ± 2.96
	55 °Brix	0 (% w/v)	45.43 ± 2.52	10.74 ± 1.39	32.32 ± 3.31
	55 °Brix	3 (% w/v)	42.43 ± 1.84	13.11 ± 0.55	28.25 ± 0.65
	55 °Brix	5 (% w/v)	47.79 ± 0.49	13.66 ± 1.12	34.04 ± 1.46
	60 °Brix	0 (% w/v)	49.76 ± 2.81	12.29 ± 0.74	36.23 ± 3.05
	60 °Brix	3 (% w/v)	46.48 ± 4.09	12.85 ± 0.59	32.21 ± 3.68
	60 °Brix	5 (% w/v)	51.39 ± 0.52	13.55 ± 0.86	38.40 ± 0.09
Main effect:					
Sucrose			*	NS	*
Sodium chloride			*	*	*
Interaction:					
Sucrose x sodium chloride			NS	NS	NS

Table 4.2 (Continued)

4th	50 °Brix	0 (% w/v)	44.23 ± 1.09	11.58 ± 0.23	30.98 ± 0.67
	50 °Brix	3 (% w/v)	42.52 ± 1.84	14.49 ± 1.16	27.84 ± 1.21
	50 °Brix	5 (% w/v)	44.52 ± 0.29	15.21 ± 1.69	28.96 ± 2.06
	55 °Brix	0 (% w/v)	48.03 ± 1.02	11.32 ± 0.12	35.06 ± 1.13
	55 °Brix	3 (% w/v)	47.17 ± 1.40	13.62 ± 0.41	32.58 ± 1.49
	55 °Brix	5 (% w/v)	50.08 ± 2.68	15.75 ± 0.64	34.21 ± 2.65
	60 °Brix	0 (% w/v)	52.14 ± 0.95	12.49 ± 0.76	38.37 ± 1.75
	60 °Brix	3 (% w/v)	50.37 ± 2.27	13.62 ± 0.85	35.90 ± 2.44
	60 °Brix	5 (% w/v)	53.42 ± 1.00	14.06 ± 0.81	39.23 ± 1.49
Main effect:					
Sucrose			*	NS	*
Sodium chloride			*	*	*
Interaction:					
Sucrose x sodium chloride			NS	NS	NS
5th	50 °Brix	0 (% w/v)	47.25 ± 0.29	12.33 ± 1.44	33.33 ± 1.56
	50 °Brix	3 (% w/v)	46.65 ± 1.06	14.36 ± 1.49	30.86 ± 1.55
	50 °Brix	5 (% w/v)	48.05 ± 1.77	14.99 ± 0.35	32.19 ± 1.37
	55 °Brix	0 (% w/v)	50.24 ± 1.16	12.35 ± 0.81	36.37 ± 0.49
	55 °Brix	3 (% w/v)	50.55 ± 0.18	15.29 ± 1.37	34.68 ± 1.57
	55 °Brix	5 (% w/v)	52.83 ± 1.19	15.85 ± 0.27	36.25 ± 2.08
	60 °Brix	0 (% w/v)	54.85 ± 1.29	12.81 ± 1.55	40.50 ± 2.04
	60 °Brix	3 (% w/v)	54.07 ± 1.65	14.22 ± 0.12	39.55 ± 2.26
	60 °Brix	5 (% w/v)	56.45 ± 2.35	14.45 ± 0.21	41.89 ± 2.33
Main effect:					
Sucrose			*	NS	*
Sodium chloride			*	*	NS
Interaction:					
Sucrose x sodium chloride			NS	NS	NS

* Significant effect at $p<0.05$

As shown on Table 4.2, the addition of sucrose showed a significant effect on water loss ($p<0.05$), which there is a significant increase in water loss for the sample pretreated with higher concentration of sucrose (Appendix B.3 and B.4). Moreover after three hours of immersion, the addition of sodium chloride showed a significant effect on water loss ($p<0.05$), which there is a significant increase in water loss for the sample pretreated with ternary solution compared to the sample pretreated with binary solution (Appendix B.3 and B.4). The result was in a good agreement with the study done by Alves *et al*. (2005), studied on osmotic dehydration of acerola fruit. They found that by replacing 10 ^{o}Brix of sucrose with 10% of sodium chloride in 60 ^{o}Brix of sucrose solution increased the water loss during osmotic dehydration process. Mayor *et al*. (2007), studied on osmotic dehydration kinetics of pumpkin fruits using ternary solutions of sodium chloride and sucrose, also found that the addition of 7.5% of sodium chloride to 45 ^{o}Brix of sucrose solution increased the water loss during osmotic dehydration process. The reason is because the addition of sodium chloride to sucrose solution leads to the lower water activity of solution. This result agreed well with the result of water activity of solution, as shown Table 4.3. The lower water activity increases the osmotic pressure of the solutions, which increase the driving force of the process, thus increase the rate of water removal. Moreover, from Table 4.3, there is a difference on pH and viscosity between each treatment, but the difference on pH and viscosity is not big enough to affect the mass transfer process.

Table 4.3 The properties of osmotic solution used in this study

Treatment (sucrose : salt) °Brix	Aw	pH	Viscosity (cp)
50:0	0.930 ± 0.01	7.54 ± 0.00	14.05 ± 0.64
50:3	0.902 ± 0.01	7.25 ± 0.22	16.40 ± 0.99
50:5	0.880 ± 0.00	7.14 ± 0.17	16.95 ± 0.21
55:0	0.912 ± 0.01	7.62 ± 0.11	20.95 ± 1.77
55:3	0.882 ± 0.01	7.23 ± 0.06	26.00 ± 1.41
55:5	0.854 ± 0.00	7.08 ± 0.12	25.85 ± 0.78
60:0	0.894 ± 0.01	7.585 ± 0.05	38.05 ± 0.21
60:3	0.857 ± 0.01	7.21 ± 0.08	45.65 ± 0.21
60:5	0.832 ± 0.00	7.10 ± 0.08	50.20 ± 0.85

For solid gain, as shown in Table 4.2, there is no effect of addition of sucrose to solid gain ($p \geq 0.05$), but there is an effect of addition of sodium chloride to solid gain during osmotic dehydration process ($p < 0.05$), which there is a significant increase in solid gain for the sample pretreated with ternary solution compared to the sample pretreated with binary solution (Appendix B.5 and B.6). This result agreed well with the study done by Alves *et al*. (2005), studied on osmotic dehydration of acerola fruit, they found that by replacing 10 °Brix of sucrose with 10% of sodium chloride in 60 °Brix of sucrose solution increased the solid gain during osmotic dehydration process. The same result was also found by Taiwo *et al*. (2003), studied on osmotic dehydration of strawberry halves. They found that by replacing 2.5 °Brix of sucrose with 2.5% of sodium chloride in 50 °Brix of sucrose solution increased the solid gain during osmotic dehydration process. The increase in the solid gain might be because the addition of sodium chloride contributes to the lower water activity of solution (as shown Table 4.3). The lower water activity leads to the increase of osmotic pressure gradient and consequent loss of functionality of cell plasmatic membrane that allows solutes to enter. Another reason is because of smaller molecular size of sodium chloride. Sodium chloride thus can be easier to penetrate into the fruit membrane.

For weight reduction, from Table 4.2, the addition of sucrose showed a significant effect on weight reduction ($p<0.05$) during osmotic dehydration process, which there is a significant increase in weight reduction for the sample pretreated with higher concentration of sucrose (Appendix B.7 and B.8). The reason is because the addition of sucrose has a significant effect in increasing the water loss, but has no significant effect in increasing the solid gain. Moreover, at the first two hours of osmotic dehydration process, there is no effect of addition of sodium chloride on weight reduction ($p\geq0.05$), but after three hours of immersion, the addition of sodium chloride showed a significant effect on weight reduction ($p<0.05$), which there is a significant increase in weight reduction for the sample pretreated with ternary solution compared to the sample pretreated with binary solution (Appendix B.7 and B.8). However, at 5th hour of immersion, there is no effect of addition of sodium chloride on weight reduction ($p\geq0.05$). This might be because during this hour, less water loss is taken out due to lower osmotic pressure gradient between fruit and solution, and more solid penetrated into the fruit membrane, thus the weight reduction was decreased. The result was different from that reported by Alves *et al*. (2005), studied on osmotic dehydration of acerola fruit. They found that by replacing 10 °Brix of sucrose with 10% of sodium chloride in 60 °Brix of sucrose solution increased the weight reduction during osmotic dehydration process. The different result might be because of the lower amount of the sodium chloride that added to the solution in this study, which is only 3 and 5%. Even though the sodium chloride has the ability to increase the osmotic pressure of the solution which can increase the driving force of the process, but the amount of solid added was not high enough to cause significant effect on weight reduction during the process.

From the results in Table 4.2, there was a different in water loss and solid gain for each treatment. This affects the drying characteristics and final product quality of osmodehydrated papaya. Therefore, all nine treatments from this Section were used for the next step.

4.3 Drying characteristics

4.3.1 Drying curve

The drying curve for osmosed papaya in different concentrations of sucrose is shown on Figure 4.2. As shown in Figure 4.2 (a), all the samples reached the constant weight after 13 hours of drying process. Moreover, there was a difference in initial moisture content of each sample due to the difference in mass transfer during osmotic dehydration before drying process. Since there is a difference in initial moisture content of each sample, moisture ratio (MR) was used for plotting the drying curve. From figure 4.2 (b), which shows a plot of MR vs time, the sample pretreated with higher addition of sodium chloride is likely to reach lower moisture ratio faster compared to the sample pretreated with lower and without addition of sodium chloride due to the different drying rate.

