ผลของการแช่อิ่มที่ภาวะสุญญากาศและวิธีทำแห้งต่อสมบัติทางเคมีกายภาพ การต้านออกซิเดชัน และประสาทสัมผัสของมะเดื่อฝรั่ง *Ficus carica* L.

นางสาวดวงกมล สุมนาชยานันท์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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EFFECTS OF VACUUM IMPREGNATION AND DRYING METHODS ON PHYSICOCHEMICAL, ANTIOXIDATION AND SENSORY PROPERTIES OF FIG *Ficus carica* L.

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ดวงกมล สุมนาชยานันท์: ผลของการแช่อิ่มที่ภาวะสุญญากาศและวิธีทำแห้งต่อสมบัติทางเคมีกายภาพ การต้านออกซิเดชันและประสาทสัมผัสของมะเดื่อฝรั่ง *Ficus carica* L. (EFFECTS OF VACUUM IMPREGNATION AND DRYING METHODS ON PHYSICOCHEMICAL, ANTIOXIDATION AND SENSORY PROPERTIES OF FIG *Ficus carica* L.) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: รศ. ดร.นินนาท ชินประหัษฐ์, อ.ที่ปรึกษาวิทยานิพนธ์ร่วม: ผศ.ดร.ชาลีดา บรมพิชัยชาติกุล, 145 หน้า.

งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษากระบวนการแช่อิ่มและทำแห้งมะเดื่อฝรั่งที่รวดเร็ว ประหยัดเวลา มีประสิทธิภาพในการรักษาคุณภาพของผลิตภัณฑ์มะเดื่อฝรั่งแห้งโดยเฉพาะสมบัติต้านออกซิเดชัน และมีลักษณะทางประสาทสัมผัสเป็นที่ยอมรับของผู้บริโภค ขั้นตอนแรกศึกษาผลของการแช่อิ่มที่ภาวะสุญญากาศ (6.8 หรือ 13.5 kPa) นาน 10 นาที ตามด้วยภาวะบรรยากาศปกติจนครบเวลา 4 ชั่วโมง เปรียบเทียบกับการแช่อิ่มที่ภาวะบรรยากาศปกตินาน 4 ชั่วโมง พบว่า มะเดื่อฝรั่งแช่อิ่มทุกตัวอย่างมีค่าสีและค่าลักษณะเนื้อสัมผัสไม่แตกต่างกัน ($p > 0.05$) และพบว่าตัวอย่างหลังแช่อิ่มมีสมบัติต้านออกซิเดชัน ได้แก่ ปริมาณสาร total phenolics (TP), total monomeric anthocyanins (TMA) และค่า the ferric reducing ability of plasma (FRAP) ลดลงจากผลสดประมาณ 10-20, 30-40 และ 8-45% ตามลำดับ อย่างไรก็ตาม การแช่อิ่มช่วยลดค่า water activity (a_w) และปริมาณความชื้นของตัวอย่าง โดยที่ความดันสุญญากาศ 13.5 kPa ส่งผลให้ตัวอย่างหลังแช่อิ่มมีค่าการสูญเสียน้ำ (WL) ค่าการลดลงของน้ำหนัก (WR) ค่า TP และ FRAP สูงที่สุด ($p \leq 0.05$) ดังนั้นจึงเลือกตัวอย่างที่แช่อิ่มที่ความดันดังกล่าวมาทดลองในขั้นต่อไป โดยศึกษาอิทธิพลของอุณหภูมิและรูปทรงของมะเดื่อฝรั่งระหว่างการทำแห้งผลที่แช่อิ่มแล้ว โดยแปรเป็นแบบทั้งผล แบบชิ้นแบน และแบบผ่าครึ่งที่อุณหภูมิลมร้อนเป็น 55, 60, 70 และ 90°C พบว่า อุณหภูมิที่สูงขึ้นส่งผลให้อัตราการทำแห้งสูงขึ้น และมะเดื่อฝรั่งแบบผ่าครึ่ง มีอัตราการทำแห้งสูงกว่าแบบชิ้นแบนและแบบทั้งผลตามลำดับ และยังมีค่า TP และ FRAP สูงที่สุด จึงเลือกตัวอย่างแช่อิ่มแล้วผ่าครึ่งมาใช้ในการศึกษาวิธีทำแห้งด้วยไมโครเวฟแบบสุญญากาศที่ 960 W ความดันสุญญากาศ 8 kPa นาน 20 นาที จนกระทั่งตัวอย่างมีปริมาณความชื้นน้อยกว่า 30% wet basis เปรียบเทียบกับการทำแห้งแบบหลายขั้นตอน (multistage drying) ที่อุณหภูมิ 90°C นาน 90 นาที ตามด้วย 70°C นาน 150 นาที และ 60°C และการทำแห้งด้วยลมร้อน (hot-air drying) ที่ 60°C พบว่า การทำแห้งด้วยไมโครเวฟแบบสุญญากาศและการทำแห้งแบบหลายขั้นตอนช่วยลดเวลาในการทำแห้งได้เมื่อเปรียบเทียบกับการทำแห้งด้วยลมร้อน โดยตัวอย่างแช่อิ่มและทำแห้งที่ได้มีค่าสี ได้แก่ ค่า L^* และ hue angle ไม่แตกต่างกัน ($p > 0.05$) ตัวอย่างที่ทำแห้งแบบหลายขั้นตอนมีค่า a^*, b^* และ chroma สูงที่สุด ในขณะที่ตัวอย่างที่ทำแห้งด้วยลมร้อนมีค่าดังกล่าวต่ำที่สุด การทำแห้งด้วยไมโครเวฟแบบสุญญากาศทำให้ตัวอย่างมีค่า hardness, cutting work และ adhesiveness สูงที่สุด ($p \leq 0.05$) ส่วนการทำแห้งด้วยลมร้อนทำให้ตัวอย่างมีค่า hardness ต่ำที่สุด ($p \leq 0.05$) เมื่อพิจารณาสมบัติต้านออกซิเดชัน พบว่า การทำแห้งส่งผลให้ค่า TP, TMA และ FRAP ลดลง ($p \leq 0.05$) เมื่อเปรียบเทียบกับตัวอย่างสดหรือแช่อิ่ม อย่างไรก็ตาม พบว่าการทำแห้งด้วยไมโครเวฟแบบสุญญากาศมีประสิทธิภาพในการรักษาสมบัติต้านออกซิเดชันสูงที่สุด ($p \leq 0.05$) และยังมีลักษณะทางประสาทสัมผัสเป็นที่ยอมรับมากที่สุด โดยมีคะแนนความชอบด้านเนื้อสัมผัสและความชอบโดยรวมสูงที่สุด ตลอดระยะเวลาเก็บ 8 สัปดาห์ พบว่าโดยทั่วไปตัวอย่างมีปริมาณความชื้นและค่า a_w เพิ่มขึ้น ส่วนค่าลักษณะเนื้อสัมผัส ค่าสี (L^* และ chroma) และค่า TP มีค่าลดลง ส่วน FRAP มีค่าลดลงแล้วเพิ่มขึ้นหลังจากสัปดาห์ที่ 4 อย่างไรก็ตาม การทำแห้งด้วยไมโครเวฟแบบสุญญากาศ ยังคงช่วยรักษาคุณภาพด้านสีและสมบัติต้านออกซิเดชันได้ดีที่สุด

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DUANGKAMON SUMANACHAYANUN: EFFECTS OF VACUUM IMPREGNATION AND DRYING METHODS ON PHYSICOCHEMICAL, ANTIOXIDATION AND SENSORY PROPERTIES OF FIG *Ficus carica* L. ADVISOR: ASSOC. PROF. NINNART CHINPRAHAST, Ph.D., CO–ADVISOR: ASST. PROF. CHALEEDA BOROMPICHAICHARTKUL, Ph.D., 145 pp.

This research aimed to study the rapid osmotic dehydration (OD) and drying process which is time-saving and effective in maintaining the quality attributes especially antioxidant and sensory properties of the prepared figs. Firstly, effects of vacuum impregnation (VI) (6.8 or 13.5 kPa) for 10 min, followed by atmospheric restoration until 4 h, in comparison with conventional OD for 4 h were studied. All the prepared samples had no significantly different ($p > 0.05$) color values and physical texture values and it was evident that the vacuum impregnated samples had the reduced values of total phenolics (TP), total monomeric anthocyanins (TMA) and ferric reducing ability of plasma (FRAP) by 10-20, 30-40 and 8-45%, respectively, when compared with those values of fresh figs. However, the OD helped to decrease water activity (a_w) and moisture content of the samples. The vacuum pressure (VP) of 13.5 kPa resulted in the significantly ($p \leq 0.05$) highest water loss (WL), weight reduction (WR), TP content and FRAP value, thus, the sample pretreated at this VP was used further for a study of influences of drying temperature (55, 60, 70 and 90^{o}C) and fruit shape (whole, pressed and half). It was found that an increasing temperature yielded higher drying rate and the half fruits had higher drying rate in comparison with those values of the pressed and the whole fruits, respectively. In addition, the half fruit also had the highest TP and FRAP values. Thus, it was selected to further investigate for the effects of microwave-vacuum drying (MWVD) at 960 W, VP of 8 kPa for 20 min, in compassion with multistage drying at 90^{o}C for 90 min, followed by 70 ^{o}C for 150 min and 60^{o}C and the hot-air drying at 60^{o}C until the sample having moisture content less than 30% (w.b.). It was evident that either the MWVD or the multistage drying helped reduce the drying time. The resultant VI and dehydrated samples had not significantly different values of L^* and hue angle. The multistage-dried samples had the highest a^*, b^* and chroma values, whereas the hot-air dried samples had the lowest values. MWVD gave the samples with the highest ($p \leq 0.05$) hardness, cutting work and adhesiveness, whereas hot-air drying gave the lowest ($p \leq 0.05$) hardness value. TP and TMA contents and FRAP value were reduced ($p \leq 0.05$) by drying when compared with fresh or VI samples. However, MWVD was effective enough for maintaining the highest ($p \leq 0.05$) antioxidant activity and yielding the sample with the highest sensory scores including texture and overall preference. During storage of 8 weeks, it was generally found that moisture content and a_w of the three samples increased while textural, color (L^* and chroma) values and TP content decreased. The FRAP value decreased and then increased from the fourth week onwards. However, the MWVD process still maintained the best color and antioxidant property during storage.

Department: Food Technology Student's Signature .....

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CONTENTS

Page

Page

LIST OF TABLES

Table Page

Table Page

LIST OF FIGURES

NOMENCLATURE

a^* = Redness

A = Absorbance

$A_{corrected}$ = Corrected absorbance

A_{final} = Absorbance of the sample after 30 min holding time

$A_{initial}$ = Absorbance of 1,000 µl FRAP solution

ANOVA = Analysis of variance

A.O.A.C. = Association of official chemists

A.R. = Analytical

a_w = Water activity

b^* = Yellowness

CRD = Completely randomized design

DA = Descriptive analysis

DAD = Diode array detector

d.b. = Dry basis

DF = Dilution factor

DNMRT = Duncan's new multiple range test

△E = Color difference

FRAP = Ferric reducing ability of plasma

FW = Fresh weight

GAE = Gallic acid equivalent

HDM = Hydrodynamic mechanisms

HFCS = High fructose corn syrup

HPLC= High performance liquid chromatography

L^* = Lightness

M_e = the equilibrium moisture content (d.b.)

M_o = initial sample weight (g) or Moisture content (d.b.) at initial time o

M_t = final sample weight (g) or Moisture content (d.b.) at time t

MR = Moisture ratio

MS = Mass spectroscopy

MW = Molecular weight

MWVD = Microwave-vacuum drying

OD = Osmotic dehydration

OS = Osmotic solution

p_2 = Atmospheric pressure

PP = Polypropylene

PPO = Polyphenol oxidases

QDA = Quantitative descriptive analysis

RCBD = Randomized complete block design

RF = Radio frequency

SG = Solid gain

SEM = Scaning electron microscopy

t_1 = Short time

t_2 = Specific time

TE = Trolox equivalent

TMA = Total monomeric anthocyanins

TP = Total phenolics

TPTZ = Tripyridyltriazine

TSS = Total soluble solids

VI = Vacuum impregnation

VP = Vacuum pressure

w.b. = Wet basis

WL = Water loss

WR = Weight reduction

X_{so} = Initial total soluble solids of the sample

X_{st} = Final total soluble solids of the sample

X_{wo} = Initial water content of the sample (% w.b.)

X_{wt} = Final water content of the sample (% w.b.)

CHAPTER I

INTRODUCTION

The fig is one of the most important fruit species in the Mediterranean area and has high nutritive values. A major benefit of this fruit is its high level of phenolics including anthocyanins which are important components of the color, flavor, and aroma of fresh fruits and also have beneficial effects for human health since they can act as antioxidants. The Royal Project Foundation brought figs to Thailand as a substitute crop for opium poppies and many fig varieties were successfully grown and increasingly popular particularly Dauphine. Figs are widely consumed fresh but handling and transportation of this form is difficult due to their very short shelf life. Therefore, they are most suitable for processing into dried form since drying prolongs its storability, brings about a substantial weight and volume reduction which allows convenient transportation and obtains new products.

Dried figs can commonly be obtained from conventional method. Nevertheless, serious degradation of quality attributes may be caused by high temperature and long drying time. VI was used as a pretreatment before drying to improve qualities and some mass transfer as it can partially reduce water at low pressure without heating and requiring less heating during the following step. Apart from VI, the application of the MWVD to achieve a shorter drying time and a high quality product at low oxygen and drying temperature was compared to convective and multistage drying. Thus, this research was aimed to study the effect of VI on various properties of VI figs and study effects of drying methods in order to obtain higher quality dried product particularly with antioxidant and sensory properties. Moreover, the stability of dried samples was also investigated.

CHAPTER II

LITERATURE REVIEW

2.1 Fig

Fig (*Ficus carica* L.), belonging to botanical family Moraceae, is one of the earliest cultivated fruits that has been grown for thousands years in tropical and subtropical regions of the world. Fig tree is native to the areas from Asiatic Turkey to northern India and then spreads to countries around the Mediterranean (Vinson, 1999). There are many cultivated varieties in each class of figs. Most popular among these are Celeste, Brown Turkey, Brunswick and Marseilles (Morton, 1987).

The Royal Project Foundation brought figs to Thailand as a substitute crop for opium poppies. Many fig varieties such as Brown Turkey, Celeste, Kadota, Conadria and Dauphine were successfully grown especially in the northern region of the country. The most popular among these is Brown Turkey. However, Dauphine (Figure 2.1), an important variety in France and Japan, is increasingly popular (Punsri and Thongtham, 1983).

Figure 2.1 Growth and development of the syconia of common fig cv 'Dauphine'

Source: Modified from Punsri and Thongtham (1983)

The fig fruit is a syconium type which has a round, fleshy, hollow, and edible receptacle and bears numerous tiny unisexual flowers on its inner surface. An individual flower matures into a drupelet (Desai and Kotecha, 1995). The fruit may be obovoid, turbinate, or pear-shaped, 2.5 to 10 cm long, and varies in color from yellowish-green to coppery, bronze, or dark-purple. It has thin and tender skin and whitish, pale-yellow, or amber, or more or less pink, red or purple fleshy wall with large, medium, small or minute seeds and the number of them ranging from 30 to 1,600 per fruit. Unripe fruit is gummy with latex while juicy and sweet when ripe (Morton, 1987). Fig is a nonstony fruit which has a double-sigmoid growth pattern with three stages of growth. The size and weight will increase during the first and third stages, while no weight gains in the second stage. It is a climacteric fruit which ethylene production increases rapidly with onset of climacteric rise at the end of the third stage (Marei and Crane, 1971).

Fig contains vitamins and minerals which vary with cultivar (Bolin and King, 1980). It is an excellent source of dietary fiber, amino acids, rich in sugars, predominantly fructose and glucose and also contains carotenes, sterols and phytosterols, is fat and cholesterol-free (Jeong and Lachance, 2001; USDA, 2002; Solomon *et al*., 2006; Caliskan and Polat, 2011). Several organic acids such as citric, fumaric, succinic, malonic, oxalic and malic acid are present in small amounts (Desai and Kotecha, 1995). Its fruit has a distinct flavor that varies considerably depending on the cultivar and/or processing method. Jennings (1977) found that the major component of fig volatiles was ethyl acetate. A major benefit of this fruit is its high level of phenolics including anthocyanins. Solomon *et al*. (2006) showed that the higher the polyphenol content, particularly anthocyanins, in fig fruit, the higher their antioxidant activity. Antioxidants from figs can protect plasma lipoproteins from oxidation and significantly elevate plasma antioxidant capacity for 4 h after consumption (Vinson *et al*., 2005). The

phenolic content in fig is usually influenced by the cultivar, one fruit part to the others and heavily dependent on the growing technology in the orchard (Veberic *et al*., 2005; Solomon *et al*., 2006; Veberic, Colaric and Stampar, 2008; Caliskan and Polat, 2011). Caliskan and Polat (2011) concluded that black fig accessions contained the highest levels of total phenolics, total anthocyanins and total antioxidant capacity, whereas the yellow and green accessions contained the lowest levels. Solomon *et al*. (2006) reported that the skin of fig is a major and beneficial source of anthocyanins and polyphenols that should not be discarded. Veberic *et al*. (2008) found that fig trees in the northern Mediterranean region produce one or two crops per year, depending on the cultivar. However, the second crop was higher in the content of total phenolics due to the reasons that the fruits develop in warmer, drier and sunnier environmental conditions than the first crop. Figs are widely consumed fresh, either peeled or not but fresh fruits have a very short shelf life (usually from 7 to 10 days) compared with other fruits (Sozzi *et al*., 2005). Handling and transportation of figs is difficult due to bruising and they cannot be stored long enough under refrigeration. Therefore, they are most suitable for processing into dried, canned, or frozen products depending on the cultivar (Desai and Kotecha, 1995). Dried form is very popular, since drying prolongs its storability (Veberic *et al*., 2008). Dried fig is an important source of nutrients (Table 2.1) and it also possesses relatively high amounts of crude fiber and polyphenols (Vinson, 1999) and the dried fruits can commonly be obtained from conventional method particularly sun-drying which requires only low capital, simple equipment and low energy input (Piga *et al*., 2004). Generally, partially dried fruits are gathered from the ground and exposed to direct sunlight until dehydration is completed resulting in risky contamination of *Aspergillus* fungal whose numbers dramatically increases with prolonged exposure (Tosun and Delen, 1998).