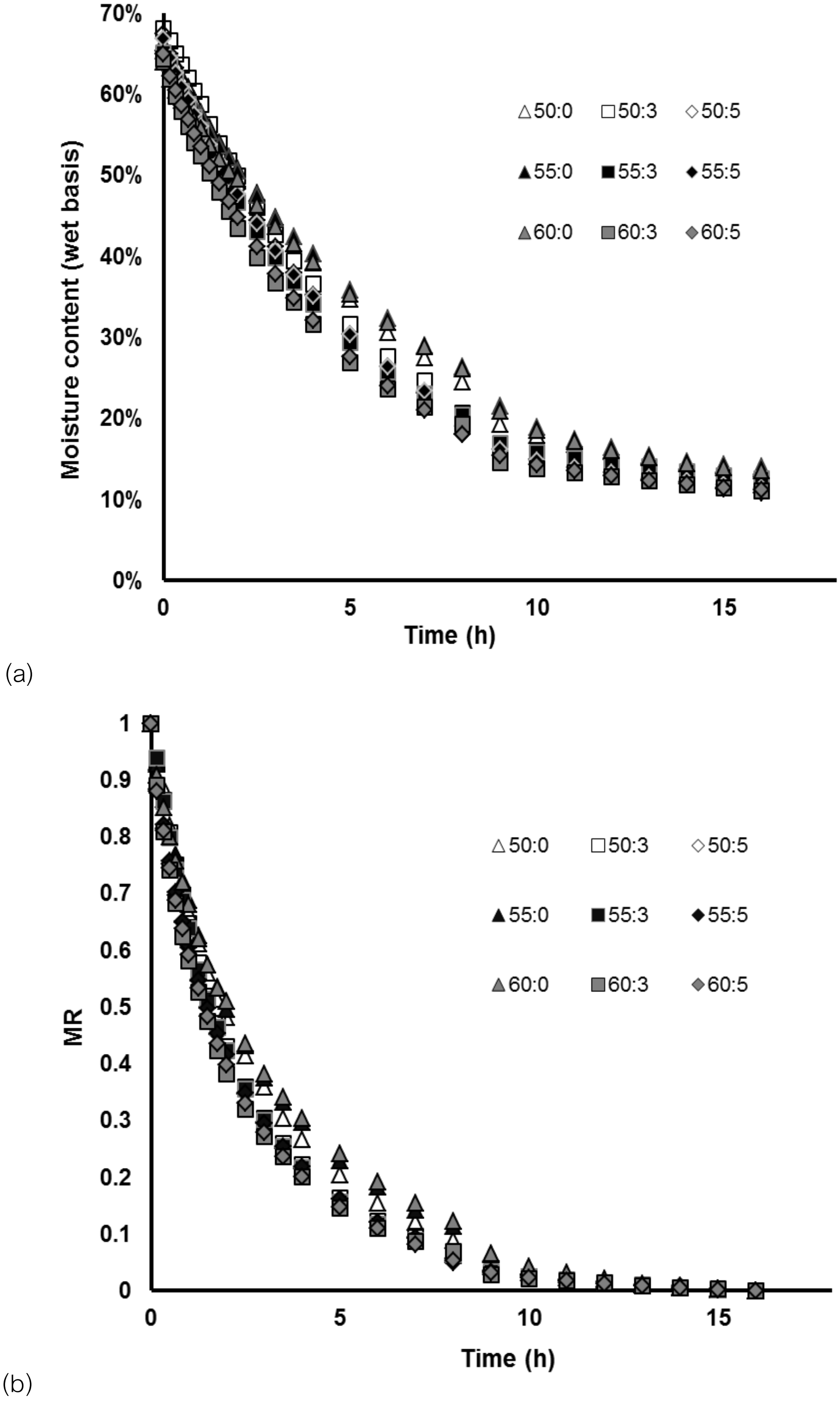


Figure 4.2 The drying curve, plot of moisture content vs time (a), plot of moisture ratio vs time (b), for osmosed papaya pretreated with binary and ternary solution.

4.3.2 Mathematical drying model

The drying kinetics of dried papaya can be described using an appropriate thin layer mathematical drying model. The purpose of evaluating the mathematical model was for the describing the drying behavior better, for the optimization of the drying performance and for quality control. In this study, the drying equation was predicted by fitting the experimental data to three exponential mathematical drying models: Page, Henderson and Pabis, and modified Henderson and Pabis models. Statistical coefficient parameters for these three mathematical models compared to the experimentally derived MR data can be seen in Table 4.4.

In this study, the obtained values of correlation coefficient (r), mean residual least square (MRS), and root mean square error (RMSE) were used to find the best fitting of the three mathematical models based on the criteria of the lowest values of MRS and RMSE, and the highest value of r.

As shown in Table 4.4, compared to the other two models, the modified Henderson and Pabis model was found to give the best fit with experimental data for all treatments, except for the treatment with 60 °Brix sucrose and 5% sodium chloride, which Page model was found to be the best model to fit the experimental data for the the treatment with 60 °Brix sucrose and 5% sodium chloride.

This result was in good agreement with study done by Karathanos (1999) which use corinthian raisins as the sample and Korsrilabut *et al*. (2010) which use cantaloupe as the sample. From their studies, the best model for predicting the drying curve of the high sugar containing fruit products is the modified Henderson and Pabis model. The model is suitable because during the drying process of the product with high sugar content, there are three weight loss mechanisms involved, (1) the decrease of weight due to sugar decomposition, (2) weight loss due to the water removal, and (3) the weight loss correspond to the least attractively bound water, which may be the water content not bound directly to the solids, but it is attached to other water molecules and its association with the solids is loose.

Table 4.4 Statistical coefficient parameters for the three different mathematical models compared to the experimentally derived MR data

Model	Treatment	*K**	MRS	RMSE	r
Page	50:0	0.3878	$1.10x10^{-4}$	0.0103	0.9995
	50:3	0.4345	$8.70x10^{-5}$	0.0092	0.9996
	50:5	0.5001	$3.40x10^{-5}$	0.0057	0.9998
	55:0	0.3769	$1.37x10^{-4}$	0.0115	0.9994
	55:3	0.4460	$8.70x10^{-5}$	0.0092	0.9996
	55:5	0.4937	$4.30x10^{-5}$	0.0064	0.9998
	60:0	0.3832	$2.03x10^{-4}$	0.0139	0.9991
	60:3	0.5351	$5.40x10^{-5}$	0.0072	0.9997
	60:5	0.5206	$2.00x10^{-5}$	0.0044	0.9999
Henderson and Pabis	50:0	0.3372	$2.86x10^{-4}$	0.0166	0.9987
	50:3	0.3913	$2.48x10^{-4}$	0.0155	0.9990
	50:5	0.3926	$4.62x10^{-4}$	0.0211	0.9978
	55:0	0.3076	$3.72x10^{-4}$	0.0189	0.9982
	55:3	0.3997	$2.84x10^{-4}$	0.0165	0.9988
	55:5	0.3935	$4.61x10^{-4}$	0.0211	0.9978
	60:0	0.2949	$4.61x10^{-4}$	0.0211	0.9977
	60:3	0.4247	$6.36x10^{-4}$	0.0247	0.9971
	60:5	0.4142	$4.57x10^{-4}$	0.0209	0.9979
Modified Henderson and Pabis	50:0	0.2899	$0.75x10^{-4}$	0.0085	0.9997
	50:3	0.3113	$4.22x10^{-5}$	0.0064	0.9998
	50:5	0.3157	$3.12x10^{-5}$	0.0055	0.9998
	55:0	0.2638	$0.99x10^{-4}$	0.0098	0.9996
	55:3	0.3102	$2.88x10^{-5}$	0.0053	0.9999
	55:5	0.3202	$2.39x10^{-5}$	0.0048	0.9999
	60:0	0.2527	$1.37x10^{-4}$	0.0115	0.9994
	60:3	0.3049	$3.29x10^{-4}$	0.0056	0.9998
	60:5	0.3261	$2.11x10^{-5}$	0.0045	0.9999

*K** is the drying rate constant obtained from each mathematical model

4.3.3 Drying rate

As shown in Table 4.4, the treatment with higher amount of addition of sodium chloride showed the higher *K** value compared to the treatment with lower and no addition of sodium chloride, which means the higher amount of sodium chloride added to the sucrose solution led to the increase in the drying rate during drying. Furthermore, the treatment with higher concentration of sucrose showed lower *K** value compared to the treatment with lower concentration of sucrose. This means the higher concentration of sucrose led to the decrease in the drying rate during drying. Moreover, as shown in Figure 4.3, we can see that the treatment with higher addition of sodium chloride to the solution showed the higher drying rate throughout drying period compared to the treatment with lower and no addition of sodium chloride. This behavior was caused by the presence of NaCl which interferes with the sucrose gained by the product, thus inhibit the formation of crust by sugar molecules. This result is appropriate with the theory proposed by Tsamo *et al*. (2005), that the increase in the drying rate is because the crust formation is unlikely to occur on the surface of the sample pretreated with ternary solution, especially in the presence of sodium chloride.

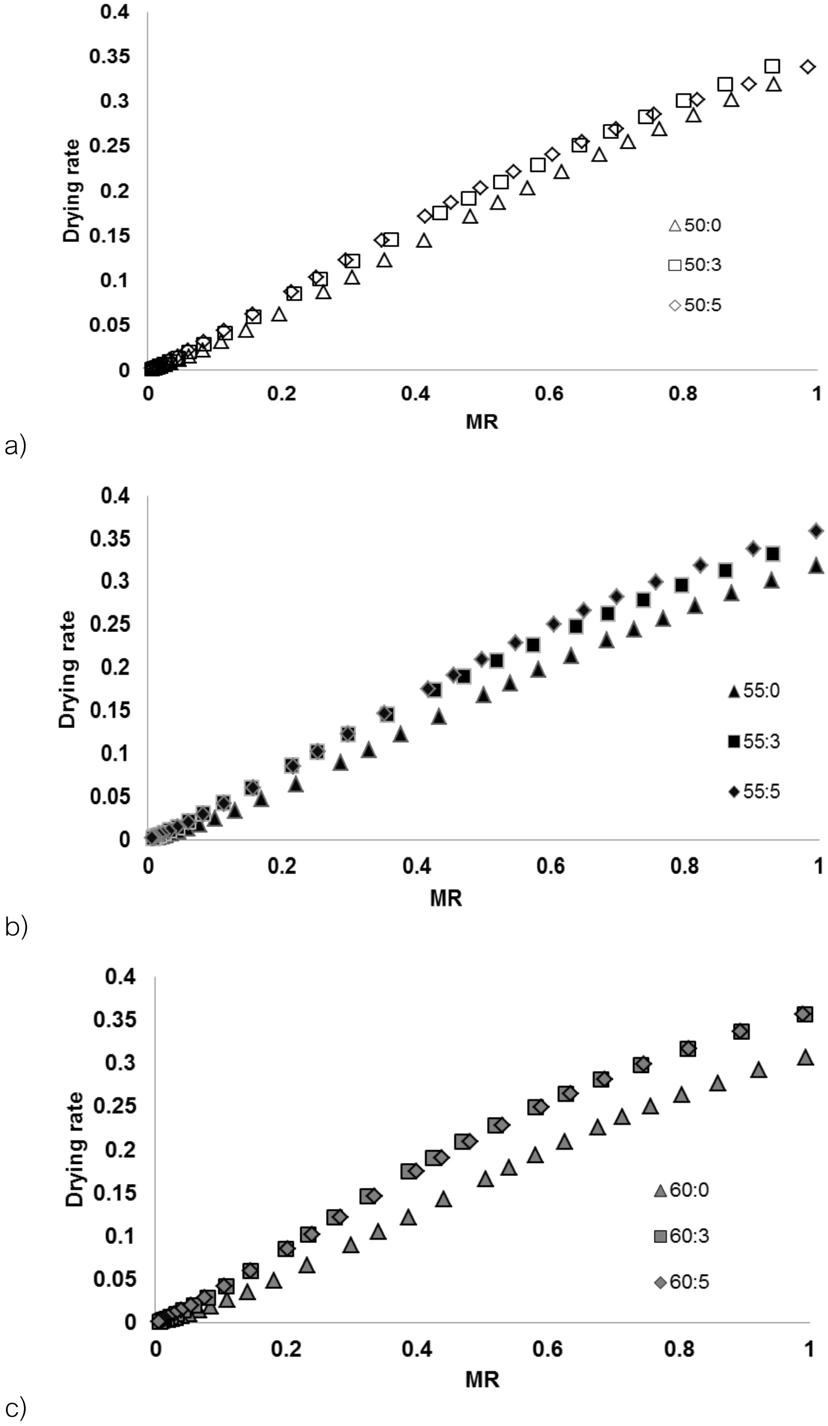


Figure 4.3 The plot of the drying rate versus the moisture ratio of osmosed papaya pretreated with binary and ternary solution with 50 (a), 55 (b), and 60 °Brix (c) of sucrose.

4.3.4 Drying time

In this study, the osmosed papayas were dried until the moisture content reached about 16% (wet basis) in order to measure the characteristics after drying. The information obtained from the drying curve was used to determine the drying time. The drying time for osmosed papaya pretreated with binary and ternary solution is shown in Table 4.5.

Table 4.5 The drying time for osmosed papaya pretreated with binary and ternary solution

Treatment	Drying time (minutes)
50:0	690
50:3	615
50:5	570
55:0	690
55:3	615
55:5	600
60:0	615
60:3	570
60:5	570

As shown in Table 4.5, for all three sucrose solution, the treatments with the higher level of addition of sodium chloride showed the shorter drying time compared to the treatments with lower and without addition of sodium chloride. Although the treatments with the lower addition of sodium chloride have lower initial moisture content compared to the treatments with higher addition of sodium chloride (as shown on Figure 4.2), but during drying process, the treatments with the higher addition of sodium chloride are likely to reach the 16% of moisture content faster compared to the treatments with lower and without addition of sodium chloride. The shorter drying time is because the sample pretreated with ternary solution has higher drying rate compared to the sample pretreated with binary solution as shown in Table 4.4 and Figure 4.3.

4.4 Determination of physical and chemical properties of osmosed-air dried papaya

The difference in osmotic concentration treatment led to the difference in solid gain and drying rate. It might lead to the difference in qualities of final product. In this study, the physical and chemical properties of dried papaya from nine treatments were determined in the following aspects: moisture content, water activity, water mobility, texture, color, shrinkage, and microstructure analysis. The sensory analysis was also performed.

4.4.1 Moisture content and water activity

Moisture content and water activity (a_w) is key quality factor of dried fruits to determine shelf life. Too high moisture content and water activity lead to the growth of microorganism which can shorten the shelf life of the product. While too low moisture content and water activity lead to product quality damages such as color changes and nutrients loss. The moisture content and water activity after drying of osmosed papaya pretreated with binary and ternary solution are shown in Table 4.6 and Table 4.7, respectively.

Table 4.6 The moisture content after drying for osmosed papaya pretreated with binary and ternary solution

Treatment		Sodium chloride		
		0 % (w/v)^{NS}	3 % (w/v)^{NS}	5 % (w/v)^{NS}
Sucrose	50 ^{o}Brix^{NS}	16.39 ± 0.33	16.41 ± 1.15	16.30 ± 0.16
Sucrose	55 ^{o}Brix^{NS}	16.52 ± 0.72	16.66 ± 0.81	16.23 ± 0.95
Sucrose	60 ^{o}Brix^{NS}	16.50 ± 0.69	16.63 ± 0.89	16.20 ± 1.15

NS means in the same column or row are not significantly different ($p \geq 0.05$)

Table 4.7 The effect of addition of sucrose and sodium chloride on water activity of osmosed-air dried papaya

Sucrose concentration	Sodium chloride (% w/v)	Water activity
50 °Brix	0	0.73 ± 0.01
50 °Brix	3	0.67 ± 0.01
50 °Brix	5	0.61 ± 0.00
55 °Brix	0	0.73 ± 0.00
55 °Brix	3	0.68 ± 0.01
55 °Brix	5	0.61 ± 0.02
60 °Brix	0	0.72 ± 0.00
60 °Brix	3	0.67 ± 0.01
60 °Brix	5	0.61 ± 0.02
Main effect:		
Sucrose		NS
Sodium chloride		*
Interaction:		
Sucrose x Sodium chloride		NS

* Significant effect at $p<0.05$

In this study the osmosed papaya was dried until the moisture content reached about 16% (wet basis) as shown in Table 4.6. The commercial available dried fruit product normally has the water content below 18% and a_w below 0.65. In this study, as shown in Table 4.7, although all the treatment has moisture content about 16% (wet basis), some of the treatment still has water activity above 0.65. However, this can still be considered as acceptable, because further drying process can affect the final product quality.

Moreover, as shown in Table 4.7, there was a significant effect of addition of sodium chloride to water activity of osmosed-air dried papaya ($p<0.05$). Among the treatments with the same sucrose concentration, the treatment with the higher addition of sodium chloride showed significantly lower water activity compared to the treatment with lower and without addition of sodium chloride (Appendix B.9). The lower water activity in those samples was because sodium chloride possesses ability to lower water activity better than sucrose. The dissociation of sodium chloride into two ions in solution is more effective in decreasing water activity compared to sucrose on a mole to mole basis (Chenlo *et al.*, 2002). This phenomenon was confirmed by the difference in the water activity of binary and ternary solution as shown in Table 4.3.

Moreover, from Table 4.7, there was no significant effect ($p \geq 0.05$) of addition of sucrose to water activity of osmosed-air dried papaya, and the interaction of sucrose and sodium chloride had no significant effect ($p \geq 0.05$) to water activity of osmosed-air dried papaya (Appendix B.9).

4.4.2 Water mobility

In this study, the water mobility was determined using nuclear magnetic resonance (NMR) spectroscopy. The measurement was done based on the longitudinal relaxation time (T_1). The T_1 represents the degree of water bound to other chemical species, which the lower value of T_1 means that the water mobility is lower. The longitudinal relaxation time for osmosed-air dried papaya pretreated with binary and ternary solution can be seen in Table 4.8.

As shown in Table 4.8, there was a significant effect of addition of sodium chloride to longitudinal relaxation time (T_1) of osmodehydrated papaya ($p<0.05$). Among the treatments with the same sucrose concentration, the treatment with the higher addition of sodium chloride has significantly lower T_1 compared to the treatment with lower and without addition of sodium chloride (Appendix B.10). The lower water mobility of the treatments with higher addition of sodium chloride could be due to the high hydrophilicity of sodium chloride, which allows them to bind more water in the samples (Sigon *et al.*, 1996). The result on water mobility also supported the result of lower water activity of the samples due to the higher addition of sodium chloride.

Moreover, there was also a significant effect ($p<0.05$) of addition of sucrose to T_1 of osmodehydrated papaya (Appendix B.10). Sucrose also has a good ability to bind with water, which the addition of sucrose allows them to bind more water in the samples and affects T_1. However, there was no significant effect of the interaction of sucrose and sodium chloride ($p \geq 0.05$) to T_1 of osmodehydrated papaya.

Table 4.8 The effect of addition of sucrose and sodium chloride on longitudinal relaxation time of osmodehydrated papaya

Sucrose concentration	Sodium chloride (% w/v)	T_1 (s)
50 °Brix	0	0.54 ± 0.01
50 °Brix	3	0.51 ± 0.02
50 °Brix	5	0.50 ± 0.05
55 °Brix	0	0.49 ± 0.01
55 °Brix	3	0.48 ± 0.04
55 °Brix	5	0.48 ± 0.02
60 °Brix	0	0.54 ± 0.02
60 °Brix	3	0.52 ± 0.01
60 °Brix	5	0.49 ± 0.02
Main effect:		
Sucrose		*
Sodium chloride		*
Interaction:		
Sucrose x Sodium chloride		NS

* Significant effect at $p<0.05$

4.4.3 Texture

Most food processes that involve heat and mass transfers undergo physical modifications to the product. The texture properties also affect the sensory characteristics, thus affecting the quality and acceptance of the product by the consumer. In this study, the texture of osmosed-air dried papaya was determined by two methods: (1) the cutting work was evaluated under the use of BSK blade, (2) texture profile analysis (TPA) was evaluated using compression plate. Both cutting work and TPA test represents similar measurement on the hardness of texture of food product, and the values from both measurements are correlated to each other. The result of cutting work and TPA for osmodehydrated papaya pretreated with binary and ternary solution can be seen in Table 4.9 and 4.10, respectively.

Table 4.9 The effect of addition of sucrose and sodium chloride on cutting work of osmosed-air dried papaya

Sucrose	Sodium chloride (% w/v)	Cutting force (g_f)	Cutting energy (g_f.s)
50 °Brix	0	8114.71 ± 1021.91	23951.00 ± 1898.77
50 °Brix	3	6627.64 ± 1169.94	17601.21 ± 2732.34
50 °Brix	5	5557.79 ± 808.67	15643.43 ± 1910.92
55 °Brix	0	7546.36 ± 1471.79	23232.00 ± 2447.32
55 °Brix	3	5998.00 ± 1026.81	16912.29 ± 1069.59
55 °Brix	5	4838.86 ± 618.98	13884.29 ± 1364.72
60 °Brix	0	8320.86 ± 1479.16	24529.29 ± 3185.94
60 °Brix	3	6386.14 ± 592.55	18142.43 ± 2635.12
60 °Brix	5	6084.86 ± 903.94	16929.07 ± 1499.56
Main effect:			
Sucrose		*	*
Sodium chloride		*	*
Interaction:			
Sucrose x Sodium chloride		NS	NS

* Significant effect at $p<0.05$

Table 4.10 The effect of addition of sucrose and sodium chloride on texture profile analysis of osmodehydrated papaya

Sucrose	Sodium chloride (% w/v)	Hardness (g_f)	Cohesiveness	Chewiness (g_f)	Adhesiveness (g_f.s)
50 °Brix	0	2471.27 ± 259.73	0.163 ± 0.024	281.07 ± 82.36	-0.295 ± 0.296
50 °Brix	3	935.22 ± 167.99	0.173 ± 0.007	132.89 ± 29.92	-0.235 ± 0.333
50 °Brix	5	755.73 ± 144.66	0.170 ± 0.017	104.86 ± 33.92	-0.342 ± 0.249
55 °Brix	0	2614.25 ± 237.46	0.164 ± 0.020	300.00 ± 68.90	-0.416 ± 0.370
55 °Brix	3	993.01 ± 147.54	0.171 ± 0.013	136.98 ± 28.71	-0.297 ± 0.224
55 °Brix	5	860.54 ± 158.96	0.174 ± 0.021	121.42 ± 34.36	-0.236 ± 0.266
60 °Brix	0	2300.46 ± 356.64	0.166 ± 0.025	271.91 ± 84.87	-0.305 ± 0.263
60 °Brix	3	1058.73 ± 179.39	0.173 ± 0.013	147.23 ± 28.79	-0.199 ± 0.251
60 °Brix	5	867.18 ± 138.06	0.179 ± 0.013	129.47 ± 23.44	-0.249 ± 0.323
Main effect:					
Sucrose		NS	NS	NS	NS
Sodium chloride		*	*	*	NS
Interaction:					
Sucrose x Sodium chloride		*	NS	NS	NS

* Significant effect at $p<0.05$

In this study, cutting work was presented in term of cutting force and cutting energy, while TPA was presented in term of hardness, cohesiveness, chewiness, and adhesiveness. As shown in Table 4.9, there was a significant effect of addition of sodium chloride to cutting force and cutting work of osmodehydrated papaya. Thus, there is a significant decrease ($p<0.05$) in cutting force and cutting energy for the sample pretreated with ternary solution compared to the sample pretreated with binary solution (Appendix B.11 and B.12). Moreover, as shown in Table 4.10, there is also an effect of addition of sodium chloride to hardness, cohesiveness, and chewiness of osmodehydrated papaya ($p<0.05$), but not on adhesiveness. The samples pretreated with ternary solution showed a significant decrease in hardness and chewiness, and a significant increase in cohesiveness compared to the samples pretreated with binary solution (Appendix B.13, B.14, B.15, and B.16). The difference in texture between the treatment with and without the addition of sodium chloride was because the crust formation that are likely to occur at the surface of the product pretreated with only sucrose, and also the sodium chloride has ability to bind with the water better than sucrose (Sigon *et al*., 1996), which also contributes to the texture.