Table 2.1 Nutrient composition of dried figs

Constituent	Amount per 100 g Serving	
	Calimyrna	Mission
Protein (g)	3.00	2.82
Carbohydrate (g)	58.20	50.10
Fat (g)	1.90	0.90
Energy (cal)	253.00	212.00
Vitamin C (mg)	3.60	3.60
Vitamin B1 (mg)	0.079	0.061
Vitamin B2 (mg)	0.083	0.078
Vitamin A (IU)	142.00	92.00
Niacin (mg)	0.71	0.59
Calcium (mg)	174.00	130.00
Iron (mg)	2.50	2.40
Phosphorus (mg)	70.00	57.00
Magnesium (mg)	60.00	59.00
Copper (mg)	0.34	0.32
Zinc (mg)	0.48	0.43
Potassium (mg)	682.00	575.00
Sodium (mg)	10.00	10.00

Source: Modified from Bolin and King (1980)

2.2 Phenolic Compounds

Phenolic compounds are common plant secondary metabolites which are important components of the color, flavor, and aroma of fresh fruits, vegetables and their products. They also have beneficial effects for human health since they can act as

antioxidants by reducing or donating hydrogen to other compounds, scavenging free radicals, and quenching singlet oxygen (Merken and Beecher, 2000; Fattouch *et al*., 2007; Costa *et al*., 2009). In addition to antioxidative roles, phenolic compounds have antimutagenic or anticarcinogenic, antiinflammatory, or antimicrobial activities (Eberhardt, Lee and Liu, 2000; Kim, Choi and Chung, 2000).

2.2.1 Anthocyanins and their changes during processing

Anthocyanins are part of the large group of compounds commonly referred to as phenolics and belong to the subgroup known as flavonoids. They possess the characteristic C_6-C_3-C_6 carbon skeleton and are glycosides of polyhydroxy and polymethoxy derivatives of 2-phenylbenzopyrylium or flavylium cation which provide colors ranging from blue to orange in plants. Its color may be changed due to changes of pH, temperature, oxygen or light (Perera and Baldwin, 2001).

Anthocyanin pigments can undergo reversible structural transformations relying on the pH in an aqueous medium (Figure 2.2). They are the blue quinonoidal base (A), the red flavylium cation (AH^+), the colorless carbinol pseudobase (B), and the colorless chalcone (C) (von Elbe and Schwartz, 1996). The flavylium structure dominates in a solution of malvidin-3-glucoside at low pH, while the colorless carbinol dominates at pH 4-6. The greatest tinctorial strength of anthocyanins prevails at approximately pH 1.0, when they are in the un-ionized state. At pH 4.5, these pigment molecules in fruit juices are slightly bluish. If yellow flavonoids are present, as is common in fruits, the juice color will be green (Perera and Baldwin, 2001).

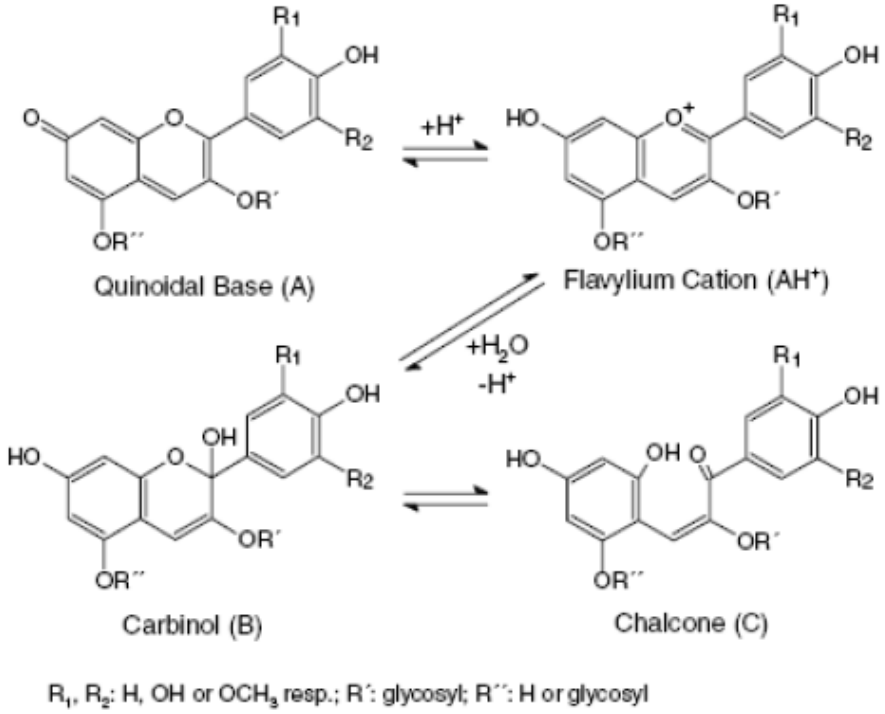


Figure 2.2 Structural conformation change of anthocyanins

Source: Brouillard (1982)

Temperature may affect anthocyanins degradaion. Heating shifts the equilibrium toward the colorless chalcone and the reverse reaction is slower than the forward reaction. Nevertheless, the thermal degradation mechanism of anthocyanin has not been exactly explained (Perera and Baldwin, 2001). Markakis, Livingston and Fellers (1957) showed that the first step of this degradation relates to the colorless carbinol pseudobase formation and subsequent opening of the pyrylium ring to form the chalcone following by hydrolysis of the glycosidic bond. Adams (1973) proposed that when heat these compounds at pH 2-4, the glycosidic bonds are hydrolyzed, resulting in subsequent conversion of the aglycone to a chalcone and followed by formation of an α-diketone. The thermal degradation products of cyanidin 3-glycoside comprise chalcones and α-diketone, protochuic acid, quercetin and phloroglucinaldehyde

(Jackman and Smith, 1992). These primary breakdown products are considered to cause formation of brown-colored products (Perera and Baldwin, 2001).

The destruction of anthocyanins seems to be accelerated by oxygen. Daravingas and Cain (1968) reported that replacement of the oxygen atmosphere with nitrogen enhanced anthocyanin pigment stability in black raspberries juice.

Exposure of anthocyanins to ultraviolet or visible light and other sources of ionizing radiation generally cause decomposition which appears to be mainly photooxidative (Sweeny, Wilkinson and Iacobucci., 1981). The light would produce an excited state-anthocyanin via electron transfer, thus, inducing these pigments to photochemical decomposition (Perera and Baldwin, 2001).

Anthocyanases, enzymes found in plant tissues and involved in the oxidative discoloration of anthocyanins, are devided into two distinct groups, depending on their activity. They are glycosidases and polyphenol oxidases (PPO). Glycosidases hydrolyse the glycosidic bonds of the anthocyanins to yield free sugar and aglycone. The aglycone is unstable and spontaneously transforms to colorless derivatives (Forsyth and Quesnel, 1957). PPO acts on anthocyanins in the presence of *o*-diphenols to produce oxidized anthocyanins (Peng and Markakis, 1963), which may subsequently react with each other, or with amino acids or proteins to yield brown-colored polymers (Perera and Baldwin, 2001).

2.3 Drying Processing of Fruits

Drying is considered as one of the conventional methods used to preserve fruits, as the reduction of moisture or water activity in the products greatly prevents microbial and chemical deterioration and extends the shelf life. Moreover, it also brings about a substantial weight and volume reduction which allows safe storage and convenient

transportation (Doymaz and Pala, 2003; Duan *et al*., 2010). Dehydration of fruit requires 3 steps including selection, pretreatments and drying.

2.3.1 Fruit Selection

Careful selection for the most appropriate characteristics of raw materials is a step required in fruit processing since they can affects the qualities of dried products. The harvest maturity of figs is based on color and firmness (Desai and Kotecha, 1995). Black Mission figs should be light to dark purple rather than fully black, and should yield to slight pressure rather than being soft ripe. Calimyrna white figs should be yellowish-white to light yellow and yield to firm to slight pressure at the best harvest maturity (Ryall and Pentzer, 1974). A sudden increase in final fruit size and opening of ostiole are the other indices of ripening (Desai and Kotecha, 1995). According to Rodriguez *et al*. (1975), fruits of medium and uniform size and of good flavor and color are suitable for processing.

2.3.2 Pretreatments

Preparative treatments applied to fruits prior to drying are necessary to ensure a reasonable short drying time and to retard deteriorative changes (Desai and Kotecha, 1995). In addition to drying process improvement, pretreatment methods may be used to maintain or improve quality of the dried product.

2.3.2.1 Blanching

Blanching is a common pretreatment method generally performed by heating the fruits with steam or hot water with the purpose of stabilizing them because of its capability to destroy microorganisms and to inactivate enzymes (Cruz, Vieira and Silva, 2006), improving color and brightness of products and preventing discoloration, making the product more attractive (Ihl, Monsalves and Bifani, 1998; Chinprahast *et al*.,

2013), reducing the loss of antioxidants, improving the retention of antioxidant capacity in the final product and modifying the fruit texture to increased mass transfer phenomena (Giovanelli *et al*., 2012).

Siegel, Markakis and Bedford (1971) proved that steam blanching before freezing of tart cherries was effective in destroying the endogenous anthocyanase activity. According to Chinprahast *et al*. (2013), increased blanching temperature and time significantly ($p \leq 0.05$) decreased PPO activity and resulted in lighter blanched Indian gooseberry. Giovanelli *et al*. (2012) reported that the blanching step reduced the loss of phenolic compounds, improved the retention of antioxidant capacity in the osmo-dehydrated blueberries which can be ascribed to the inactivation of the endogenous PPO. Additionally, increasing mass transfer phenomena in the course of the osmotic dehydration was also attained. Higher sugar and solids gain (SG) as well as water and weight loss were higher in blanched sample than in unblanched ones which related to steam-induced phenomena of cellular lysis and cell wall swelling and it could be confirmed that blanching treatment increased skin permeability, probably by dissolving the hydrophobic waxy layer and by weakening cell walls and membranes (Giovanelli *et al*., 2012).

Nevertheless, a deleterious change in the product by the loss of nutrients through thermal degradation, diffusion and leaching is caused by blanching (Günes and Bayindirh, 1993). Moreover, the blanching pre-treatment resulted in a little decrease in total phenolic concentration of blueberries but a slight increase in total anthocyanin value. This increase could be due to a higher extractability of anthocyanins, during chemical assay, from the thermally treated skins (Giovanelli *et al*., 2012).

2.3.2.2 Osmotic treatment and vacuum impregnation (VI)

Osmotic dehydration (OD) is a water removal process achieved by soaking samples (mostly fruits and vegetables) in a hypertonic sugar, salt, or combined solution, to reduce the water content. The water from the fruit diffuses into the osmotic solution (OS) and solutes from the solution diffuse opposite into the fruit as a result of the difference in osmotic pressure between the fruit and the solution. In addition, leaching of product solutes (sugars, acids, pigments, minerals, and vitamins) into the solution occurs in small quantity (Raoult-Wack, 1994) as shown in Figure 2.3.

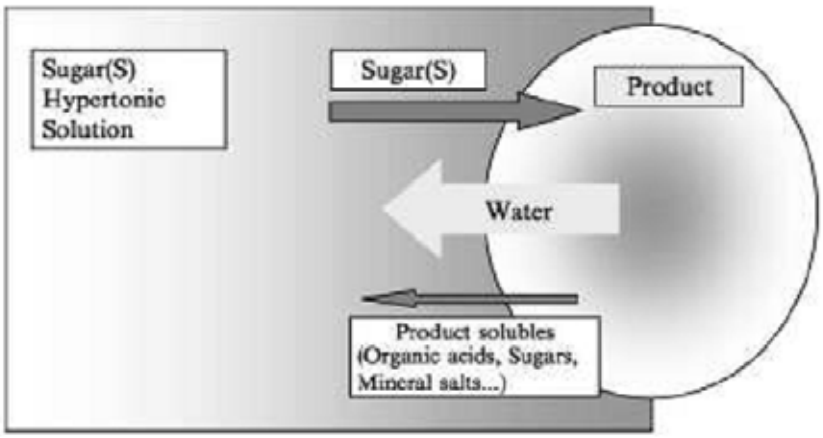


Figure 2.3 Mass transport processes during OD

Source: Torreggiani and Bertolo (2004)

As described by Zhao and Xie (2004), the term impregnation means being filled, saturated, or the process of permeating. Impregnation sometimes is used interchangeably with infusion and infiltration. Vacuum impregnation (VI), which is a variant of OD, is performed in two steps, Firstly, sample is immersed in the liquid phase under vacuum pressure (VP) of p_1 ~5-10 kPa (~50–100 mbar) for a short time (t_1) resulting in expansion and outflow of internal gas in the product.

Gas release takes the product pore native liquid with it. In the second step, atmospheric pressure (p_2) is restored in the system for a specific time (t_2) with compression causing a reduction in volume significantly in the gas remaining in the pores and thus to the subsequent influx of external liquid into the porous structure (Fito *et al*., 2001b; Zhao and Xie, 2004).

VI is frequently used as a pretreatment before complementary processing steps such as drying. It is developed to improve some mass transfer processes (as dewatering) and produces some changes in food composition as it can quickly introduce external liquids into the porous structures of sample in a controlled way (Zhao and Xie, 2004). In addition, hydrodynamic mechanisms (HDM) and deformation relaxation phenomena are the coupled action promoted by pressure changes (Fito, 1994).

The advantages of VI in food processing, especially in fruit processing, are quality improvement and energy saving. This technique can reduce heat damage to plant tissues by using a gentle treatment at a relatively low processing temperature and preserve color, natural aroma and flavor and any heat-labile nutrients. Loss of fresh fruit volatile flavor components during common air dehydration is prevented by using sugar or syrup as VI solutions (Ponting, 1973; Escriche *et al*., 2000; Talens *et al*., 2002). VI can prevent discoloration of fruit pieces from enzymatic and oxidative browning without using antioxidants because oxygen from the pores is removed (Ponting *et al*., 1966; Contreras and Smyrl, 1981; Alzamora *et al*., 2000). Additionally, the pore structure of the product is filled with functional food ingredients, such as firming agents, antioxidants, and antimicrobial ingredients to effectively improve quality and extend shelf-life (Zhao and Xie, 2004). VI pretreatment may succeed energy saving by removing water in the liquid form without heating and requiring less heating during the following processing

steps to partially remove water (Lewicki and Lenart, 1992; Barbosa-Cánovas and Vega-Mercado, 1996a).

a) Factors affecting VI process and the quality of finished products

Factors affecting VI process and the quality of the finished products are raw material compositions and processing conditions such as type, concentration and temperature of the VI solution, solution/sample ratio, agitation, pressure and immersion time under vacuum, time to restore atmospheric pressure and also including pretreatment of the samples.

Different types of solutions affect plant tissue cells differently. As stated by Zhao and Xie (2004), water leaving the cell causes the cells shrink or shrivel in hypertonic solutions. OD of samples occurs concurrently leading to changes in the chemical and physical properties of a product and promoting turgor losses and complete loss of cell elasticity after plasmolysis. The selection of VI solution should also be taken into scrutiny of nontoxicity, good sensory characteristics, high solubility, and low cost. In general, any soluble solute or miscible solvent can be used as a VI solution. Low molecular weight carbohydrate solutes rapidly penetrate the samples. Therefore, they may be used for this processing. The smaller the molecular weight, the faster the diffusion. However, they may affect flavor of impregnated products. Sensory study indicated that high fructose corn syrup (HFCS) dehydrated fruit is sweeter than that treated with sucrose solution (Kaymak-Ertekin and Sultanoglu, 2000). Sucrose solution was observed to be slightly better than glucose solution since less discoloration and sugar gain in a strawberry product were obtained (Yang and Maguer, 1992). Solubility which is usually influenced by molecular weight, rate of mass transfer, and permeability is another important characteristic. The solute used at the appropriate concentration and

temperature must dissolve in the systems. Sodium chloride plays its role as the inhibitor of the initiating enzyme of browning, i.e. PPO (Ponting, 1960). Its mechanism is that it actually attaches, via the interaction with copper at the active center of the enzyme, which catalyzes the reaction of converting phenol to quinone (Iyengar and McEvily, 1992). It has been proved to be a more permanent agent for retardation of enzymatic browning than other methods used and reduce water activity of the product thus resulting in preventing microbial spoilage (Coultate, 1989). Mixed solutions composing of two or more solutes were also utilized (Raoult-Wack, 1994). To obtain a maximum WL with low SG, blends of sucrose and salt are used in fruit processing. Adding a small quantity of sodium chloride to a sucrose solution tremendously increased the dewatering rate in fruits (Sereno, Moreira and Martinez, 2001). The interaction between sucrose and salt was also found to limit the salt residue in the fruit samples. Due to its lower molecular weight, a small incremental increase in the sodium chloride concentration contributes to significant change in osmotic pressure, whereas the same incremental increase in the sucrose concentration (higher molecular weight) does not. This means that diffusion coefficients are more sensitive to changes in sodium chloride concentration than in sucrose concentration (Ade-Omowaye *et al*., 2002). A significant decrease in organoleptic quality may be avoided by using low salt concentrations. A high level of sugar can reduce the taste threshold for salt. Conversely, salt can enhance the sweetness of sucrose (Ade-Omowaye *et al*., 2002).

Lazarides and Mavroudis (1995) observed a corresponding increase in dehydration rate with increased solution concentration due to an increased osmotic pressure difference. In general, an increase in temperature increases the WL, while not causing a significant change in SG (Kaymak-Ertekin and Sultanoglu, 2000).

According to Zhao and Xie (2004), high temperature can accelerate the osmotic process, but may cause negative effects on color, texture, and flavor of samples. Optimal temperature depends on the type of the raw materials used, the type of finished product, and the speed of processing. Roastogi and Raghavarao (1996) found that increasing concentration and temperature of the OS resulted in a certain extent of the increased rate of mass transfer but undesirable changes in flavor, texture and color occurred.

To ensure the retention of a constant solution concentration during processing, a high solution to sample ratio may be used. Nevertheless, it increases cost and necessitates solution recycling. Lenart and Flink (1984) suggested that a value of 4–6 might be optimal for the best osmotic effect.

Effect of agitation on WL and SG in impregnation processing is confirmed by Peanagiotou, Karathanos and Maroulis (1998). WL is higher in the region of turbulent rather than laminar flow and when the sample is agitated in solution, VI processing can be speeded up. However, SG is not affected significantly by agitation between the two regions (Mavroudis, Gekas and Sjoholm, 1998). In some cases, the advantages of agitation do not justify the cost (Ponting *et al*., 1966).

Mass transfer in osmotic processing is much faster under vacuum due to the coupling of osmotic/diffusional mechanism and HDM (Fito, 1994; Fito *et al*., 1994). Changes in the structure of the product produced by VP cause the changes in dehydration kinetics. Thus, lower solution temperature or shorter impregnation time to gain a higher WL rate may be used (Zhao and Xie, 2004). Mújica-Paz *et al*. (2003b) studied the effect of VP (135–674 mbar) and its application time (3–45 min) on the volume of isotonic solution impregnated into slices of mango, apple, papaya, banana,

peach, melon and mamey. The result showed that VP and time influenced the volume in all fruit slices significantly. In general, the higher the vacuum, the greater the volume of impregnated solution (Zhao and Xie, 2004). Mújica-Paz *et al*. (2003a) further evaluated the combined effects of vacuum level (135–674 mbar) and concentration of OS (41–60°Brix) on dehydration parameters of apple, mango and melon. The authors found that a VP of 674 mbar and 50°Brix syrup in apple and mango, and 593 mbar and 57°Brix in melon resulted in the lowest final water activity level.

According to Zhao and Xie (2004), the effect of impregnation time on sample deformation and on the amount of solutes impregnated into samples counts on the property of raw material, vacuum level, and other factors. It was suggested that the VI solution concentration of 50-75°Brix, temperature of 20-50°C, VP of 50-200 mbar, vacuum time of 10-30 min, and atmospheric restoration time in minutes to hours are commonly used for dehydrated foods.

b) Effects of OD and VI on microstructural, physicochemical and antioxidant properties of products

Torreggiani and Bertolo (2001) analyzed the microstructure of strawberry by light and transmission electron microscopy and showed that tissues subjected to vacuum had better cellular tissue integrity. Mauro, Tavares and Menegalli (2002) evaluated the effect of sucrose solutions on the cellular structure of potato tissue in equilibrium at 27°C with a histological technique to photograph the potato cells after osmotic treatment. The result showed that the long time exposure to osmotic solutions in equilibrium contributed to degradation of cell structure. According to Alzamora and Gerschenson (1997), dehydration of the tissue leads to plasmolysis, but the cellular wall shrinks much less as compared to that presents in osmosed tissue at normal pressure. Furthermore, a much better preserved cell wall which is similar to fresh fruit texture was

observed by transmission electron microscopy when VI was used to decrease water activity. Roastogi, Angersbach and Knorr (2000) explained that the cell damage could be caused by WL during VI leading to the reduction in size, which results in the loss of contact between cell membrane and cell wall. Additionally, varying type of sugars also has dissimilar effects on the microstructure of samples. For instant, sucrose can increase shrinkage of cells but glucose can maintain cellular integrity (Monsalve-Gonález, Barbosa-Cánovas and Cavalieri, 1993; Muntada *et al*., 1998).

Texture, color and total acids are mostly affected by VI owning to change in product density, especially in highly porous samples. VI strongly reduces firmness and sample dehydration takes place simultaneously. The losses of cell turgor and elasticity, the alteration of cell resistance, the increase in viscous character, the changes in air and liquid volume fractions in the product as well as in sample size and shape are further promoted by dehydration (Pitt, 1992; Fito *et al*., 2000; Chiralt *et al*., 2001). The loss of turgor pressure is either due to plasmolysis or disruption of the tonoplast and plasmalemma. The loss in elasticity is owing to the air–liquid exchange during the vacuum operation (Alzamora *et al*., 1997, 2000). Chiralt *et al*. (2001) found that VI decrease retention of mechanical properties in kiwifruit and mangoes, but not on strawberries.

Fito and Chiralt (2000) reported that VI treatment significantly results in color changes in apple, strawberry and papaya more than in apricot, banana and kiwifruit. Alzamora *et al*. (2000) showed that for light colored fruits sensitive to enzymatic browning discoloration, air leaves the pores of the fruits during vacuum treatment, reduces the oxygen concentration in the sample tissues, consequently the oxidative reaction rates slowed down thus yielding the final product with a good natural color.

The effect of VI treatment on acidity of fruits relies on the nature of raw material and type and concentration of VI solution. Torreggiani (1993) reported no significant change of pH value of the fruit and vegetable samples before and after VI processing. Native soluble acids are partially removed from fruit during VI processing, causing the reduced total titratable acidity in high concentration of VI solution (Zhao and Xie, 2004).

Osmo-dehydrated dried berries showed a slightly higher loss in anthocyanin contents as compared to the untreated dried ones, while no differences in the antioxidant activity were observed between the untreated and osmo-dehydrated dried blueberries (Lohachoompol, Srzednicki and Craske, 2004). From the study of Giovanelli *et al*. (2012), total phenolics and antioxidant activity were scarcely influenced by pretreatment, osmosis time and osmotic solution and by their interactions. In contrast, total and individual anthocyanins were significantly influenced by these factors and their interactions. However, both total polyphenols and total anthocyanins were partially lost in the osmotic treatments. In particular, higher losses were observed for total anthocyanins in the unblanched samples, with no differences related to the kind of osmotic solution used. Substantial losses in anthocyanins could be explained by the rationales that these molecules are naturally water soluble and localized in the skin, therefore they are removed by dissolution into the osmotic solution (Osorio *et al*., 2007).

2.3.3 Drying methods

Drying is ordinarily considered as one of the major methods used to preserve foods, keeping it in a stable and safe condition because it reduces water activity and greatly prevents microbial and chemical deterioration and extends the shelf life much longer than that of fresh fruit products. Moreover, it also helps to obtain the desired

physical form, color, flavor or texture, reduce the volume or the weight for transportation and produce new products which would not otherwise be feasible (Mujumdar, 1997; Doymaz and Pala, 2003; Duan *et al*., 2010).

The main factor affecting the drying and product qualities is drying method which utilizes different conditions such as the drying chamber temperature, pressure and drying time. Furthermore, the pretreatment and characteristics of raw materials such as shape and size of the samples are requisites which should be considered.

Xanthopoulos, Yanniotis and Lambrinos (2010) found that drying rate of the peeled fig was higher than the unpeeled figs. Ganjyal, Hanna and Devadattam (2003) found that drying rate of the sliced sapota was higher than the quarter and the half-cut sample, respectively. Madamba (2003) concluded that drying air temperature and slice thickness were significant factors during the hot-air drying stage of coconut. Piga *et al*. (2004) concluded that pretreatments drastically reduced the drying duration and the main quality changes were browning of the peel, especially for non-treated figs.

2.3.3.1 Hot-air drying

According to Yemiş, Bakkalbası and Artık (2012), the conventional sun-drying method is one of the oldest known methods of food preservation and has been widely used for drying of many fruits because of its simplicity and low operating cost. As far as the conventional drying is concerned, figs are hand-picked in a semi-dried form and are subsequently sun-dried for a week. However, as reviewed by Barbosa-Cánovas and Vega-Mercado (1996b), mechanical air dehydration has gained importance because it has many advantages over sun-drying. These include such aspects as i) better sanitary conditions because contamination by dust and other foreign matters is reduced, ii) accurately set drying parameters, control and change over the entire

processing time, hence a more consistently uniform product and less quality degradation can be achieved, iii) dehydration is not conditioned by rain or weather changes, and iv) when a constant rate of drying is reached, increasing the air flow can contribute to shorter drying times. Additionally, labor costs are substantially reduced.

A high moist product dried by hot airflow generally experiences a warming-up period, a constant drying rate period, and one or several falling rate periods (Zhang *et al*., 2006). A long time and low energy efficiency are limitation of drying with only hot airflow especially during the falling rate periods. This is mainly caused by rapid reduction of surface moisture and consequent shrinkage, which often contributes to reduce moisture transfer and, sometimes, reduced heat transfer. Serious degradation of quality attributes such as structure, color, flavor and nutrients, or through oxidation may be caused by prolonged exposure to elevated drying temperature (Zhang, Li and Ding, 2003; 2005). Vega-Gálvez *et al*. (2012) studied the effects of temperature and air velocity on the drying kinetics and quality attributes of apple (var. *Granny Smith*) slices during drying at 40, 60 and 80^{o}C, as well as at air velocities of 0.5, 1.0 and 1.5 m/s. The results exhibited that dehydration was faster when air temperature and air velocity increased. Other quality attributes like color difference ($\triangle$E) and DPPH-radical scavenging activity decreased at higher temperature. At 80^{o}C, antioxidant activity values did not differ much from that measured at 40^{o}C. Total phenolics (TP), on the other hand, showed unexpectedly least destruction at 80^{o}C and 1.5 m/s. This was probably due to short drying time and therefore less exposure of the phenolics to thermal effect. The authors also revealed that during the hot air drying process, destruction of low molecular weight sugars occurred in the dried apples. The long chain biopolymers were more resistant to heat treatment and being decisive for firmness of the dried apple

samples, the value being highest at 80°C. Microstructure analysis also showed that cell disruption occurred at high temperature, and increased at high air velocity.

Hot-air drying can be combined with other drying methods. Ilknur (2007) used three different drying methods which are microwave, air, and combined microwave-air drying and found that the combined method was suitable for drying of pumpkin slices and this was evaluated with regards to the energy consumption during drying, drying period, average drying rate and color criteria. Hu *et al*. (2006) developed a method of drying edamames by hot-air drying and vacuum microwave combination and found that the optimized combination drying process shortened the drying time significantly when compared to conventional hot-air drying, as well as greatly decreased mass loads on the vacuum microwave dryer.

2.3.3.2 Multistage drying

Recently, the trend is to minimize chemical degradation reactions and maximize nutrients retention to yield better quality products with reduced environmental impact and minimized energy consumption (Cernîşev, 2010). Among many factors affecting the quality attributes during drying, the most important ones are moisture content and temperature (Strumiłło, Markowski and Adamiec, 1991; Adamiec *et al*., 1995). Several irreversible chemical reactions as well as structural, physical and mechanical modifications are resulted from the decrease in moisture content and the higher temperature of the material during drying (Cernîşev, 2010). Furthermore, drying processes are highly energy consuming. The objectives of an energy efficient process and the highest possible product quality are conflicting in many cases. Most energy-saving measures are harmful for quality aspects. Fast drying operated with high temperatures may reduce the cost of processing but adverse reactions causing quality

degradation of the product may predominate (Cernîşev, 2010). Interaction of product quality with energy efficiency of the operating conditions in drying can be optimized (Ho *et al*., 2001). Thus, drying condition should be selected depending on economic considerations including product price as a function of its quality and processing costs relying on total drying time and the drying air parameters (Olmos *et al*., 2002). From the study of Cernîşev (2010), a multistage drying process of tomato was developed. In this method, drying was maintained at decreasing air temperature and arranged in such a manner that the temperature inside the fruit did not exceed acceptable level of 55°C. Higher product quality and shorter drying time in comparison with the conventional drying at constant air conditions were observed. Kim *et al*. (2006) dried red peppers at 80°C for 5 h, then 60°C for 18 h or 70°C for 6 h and found that short time and low temperature drying of cut pods was more effective than conventional drying in reducing the destruction of the antioxidant activity and color.

2.3.3.3 Microwave vacuum drying (MWVD)

According to Zhang, Jiang and Lim (2010), microwaves are part of the electromagnetic spectrum. There are two mechanisms involving its energy absorption in foods which are dipolar relaxation and ionic conduction. These interactions are with the electric field of the radio frequency (RF) and microwaves. Water in food is often the primary component responsible for dielectric heating. Owning to their dipolar nature, water molecules attempt to follow the electric field because they alternate at very high frequencies and generate heat due to such rotations. The second major mechanism of heating in microwaves and RF energy is the migration of ions, such as those present in salty food under the effect of the electric field leading to heat production. As described by Rao, Rizvi and Datta (2005), both the dielectric constant and the dielectric loss factor measure the ability of the material to interact with the electric field of the

microwaves. The dielectric constant is a measure of the food material's ability to store electromagnetic energy, whereas the dielectric loss is the material's ability to dissipate electromagnetic energy (which results in heating).

Many advantages of microwave drying include increasing process speed, uniform heating throughout the material, often the bulk heating effect does produce uniform heating, avoiding the large temperature gradients that occur in conventional heating systems, efficiency of energy conversion, better and more rapid process control, usually less floor space requirements, selective heating may occur, improving product qualities, and also producing desirable chemical and physical effects (Datta, Sumnu and Raghavan , 2005; Liapis and Bruttini, 2007).

Although uniform heating can be realized in theory, in actuality the key problem is in the inherent no uniform distribution of the microwave field, which leads to uneven temperature distribution in the drying material (Dolan and Scott, 1994). Although reduction of water resulting in decreasing in the loss factors of the food materials, and the conversion of microwave energy into heat is reduced at lower moisture content, the product temperature may still continue to go up, leading to overheating or charring (Bouraoui, Richard and Durance, 1994). Other drying methods can be combined with microwave drying to overcome these drawbacks (Zhang *et al*., 2010). Desirable quality attributes of dried wild cabbage were achieved by using microwave vacuum and hot-air drying (Xu *et al*., 2004).

During vacuum drying, low pressure causes high energy water molecules diffuse to the surface and evaporate. Due to this phenomenon, water vapor concentrates at the surface and the low pressure causes the boiling point of water to be reduced. Therefore, vacuum drying oxidation is prevented due to the absence of air,

and thereby maintains the color, texture and flavor of the dried products. In the absence of convection, microwaves can be combined with vacuum drying to improve its thermal efficiency (Zhang *et al*., 2006). From the study of Drouzas and Schubert (1996), vacuum microwave drying of banana slices at a microwave power supply of 150 W and under a vacuum of less than 2500 Pa was achieved in less than 30 minutes without exceeding 70°C and the quality of the product was good enough and comparable to that of freeze dried product. The excellent taste and flavor with no shrinkage or change in color of dried product were also provided. In microwave vacuum drying of model fruit gel (simulated concentrated orange juice), moisture content was reduced from 38.4% to less than 3% in less than 4 min while conventional air drying took more than 8 h to reach 10% moisture (Drouzas, Tsami and Saravacos, 1999). A study on microwave vacuum drying of carrot slices exhibited the microwave vacuum dried product had softer texture and lesser color deterioration than the sample treated by air drying (Lin, Durance and Scaman, 1998). The microwave vacuum drying yielded beetroot cubes with high antioxidant activity comparable to that obtained by freeze drying and higher than those dehydrated by conventional drying (Figiel, 2010).

The application of the MWVD method to achieve a faster drying rate and a high quality product of an attractive shape, color, texture and flavor and antioxidant properties has directed the attention of many investigators to the drying of banana, strawberries, apples and raspberries (Drouzas and Schubert, 1996; Böhm *et al*., 2006; Erle and Schubert, 2001; Bórquez, Canales and Redon, 2010). Therefore, this method has been applied to figs which contain high level of antioxidants and compared to convective and multistage drying in this research. However, the initial high quality product could be rapidly deteriorated greater than the lower initial quality one (Tang and Chen, 2000; Yen, Shin and Chang, 2008). Thus, dried samples stability was analyzed.

CHAPTER III

MATERIALS AND METHODS

3.1 Raw Materials

- The figs of Dauphine variety were purchased from an orchard (Amphoe Sri Racha, Chonburi Province, Thailand) during period of June 2012 to March 2013 and transported to the laboratory within a day. The fruits were carefully hand-picked in its commercial maturity stage, which were determined by softening of the fruit and development of its typical fruit taste and color. The fruits were sorted for the weight of 60-70 g and 4-6 cm diameter.

- Commercial sugar (sucrose), Food grade (Mitr Phol Sugar Corp, Bangkok, Thailand)

- Sodium chloride, Food grade (Tokuyama, Co., Ltd., Tokyo, Japan)

3.2 Methods

3.2.1 Evaluation of physicochemical and antioxidant properties of whole fresh figs

3.2.1.1 Physical property

a) Fruit peel color was measured using a colorimeter (Chroma Meter CR-300, Minolta Co., Osaka, Japan) in which color parameters were expressed as *L**, *a**, *b**, chroma and hue angle. Negative L values indicate darkness and positive *L** values indicate lightness. Negative *a** values indicate green color, and positive *a** values indicate red color. Negative *b** values indicate blue color, and positive *b** value indicate yellow color. The chroma value, calculated as chroma = $(a^2 + b^2)^{1/2}$, indicates color intensity. Hue angle, a parameter that has been shown to be effective in predicting visual color appearance, was calculated using the formula; hue angle = $\tan^{-1}$ (b/a),

where 0^{o} or 360^{o} = red-purple, 90^{o} = yellow, 180^{o} = green, and 270^{o} = blue (Zerbini and Polesollo, 1984). Eight fruits were randomly selected and measured at three random positions per fruit.

b) Hardness of fruits was evaluated using a texture analyzer (Stable Micro System Model TA.XT2i, Godalming, UK) assembled with a cylindrical probe (P/2). The test conditions were pre-test speed of 1.5 mm/s, test speed of 1.5 mm/s, post-test speed of 10 mm/s, distance of 50 mm and trigger force of 10 g, respectively. The parameter reported was the maximum peak force (N). Eight fruits were randomly selected and measured (Appendix A.1).

c) Total soluble solids were measured using a hand refractometer (Atago model 2210-w06, Tokyo, Japan) (Appendix A.2).

d) Water activity (a_w) was measured by a water activity meter (AquaLab Series 3 TE, Pullman, WA, USA) (Appendix A.3).

3.2.1.2 Chemical property

a) Proximate compositions including moisture, equilibrium moisture content, ash, protein, lipid and crude fiber were analyzed (A.O.A.C., 1995: Appendix A.4-9) with duplicate determination. Total carbohydrates content was obtained as a difference from 100%.

b) pH value was measured by a pH meter (Eutech Model pH 2700, Singapore) (Appendix A.10).