Moreover, the addition of sucrose also had a significant effect ($p<0.05$) to cutting force and cutting work of osmodehydrated papaya (Appendix B.11 and B.12), but the addition of sucrose had no significant effect ($p\geq0.05$) to hardness, cohesiveness, chewiness, and adhesiveness of osmodehydrated papaya (Appendix B.13, B.14, B.15, and B.16). For the interaction of sucrose and sodium chloride, there was a significant effect ($p<0.05$) to hardness of osmodehydrated papaya.

4.4.4 Color

Color has a great impact on consumer acceptance of the dried fruit products. The color of the fruit may change considerably during drying process, which the main cause responsible for these changes is the degradation or loss of fruit pigments and development of both enzymatic and non-enzymatic browning during the process. In this study, the color was determined using CIELAB color system. The L* value represents lightness, a* value represents redness, b* value represents yellowness, and ΔE value represents the difference between two colors in a color space. The color values of osmodehydrated papaya and color difference between osmodehydrated papaya pretreated with binary and ternary solution are shown in Table 4.11.

Table 4.11 The effect of addition of sucrose and sodium chloride on color values of osmodehydrated papaya and color difference among osmodehydrated papaya pretreated with binary and ternary solution

Sucrose	Sodium chloride (% w/v)	L*	a*	b*	ΔE
50 °Brix	0	24.52 ± 1.40	8.65 ± 1.39	7.80 ± 1.58	-
50 °Brix	3	23.95 ± 0.54	9.09 ± 1.28	7.49 ± 0.82	0.787^{+}
50 °Brix	5	23.59 ± 1.21	9.27 ± 1.21	7.16 ± 1.45	1.293^{+}
55 °Brix	0	24.43 ± 1.09	8.36 ± 0.99	7.48 ± 0.83	-
55 °Brix	3	23.84 ± 0.82	8.64 ± 0.65	7.13 ± 0.57	0.744^{++}
55 °Brix	5	23.53 ± 0.99	8.90 ± 1.15	7.02 ± 0.68	1.143^{++}
60 °Brix	0	24.38 ± 1.09	8.42 ± 0.67	7.53 ± 0.75	-
60 °Brix	3	23.89 ± 1.02	8.74 ± 1.29	7.03 ± 0.83	0.771^{+++}
60 °Brix	5	23.53 ± 1.13	8.97 ± 1.37	6.92 ± 1.17	1.182^{+++}
Main effect:					
Sucrose		NS	*	*	
Sodium chloride		*	*	*	
Interaction:					
Sucrose x Sodium chloride		NS	NS	NS	

* Significant effect at $p<0.05$

$^{+}$ Comparison with 50 °Brix sucrose : 0% NaCl

$^{++}$ Comparison with 55 °Brix sucrose : 0% NaCl

$^{+++}$ Comparison with 60 °Brix sucrose : 0% NaCl

As shown in Table 4.11, there was a significant effect of addition of sodium chloride to L* value (lightness), a* value (redness), and b* value (yellowness) of osmodehydrated papaya ($p<0.05$). The sample pretreated with the addition of sodium chloride to the binary solution showed a significant decrease in L* value and b* value, but a significant increase in a* value compared to the sample pretreated without addition of sodium chloride on the solution (Appendix B.17, B.18, and B.19). This result was in a good agreement with Ali *et al.* (2010), studied on osmotic dehydration of tomato rings, they also found that the osmotic dehydration pretreatment using sucrose-salt solution with the ratio (1:1.5) affects the color of tomato rings with a significant decrease in L* value and b* value, but a significant increase in a* value compared to the one pretreated only with sucrose solution.

Moreover, there was also a significant effect ($p<0.05$) of addition of sucrose to a* value and b* value of osmodehydrated papaya (Appendix B.18 and B.19), but there was no significant effect ($p\geq0.05$) of the interaction of sucrose and sodium chloride to L* value, a* value, and b* value of osmodehydrated papaya.

In this study, ΔE value is the color difference between sample pretreated with and without addition of sodium chloride at the same concentration of sucrose. From Table 4.11, for all sucrose concentration, the ΔE value of sample pretreated with the addition of 3% sodium chloride was lower than 1, which ΔE value less than 1 means the color difference cannot be distinguished by human eye (Upton, 2006 : online). However, when the addition of sodium chloride was increased to 5%, the ΔE value was more than 1, but still less than 2. That might be possible that the addition of sodium chloride lead to the greater change in color. The color difference between the samples pretreated with binary and ternary solution may come from the crust formation that unlikely to occur on the sample with addition of sodium chloride, this crust formation contributed to the lightness and yellowness of the product.

4.4.5 Volume shrinkage

Shrinkage is usually observed during osmotic dehydration process, which this phenomenon happens because there are compositional changes and mechanical stresses associated to mass transfers during osmotic dehydration. In dried fruit products, the high shrinkage leads to product with poor texture quality (Mayor *et al*., 2011). In this study, the volume shrinkage was monitored with liquid displacement method using n-heptane, organic solvent, as the liquid medium because it does not interact with the constituents of the samples, especially sugar and salt; and with its lower density, the complete submergence of the dried papaya in n-heptane can be achieved. In this study, the shrinkage for osmodehydrated papaya pretreated with binary and ternary solution was determined in respect to fresh papaya and in respect to osmosed papaya, the results are shown in Table 4.12.

As shown in Table 4.12, there was no significant effect ($p \geq 0.05$) of addition of sodium chloride to shrinkage of osmodehydrated papaya (Appendix B.20 and B.21). However, the samples pretreated with the higher percentage of sodium chloride were likely to have higher shrinkage compared to the sample pretreated with the lower and without addition of sodium chloride. The higher shrinkage comes from the fact that plasmolysis is likely to occur in samples pretreated with higher addition of salt. Plasmolysis is the phenomenon which the cell loses enough liquid for its hydrostatic pressure to drop sufficiently to lead to the formation of a space between the protoplast and the cell wall. Plasmolysis is usually accompanied by shrinkage and deformation of cells (Mayor *et al*., 2008). The occurrence of plasmolysis was confirmed by the result of sodium chloride addition on the microstructure analysis of the samples in Section 4.4.6.

Moreover, the addition of sucrose had a significant effect ($p<0.05$) to the shrinkage in respect to fresh papaya, which the sample pretreated with the higher addition of sucrose showed a significant increase in shrinkage compared to the sample pretreated with the lower addition of sucrose (Appendix B.20). However, there was no significant effect ($p \geq 0.05$) of the interaction of sucrose and sodium chloride to the shrinkage of osmodehydrated papaya.

Table 4.12 The effect of addition of sucrose and sodium chloride on shrinkage of osmodehydrated papaya

Sucrose concentration	Sodium chloride (% w/v)	Shrinkage (%) Fresh:Dried[+]	Shrinkage (%) Osmosed:Dried[++]
50 °Brix	0	74.94 ± 3.23	65.82 ± 3.20
50 °Brix	3	75.16 ± 3.29	66.96 ± 7.26
50 °Brix	5	75.86 ± 2.49	67.95 ± 7.03
55 °Brix	0	75.99 ± 2.86	66.47 ± 6.59
55 °Brix	3	76.42 ± 2.46	67.46 ± 4.86
55 °Brix	5	77.18 ± 2.38	68.33 ± 3.03
60 °Brix	0	77.07 ± 1.82	68.38 ± 3.57
60 °Brix	3	77.62 ± 1.83	69.07 ± 2.63
60 °Brix	5	77.98 ± 1.74	69.04 ± 2.10
Main effect:			
Sucrose		*	NS
Sodium chloride		NS	NS
Interaction:			
Sucrose x Sodium chloride		NS	NS