3.2.1.3 Evaluation of total phenolics (TP), total monomeric anthocyanins (TMA) contents and antioxidant activities of crude extract

a) Extraction of anthocyanins and phenolics was performed according to the modified method of Stojanovic and Silva (2007). Fifty grams of manually chopped

figs were added to 80 ml of methanol (J.T. Baker, Phillipsburg, NJ, USA) containing 4% acetic acid (QRëc, New Zealand) and homogenized for 2 min using a homogenizer (Ystral, X10/25, Ballrechten-Dottingen, Germany) at 24,000 rpm. After recovery of the homogenate, 20 ml of extraction solvent was used to wash the homogenate and pooled with the first homogenate. The pooled homogenate was kept at 4°C for 15 h, and then centrifuged at 4,000 *x g* for 15 min at 10°C using a Rotanta 460R centrifuge (Hettich Zentrifugen, Tuttlingen, Germany). The pellet was washed with 50 ml of methanol containing 4% acetic acid and centrifuged again under the same conditions. The resultant supernatants were combined and kept at -18°C until used.

b) TP content was determined by the Folin-Ciocalteu assay (Waterhouse, 2005; Appendix A.11) with duplicate determination.

c) TMA content was determined by the pH differential method (Giusti and Wrolstad, 2005; Appendix A.12) with duplicate determination.

d) The antioxidant activity of the crude extract was determined by the ferric reducing ability of plasma, FRAP assay (Benzi and Strain, 1996; Appendix A.13) with some modifications and duplicate determination.

The experiments were performed with 4 replicates except for Sections 3.2.1.1b and 3.2.1.2a which were done with triplicate and reported as data of the raw material.

3.2.2 Effect of VI on physicochemical and antioxidant properties of figs

Sample preparation

Figs were washed with potable water and blanched in boiling water for 1 min (blanching water to fruit mass ratio was 9:1) (Piga *et al.*, 2004). After blanching, the fruits were cooled down to ambient temperature (30 ± 1°C) with iced water immediately. The treated fruits were drained and blotted dry with adsorbent paper.

OD and VI

VI was carried out in a vacuum oven (Hotpack laboratory 273600, Warminster, PA, USA) according to the modified method of Chinprahast *et al.* (2013). Osmotic solution of 60.0 % (w/v) sucrose and 1.0 % (w/v) sodium chloride was prepared. A mass ratio of blanched samples to VI solution was 1:4 w/w. Treatments were applied to whole fruit at VP of 6.8, and 13.5 kPa, for 10 min and followed by a 10-min relaxation (restoration) period at atmospheric pressure and ambient temperature (30 ± 1^{o}C). The VI samples were drained from the solution and separately put into a new VI solution, each of the exactly same concentration, and restored at atmospheric pressure for an additional 4 h. Subsequently, the fruits were drained and blotted with adsorbent paper. In this experiment, the OD at atmospheric pressure for 4 h served as the control.

Evaluation of physicochemical and antioxidant properties of processed figs

3.2.2.1 Physical property

a) The OD and VI fruit peel color was measured using a colorimeter as described in Section 3.2.1.1a.

b) Textural property which is hardness, cutting work and adhesiveness were measured using a texture analyzer with a HDP/BSK blade cutter. The test conditions were pre-test speed of 2.0 mm/s, test speed of 2.0 mm/s, post-test speed of 10 mm/s, distance of 50 mm and trigger force of 10 g, respectively. Eight fruits were randomly selected and measured (Appendix A.1).

c) Microstructure analyses were carried out according the modified method of Moreno *et al*. (2004) and compared to the fresh one using a

scanning electron microscope (SEM, JEOL, Tokyo, Japan) with 15 kV accelerating voltage and 50x zoom level (Appendix A.14).

d) Total soluble solids were measured according to Section 3.2.1.1c.

e) a_w was measured by a water activity meter

3.2.2.2 Chemical property

a) Moisture content was analyzed as described in Section 3.2.1.2a.

b) pH was measured according to Section 3.2.1.2b.

3.2.2.3 Mass transfer

Mass transfer parameters which are water loss (WL), solids gain (SG) and weight reduction (WR) were calculated using Eq. 1 to 3 (Shi, Fito and Chiralt, 1995).

$$\text{Water loss (\%)} = \frac{(M_o \times X_{wo}) - (M_t \times X_{wt})}{M_o} \quad \text{.....(1)}$$

$$\text{Solids gain (\%)} = \frac{(M_t \times X_{st}) - (M_o \times X_{so})}{M_o} \quad \text{.....(2)}$$

$$\text{Weight reduction (\%)} = \frac{(M_o - M_t)}{M_o} x100 \quad \text{.....(3)}$$

Where M_o = initial sample weight (g), M_t = final sample weight (g), X_{so} = initial total soluble solids of the sample, X_{st} = final total soluble solids of the sample, X_{wo} = initial water content of the sample (% w.b.) and X_{wt} = final water content of the sample (% w.b.).

3.2.2.4 Evaluation of TP, TMA contents and antioxidant activities of crude extract

Extraction and determination of TP, TMA contents and the antioxidant activity of the crude extract of the processed figs were performed according to Sections 3.2.1.3a, b, c and d, respectively.

3.2.2.5 Statistical analysis

The experimental design was completely randomized design (CRD) with 4 replicates. Analysis of variance (ANOVA) of the experimental data was performed and Duncan's New Multiple Range Test (DNMRT) was used to evaluate the differences between means at the significance level of 95% ($p \leq 0.05$) (Cochran and Cox, 1992) using analytical software SPSS statistics (Version 17.0, SPSS Inc. Chicago, IL, USA). The results of high antioxidant property were used as criteria to select for further study.

3.2.3 Effects of temperature and shape on drying, physicochemical and antioxidant properties of VI figs

The VI at a VP of 13.5 kPa, the most effective condition in reduction of moisture content and retention of antioxidant property, was chosen from Section 3.2 to prepare samples in this study. The three shapes of VI figs, as whole fruits, pressed fruits (pressed along the longitudinal axis after drying at a specific temperature for 12 h and thickness measured, with a vernier caliper, to be 1 ± 0.2 cm all over) and half fruits (cut into 2 halves along the longitudinal axis), were dried in a tray dryer (Yeo heng model HAL100S, Bangkok, Thailand) at air velocity of 0.5 m/s and temperatures of 55, 60, 70, and 90 °C. The initial weight of the samples used per tray was about 300 g.

3.2.3.1 Drying characteristics

The weight of the sample was recorded up to two decimal places at designed time intervals until a constant weight was obtained. The experiment was performed in duplicate.

Physical property

- a_w at equilibrium moisture content was measured by a water activity meter.

Chemical property

- Initial and equilibrium moisture contents were determined for each sample set according to 3.2.1.2a.

- Moisture ratio (MR) was calculated for each time intervals as ratio of moisture removed at a particular time interval to the total moisture removed. Plots of MR against time were obtained for the different temperature and shapes of the sample. MR was calculated according to Eq. 4

$$MR = \frac{(M_t - M_e)}{(M_o - M_e)} \qquad \text{.....(4)}$$

where M_t and M_o are the moisture content (d.b.) at initial time *o* and time *t*, respectively. M_e is the equilibrium moisture content (d.b.).

3.2.3.2 Evaluation of TP content and antioxidant activities of crude extract

According to the Codex Alimentarius Commission (2008), the moisture content and a_w level of dried fig fruits must be below the critical levels (moisture content can be set at 24% (w.b.) and a_w of less than 0.65). However, the hot-air drying process in this research was concluded when the final moisture content reached 30% (w.b.)

according to the value normally practiced in commercial products. After drying the three shapes of VI figs at 60°C until the final moisture content reached this specified value, extraction of phenolics was performed according to the modified method of Stojanovic and Silva (2007). Dried figs were homogenized using a commercial blender (Dynamic Co. of America, New Hartford, CT, USA) Model 31BL92 for 5 min at the high setting. Five grams of samples were mixed with 20 ml of solvent (methanol containing 4% acetic acid) and kept at 4°C for 15 h with vigorous shaking every 3 h prior to centrifugation. The samples were centrifuged at 4,000 *x g* for 15 min at 10°C using a centrifuge. The pellet was washed with 50 ml of methanol containing 4% acetic acid and centrifuged again under the same conditions. Resulting supernatants were combined and kept at -18°C until used.

Determination of TP content and the antioxidant activity of the crude extract of the processed figs were performed according to Sections 3.2.1.3b and d, respectively. The results of high antioxidant property were used as criteria to select the most appropriate shape of VI figs for further study.

3.2.3.3 Statistical analysis

The experimental design used for studying the effects of temperature and shape on a_w and moisture content at equilibrium was 3x4 factorial in CRD with duplicate and CRD with duplicate for Section 3.2.3.2. ANOVA of the experimental data was performed. DNMRT was used to evaluate the differences between means at $p \leq 0.05$ (Cochran and Cox, 1992) using analytical software SPSS statistics.

3.2.4 Effects of drying methods on physicochemical, antioxidant and sensory properties of VI figs

Fig fruits vacuum impregnated at a VP of 13.5 kPa and with a half-shape were most suitably selected from the previous experiments and used in the present stage of the research in order to compare the effect of three drying methods, viz hot-air drying, multistage drying and MWVD as follows.

3.2.4.1 Hot-air drying

The samples were distributed uniformly as a single layer and dried at a temperature of 60°C and an air velocity of 0.5 m/s for 18 h or until the final moisture content reached 30% w.b. using a tray dryer (Yeo heng Model HA-100S, Bangkok, Thailand).

3.2.4.2 Multistage drying

The samples were distributed uniformly as a single layer and dried at an air velocity of 0.5 m/s and a temperature of 90°C for 90 min followed by 70°C for 150 min and 60°C for 8 h or until the final moisture content reached 30% w.b. with a tray dryer.

3.2.4.3 MWVD

The samples were pre-dried at 90°C for 2 h with a tray dryer and subjected to MWVD at 960 W microwave power in order to maintain the temperature of the material inside the drying chamber below 40°C and absolute pressure in the vacuum chamber was 8 kPa for 20 min or until the final moisture content reached 30% w.b. using a microwave-vacuum dryer (March Cool, Bangkok, Thailand) (Figure 3.1).

Figure 3.1 Microwave-vacuum dryer

3.2.4.4 Physical property

a) The dried fruit peel color was measured using a colorimeter as described in 3.2.1.1a.

b) Textural property which is hardness, cutting work and adhesiveness were measured using a texture analyzer with a HDP/BSK blade cutter and the test conditions followed Section 3.2.2.1b except for the distance which was 20 mm.

c) Microstructure analyses were carried out as described in Section 3.2.2.1c.

3.2.4.5 Evaluation of TP, TMA contents and antioxidant activities of crude extract

Extraction and determination of TP, TMA contents and the antioxidant activity of the crude extract of the dried figs were performed according to Sections 3.2.3.2, 3.2.1.3b, c and d, respectively.

3.2.4.6 Sensory characteristics of dried figs

a) Descriptive Analysis (DA) of dried figs

Dried figs (with the aforementioned drying methods) were labeled with three-digits random numbers and served to the panelists on a white plate. Twenty graduate students from the Department of Food Technology, Chulalongkorn University were recruited and used as the panelists. They had acuity for the four basic tastes and also had experiences in testing of food products with various sensory evaluation methods. They were trained to familiarize themselves for the same standard of evaluation and understand the whole idea for each sensory attribute. Brown color, texture (hardness and chewiness) and flavor (natural flavor of fig and cooked flavor) were evaluated using scale from 0 to 10 on a line scale. After the panelists completed their judgments, the distance was measured from the left end point of the line to each point marked by the panelist, then recorded as intensity ratings between 0.0 and 10.0 for each product (Larmond, 1982) (Appendix B.1). The experiment was conducted under white fluorescence light in an air-conditioned room (25^{o}C).

b) Affective test

Dried figs which (with each drying method) were labeled with three-digits random numbers and served to the panelists on a white plate. Sensory characteristics, including color, flavor, texture and overall preference were evaluated by 50 untrained panelists. Nine-point hedonic scale was used in a sensory ballot (Appendix B.2).

3.2.4.7 Statistical analysis

The experimental designs used for Section 3.2.4 were mainly CRDs with 4 replicates and randomized complete block design (RCBD) for Section 3.2.4.6. ANOVA of the experimental data was performed and DNMRT was used to separate the means at the same significant level using analytical software SPSS statistics.

3.2.5 Effects of storage time and drying method on physicochemical and antioxidant properties of dried figs

After VI and drying, sixty grams of each samples were packed into a polypropylene (PP) bag (size 127 x 203 mm and thickness of 0.075 mm), heat-sealed and stored at room temperature (30 ± 1°C) in an open atmosphere. The following analyses were conducted on 0, 2, 4, 6 and 8 weeks, respectively.

3.2.5.1 Physical property

a) a_w was measured by a water activity meter.

b) The dried fruit peel color was measured as described in 3.2.4.4a.

c) Textural properties including hardness, cutting work and adhesiveness were measured followed Section 3.2.4.4b.

3.2.5.2 Chemical property

a) Moisture content was determined according to 3.2.1.2a.

3.2.5.3 Evaluation of TP, TMA contents and antioxidant activities of crude extract

Extraction and determination of TP, TMA contents and the antioxidant activity of the crude extract of the dried figs were performed according to Sections 3.2.3.2, 3.2.1.3b, c and d, respectively.

3.2.5.4 Statistical analysis

The experimental design was 3x5 factorial in CRD with duplicate. ANOVA of the experimental data was performed and DNMRT was used to separate the means at the same significant level using analytical software SPSS statistics.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Physicochemical and antioxidant properties of whole fresh figs

The whole figs used in this study (Figure 4.1) have the syconium with deep red color, soft and leathery skin and sugary fluid. The flesh was rather dry. The characteristics of this variety of fruits in Thailand were reported previously by Punsri and Thongtham (1983). At the second rapid growth phase, the size increased with more internal development until it reached maturity. The syconium developed more intense reddish purple color with sugary fluid and the flesh was rather dry. Eye scale turned to deep red color, syconium became soft and skin became leathery. Growth and development of the syconium of Dauphine fig cultivar extended within approximately 133 days.

Figure 4.1 An example of fig (Dauphine variety)

Table 4.1 Physicochemical and antioxidant properties of whole fresh figs

Characteristic	Mean ± standard deviation
Color	
L	46.75 ± 3.38
a*	17.89 ± 1.62
b*	23.36 ± 1.83
Hue angle (^{o})	57.43 ± 6.74
Chroma value	29.78 ± 1.69
Hardness (N)	1.47 ± 0.22
TSS (^{o}Brix)	14.80 ± 0.20
a_w	0.996 ± 0.002
Proximate compositions (%w.b.)	
Moisture	86.44 ± 1.40
Ash	0.53 ± 0.05
Protein	0.76 ± 0.05
Lipid	0.09 ± 0.01
Crude fiber	2.56 ± 0.04
Carbohydrate	9.62 ± 1.47
pH	4.42 ± 0.50
Antioxidant property	
TP (mg GAE/100 g w.b.)	47.78 ± 2.71
TMA (mg/100 g w.b.)	2.99 ± 0.32
FRAP value (μmol TE/100 g w.b.)	117.05 ± 3.55

Processors have to evaluate variable differences of fruits since the range of color tones, texture, and the stability of these characteristics in any specific processing method to be employed are points to be considered when selecting raw materials. Visual factors such as size, shape and color are concerned by the grower. However, factors such as quality of texture, color and nutritional value are major importance and, therefore, it is necessary that the grower and processor maintain close contact during the lead-up to harvest so that optimization of yields can be effected. In addition, Flesh firmness, color and also TSS are most currently used as maturity indices (Taylor, 1998; Kader, 2002). The texture, color and TSS of figs used in this study were evaluated and shown in Table 4.1.

In this study, the results of proximate analyses (Table 4.1) are comparable to those properties reported by Morton (1987) who reported the following figures: 77.5-86.8 g moisture, 0.48-0.85 g ash, 1.2-1.3 g protein, 0.14-0.30 g lipid, 1.2-2.2 g fiber and 17.1-20.3 g carbohydrate per 100 g edible portion of figs.

Water is the most abundant component in fruit (more than 80%). Generally, values up to 86% are reported for figs (Wills, Lim and Greenfield, 1987). However, the maximum water content varies between individual fruit of the same kind which might be affected by cultural conditions (Salunkhe, Bolin and Reddy, 1991).

Ash content indicates inorganic residue remaining after destruction of organic matter. It may be exactly equivalent to the mineral matter as some losses may occur due to volatilization or some interaction between constituents. High ash content may be suggestive of the presence of adulterants (Ranganna, 1977). The ash content of Dauphine figs used in this study was also within the range of those values reported elsewhere.

Proteins usually contribute less than 1% to the fresh mass of fruit. The protein content of fresh fruit is calculated by multiplying the total nitrogen content by a factor of 6.25. This figure is based on the fact that protein contains about 16% nitrogen and that all nitrogen, not considering other simple nitrogenous substances that may be present in the uncombined form, is present as protein (Fourie, 1998). Enzymes are important proteins in fruits responsible for the chemical changes that they initiate and are involved in fruit ripening and senescence (Seymour, Taylor and Tucker, 1993). Ficin is a proteolytic enzyme occurring only in the latex of figs and reacts with proteins of the human skin when this fruits are handled. This reaction causes dermatitis, and some individuals are so adversely affected that they cannot ingest the fresh ones (Macrae, Robinson, and Sadler, 1993). Phenoloxidases in figs are responsible for the discoloration of cut surfaces when exposed to air (Fourie, 1998). The protein content (0.76%) of Dauphine figs was relatively lower than the reported value (1.2-1.3%)

Lipids constitute only 0.1-0.2% of most fresh fruits, however, lipids are very important because they make up the surface wax and cuticle which leads to fruit appearance and protect the fruit against water loss and pathogens. The lipid content (0.09%) found in this study was also comparable to the minimum reported value (0.1%). Moreover, they are also important constituents of cell membranes (Kader, 2002).

Crude fiber is the organic residue which is composed largely of cellulose together with a little lignin found mainly in cell walls and varies greatly among commodities. These large molecules are broken down into simpler and more soluble compounds resulting in fruit softening (Kader, 2002). The crude fiber (2.6%) in the fig raw material was a little higher than the maximum reported value (2.2%). However, as the figure obtained tends to vary with the conditions employed, it is important to adopt a standardized procedure in order to obtain consistent results (Ranganna, 1977).

Carbohydrates are the most abundant and widely distributed food component derived from plants. Fresh fruits vary greatly in their carbohydrate content (Kader and Barrett, 1996). Conrastingly, the carbohydrate content (9.6%) of Dauphine fig was extremely lower than the reported values (17.1-20.3%).