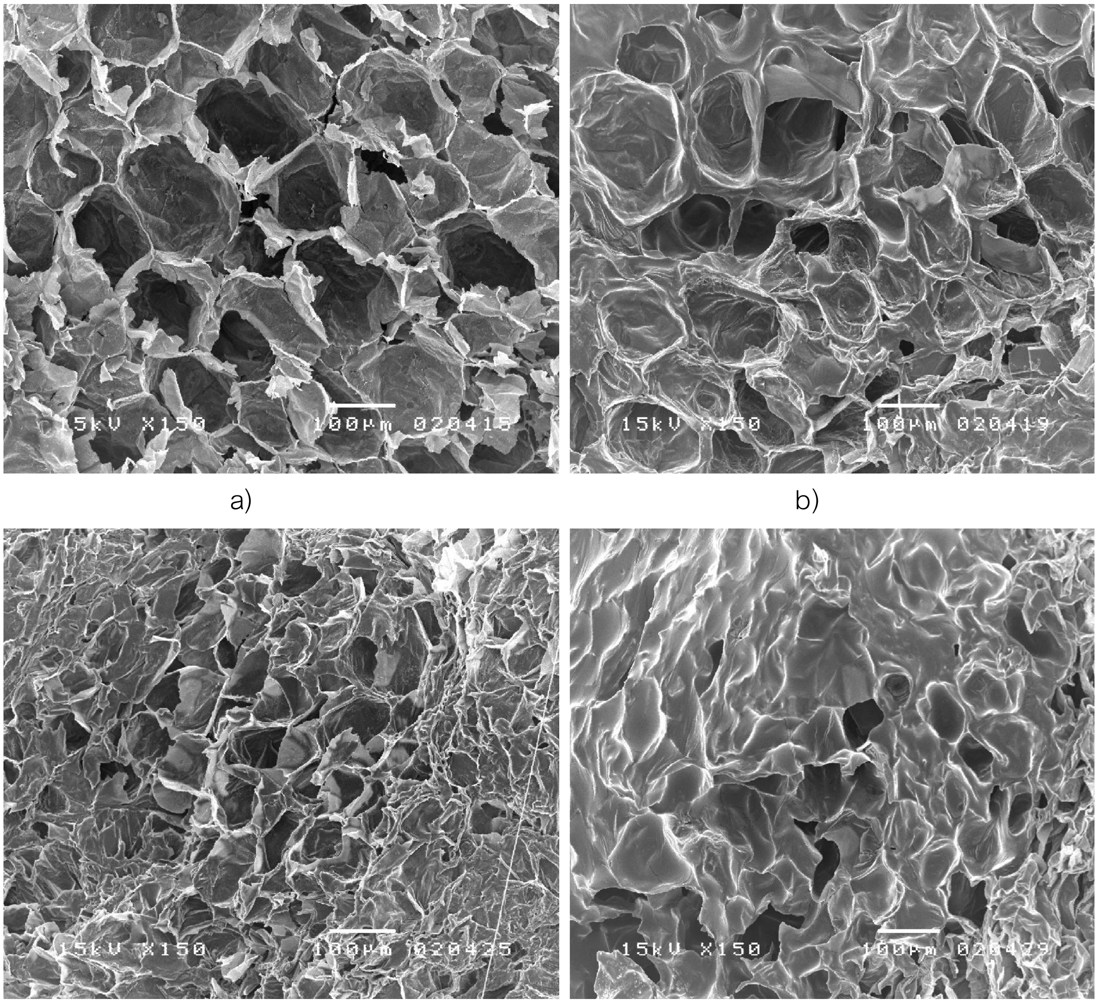
* Significant effect at $p<0.05$

[+] Volume comparison of fresh papaya to dried papaya

[++] Volume comparison of osmosed papaya to dried papaya

4.4.6 Microstructure

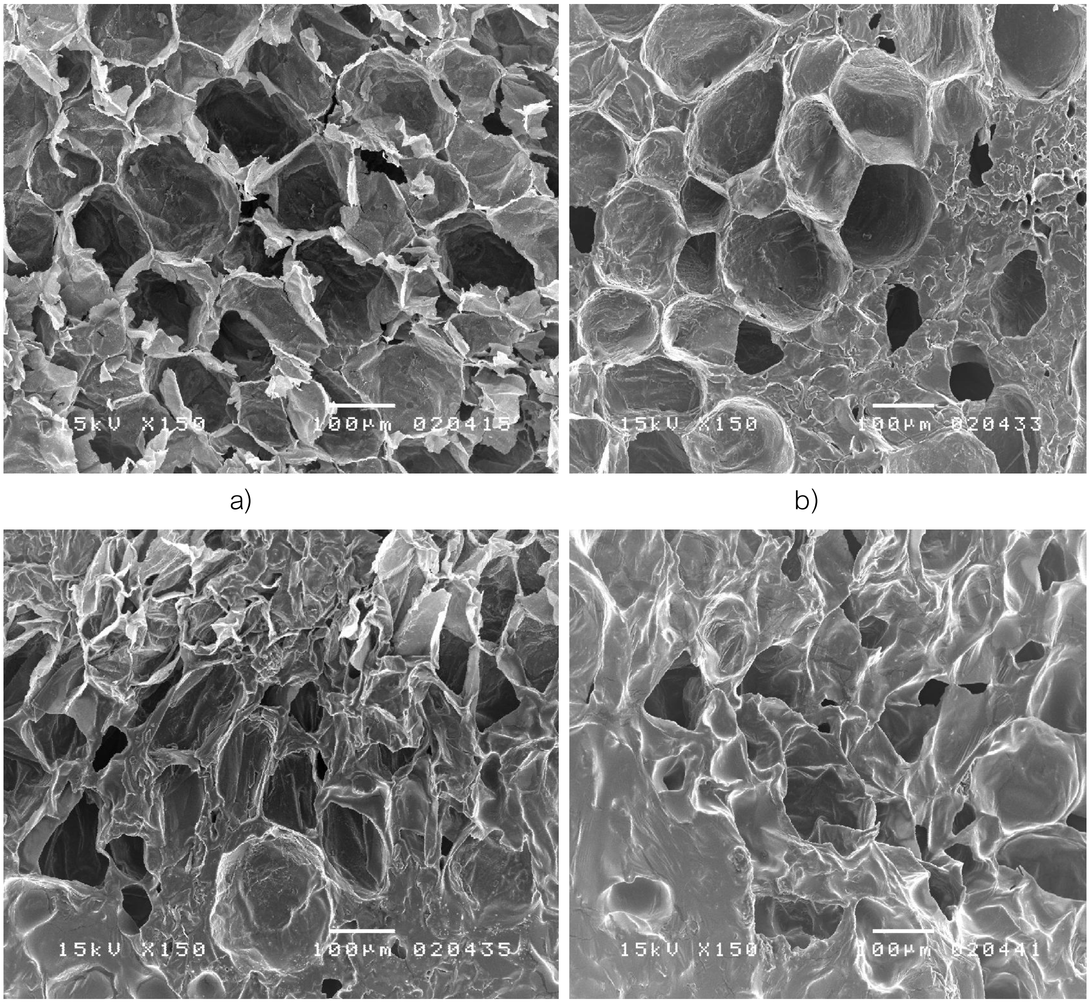
A scanning electron microscope is a type of electron microscope that images a sample by scanning a sample with a beam of electrons in a faster scan pattern. The electrons interact with the atoms that make up the sample and produce a signal giving information on the sample's surface topography, composition, and other properties such as electrical conductivity (Moore, 2012 : online). In this study, the microstructure analysis of the osmodehydrated papaya was examined using scanning electron microscope with 15 kV accelerating voltage and 150x zoom level. The results of microstructure analysis are shown in Figure 4.4, 4.5, and 4.6.



a) b)

c) d)

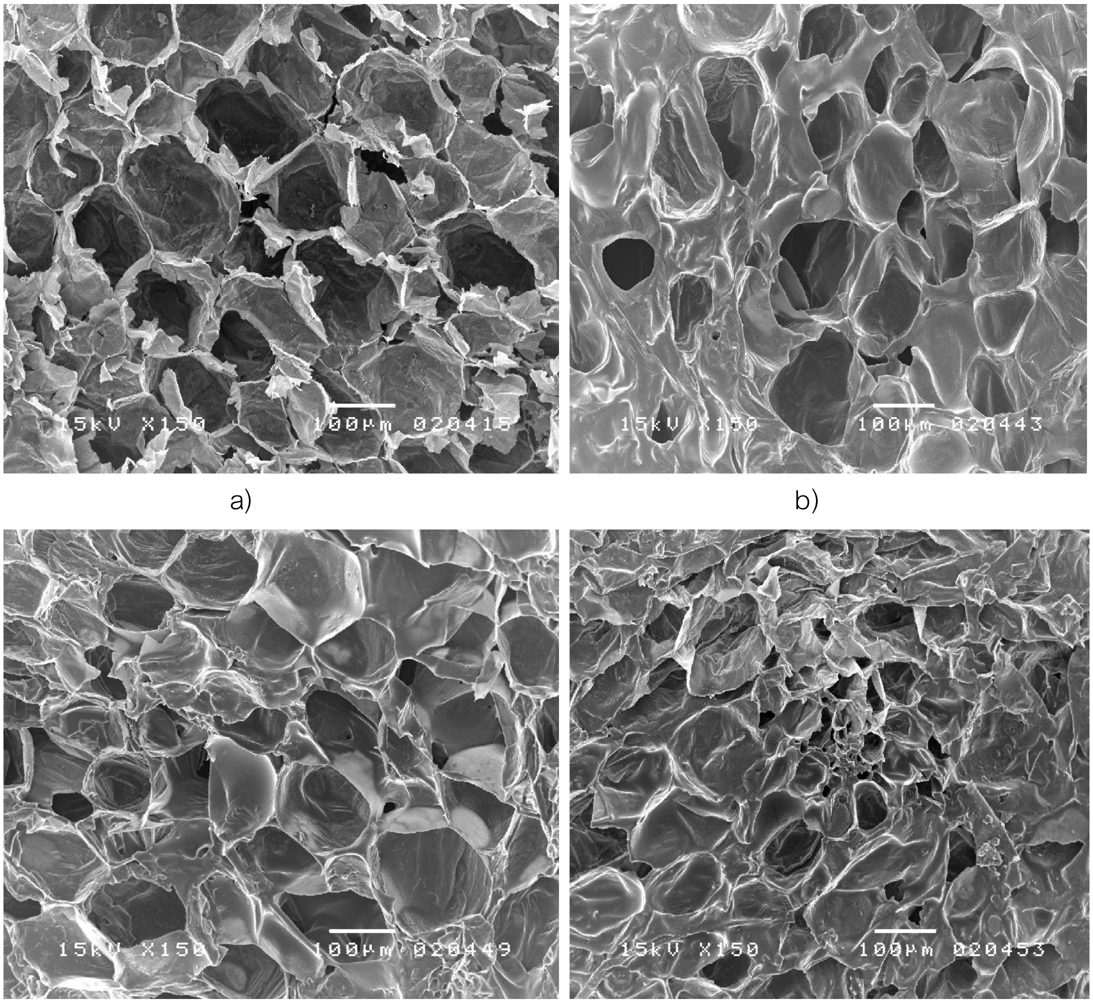
Figure 4.4 The microstructure of fresh papaya (a), osmodehydrated papaya pretreated with 50 °Brix of sucrose (b), 50 °Brix of sucrose + 3% (w/v) of sodium chloride (c), and 50 °Brix of sucrose + 5% (w/v) of sodium chloride (d).



a) b)

c) d)

Figure 4.5 The microstructure of fresh papaya (a), osmodehydrated papaya pretreated with 55 °Brix of sucrose (b), 55 °Brix of sucrose + 3% (w/v) of sodium chloride (c), and 55 °Brix of sucrose + 5% (w/v) of sodium chloride (d).



a) b)

c) d)

Figure 4.6 The microstructure of fresh papaya (a), osmodehydrated papaya pretreated with 60 °Brix of sucrose (b), 60 °Brix of sucrose + 3% (w/v) of sodium chloride (c), and 60 °Brix of sucrose + 5% (w/v) of sodium chloride (d).

As shown in Figure 4.4 (a), 4.5 (a), and 4.6 (a), the microstructure analysis of fresh papaya showed the good shape of parenchyma cell, with the good round shape of cell, good boundary between each cell, and high degree of cell compartment. For the sample pretreated with binary solution, as shown in Figure 4.4 (b), 4.5 (b), and 4.6 (b), the good shape of parenchyma cell with high degree of cell compartment and good boundary between each cell was still maintained for the sample pretreated with 50 and 55 °Brix of sucrose. However, for the sample pretreated with 60 °Brix of sucrose, the disruption and deformation of cell shape occurred. This was due to the loss of turgor pressure. Moreover, from Figure 4.4 (c), 4.5 (c), and 4.6 (c), at the addition of 3% sodium chloride, the loss of boundary between each cell occurred, cell compartment started to disintegrate, and the cell was swollen for the sample pretreated with 60 °Brix of sucrose. This was due to an increase in osmotic pressure gradient. And at the addition of 5% sodium chloride, as shown in Figure 4.4 (d), 4.5 (d), and 4.6 (d), the cell shape of sample for all conditions was disrupted and deformed more than those at the condition with the addition of 3% sodium chloride.

The disruption of the shape and deformation of the structure of papaya cell is likely to be formed because of the plasmolysis, which likely to be happened on the samples that pretreated with osmotic dehydration with ternary solution. This behavior occurred due to the addition of the sodium chloride, which increased the osmotic pressure during osmotic dehydration. In general, the increase of osmotic pressure increases both water and solute diffusivity during osmotic dehydration process, but results in the disruption of the shape and deformation of the cellular structure (Monnerat *et al.*, 2010).

4.5 Sensory analysis of osmosed-dried papaya

Based on the result of microstructure and shrinkage analysis, four treatments were selected as the sample for sensory analysis. They were the sample pretreated with 50 °Brix of sucrose, 50 °Brix of sucrose and 3% (w/v) of sodium chloride, 55 °Brix of sucrose, and 55 °Brix of sucrose and 3% (w/v) of sodium chloride.

The sensory analysis was done using descriptive test and acceptance test. Descriptive test was used to determine the intensity of the sensory attributes of osmodehydrated papaya samples, while acceptance test was used to determine the quality acceptability of osmodehydrated papaya.

4.5.1 Descriptive test

Fifteen panelists were used in descriptive test. They were each asked to rate the intensity of sensory attributes with the scale from 0 to 10 on a 15 cm line scale. The attributes evaluated were color (yellowness and redness), shrinkage, texture (hardness and chewiness), and taste (sweetness and saltiness).

In this study, the panelists were trained to make all of them have the same standard of evaluation and understand the whole idea for each sensory attribute. The results of descriptive test are shown in Table 4.13.

Table 4.13 Sensory attributes of osmodehydrated papaya pretreated with four different treatments

Attribute	Treatment			
	50:0	50:3	55:0	55:3
Yellowness	4.41 ± 1.51^{a}	2.92 ± 1.15^{b}	4.69 ± 1.50^{a}	2.88 ± 0.95^{b}
Redness	3.96 ± 1.22^{b}	6.87 ± 0.69^{a}	3.94 ± 1.19^{b}	7.24 ± 0.71^{a}
Shrinkage^{NS}	5.01 ± 1.55	5.23 ± 1.43	5.13 ± 1.93	5.91 ± 1.33
Hardness	5.87 ± 1.89^{b}	4.30 ± 1.56^{c}	7.02 ± 1.12^{a}	4.71 ± 1.76^{c}
Chewiness	4.36 ± 1.79^{a}	5.69 ± 1.68^{ab}	5.39 ± 1.93^{ab}	5.87 ± 1.62^{a}
Sweetness	6.52 ± 1.05^{b}	3.38 ± 1.79^{c}	6.83 ± 1.04^{a}	3.23 ± 1.22^{c}
Saltiness	2.24 ± 0.89^{b}	6.77 ± 1.39^{a}	2.30 ± 0.90^{b}	6.86 ± 1.09^{a}

a, b, and c means in the same row which do not share the same superscript letter differ significantly ($p<0.05$)

As shown in Table 4.13, for the color attributes, the panelists were able to tell color difference and likely to scale the product with addition of sodium chloride less yellow and redder for the samples pretreated with ternary solution. This result was not in a good agreement with the CIELAB from Section 4.4.4. The results in Table 4.13 showed that the addition of sodium chloride showed a strong effect on product color.

For the shrinkage, there was no significant difference for this attribute. However, the panelists were likely to point higher shrinkage on the samples pretreated with ternary solution. This result also supported the result in Section 4.4.5.

The result of texture attributes in term of hardness, it showed that the panelists were likely to point lower hardness on the samples pretreated with ternary solution. The result of texture attributes in term of hardness was in the same trend with the result from Section 4.4.3. However, in term of chewiness, it showed that the panelists were likely to point higher chewiness on the samples pretreated with ternary solution. This result was different from those obtained in Section 4.4.3.

For the taste attributes in term of sweetness, the panelists were likely to scale lower sweetness score on the samples pretreated with ternary solution. The reason is because of the addition of sodium chloride, which covers the sweet taste of the samples. Moreover, the panelists were likely to scale higher sweetness on the sample pretreated with 55 ^{o}Brix of sucrose compared to the sample with 50 ^{o}Brix of sucrose; this was because of the higher addition of sucrose.

For the taste attributes in term of saltiness, the panelists were likely to scale higher saltiness on the samples pretreated with ternary solution. The reason was because of the higher addition of sodium chloride contributes saltier taste of the samples.

4.5.2 Acceptance test

Fifty panelists were used in acceptance test. They were each asked to rate each sensory attribute on a 7-point hedonic scale from 1 (dislike extremely) to 7 (like extremely) with the score of 4 for “neither like nor dislike”. The sample received a score of higher than 4.0 was considered as acceptable. The sensory attributes to be determined were color, texture, appearance, taste, and overall acceptance. The results of acceptance test are shown in Table 4.14.

Table 4.14 The 7-point hedonic scale of osmodehydrated papaya pretreated with four different treatments

Treatment	Color	Texture^{NS}	Appearance	Taste	Overall^{NS}
50:0	3.98 ± 1.00^{c}	4.71 ± 1.18	4.25 ± 0.96^{bc}	5.08 ± 1.01^{a}	4.77 ± 0.95
50:3	5.73 ± 1.01^{a}	4.88 ± 1.41	5.46 ± 1.01^{a}	3.77 ± 1.59^{b}	4.40 ± 1.05
55:0	3.85 ± 1.09^{c}	4.40 ± 1.25	3.96 ± 1.22^{c}	4.85 ± 1.30^{a}	4.44 ± 1.13
55:3	5.31 ± 1.09^{b}	4.71 ± 1.20	4.54 ± 1.47^{b}	3.87 ± 1.58^{b}	4.42 ± 1.32

a, b, and c means in the same column which do not share the same superscript letter differ significantly ($p<0.05$)

As shown in Table 4.14, the color acceptance of the sample from each treatment was significantly different ($p<0.05$). The sample pretreated with 50 °Brix of sucrose and 3 °Brix of sodium chloride has the highest score, followed by the sample pretreated with 55 °Brix of sucrose and 3 °Brix of sodium chloride. For appearance acceptance, the sample pretreated with 50 °Brix of sucrose and 3 °Brix of sodium chloride has the highest score, followed by the sample pretreated with 55 °Brix of sucrose and 3 °Brix of sodium chloride. It can be concluded that the use of ternary solution contributes to better color and appearance acceptance of osmodehydrated papaya.

For the texture acceptance, there was no significant difference ($p\geq0.05$). However, the samples pretreated with ternary solution had significantly lower score of taste ($p<0.05$) compared to the samples pretreated with binary solution. And the overall acceptance was not significantly different ($p\geq0.05$) and the score was higher than 4.0, therefore all of the samples can be considered as acceptable. However, the standard deviation of the overall score was quite high, which may come from the difference taste preference of panelists.

CHAPTER V

CONCLUSION AND SUGGESTION

Conclusion

The use of ternary solution significantly affected the water loss and solid gain during osmotic dehydration of papaya. There was a significant increase in water loss and solid gain for the sample pretreated with ternary solution compared to the sample pretreated with binary solution. Moreover, the samples pretreated with ternary solution had a higher drying rate, leading to shorter drying time. In general, the modified Henderson & Pabis model appeared to be the best model to predict the drying curve of osmosed papaya in both binary and ternary osmotic solution.

The use of ternary solution affected final product quality. The addition of sodium chloride affected water activity, water mobility, color, and texture properties of osmodehydrated papaya. For the shrinkage, although the use of ternary solution had no significant effect on shrinkage, but the sample pretreated with the ternary solution was likely to show higher shrinkage compared to the sample pretreated with binary solution. Moreover, from the microstructure analysis, the disruption of the shape and deformation of the cell structure of papaya was likely to occur in the sample pretreated with ternary solution compared to the sample pretreated with binary solution. Based on sensory analysis, the use of ternary solution showed a better color and appearance, but the samples pretreated with ternary solution showed a lower taste acceptance compared to the samples pretreated with binary solution. However, the overall acceptance of all treatments was not significant different and can be considered as acceptable.

Suggestion for Future Studies

The use of ternary solution lowers the drying time of osmodehydrated papaya. Therefore, it is interesting to examine the nutritional quality of osmodehydrated papaya, such as β-carotene and lycopene. Moreover, the application of two-stage drying to maintain the nutritional quality should also be examined.

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APPENDICES

APPENDIX A

QUESTIONNAIRES FOR SENSORY EVALUATION

A.1 Descriptive sensory test

QUESTIONNAIRE FOR SENSORY EVALUATION OF DRIED PAPAYA

Name: ……………….. Date: ……………..

Please indicate the intensity of each attribute by putting a mark on the line scale at the point which represents the intensity that you have perceived.

1. Color

- Yellowness

Slight Very

- Redness

Slight Very

2. Shrinkage

Slight Very

3. Texture

- Hardness (Force required to compress a food between the molars)

- Chewiness (The energy required to chew a solid food to the point required for swallowing it)

4. Taste

- Sweetness

- Saltiness

A.2 Acceptance sensory test

QUESTIONNAIRE FOR SENSORY EVALUATION OF DRIED PAPAYA

Name: ……………….. Date: ……………..

Have you ever tried dried fruit product before?

Please evaluate the dried papaya samples to indicate how much you like or dislike the samples by putting the number from 1 to 7.

1. Dislike extremely
2. Dislike very much
3. Dislike slightly
4. Neither like nor dislike
5. Like slightly
6. Like very much
7. Like extremely

	Sample			
	315	539	795	379
Color				
Texture				
Appearance				
Taste				
Overall				

APPENDIX B

ADDITIONAL DATA

B.1 The effect of different sucrose concentrations on WL, SG, and WR during osmotic dehydration of papaya

		Mass transfer (Mean ± SD)		
		WL	SG	WR
Hour	Treatment			
1	Iso	0.67 ± 0.07	0.17 ± 0.00	0.47 ± 0.05
	45	25.84 ± 2.52^{a}	7.82 ± 0.34^{a}	16.53 ± 2.40^{a}
	50	29.06 ± 0.16^{ab}	7.77 ± 0.59^{a}	20.57 ± 0.44^{ab}
	55	31.79 ± 2.85^{bc}	7.88 ± 0.59^{a}	22.98 ± 2.84^{bc}
	60	35.03 ± 2.85^{c}	7.91 ± 0.34^{a}	26.38 ± 2.57^{c}
2	Iso	1.01 ± 0.03	0.17 ± 0.00	0.53 ± 0.05
	45	31.07 ± 1.87^{a}	10.27 ± 0.29^{a}	19.49 ± 2.56^{a}
	50	35.91 ± 2.49^{ab}	9.79 ± 0.68^{a}	24.40 ± 2.14^{ab}
	55	39.89 ± 1.12^{bc}	9.28 ± 1.48^{a}	28.93 ± 0.56^{bc}
	60	44.39 ± 4.30^{c}	10.49 ± 1.51^{a}	33.42 ± 4.19^{c}
3	Iso	0.96 ± 0.04	0.16 ± 0.00	0.61 ± 0.04
	45	35.57 ± 1.83^{a}	11.63 ± 0.72^{a}	21.98 ± 3.06^{a}
	50	40.38 ± 1.29^{b}	10.75 ± 0.85^{a}	27.01 ± 0.53^{a}
	55	45.43 ± 2.52^{c}	10.74 ± 1.39^{a}	32.32 ± 3.31^{b}
	60	49.76 ± 2.81^{d}	12.29 ± 0.74^{a}	36.23 ± 3.05^{b}