Most fresh fruits are acidic. pH of fig samples used in this study reflected their acidity. Acid content usually decreases during ripening due to the utilization of organic acids during respiration or their conversion to sugars (Kader, 2002).

Phenolics are an important constituent of fruit quality because of their contribution to the taste, color and nutritional properties of fruit. In this study, the data of antioxidant properties were compatible to those values of the species reported by Caliskan and Polat (2011) who found the TP contents ranging from 28.6 to 211.9 mg GAE/100 g (fresh weight, FW) with an average of 51.8 mg GAE/100 g FW, the amount of TMA ranging from 0.0 to 298.9 g cy-3-rutinoside/g FW, with an average of 18.2 g cy-3-rutinoside/g FW.

The ranges of the reported chemical figures including TP and TMA of figs were very widely varied due to the variations between variety, maturity state, different environmental conditions, time of harvest and were heavily dependent on the growing technology in the orchard and procedure analysis (Veberic *et al*., 2005; Solomon *et al*., 2006; Veberic *et al*., 2008; Caliskan and Polat, 2011; Yemiş *et al*., 2012).

Yemiş *et al*. (2012) characterized and quantified anthocyanins in three fresh fig varieties cultivated in Turkey by HPLC/DAD and HPLC/MS and conclued that the most abundant anthocyanin pigment in all the studied varieties was cyanidin-3-rutinoside. Although considerable quantitative differences in anthocyanin composition of these fruits were shown among cultivars, all cultivars had a similar qualitative profile.

4.2 Effect of VI on physicochemical and antioxidant properties of figs

VI can improve quality of products as it operates at a low temperature and with minimum oxygen content using sugar or syrup as VI solutions. Therefore, it can preserve color, texture and prevent loss of fresh fruit components including antioxidants. Moreover, it can save energy by removing water partially without heating leading to reduction of drying time necessary for optimal preservation of fruits. Thus, conventional OD and VI at two VP levels were used to compare their effects on physical properties of the pretreated figs.

Table 4.2 Color values of figs from various treatments

Treatments	L^{*ns}	a^{*}	b^{*ns}	Hue angle (^{o})^{ns}	Chroma^{ns}
OD	60.67 ± 2.98	-4.22^{a} ± 0.36	39.02 ± 2.65	264.26 ± 1.23	39.34 ± 2.68
VI (6.8 kPa)	60.22 ± 1.04	-5.20^{b} ± 0.42	37.88 ± 1.59	260.56 ± 3.49	38.29 ± 1.57
VI (13.5 kPa)	59.75 ± 3.24	-4.87^{ab} ± 0.61	38.21 ± 3.75	263.66 ± 1.90	38.52 ± 3.79

^{a,b} Means (± standard deviation) in the same column with different letters are significantly different ($p \leq 0.05$).

^{ns} not significantly different ($p > 0.05$).

Color assessment in food is of great interest in the food industry. VI can reduce heat damage to plant tissues by using a gentle treatment at a relatively low processing temperature and preserves color (Ponting, 1973; Escriche *et al*., 2000; Talens *et al*., 2002). It also prevents discoloration of fruit pieces from enzymatic and oxidative browning without using antioxidants because oxygen from the pores is removed (Ponting *et al*., 1966; Contreras and Smyrl, 1981; Alzamora *et al*., 2000). However, the loss of color is one of the most significant changes during the OD process.

From the data obtained (Table 4.1 and 4.2), the *L**, *b**, hue angle and chroma values increased after OD or VI, which might be resulted from a higher transfer of anthocyanins from fruits into the osmotic solution, making the products ‘‘lighter’’ and indicating a fading of the typical dark color of figs. Apparently enough, the *b** values also straightforwardly increased indicating the significant effects of either OD or VI to leach out more anthocyanins resulting in the lower blue but higher yellow (*b**) values. Osorio *et al*. (2007) confirmed the transfer of important anthocyanin pigments from the fruits to the solutions during the dewatering-impregnation-soaking process of Andes berry and tamarillo, suggesting the potential use of these resultant solutions as natural additives (color) in the industry. From the study of Deng and Zhao (2008), the OD apples had higher *L** values than those not subjected to osmotic treatment representing the decreased degree of browning discoloration in osmotic samples, probably because OD provoked a decrease in PPO activity responsible for browning (Chiralt and Talens, 2005) and the concentration gradient resulted in partial loss of fruit pigments. These color differences were also observed visually. However, no significant differences ($p > 0.05$) in *L**, *b**, hue angle and chroma values were found among three different osmotic conditions used in this research.

Table 4.3 Textural property of figs from various treatments

Treatments	Hardness (N)[ns]	Cutting work (N.sec)[ns]	Adhesiveness (N.sec)[ns]
OD	14.74 ± 1.57	124.33 ± 10.84	1.45 ± 0.13
VI (6.8 kPa)	14.59 ± 1.57	129.09 ± 10.83	1.38 ± 0.13
VI (13.5 kPa)	15.23 ± 1.49	127.60 ± 10.60	1.16 ± 0.71

[ns] not significantly different ($p > 0.05$).

The application of vacuum induced greater firmness by replacing the osmotic solution (OS) into pores due to air loss, thus obtaining a more compact but less deformed tissue than that produced at atmospheric pressure (Moreno *et al*., 2000). Nevertheless, in this study (Table 4.3), VI did not affect the texture property (hardness, cutting work and adhesiveness) of the samples ($p > 0.05$). This was probably due to no textural difference of all the OD and VI samples as they are still having high and similar moisture contents (Table 4.4).

To better understand the effect of different OD treatments at cell level on mass transfer and texture characteristics, a scanning electron microscopy (SEM) technique was suggested for observing structural changes of samples (Moreno *et al*., 2004). Figure 4.2a shows the microstructure of fresh fig. A high degree of cell compartmentation and small intracellular spaces were observed. The distribution of cell size was uniform in the cut sections (Moreno *et al*., 2004). The cellulose of the cell wall gives rigidity and strength to the structure, whereas pectin and hemicelluloses of the middle lamella give plasticity and dictate the degree to which the cells can be pulled apart during deformations (Lewicki and Porzecka-Palak, 2005).

The effects of OD and VI treatments are shown in Figure 4.2b to 4.2d. After osmotic treatment, SEM micrographs showed the breakdown of cell walls, a decreased intercell contact and collapse of cell structure of samples, which may be explained by the native liquid loss. The cellular tissue exposed to VI or OD presented different alterations of cellular structures corresponding to the different mass transfer. From the data obtained, it was obvious that the higher VP could result in shrinkage of cells and increasing numbers of pores which could be caused by increasing WL during VI and vacuum application (Table 4.5). It was observed that the integrity of structure was greater in OD than VI treatments explaining the differences found in TSS and SG values

(Table 4.4 and 4.5). This could be due to such materials as polymeric compounds or concentrated sugars, which may be formed by interactions of middle lamella pectin with osmotic solution solutes (Moreno *et al*., 2004).

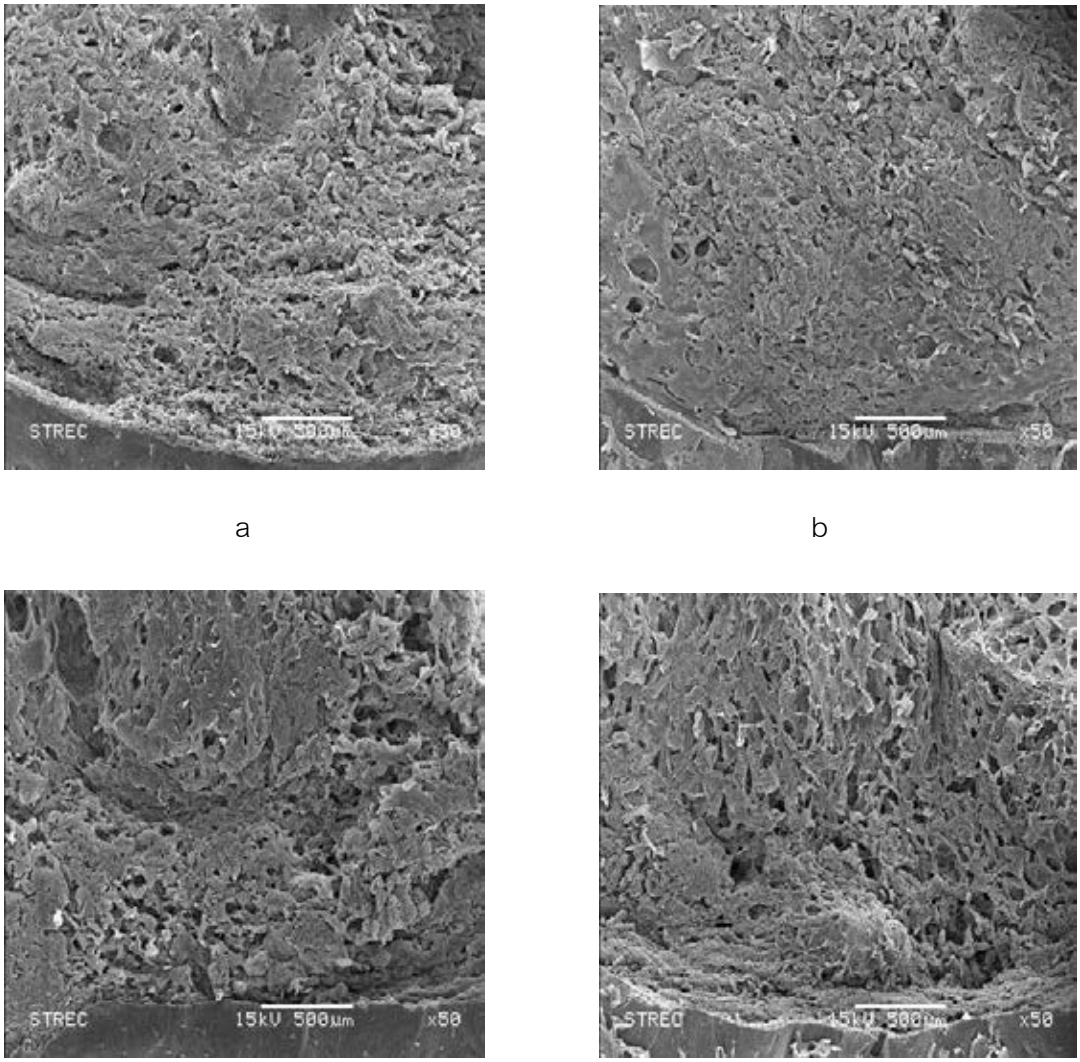


Figure 4.2 Microstructure of fresh fig in different treatments: fresh fig (a), OD fig (b), VI fig (6.8 kPa) (c) and VI fig (13.5 kPa) (d).

Table 4.4 shows the compositions, a_w and pH of fresh and processed figs. It was found that OD and VI resulted in reduction of moisture content ($p \leq 0.05$) but increased

TSS. These results can be described by Dixon and Jen (1977) in that OD is applied with the goal of modifying the composition of food material through partial water removal and impregnation of solutes. During the osmotic process, there are two major simultaneous countercurrent flows due to water and the osmotic solute activity: flow of water from the food into the osmotic solution and flow of solutes from the solution into the food. In this multiphase food system, mass transfer rates are attributed to the water and solute activity gradients across cell membranes as both solutes and water seek equilibrium.

Table 4.4 Compositions, a_w and pH of figs from various treatments

Treatments	Moisture (% w.b.)	TSS (^{o}Brix)	a_w ^{ns}	pH^{ns}
Fresh fig	86.44^{a} ± 1.40	14.80^{b} ± 0.16	0.996 ± 0.002	4.42 ± 0.50
OD	80.78^{b} ± 0.86	16.55^{a} ± 0.41	0.996 ± 0.003	4.93 ± 0.01
VI (6.8 kPa)	82.51^{b} ± 0.62	14.38^{bc} ± 0.72	0.991 ± 0.004	4.92 ± 0.02
VI (13.5 kPa)	82.28^{b} ± 2.09	14.00^{c} ± 0.25	0.993 ± 0.005	4.73 ± 0.24

$^{a,b...}$ Means (± standard deviation) in the same column with different letters are significantly different ($p \leq 0.05$).

^{ns} not significantly different ($p > 0.05$).

The treatment at too high VP could decrease TSS value as it may force gas and liquid of the plant tissues to rapidly diffuse outwards, resulting in size reduction of the pores (or even collapse), thus obstructing the subsequent inflow of liquid resulting in low TSS value (Fito *et al*., 2001a). For pH value, it was increased, although not significantly, because during osmotic concentration, elution of low-molecular weight substances (organic acids, vitamins) occurred. This elution, although quantitatively insignificant in

the mass exchange, can have a significant influence on the final nutritive values and sensory properties of foods (Lenart, 1996).

Table 4.5 WL, SG and WR from various treatments

Treatments	WL(%)	SG(%)	WR(%)
OD	$14.46^{b} \pm 1.93$	$0.82^{a} \pm 0.05$	$10.80^{b} \pm 1.01$
VI (6.8 kPa)	$13.91^{b} \pm 1.37$	$0.80^{a} \pm 0.04$	$10.13^{b} \pm 0.87$
VI (13.5 kPa)	$19.92^{a} \pm 0.73$	$0.55^{b} \pm 0.06$	$19.21^{a} \pm 0.88$

[a,b] Means (± standard deviation) in the same column with different letters are significantly different ($p \leq 0.05$).

It was found that the higher vacuum pressure, the higher WL and WR but the SG was decreased ($p \leq 0.05$). Difference between WL and SG values are resulted from the molecular weight or diffusion coefficients of water and sugar in the product (Bolin *et al*., 1983). The mass transfer in osmotic processing is much faster under vacuum due to the coupling of osmotic/diffusional mechanism and HDM (Fito 1994). Shi and Maupoey (1993) reported that higher WL rate can be obtained in low-pressure systems but SG differs marginally between OD and VI treatments because the main factor affecting the SG is only the biological microstructural characteristics of plant tissue. Moreover, different kinds of fruits may react differently to VI when SG is taken into account. Mújica–Paz *et al*. (2003a) found that VP affected SG of mango. The application of high VP can open the fibrous structure of the sample, producing spaces that can be filled with a low concentration OS (with low viscosity), which can exit tissue together with native liquid during the relaxation period at atmospheric pressure, yielding low SG values. This phenomenon was also observed in our study in that the higher the VP, the lower the SG. Certain solutes impregnated into the pores were found to protect natural tissue structure, thus improving texture and lowering drip loss in sequential drying by limiting

collapse and cellular disruption (Bolin and Huxsoll 1993). In many cases, however, extensive solute uptake is undesirable, because of its negative impact on taste and the nutritional profile of the product (Lazarides, 2001). In every case, solute uptake leads to the development of a concentrated solids layer under the surface of the fruit, upsetting the osmotic pressure gradient across the fruit-medium interface and decreasing the driving force for water flow (Hawkes and Flink, 1978). Besides its negative impact on the rate of water loss during OD, solute uptake blocks the surface layers of the product, posing an additional resistance to mass exchange and lowering the rates of complimentary dehydration (Lenart and Grodecka, 1989). Conclusively, vacuum treatment, particularly at VP of 13.5 kPa is effective in increasing water diffusion and results in a noticeable increase in WL and WR. In this study, the low WL, WR (less than 20%) and SG (less than 1%) were observed. These values are remarkably different from the values reported elsewhere. This is probable due to influences of peel, size and geometry of sample. García-Segovia *et al*. (2010) found that the effect of peeling was important and a higher WL was found for peeled Aloe vera. Falade, Igbeka and Ayanwuyi (2007) found that WL and SG of watermelon immersed into 50^{o}Brix sucrose solution at 40^{o}C for 4 h increased to approximately 60 and 20%, respectively, while samples thickness decreased due to the width ratio and the increase on surface area in contact with the osmotic solution. According to Lerici *et al*. (1985), higher specific surface (the surface/volume ratio) samples, i.e., rings, gave higher WL and SG values than lower specific surface shapes, i.e., cubes.

Table 4.6 Total phenolics, total anthocyanins contents and FRAP value from various treatments

Treatments	Total phenolics		Total anthocyanins		FRAP value	
	(mg GAE/100 g)	(mg GAE/100 g d.b.)	(mg/100 g)^{ns}	(mg/100 g d.b.)^{ns}	(μmol TE/100 g)	(μmol TE/100 g d.b.)
OD	54.03^{ab} ± 1.85	281.11^{b} ± 9.65	2.48 ± 0.24	12.91 ± 1.23	91.12^{b} ± 6.21	474.07^{b} ± 32.30
VI (6.8 kPa)	50.88^{b} ± 3.11	290.90^{b} ± 17.76	2.44 ± 0.45	13.92 ± 2.57	128.37^{a} ± 7.14	733.98^{a} ± 40.82
VI (13.5 kPa)	55.87^{a} ± 1.08	315.31^{a} ± 6.12	2.72 ± 0.25	15.33 ± 1.44	140.53^{a} ± 14.47	793.05^{a} ± 81.67

^{a,b} Means (± standard deviation) in the same column with different letters are significantly different ($p \leq 0.05$).

^{ns} not significantly different ($p > 0.05$).

The TP, TMA contents, and FRAP values of OD and VI figs are compared with the fresh one (Table 4.2 and 4.6). Change in TP including anthocyanin concentrations, expressed in mg per 100 g (wet basis) of product, cannot be used to determine the degradation rate of substances that occurs during the different processes because of the different moisture contents of the samples (Stojanovic and Silva, 2007). However, it is useful in comparison with the results of other authors, as well as from a nutritional standpoint. From a nutritional standpoint, consuming 100 g of dehydrated product would be equal to or more advantageous than eating 100 g of fresh product, since dried products contain the same or higher amounts of TP and TMA, depending upon pretreatment (Stojanovic and Silva, 2007). Approximately 10-20, 30-40 and 8-45% of TP, TMA and FRAP values, respectively, were lost during OD and VI (calculated in 100 g d.b.). OD and VI induced loss of phenolics including anthocyanins by migration into the osmotic solution. The highest significant decrease in the TP was observed in the sample that was osmotically treated at asmospheric pressure. This was almost identical to anthocyanins lost in the same process.