Table B.1 (Continued)

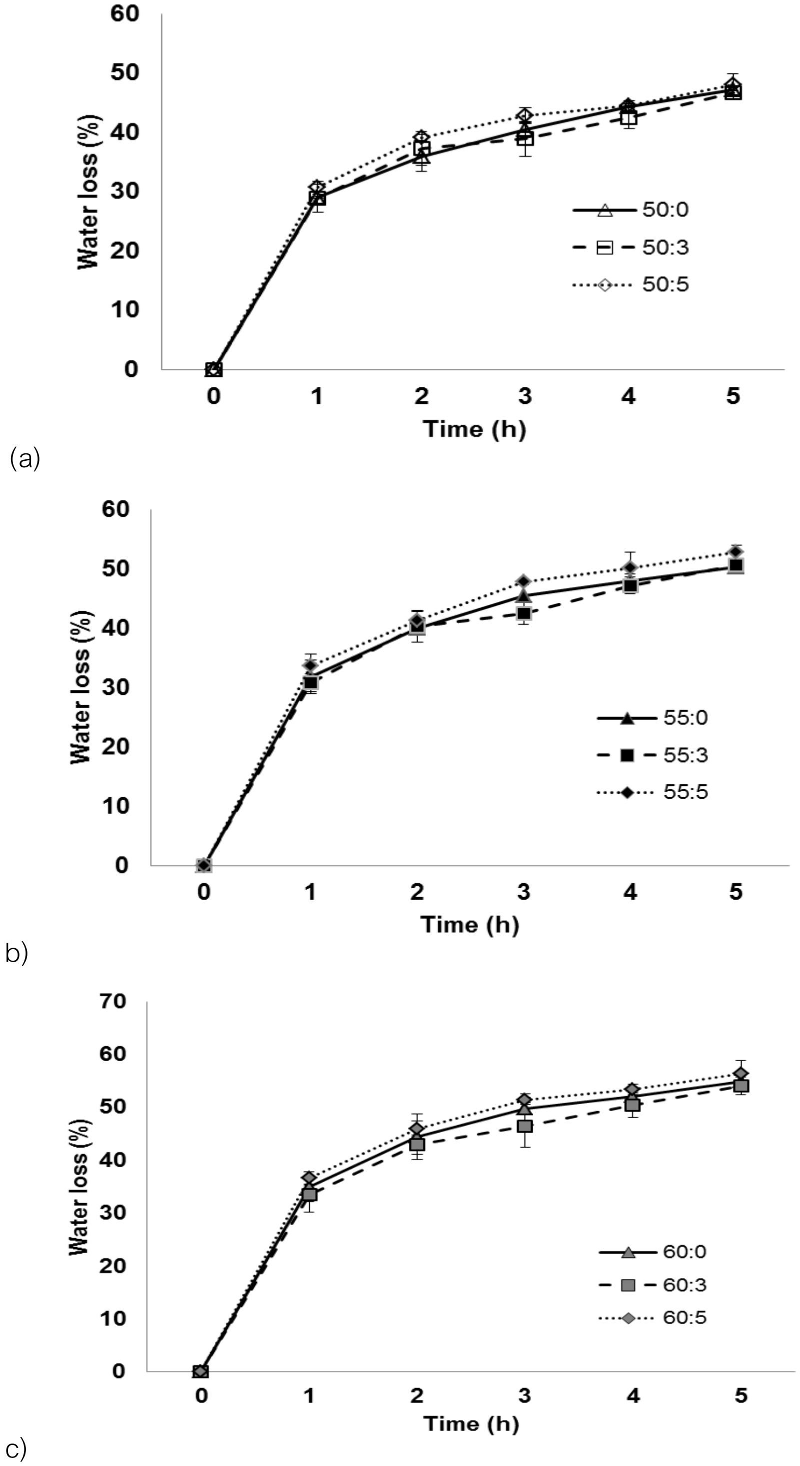
4	Iso	1.13 ± 0.17	0.16 ± 0.00	0.66 ± 0.03
	45	37.89 ± 0.60^{a}	13.09 ± 1.00^{a}	22.80 ± 0.43^{a}
	50	44.23 ± 1.09^{b}	11.58 ± 0.23^{a}	30.98 ± 0.67^{b}
	55	48.03 ± 1.02^{c}	11.32 ± 0.12^{ab}	35.06 ± 1.13^{c}
	60	52.14 ± 0.95^{d}	12.49 ± 0.76^{b}	38.37 ± 1.75^{d}
5	Iso	1.18 ± 0.17	0.15 ± 0.00	0.78 ± 0.06
	45	40.70 ± 2.27^{a}	13.28 ± 0.68^{a}	25.94 ± 3.49^{a}
	50	47.25 ± 0.30^{b}	12.33 ± 1.44^{a}	33.33 ± 1.56^{b}
	55	50.24 ± 1.16^{c}	12.35 ± 0.81^{a}	36.37 ± 0.49^{b}
	60	54.85 ± 1.30^{d}	12.81 ± 1.55^{a}	40.50 ± 2.04^{c}

a, b, c, and d means in the same column at the same hour which do not share the same superscript letter differ significantly ($p<0.05$)

B.2 ANOVA for the effect of different sucrose concentrations on WL, SG, and WR during osmotic dehydration of papaya

Hour	Source	df	Mean square	F
1	WL	3	46.030	8.124*
	SG	3	0.012	0.050
	WR	3	51.525	9.983*
2	WL	3	96.751	13.13*
	SG	3	0.878	0.697
	WR	3	107.236	14.774*
3	WL	3	113.552	23.602*
	SG	3	1.690	1.805
	WR	3	115.916	15.511*
4	WL	3	109.914	125.905*
	SG	3	2.018	4.916*
	WR	3	135.478	108.709*
5	WL	3	105.531	50.985*
	SG	3	0.606	0.434
	WR	3	113.243	23.762*

* Sig<0.05

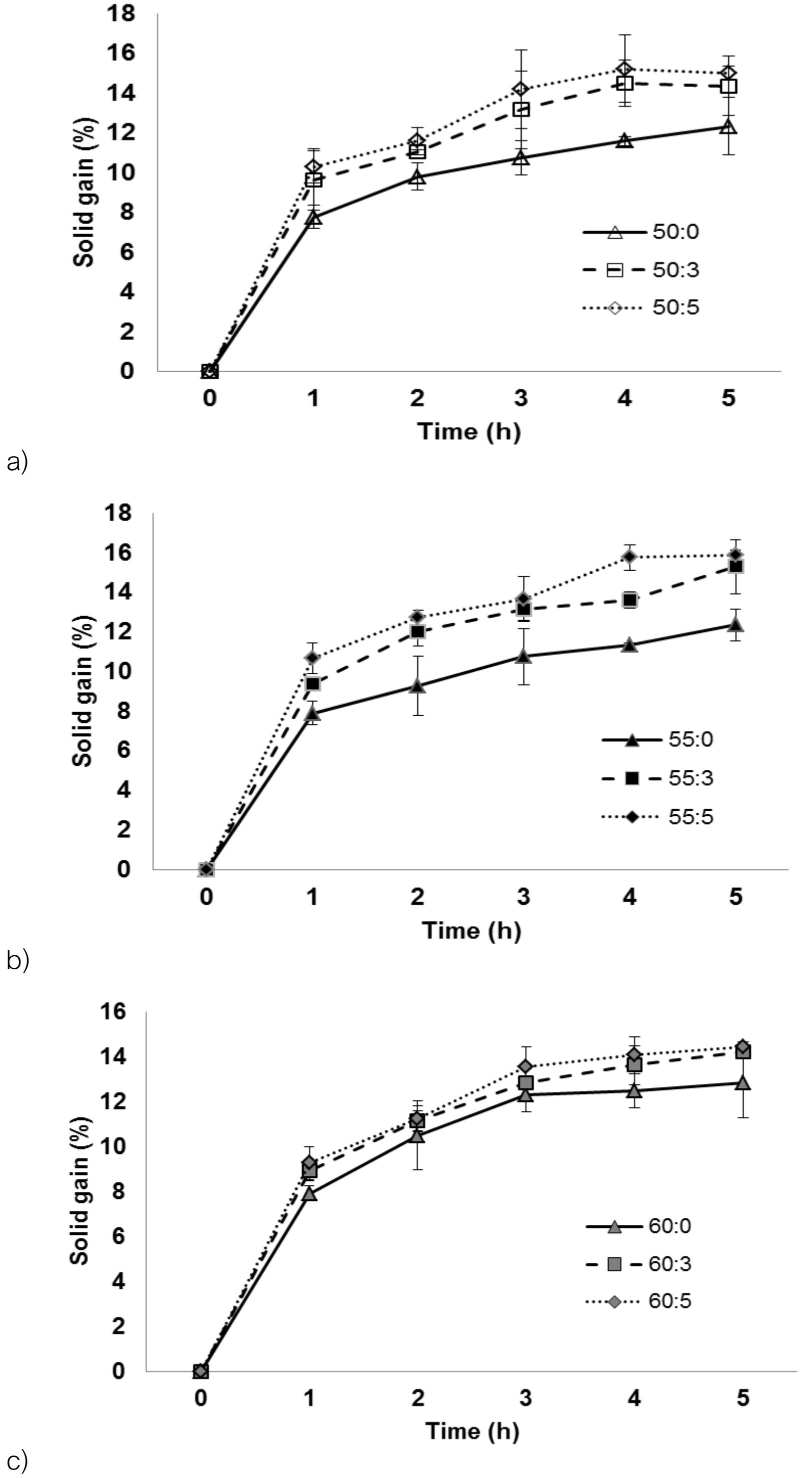


B.3 The effect of addition of 3 and 5% of sodium chloride on 50 (a), 55 (b), and 60 °Brix (c) of sucrose solution on water loss during osmotic dehydration of papaya.