Chottanom *et al*. (2012) reported that the osmotic treatment of mulberries for 6 h caused a significant reduction in anthocyanins and phenolics. The 52-61% reduction in anthocyanins and the 51-68% reduction in phenolics on a dry weight basis were found when compared to those values before treatment. Giovanelli *et al*. (2012), in a study with blueberries, exhibited total and individual anthocyanins were significantly influenced by pretreatment, osmosis time and osmotic solution and their interactions. However, both total polyphenols and total anthocyanins were partially lost in the osmotic treatments. In particular, higher losses were observed for total anthocyanins in the unblanched samples, with no differences related to the kind of osmotic solution used. Substantial losses in anthocyanins could be explained by the rationales that these molecules are

naturally water soluble and localized in the skin, therefore they are removed by dissolution into the osmotic solution (Osorio *et al*., 2007). Adding sugar solution increased the pH value of solution and figs, and increased the percentage of anthocyanins in the colorless carbinol base form that is very unstable, making the pigment more susceptible to degradation by oxygen. However, fruit extract is very complex and it is difficult to distinguish which compounds contribute the most to antioxidant activity (Stojanovic and Silva, 2007). The greater VP exhibited the higher TP, TMA contents and FRAP values and the higher the polyphenol content, particularly anthocyanins, in fig fruits, the higher their antioxidant activity (Solomon *et al*., 2006). All the highest reported values were obtained at VP of 13.5 kPa because VI can prevent fruit from oxidation due to removal of oxygen from the porous structure. From the data obtained, VP of 13.5 kPa was the most effective in reduction of moisture content and retention of antioxidant property, thus, it was chosen to pretreat the samples before drying.

4.3 Effects of temperature and shape on drying kinetics, physicochemical and antioxidant properties of VI figs

Drying temperature and shape of sample significantly influence physicochemical and sensory properties of the thermally processed foods. Increasing of drying temperature can increase drying rate, whose value is also affected by different shapes of samples. Ganjyal *et al*. (2003) found that drying of sapota fruits proceeded obviously at a faster rate as the temperature increased and drying of the fruit slices was faster than the quarter-cut and the half-cut samples, respectively.

From the data obtained (Table 4.7), drying time, a_w and moisture content were dependent on the drying temperature and the shape of sample ($p \leq 0.05$). Increasing of drying temperature of samples with the same shape could decrease those values

Table 4.7 Effects of temperature and shape on drying time, a_w and moisture content of VI figs

Shapes	Drying temperature (°C)	Drying time (h)	a_w	Moisture content (% w.b.)
Whole	55	54	$0.490^{a} \pm 0.038$	$18.60^{a} \pm 1.70$
	60	57	$0.488^{a} \pm 0.002$	$19.63^{a} \pm 0.88$
	70	27	$0.353^{de} \pm 0.007$	$12.66^{bcd} \pm 1.34$
	90	15	$0.347^{de} \pm 0.021$	$9.24^{e} \pm 0.52$
Pressed	55	48	$0.482^{a} \pm 0.001$	$17.98^{a} \pm 0.64$
	60	33	$0.455^{ab} \pm 0.003$	$18.10^{a} \pm 0.62$
	70	24	$0.404^{bcd} \pm 0.003$	$14.37^{b} \pm 0.61$
	90	15	$0.385^{cd} \pm 0.003$	$10.66^{de} \pm 0.18$
Half	55	30	$0.455^{ab} \pm 0.036$	$14.16^{bc} \pm 0.98$
	60	27	$0.436^{abc} \pm 0.001$	$14.50^{b} \pm 0.45$
	70	15	$0.324^{e} \pm 0.020$	$11.56^{cde} \pm 0.21$
	90	9	$0.320^{e} \pm 0.004$	$9.40^{e} \pm 0.09$

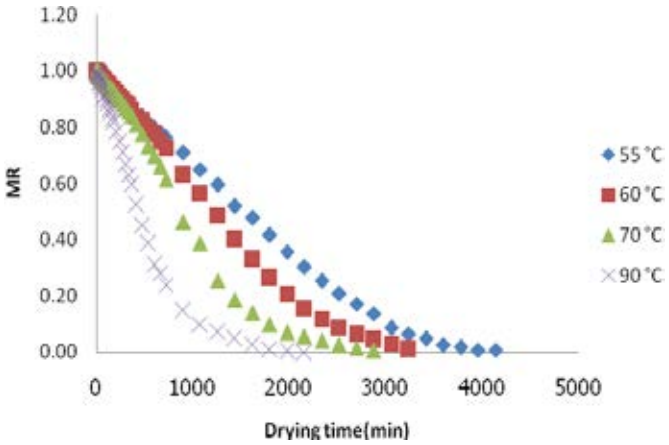
[a,b,...]Means (± standard deviation) in the same column with different letters are significantly different ($p \leq 0.05$).

since heat is the driving force for water to evaporate from the product resulting in a greater water removal together with a reduction of a_w at the higher temperature. In

addition, as the temperature increased, dehydration proceeded at a faster rate, which was obvious as the slope of the drying curve increased with the increase in the drying temperature (Figure 4.3a-4.3c). These results were similar to the results of Ganjyal *et al*. (2003), who reported that temperature had a strong effect on drying. With an increasing temperature, drying was faster due to the faster removal of moisture resulted from higher driving forces of the heat and air.

Effect of sample shape on drying time, a_w and moisture content is also considered. Decreasing of sample size at the same drying temperature could remove water and hence decreased a_w as this factor can be described by the surface area and the volume of the sample. In this research, the surface area per unit volume (cm^{-1}) of the whole, pressed and half VI fig were 1.03 ± 0.09, 2.02 ± 0.31 and 5.70 ± 2.03, respectively. Increasing of the surface area leads to increased heat and water mass transfer rate (Madamba, 2003). Therefore, the resultant a_w as affected by these two phenomena should accordingly decrease.

a



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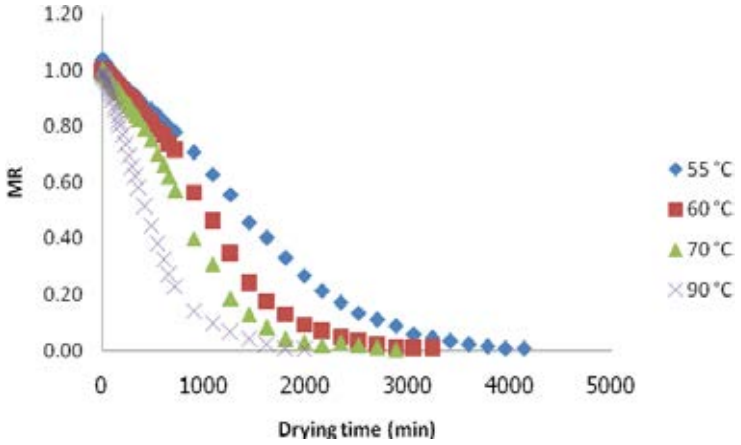

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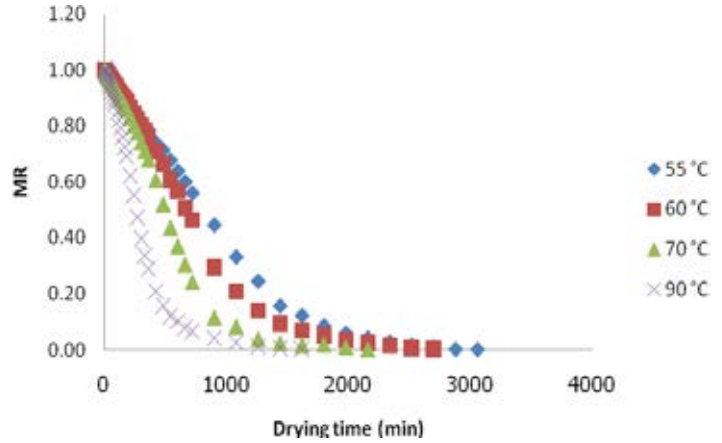
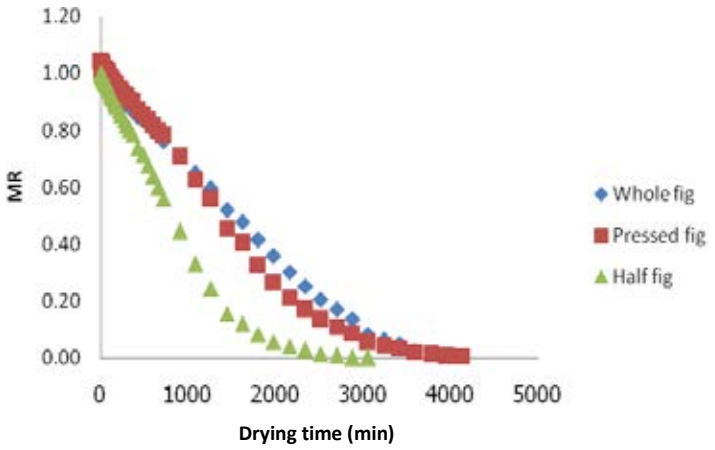


Figure 4.3 Effect of temperature on drying kinetics of fig, shown as MR vs. drying time (min). a) Whole fig b) Pressed fig and c) Half fig

Figures 4.4a-4.4d showed effect of shape on drying kinetics of figs at 55, 60, 70 and 90°C, respectively. It was obvious that drying rate of half fruits was higher than those of the pressed and whole fruits, respectively. Thus, drying time was shortest. These could be ascribed to the size or surface area per unit volume and peel of the samples. Decreasing in sample size or increasing in surface area per unit volume can improve heat and mass transfer contributing to faster water removal from samples (Madamba, 2003). Ganjyal *et al*. (2003) found that drying rate of the sliced sapota was higher than quarter, and half-cut sample, respectively. Xanthopoulos *et al*. (2010) found

that drying rate of the peeled fig was higher than that of the unpeeled sample since the peel which was a water transfer barrier had been removed. Therefore, half fig with partial peel and smaller size gave the higher drying rate than the unpeeled pressed and the whole fig. Nonetheless, the drying curves of samples were quite close at higher temperatures. This is probably due to faster water removal and consequently faster occurrence of case hardening of products having high sugar content, like figs (Xanthopoulos *et al.*, 2010). Achanta and Okos (1996) stated that case hardening could be reduced by drying at lower temperatures where drying rate was slow enough to allow gradual water loss from the surface of the product to be replenished by water from the inside of the product.

a



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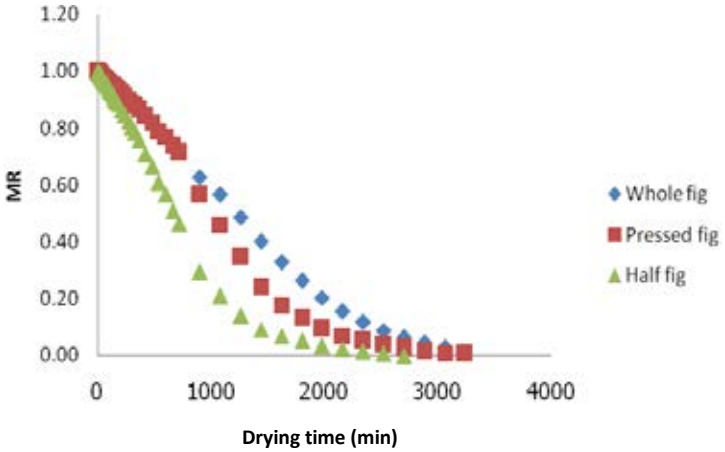

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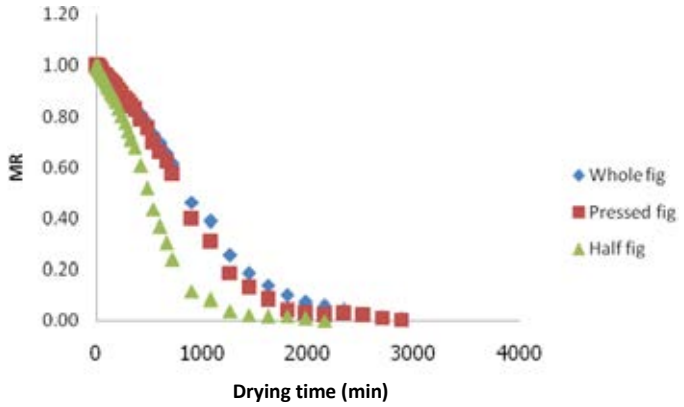

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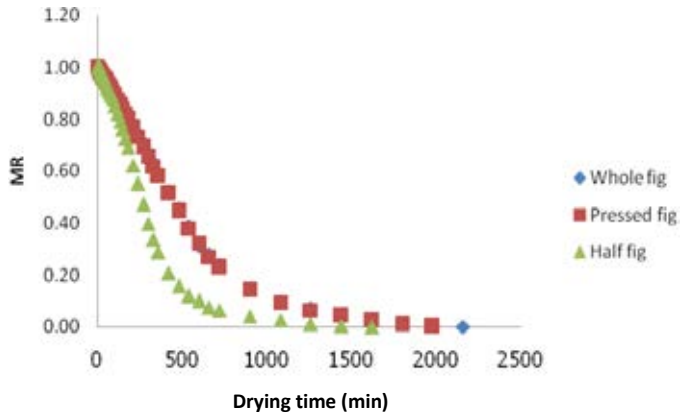


Figure 4.4 Effect of shape on drying kinetics of fig, shown as MR vs. drying time (min). a) 55°C b) 60°C c) 70 °C and d) 90 °C

Drying times of figs possessing different shapes to reach the moisture content of 30% (w.b.) are shown in Table 4.8. It seemed that the drying time was influenced by drying temperature more than shape of the sample which was obvious as the slope of the drying curve as affected by temperature was steeper than that of shape. For the sample with the same shape, increasing of drying temperature resulted in shorter drying time than changing the shape of samples.

Table 4.8 Drying times of figs until the moisture content reached 30% (w.b.)

Drying temperature (°C)	Drying time (h)		
	Whole	Pressed	Half
55	42	36	21
60	30	24	18
70	21	18	12
90	10	10	4.5

Increasing of drying temperature or changing the shape of sample could increase drying rate or shorten drying time. However, other quality attributes should be considered. For example, higher temperature or longer drying time leaded to a degradation of phenolics (Vega-Gálvez *et al.*, 2012).

Table 4.9 shows TP contents and FRAP value of dried figs with different shapes. It was found that the half sample exhibited the highest of both values. This was probably due to shorter drying time and therefore less exposure of the phenolics to thermal and oxygen deterioration effects and long drying times may promote a decrease in antioxidant activity (Garau *et al.*, 2007). However, the standard deviations for those values of the pressed sample were quite high which might be resulted from leakage of liquid from the sample during the pressing step. Conclusively, the half fig showed the highest drying rate and antioxidant property. Therefore, it was chosen to study further for effect of various drying methods.

Table 4.9 Effect of the shape of VI figs on TP contents and FRAP value

Treatments	Total phenolics (mg GAE/100 g d.b.)[ns]	FRAP value (μmol TE/100 g d.b.)
Whole	270.08 ± 1.61	315.13[b] ± 29.23
Pressed	260.86 ± 17.46	364.26[ab] ± 45.52
Half	271.83 ± 1.59	464.92[a] ± 20.79

[a,b] Means (± standard deviation) in the same column with different letters are significantly different ($p \leq 0.05$).

[ns] not significantly different ($p > 0.05$).

4.4 Effects of drying methods on physicochemical, antioxidant and sensory properties of VI figs

In this part of the research, it was postulated that different drying methods could exert varying physical properties of the processed figs. Therefore, three dying methods, viz. hot-air drying, multistage drying and MWVD were compared and the results are discussed as follows.

Drying methods and temperature significantly affected the color changes of figs. It is well known that reduced quality of food products because of browning effects is mainly due to the thermal effect of the drying (Chou and Chua, 2001). From the data obtained (Table 4.2 and 4.10), the *L**, *b**, hue angle and chroma values decreased but *a** value increased after drying. Our results about the changes in these values during drying were similar to Piga *et al*. (2004), who studied the hot-air dehydration of figs under mild processing conditions and reported that Hunter *L**, *a**, *b** and hue values of fresh figs were 62.15, -21.76, 49.85 and 113.68, respectively. At the end of drying the blanched sample, these values significantly changed to 46.56, -0.01, 38.49 and 89.96, respectively. The general trend was a decrease in lightness (*L**) and a shift to a reddish

(hue) and deeper (chroma) zone in the Hunter solid (Piga *et al*., 2004). Drastic increase in *a** value implies a redder chroma, and this increase can be attributed to the formation Maillard reaction products. The Maillard reaction products that are brown color are known as a result of the formation of various pigments such as melanoidins (Yemiş *et al*., 2012). The fact that the fig varieties include considerable amounts of fructose and glucose as reducing sugars (Caliskan and Polat, 2011) and amino acids implies that a Maillard reaction as a result of the interaction of these compounds may occur in the dried figs during drying (Yemiş *et al*., 2012).

Table 4.10 Effects of drying methods on color values of dried figs from various teatments

Treatments	$L^{*\,ns}$	a^*	b^*	Hue angle $(^o)^{ns}$	Chroma
Hot-air drying	37.69 ± 2.00	7.72^{ab} ± 0.59	21.59^{a} ± 2.09	69.05 ± 2.97	22.98^{a} ± 2.07
Multistage drying	38.18 ± 1.72	8.31^{a} ± 0.34	22.02^{a} ± 1.19	67.88 ± 1.97	23.49^{a} ± 1.37
MWVD	35.27 ± 2.76	7.10^{b} ± 0.58	16.18^{b} ± 1.60	63.75 ± 5.31	17.72^{b} ± 1.71

$^{a,b..}$ Means (± standard deviation) in the same column with different letters are significantly different ($p \leq 0.05$).

No significant differences ($p > 0.05$) in L^* value and hue angle were found among three different drying methods (Table 4.10). The highest values of a^*, b^* and chroma were found in the multistage dried sample while the lowest values were observed in the MWVD sample. Arslan and Özcan (2011) found that the decrease in L^* values of dried red bell-pepper slices can be attributed to brown pigment formation during dryings. Park and Lee (1975) reported that brown pigment in dried red peppers was due to their high levels of reducing sugars and amino acids in red pepper and

concluded that the longer drying time and higher temperatures involved in oven drying led to reduction in the lightness of the samples. Therefore, the multistage dried sample and MWVD sample (pre-dried at 90°C for 2 h) which were dried at higher temperatures for a long time were darker than hot-air dried sample. However, the hue angle, a parameter reflecting the visual color appearance, was similar to the commercial product whose *L**, *a**, *b**, hue angle and chroma were 59.16, 11.02, 30.59, 69.80° and 32.60, respectively.

Texture plays an important role on the acceptability of foods by the consumers. It is the result of complex interactions among food components (Guiné and Barroca, 2012). In this study, physical textural profiles of the samples dried with various methods are given in Table 4.11.

Table 4.11 Effects of drying methods on textural property of dried figs from various treatments

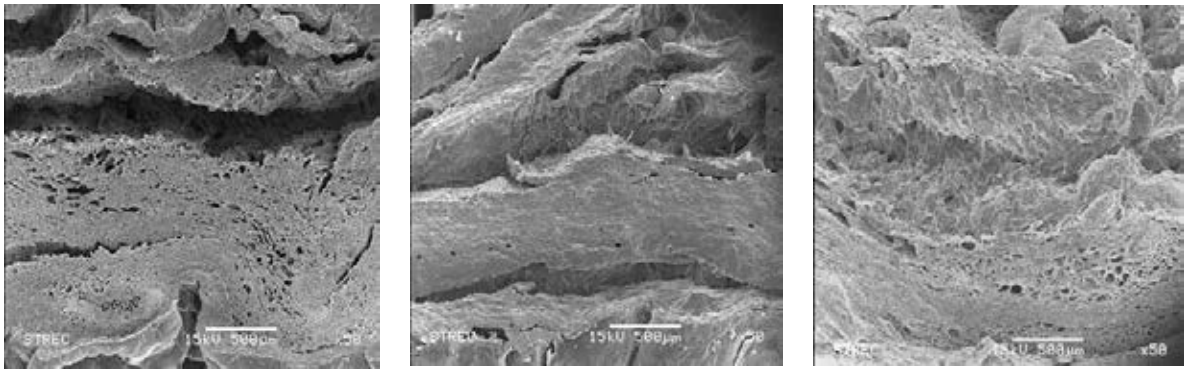
Treatments	Hardness (N)	Cutting work (N.sec)	Adhesiveness (N.sec)
Hot-air drying	$52.47^{b} \pm 1.74$	$162.35^{b} \pm 3.74$	$1.24^{b} \pm 0.01$
Multistage drying	$58.62^{a} \pm 2.04$	$154.18^{b} \pm 4.62$	$1.26^{b} \pm 0.12$
MWVD	$57.65^{a} \pm 2.66$	$300.05^{a} \pm 7.54$	$1.58^{a} \pm 0.02$

[a,b] Means (± standard deviation) in the same column with different letters are significantly different ($p \leq 0.05$).

There were significant effects of drying methods on hardness, cutting work and adhesiveness of dried fig. Hot-air dried sample showed the lower hardness than the other two samples ($p \leq 0.05$) while the MWVD sample showed the higher cutting work and adhesiveness. These results are different from the study of Lin *et al*. (1998) who

found that the MWVD carrot slices (without pre-drying) were softer than air dried samples. Other than being pre-treated differently, cellular and tissue structures of carrot and fig could be dissimilar. Also, their proximate compositions could probably differ. These aspects could possibly explain different results found in the two studies. Our result might probably be accounted for by a postulation that different drying methods produced different shapes of samples. It was observed that the half MWVD fig curled after drying leading to a greater thickness of the sample while the other methods produced the flat shapes (Appendix C). Thus, those values of MWVD samples were higher than the others. In addition, those values might increase because of case hardening effect at higher temperatures (pre-dried at 90^{o}C) as described by Xanthopoulos *et al*. (2010). They found that the peeled figs were dehydrated faster at the beginning of the process at higher temperatures (>60^{o}C) and therefore sugars were moved to the surface faster than in the unpeeled figs which resulted in faster occurrence of the phenomenon. The texture of the samples might be comparable to the commercial product in which the hardness, cutting work and adhesiveness were 66.81 N, 431.99 N. sec and 0.29 N. sec, respectively. Nevertheless, the different values might be resulted from the different raw material, pretreatment and drying method.

When comparing the tissue of dried figs (Figure 4.5) with the tissue of fresh fig (Figure 4.2a), a clear cell breakage was observed indicating loss of turgor and loss of cell content at the breakage zone of the dried sample. This probable turgor loss presents degradation and causes a possible shrinkage in the contours of the cell wall. In general, air drying of vegetable tissue is characterized by an extensive shrinkage and microstructural change (Aguilera, Chiralt and Fito. 2003; Vega-Gálvez *et al*., 2012). The microstructure of multistage dried sample was less damaged than the hot-air dried one. SEM micrographs clearly show that the drying temperature and time strongly affect the



a b c

Figure 4.5 The microstructure of hot-air dried fig (a), multistage dried fig (b) and MWVD fig (c).

microstructure of dried samples. The higher temperature (70°C) and longer drying times (225 min at 50°C) caused greater damage to the microstructure of eggplant slabs. The slabs dried at 60°C had a structure similar to fresh ones and larger pore sizes compared with the samples dried at 50°C and 70°C. On the contrary, dehydrated slabs at 50°C and 70°C showed a more wrinkled structure with respect to that of the fresh sample. In particular, the samples dried at higher temperature show a totally damage structure (Russo, Adiletta and Matteo, 2012). From Figure 4.5c, MWVD fig had porous structure because of massive and fast water vaporization during microwave-vacuum drying (Therdthai and Visalrakkij, 2012). As a result, vapor could increase total pressure inside the sample as well as enhancing the porosity (Bai-Ngew, Therdthai and Dhamuithee, 2011).

The antioxidant property was shown in Table 4.12. Depending on the drying methods, VI followed by drying process decreased the TP, TMA contents and FRAP values approximately by 10-15, 80-93 and 14-34%, respectively compared to the fresh sample (Table 4.1) and 0-3, 72-90 and 6-28%, respectively compared to the VI (13.5 kPa) sample (Table 4.6). The MWVD sample showed the highest values whereas the hot-air dried sample exhibited the higher TP and TMA but lower FRAP values than the multistage dried one. Removal of the waxy layer and microwounds on the peel caused by blanching (Piga *et al*., 2004) might increase loss of TP and TMA contents during VI. Stojanovic and Silva (2007) reported that removal of the waxy layer and ruptures caused by freezing led to high loss of anthocyanins of thawed blueberries during OD which could be mostly attributed to the leakage of anthocyanins through the cuticle and skin ruptures. This is because anthocyanins are naturally concentrated in the epidermal and sub epidermal layers of such this fruit. This rationale might also be applied for explanation of the results found in our study. Similar results were reported by Kwok *et al*. (2004) where 85% of anthocyanins were lost during air-dehydration of Saskatoon berries at 75^{o}C. Lohachoompol *et al*. (2004) reported 49% loss of anthocyanins in pretreated blueberries dehydrated in a cabinet dryer for 5.5 h, with gradual decrease of temperature from 90 to 50^{o}C. Temperature elevation (70^{o}C) caused anthocyanin degradation since they began to degrade at temperatures greater than 63^{o}C, but more importantly, it enhanced the negative influence of high sugar concentration. At high temperatures, production of furfural and 5-hydroxymethyl furfural increases, and this can degrade the pigment molecule and enhance the negative influence of oxygen (Stojanovic and Silva, 2007). Debicki-Pospišil *et al*. (1983) proposed cyanidin degradation in the presence of aldehydes in three different pathways. They also reported that aldehyde effect on pigment degradation at 70^{o}C was considerably diminished, but still proceded, when the reaction was occurring in inert nitrogen

Table 4.12 Effects of drying methods on TP, TMA contents, and FRAP value

Treatments	Total phenolics		Total anthocyanins		FRAP value	
	(mg GAE/100 g)[ns]	(mg GAE/100 g d.b.)[ns]	(mg/100 g)	(mg/100 g d.b.)	(μmol TE/100 g)	(μmol TE/100 g d.b.)
Hot-air drying	234.02 ± 17.36	316.25 ± 23.02	1.81[b] ± 0.17	2.45[b] ± 0.23	421.34[b] ± 12.79	569.38[b] ± 17.29
Multistage drying	220.58 ± 21.41	298.08 ± 29.68	1.09[c] ± 0.10	1.48[c] ± 0.13	450.70[b] ± 43.59	609.06[b] ± 58.90
MWVD	244.03 ± 10.10	316.92 ± 13.12	3.29[a] ± 0.33	4.27[a] ± 0.43	573.95[a] ± 15.13	745.39[a] ± 19.64

[a,b,...]Means (± standard deviation) in the same column with different letters are significantly different ($p \leq 0.05$).

[ns] not significantly different ($p > 0.05$).

atmosphere. This suggests that oxygen appears to accelerate the degradation, but was not a necessary prerequisite for the degradation to occur. The combination of long dehydration time, availability of oxygen, high temperature, and high sugar concentration resulted in the loss of anthocyanins (Stojanovic and Silva, 2007).

Drying of figs did not have as much influence on TP contents as it did on the anthocyanins due to the different behaviour of anthocyanins and total phenolics during drying. Similar results have been reported by Kalt, McDonald and Donner (2000) who explained that anthocyanins had a higher susceptibility to elevated temperature and oxygen than did phenolics (by more than half). Stojanovic and Silva (2007) also explained that since these were the samples with the highest moisture contents at the start of drying, the decrease in TP contents during this process can mainly be attributed to the leaching of total phenolics through the skin of berries and just partly due to the higher temperature and presence of oxygen. Nevertheless, in the dried materials, all the plant cell components adhere together in the absence of water, and possibly making the extraction compounds with solvent more difficult; as a result, the overall recoveries might be lower than expected (Li, Smith and Hossain, 2006).

Peterson (2001) showed that heat-processing reduced antioxidant capacity, but did not destroy it. MWVD could maintain better antioxidant property of dried fruits as this drying method reduced oxygen, temperature and time of drying leading to less exposure of the phenolics to thermal and oxygen deterioration effects. Igual *et al*. (2012) concluded that the drying processing of apricots may be improved by using microwave energy, as the drying time is considerably reduced and the obtained fruit had a higher TP content and antioxidant capacity. As reported by Garau *et al*. (2007), long drying times associated with low process temperature may promote a decrease in antioxidant activity. Thus, hot-air drying, which used the lower temperature but longer time, resulted

in low FRAP value although provided the sample with high TP and TMA contents when compared to multistage drying. However, it is difficult to distinguish which compounds contribute the most to antioxidant activity since the fruit extract is very complex (Stojanovic and Silva, 2007). Some authors also reported that processing caused no change to antioxidant potential of fruit and vegetables or even enhanced it due to the improvement of antioxidant properties of naturally occurring compounds or formation of novel compounds such as Maillard reaction products having a varying degree of antioxidant activity and could develop antagonistic or synergistic effects with themselves or with other constituents of the apple extract (Zielisnki and Koslowska, 2000; Manzocco *et al*., 2000).

Apart from some important physicochemical properties, the results appraised by sensory evaluation are also beneficial for selecting the most appropriate preservation technique for fruits. The descriptive test was used to determine the intensity of the sensory attributes of dried figs. As shown in Table 4.13, the panelists were able to tell that the brown color of the MWVD sample was more intense than the other two samples ($p \leq 0.05$) which supported the result in Table 4.10 from Section 4.4. This might be attributed to the formation of Maillard reaction products. The MWVD product which was pre-dried at higher temperatures for relatively long time had more intensed brown color than the samples treated by hot-air and multistage drying and the panelists could not differentiate the color between these two samples. Cernîşev (2010) reported that tomato samples dried at 80 and 90^{o}C required the shortest drying time and their sensory quality attributes were strongly modified and showed signs of deterioration. While tomatoes dried at 50 and 60^{o}C had intensive red color without signs of browning development. The difference of compositions in samples may cause different effects.

Table 4.13 Effects of drying methods on sensory attributes of dried figs as tested by DA

Treatments	Brown color	Hardness[ns]	Chewiness	Natural flavor of fig	Cooked flavor
Hot-air drying	5.49[b] ± 0.68	6.43 ± 0.70	6.30[a] ± 0.37	5.61[a] ± 0.55	5.78[a] ± 0.77
Multistage drying	5.20[b] ± 0.77	6.30 ± 0.78	4.76[b] ± 0.62	5.00[b] ± 0.00	4.80[b] ± 0.59
MWVD	6.22[a] ± 0.67	6.80 ± 0.87	6.47[a] ± 0.79	5.93[a] ± 0.69	3.23[c] ± 0.41

[a,b..] Means (± standard deviation) in the same column with different letters are significantly different ($p \leq 0.05$).

[ns] not significantly different ($p > 0.05$).

For the textural attribute, the panelists indicated that the MWVD sample was chewier than the hot-air and multistage dried samples, respectively ($p \leq 0.05$) while there was no significant difference for the hardness. However, the MWVD sample showed the highest score for this attribute. These results were in agreement with and could be explained by the results in Table 4.11 from Section 4.4 which showed that the MWVD produced the most hardness sample.

The results of natural flavor of fig and cooked flavor obviously indicated the efficiency of MWVD to maintain the natural flavor of fig and prevent the cooked flavor resulted from the Maillard reaction. This might be described by Figiel *et al*. (2010) who found that the use of hot air in any part of the drying process of fresh oregano caused important losses of volatile compounds and consequently a significant reduction of the quality of dried product and concluded that MWVD Polish oregano was of better aromatic quality than that dried using hot air at 60°C. Generally, there are different

factors affecting the loss of volatile compounds during the drying processes, for instance, the temperature reached, the interaction among volatiles and water vapor, the hydrophobic nature of volatiles, etc. During MWVD, water dipoles activated by microwaves might have different interaction with volatiles more than water being evaporated by convection. Conversely, the exposure of the volatile compounds and their precursors to oxidation processes during convective drying was high because of the large volume of air flowing through the plant tissue. The oxidation of volatile compounds was considerably decreased by reducing the air pressure in the drying chamber and by shortening of the drying time during MWVD. Another factor is the temperature of drying process. Increasing temperature might boost the process of volatiles evaporation (losses), despite of water evaporation. In this way, the temperature of the air stream in convective drying was higher than temperature of dried oregano during MWVD. Finally, it was also possible that the hydrophobic nature of some volatiles also play some roles in controlling the losses of these volatile compounds during the drying process.

The affective test was used to evaluate acceptability of dried figs. The sample received a higher score than 5.00 was considered as acceptable. From the data obtained (Table 4.14), the panelists seemed to rather accept the dried samples for the color, flavor, texture and overall preference except for the texture of hot-air dried sample. Different drying methods had a significant ($p \leq 0.05$) effect on texture and overall preference. MWVD yielded the samples with the significantly highest (best) scores of all sensory traits appraised, especially for texture and overall preference and followed by multistage and hot-air drying. It might be implied for this group of panelist that overall preference of the dried figs was mainly dependent on the texture of the samples. Lin *et al*. (1998) reported that MWVD carrot slices received significantly higher

ratings for texture and overall acceptability while hot-air dried ones received the lowest rating for all the attributes evaluated.

Table 4.14 Effects of drying methods on sensory attributes of dried figs as tested by affective test

Treatments	Color^{ns}	Flavor^{ns}	Texture	Overall preference
Hot-air drying	5.00 ± 1.81	5.38 ± 1.60	4.88^{b} ± 1.85	5.17^{b} ± 1.69
Multistage drying	5.08 ± 1.63	5.54 ± 1.53	5.46^{ab} ± 1.63	5.46^{ab} ± 1.37
MWVD	5.68 ± 1.77	5.64 ± 1.68	5.76^{a} ± 1.55	5.92^{a} ± 1.37

^{a,b} Means (± standard deviation) in the same column with different letters are significantly different ($p \leq 0.05$).

^{ns} not significantly different ($p > 0.05$).

4.5 Effects of storage time and drying method on physicochemical and antioxidant properties of dried figs

Physicochemical and antioxidant properties of dried figs stored in PP bag at an open atmosphere and room temperature (30 ± 1^{o}C) were altered depending on drying methods (Table 4.15). It was found that moisture content tended to increase during storage. The MWVD sample had significantly ($p \leq 0.05$) increased values and the highest value was at 8 weeks of storage while there was fluctuation for the multistage dried sample but no significant difference for the hot-air dried one. This was probably due to the porous structure of MWVD sample which might result in easier moisture resorption. Nimmanpipug, Therdthai and Dhamvithee (2013) found that the MWVD dried papaya cubes had a highly porous microstructure, whereas the hot-air dried ones had a

packed microstructure. Thus, the rehydration rate constant of the MWVD dried samples were significantly ($p \leq 0.05$) higher than that of its counterpart.

Table 4.15 Effects of storage time and drying method on moisture content of dried figs

Storage time (week)	Moisture content (% w.b.)		
	Hot-air drying^{ns}	Multistage drying	MWVD
0^{ns}	25.00 ± 0.96	26.60^{c} ± 0.17	25.10^{bc} ± 0.98
2^{ns}	24.76 ± 0.97	29.05^{ab} ± 0.43	24.72^{c} ± 0.76
4^{ns}	25.21 ± 0.49	26.52^{c} ± 1.91	27.91^{abc} ± 1.71
6	25.01^{B} ± 0.07	29.92^{aA} ± 0.40	28.03^{abA} ± 0.95
8	26.02^{B} ± 0.09	26.89^{bcB} ± 0.01	30.04^{aA} ± 1.39

$^{a,b..}$ Means (± standard deviation) in the same column with different lowercase letters are significantly different ($p \leq 0.05$).

^{A,B} Means (± standard deviation) in the same row with different uppercase letters are significantly different ($p \leq 0.05$).

^{ns} not significantly different ($p > 0.05$).

a_w values of the dried samples during storage are shown in Table 4.16. The multistage-dried sample seemed to have higher a_w's than the other two samples during the eight week storage. This might be due to different microstructure of each sample. Although the MWVD sample had more extensive porous structure, its a_w seemed to be lower than the multistage-dried one. As for the latter sample, its microstructure might be more packed together behaving as a barrier for moisture transfer. As a result, its a_w values were

always higher during storage. In contrast, conventional hot-air drying utilizes severe heat treatment to result in lower a_w's.

Table 4.16 Effects of storage time and drying method on a_w of dried figs

Storage time (week)	a_w		
	Hot-air drying^{ns}	Multistage drying^{ns}	MWVD^{ns}
0^{ns}	0.660 ± 0.059	0.745 ± 0.068	0.622 ± 0.051
2	0.666^{C} ± 0.001	0.755^{A} ± 0.001	0.740^{B} ± 0.001
4	0.666^{C} ± 0.001	0.763^{A} ± 0.003	0.684^{B} ± 0.002
6	0.671^{C} ± 0.001	0.743^{A} ± 0.003	0.702^{B} ± 0.002
8^{ns}	0.684 ± 0.006	0.720 ± 0.031	0.691 ± 0.004

$^{A,B..}$ Means (± standard deviation) in the same row with different uppercase letters are significantly different ($p \leq 0.05$).