B.4 ANOVA for the effect of addition of sucrose and sodium chloride on water loss during osmotic dehydration of papaya

Hour	Source	df	Mean square	F
1	Sucrose	2	69.082	15.026*
	Salt	2	15.881	3.454
	Sucrose x salt	4	0.484	0.105
2	Sucrose	2	110.455	20.404*
	Salt	2	11.943	2.206
	Sucrose x salt	4	1.952	0.361
3	Sucrose	2	163.284	31.115*
	Salt	2	50.395	9.603*
	Sucrose x salt	4	0.853	0.163
4	Sucrose	2	152.973	62.837*
	Salt	2	15.860	6.515*
	Sucrose x salt	4	0.680	0.279
5	Sucrose	2	137.242	72.165*
	Salt	2	10.458	5.499*
	Sucrose x salt	4	0.715	0.376

***** Sig<0.05

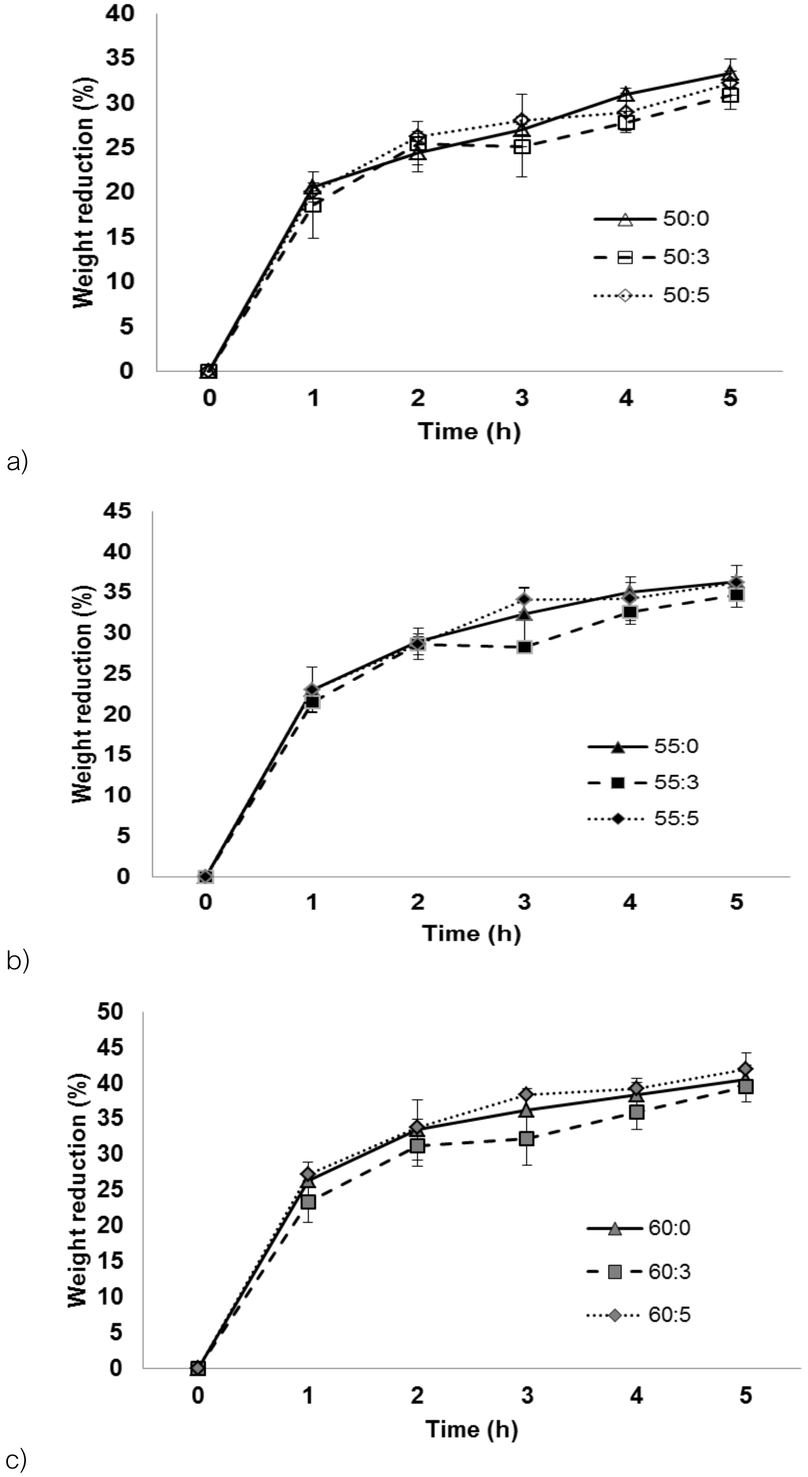


B.5 The effect of addition of 3 and 5% of sodium chloride on 50 (a), 55 (b), and 60 °Brix (c) of sucrose solution on solid gain during osmotic dehydration of papaya.

B.6 ANOVA for the effect of addition of sucrose and sodium chloride on solid gain during osmotic dehydration of papaya

Hour	Source	df	Mean square	F
1	Sucrose	2	0.978	1.673
	Salt	2	11.367	19.450*
	Sucrose x salt	4	0.482	0.824
2	Sucrose	2	0.675	0.911
	Salt	2	9.782	13.207*
	Sucrose x salt	4	1.566	2.114
3	Sucrose	2	0.354	0.234
	Salt	2	15.257	10.063*
	Sucrose x salt	4	1.221	0.806
4	Sucrose	2	0.322	4.423
	Salt	2	24.009	31.591*
	Sucrose x salt	4	1.916	2.521
5	Sucrose	2	1.227	1.166
	Salt	2	17.300	16.436*
	Sucrose x salt	4	0.762	0.724

* Sig<0.05



B.7 The effect of addition of 3 and 5% of sodium chloride on 50 (a), 55 (b), and 60 °Brix (c) of sucrose solution on weight reduction during osmotic dehydration of papaya.

B.8 ANOVA for the effect of addition of sucrose and sodium chloride on weight reduction during osmotic dehydration of papaya

Hour	Source	df	Mean square	F
1	Sucrose	2	79.186	14.096*
	Salt	2	14.993	2.669
	Sucrose x salt	4	1.435	0.255
2	Sucrose	2	124.494	25.660*
	Salt	2	2.675	0.551
	Sucrose x salt	4	2.751	0.567
3	Sucrose	2	178.359	28.246*
	Salt	2	57.256	9.067*
	Sucrose x salt	4	2.591	0.410
4	Sucrose	2	165.995	53.313*
	Salt	2	17.754	5.702*
	Sucrose x salt	4	1.783	0.573
5	Sucrose	2	164.559	51.864*
	Salt	2	8.943	2.819
	Sucrose x salt	4	1.243	0.392

* Sig<0.05

B.9 ANOVA for the effect of addition of sucrose and sodium chloride on water activity of osmodehydrated papaya

Source	df	Mean square	F
Sucrose	2	2.541×10^{-5}	0.305
Salt	2	0.057	679.268*
Sucrose x salt	4	4.002×10^{-5}	0.481

* Sig<0.05

B.10 ANOVA for the effect of addition of sucrose and sodium chloride on longitudinal relaxation time of osmodehydrated papaya

Source	df	Mean square	F
Sucrose	2	0.004	6.683*
Salt	2	0.003	5.219*
Sucrose x salt	4	0.000	0.598

* Sig<0.05

B.11 ANOVA for the effect of addition of sucrose and sodium chloride on cutting force of osmodehydrated papaya

Source	df	Mean square	F
Sucrose	2	3510220.617	1.088
Salt	2	1.251×10^8	38.768*
Sucrose x salt	4	3561183.283	1.103

* Sig<0.05

B.12 ANOVA for the effect of addition of sucrose and sodium chloride on cutting energy of osmodehydrated papaya

Source	df	Mean square	F
Sucrose	2	28493180.572	2.075
Salt	2	1.302×10^9	94.797*
Sucrose x salt	4	18748240.339	1.365

* Sig<0.05

B.13 ANOVA for the effect of addition of sucrose and sodium chloride on hardness of osmodehydrated papaya

Source	df	Mean square	F
Sucrose	2	141129.105	1.008
Salt	2	51293199.893	366.379*
Sucrose x salt	4	250759.847	1.791

* Sig<0.05

B.14 ANOVA for the effect of addition of sucrose and sodium chloride on cohesiveness of osmodehydrated papaya

Source	df	Mean square	F
Sucrose	2	0.001	3.063*
Salt	2	0.002	4.768*
Sucrose x salt	4	0.000	0.355

* Sig<0.05

B.15 ANOVA for the effect of addition of sucrose and sodium chloride on chewiness of osmodehydrated papaya

Source	df	Mean square	F
Sucrose	2	3313.950	0.946
Salt	2	468363.488	133.747*
Sucrose x salt	4	3796.471	1.084

* Sig<0.05

B.16 ANOVA for the effect of addition of sucrose and sodium chloride on adhesiveness of osmodehydrated papaya

Source	df	Mean square	F
Sucrose	2	0.023	0.321
Salt	2	0.212	2.941
Sucrose x salt	4	0.028	0.394

* Sig<0.05

B.17 ANOVA for the effect of addition of sucrose and sodium chloride on L* value of osmodehydrated papaya

Source	df	Mean square	F
Sucrose	2	0.346	0.309
Salt	2	29.184	26.077*
Sucrose x salt	4	0.043	0.038

* Sig<0.05

B.18 ANOVA for the effect of addition of sucrose and sodium chloride on a* value of osmodehydrated papaya

Source	df	Mean square	F
Sucrose	2	5.494	4.191*
Salt	2	11.932	9.102*
Sucrose x salt	4	0.097	0.074

* Sig<0.05

B.19 ANOVA for the effect of addition of sucrose and sodium chloride on b* value of osmodehydrated papaya

Source	df	Mean square	F
Sucrose	2	4.477	4.314*
Salt	2	12.245	11.799*
Sucrose x salt	4	0.287	0.276

* Sig<0.05

B.20 ANOVA for the effect of addition of sucrose and sodium chloride on shrinkage (fresh-dried) of osmodehydrated papaya

Source	df	Mean square	F
Sucrose	2	37.528	5.913*
Salt	2	7.681	1.210
Sucrose x salt	4	0.164	0.026

* Sig<0.05

B.21 ANOVA for the effect of addition of sucrose and sodium chloride on shrinkage (osmosed-dried) of osmodehydrated papaya

Source	df	Mean square	F
Sucrose	2	29.667	1.254
Salt	2	18.312	0.774
Sucrose x salt	4	1.619	0.068

* Sig<0.05

B.22 ANOVA for sensory attributes of osmodehydrated papaya pretreated with four different treatments

Attribute	Source	df	Mean square	F
Yellowness	Treatment	3	14.801	9.348*
	Block	15	2.024	1.279
Redness	Treatment	3	51.985	59.874*
	Block	15	1.274	1.468
Shrinkage	Treatment	3	2.621	1.647
	Block	15	5.158	3.241*
Hardness	Treatment	3	24.052	9.869*
	Block	15	3.054	1.253
Chewiness	Treatment	3	7.304	2.124
	Block	15	2.093	0.609
Sweetness	Treatment	3	60.830	38.711*
	Block	15	2.147	1.366
Saltiness	Treatment	3	110.141	93.831*
	Block	15	1.238	1.055

* Sig<0.05

B.23 ANOVA for hedonic scores of osmodehydrated papaya pretreated with four different treatments

Attribute	Source	df	Mean square	F
Color	Treatment	3	42.688	48.369*
	Block	47	1.751	1.984*
Texture	Treatment	3	1.922	1.287
	Block	47	1.917	1.284
Appearance	Treatment	3	20.243	15.201*
	Block	47	1.595	1.198
Taste	Treatment	3	21.514	11.714*
	Block	47	2.222	1.210
Overall	Treatment	3	1.519	1.313
	Block	47	1.537	1.328

* Sig<0.05

VITAE

Sugiharto Purnamasidi was born on August 31st, 1987 in Samarinda, Indonesia. In 2004, he entered Soegijapranata Catholic University, where he received his Bachelor of Agricultural Technology in Food Technology in 2007.

He entered the Graduate School at Chulalongkorn University in 2010, presented some parts of his research at 1st ASEAN plus Three Graduate Research Congress organized by Chiang Mai University, in Chiang Mai on March 2012, and now is working towards his M.Sc. in Food Science and Technology.