^{ns} not significantly different ($p > 0.05$).

Discoloration is a major problem associated with production of dried fruits. There is a need to develop alternative drying methods to minimize quality degradation after drying and storage. From the data obtained (Table 4.17), the L^* value of the dried figs decreased during storage. That value of the MWVD sample decreased ($p \leq 0.05$) after 6 weeks while no significant difference was obtained with the other two samples.

Table 4.17 Effects of storage time and drying method on *L** value of dried figs

Storage time (week)	*L**		
	Hot-air drying^{ns}	Multistage drying^{ns}	MWVD
0	36.30^{C} ± 0.40	40.01^{A} ± 0.16	37.60^{aB} ± 0.16
2^{ns}	34.68 ± 1.38	35.20 ± 2.67	37.98^{a} ± 1.18
4^{ns}	35.59 ± 1.48	39.08 ± 0.26	36.73^{ab} ± 0.02
6^{ns}	32.21 ± 2.89	34.96 ± 0.53	34.33^{c} ± 0.45
8^{ns}	32.56 ± 3.40	39.01 ± 3.59	35.32^{bc} ± 0.51

$^{a,b..}$ Means (± standard deviation) in the same column with different lowercase letters are significantly different ($p \leq 0.05$).

$^{A,B..}$ Means (± standard deviation) in the same row with different uppercase letters are significantly different ($p \leq 0.05$).

^{ns} not significantly different ($p > 0.05$).

No significant differences were observed for *a**, *b** and hue angle values among three samples during storage (Table 4.18-4.20). Methods of drying and extended storage within such a period of 8 week might not be causative enough for such significant changes in these values.

Table 4.18 Effects of storage time and drying method on *a** value of dried figs

Storage time (week)	*a**		
	Hot-air drying[ns]	Multistage drying[ns]	MWVD[ns]
0[ns]	8.23 ± 0.08	8.43 ± 0.38	7.73 ± 0.23
2[ns]	7.33 ± 0.47	7.44 ± 0.34	7.66 ± 0.49
4[ns]	7.20 ± 0.15	7.63 ± 0.55	6.99 ± 0.58
6[ns]	7.05 ± 0.22	7.75 ± 0.53	6.62 ± 0.20
8[ns]	7.61 ± 0.10	7.43 ± 1.53	6.97 ± 0.12

[ns] not significantly different ($p > 0.05$).

Table 4.19 Effects of storage time and drying method on *b** value of dried figs

Storage time (week)	*b**		
	Hot-air drying[ns]	Multistage drying[ns]	MWVD[ns]
0	20.22[B] ± 0.59	22.74[A] ± 0.33	17.95[C] ± 0.28
2[ns]	16.74 ± 0.40	19.42 ± 1.59	17.95 ± 0.08
4[ns]	18.86 ± 1.05	21.54 ± 1.62	17.28 ± 1.34
6[ns]	17.65 ± 0.66	19.10 ± 0.32	15.39 ± 1.61
8[ns]	17.70 ± 1.92	22.69 ± 1.23	17.88 ± 0.71

[A,B..] Means (± standard deviation) in the same row with different uppercase letters are significantly different ($p \leq 0.05$).

[ns] not significantly different ($p > 0.05$).

Table 4.20 Effects of storage time and drying method on hue angle of dried figs

Storage time (week)	Hue angle (°)		
	Hot-air drying^{ns}	Multistage drying^{ns}	MWVD^{ns}
0^{ns}	68.01 ± 0.75	69.18 ± 0.24	69.58 ± 0.11
2^{ns}	66.85 ± 0.85	64.25 ± 2.81	65.47 ± 0.19
4^{ns}	66.48 ± 3.27	67.10 ± 0.35	66.76 ± 3.44
6^{ns}	68.38 ± 1.63	65.78 ± 0.57	65.95 ± 1.08
8^{ns}	66.96 ± 1.50	67.10 ± 1.35	66.31 ± 0.43

^{ns} not significantly different ($p > 0.05$).

The chroma values are presented in Table 4.21. It was found that the value was significantly reduced in MWVD sample after 6 weeks storage while for the other two samples, the values decreased after only 2 weeks storage. The reduction of color values during storage period might be because of non-enzymatic browning process. Gögus and Eren (1998) found that brown pigments in minced dried pepper were formed in first few months but it slowed down for an extended storage period. Topuz, Feng and Kushad (2009) reported that the *L**, *a**, *b** and chroma values were reduced in dried paprika during storage and non-enzymatic browning activity continuously existed. However, the slower discoloration of the MWVD sample indicated efficiency of this drying method to maintain color quality of dried products.

Table 4.21 Effects of storage time and drying method on chroma value of dried figs

Storage time (week)	Chroma		
	Hot-air drying	Multistage drying	MWVD
0	$22.80^{aA} \pm 0.69$	$24.32^{aA} \pm 0.23$	$19.04^{aB} \pm 1.29$
2^{ns}	$18.34^{b} \pm 0.61$	$20.20^{b} \pm 0.99$	$19.71^{a} \pm 0.07$
4^{ns}	$20.38^{ab} \pm 0.89$	$22.90^{b} \pm 0.96$	$18.76^{a} \pm 1.00$
6	$18.97^{bA} \pm 0.57$	$20.87^{bA} \pm 0.49$	$16.20^{bB} \pm 1.07$
8	$19.37^{bAB} \pm 1.73$	$21.45^{bA} \pm 1.32$	$15.63^{bC} \pm 0.30$

^{a,b} Means ($\pm$ standard deviation) in the same column with different lowercase letters are significantly different ($p \leq 0.05$).

$^{A,B..}$ Means ($\pm$ standard deviation) in the same row with different uppercase letters are significantly different ($p \leq 0.05$).

^{ns} not significantly different ($p > 0.05$).

Storage stability of the texture of dried figs was also investigated. The hardness, cutting work and adhesiveness of the dried figs are shown in Table 4.22-4.24. From the data obtained, increasing storage time leaded to significant ($p \leq 0.05$) decreases of those values and the MWVD sample showed the fast reduction when compared to the other two samples. This could be explained by the result of fast water resorption of this sample with its porous structure.

Table 4.22 Effects of storage time and drying method on hardness of dried figs

Storage time (week)	Hardness (N)		
	Hot-air drying	Multistage drying^{ns}	MWVD
0^{ns}	59.86^{a} ± 1.32	55.88 ± 4.41	57.24^{a} ± 1.17
2^{ns}	58.01^{ab} ± 0.41	54.08 ± 2.96	54.01^{ab} ± 3.46
4^{ns}	56.21^{bc} ± 0.65	48.68 ± 3.19	50.57^{bc} ± 1.33
6	55.52^{cA} ± 0.53	46.28^{B} ± 2.36	47.77^{cB} ± 1.99
8	57.79^{bA} ± 0.56	48.34^{B} ± 1.64	46.59^{cB} ± 1.69

$^{a,b..}$ Means (± standard deviation) in the same column with different lowercase letters are significantly different ($p \leq 0.05$).

^{A,B} Means (± standard deviation) in the same row with different uppercase letters are significantly different ($p \leq 0.05$).

^{ns} not significantly different ($p > 0.05$).

Table 4.23 Effects of storage time and drying method on cutting work of dried figs

Storage time (week)	Cutting work (N.sec)		
	Hot-air drying^{ns}	Multistage drying^{ns}	MWVD
0	213.24^{C} ± 2.89	216.70^{B} ± 23.48	304.20^{aA} ± 13.77
2^{ns}	210.34 ± 6.86	195.57 ± 10.51	230.05^{b} ± 11.34
4^{ns}	203.66 ± 19.46	208.99 ± 18.89	209.81^{bc} ± 18.89
6^{ns}	183.01 ± 2.82	178.11 ± 8.01	178.64^{cd} ± 12.79
8^{ns}	175.79 ± 17.82	163.80 ± 14.58	167.18^{d} ± 15.56

$^{a,b..}$ Means (± standard deviation) in the same column with different lowercase letters are significantly different ($p \leq 0.05$).

$^{A,B..}$ Means (± standard deviation) in the same row with different uppercase letters are significantly different ($p \leq 0.05$).

^{ns} not significantly different ($p > 0.05$).

Table 4.24 Effects of storage time and drying method on adhesiveness of dried figs

Storage time (week)	Adhesiveness (N.sec)		
	Hot-air drying^{ns}	Multistage drying	MWVD
0	$1.77^{A} \pm 0.06$	$1.42^{aB} \pm 0.04$	$1.80^{aA} \pm 0.08$
2^{ns}	1.71 ± 0.08	$1.46^{a} \pm 0.13$	$1.60^{a} \pm 0.08$
4^{ns}	1.70 ± 0.08	$1.48^{a} \pm 0.09$	$1.64^{a} \pm 0.02$
6^{ns}	1.91 ± 0.84	$1.02^{b} \pm 0.07$	$1.63^{a} \pm 0.14$
8	$1.33^{A} \pm 0.09$	$0.80^{cB} \pm 0.03$	$1.32^{bA} \pm 0.01$

$^{a,b..}$ Means (± standard deviation) in the same column with different lowercase letters are significantly different ($p \leq 0.05$).

^{A,B} Means (± standard deviation) in the same row with different uppercase letters are significantly different ($p \leq 0.05$).

^{ns} not significantly different ($p > 0.05$).

Antioxidant property of the dried figs was also evaluated because it is one of important quality attributes. From the data obtained (Figure 4.6), TP contents decreased dramatically whereas TMA contents of the three samples were not detected from week 2 onwards. The MWVD sample had considerably smaller losses in TP contents when compared with the other two samples. The chemical structure of anthocyanins, via glycosylation and acylation by different sugars and acids, might be a main factor affecting their stability and increasing water activity and the anthocyanin degradation had a direct relationship (Garzón and Wrolstad, 2001). Moreover, long time storage resulted in exposure of these compounds to oxygen and light and other sources of

ionizing radiation generally cause decomposition which appears to be mainly photooxidative (Sweeny, Wilkinson and Iacobucci., 1981).

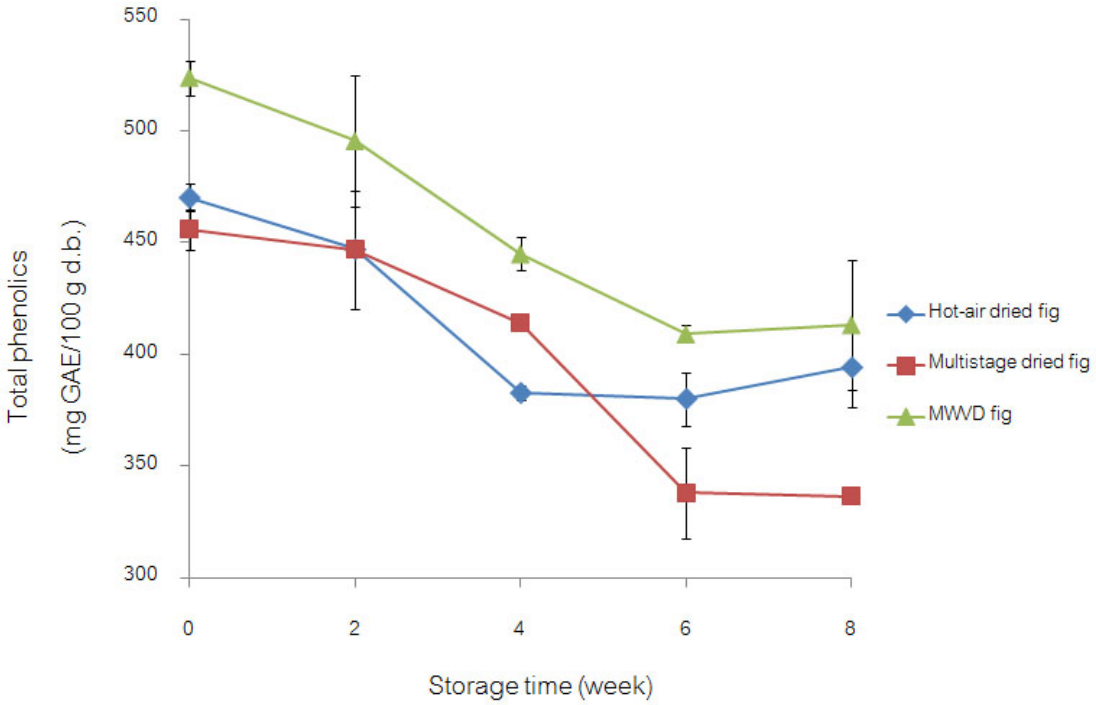


Figure 4.6 Effects of storage time and drying method on total phenolic contents of dried figs

During the 8-week storage of the three dried samples, the FRAP value decreased and then increased from the fourth week onwards, despite these samples showed the losses in TP contents. This might be related to the possible breakdown of the phenolics yielding multiple products which still possess variable antioxidant capacity (Al-Weshahy *et al.*, 2011). Michalczyk, Macura and Matuszak (2009) found a strong inverse correlation between the antiradical activity (EC_{50}) and phenolic or anthocyanin content (from -0.86 to -0.95 for phenolic; from -0.72 to -0.87 for anthocyanin) for air-dried berries.

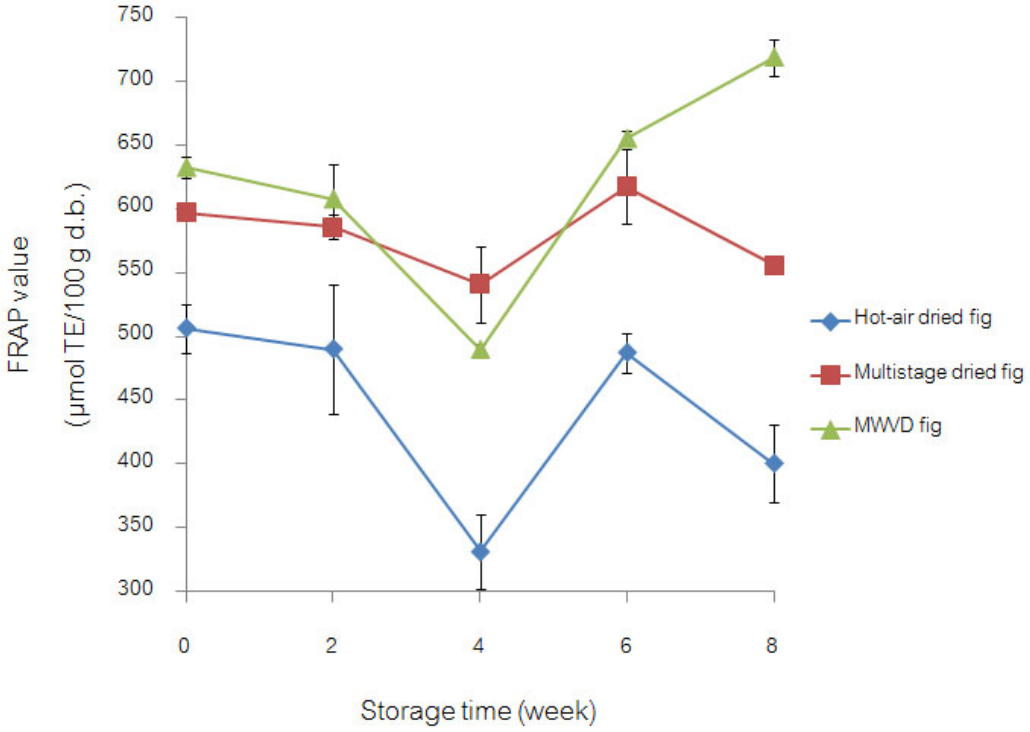


Figure 4.7 Effects of storage time and drying method on FRAP value of dried figs

CHAPTER V

CONCLUSIONS AND SUGGESTIONS

Conclusions

Although OD influenced loss of phytonutrients (TP and TMA) contents, higher VP used in VI resulted in reduction of a_w and moisture content and retention of higher antioxidant property but did not affect color and texture of samples.

 Drying temperature and shape of fig influenced drying rate significantly. Increasing of drying temperature could increase drying rate. This value of half fruits was higher than those of the pressed and whole fruits, respectively, due to size or surface area per unit volume, thickness and peel of the samples. Therefore, drying time was decreased with increased drying rate. In addition, antioxidant property of half fig was the highest, probably due to short drying time and therefore less exposure of the phenolics to thermal and oxygen deterioration effects.

 The MWVD was the effective drying method which could decrease drying time and yielded dried sample with higher antioxidant activity whereas such property of multistage drying did not differ much from hot-air drying. However, drying time of multistage drying was decreased when compared to hot-air drying.

 Different drying methods provided products of different structures. Nevertheless, MWVD yielded the samples with the significantly highest (best) scores of all sensory traits appraised, especially for texture and overall preference and followed by multistage and hot-air drying.

 Thus, VI is beneficial as a preparative step for processing Dauphine fig which is most suitably further preserved by MWVD.

 The three dried samples had increased moisture content and a_w during the 8-week storage relying on different drying methods yielding different structures of products. These changes contributed to decreases of hardness, cutting work and adhesiveness of the samples. Therefore, the MWVD sample had the highest values of moisture content and a_w and lowest values of the textural property owing to its porous structure. In term of the color, the L^* and chroma values of the three samples decreased during storage. In addition, TP content decreased with extended storage time, while the FRAP value decreased and then increased from the fourth week onwards. However, the MWVD still showed efficiency to maintain the color and antioxidant properties of the dried figs.

Suggestions

 It is interesting to study the higher level of VP as it may reduce more water content and maintain higher antioxidant property and the conditions of MWVD and multistage drying should be optimized to improve product qualities

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APPENDICES

APPENDIX A

ANALYTICAL METHODS

A.1 Textural property

Overall, the texture of fig samples was evaluated with a texture analyzer as follows:

- Hardness of fresh fig was determined using a texture analyzer (Stable Micro System Model TA.XT2i, Godalming, UK) and cylinder probe with 2 mm diameter (P/2). The test conditions were pre-test speed of 1.5 mm/s, test speed of 1.5 mm/s, post-test speed of 10 mm/s, distance of 50 mm and trigger force of 10 g, respectively. Typical curve is shown in Figure A.1 and the value of hardness is presented by the positive peak force in N.

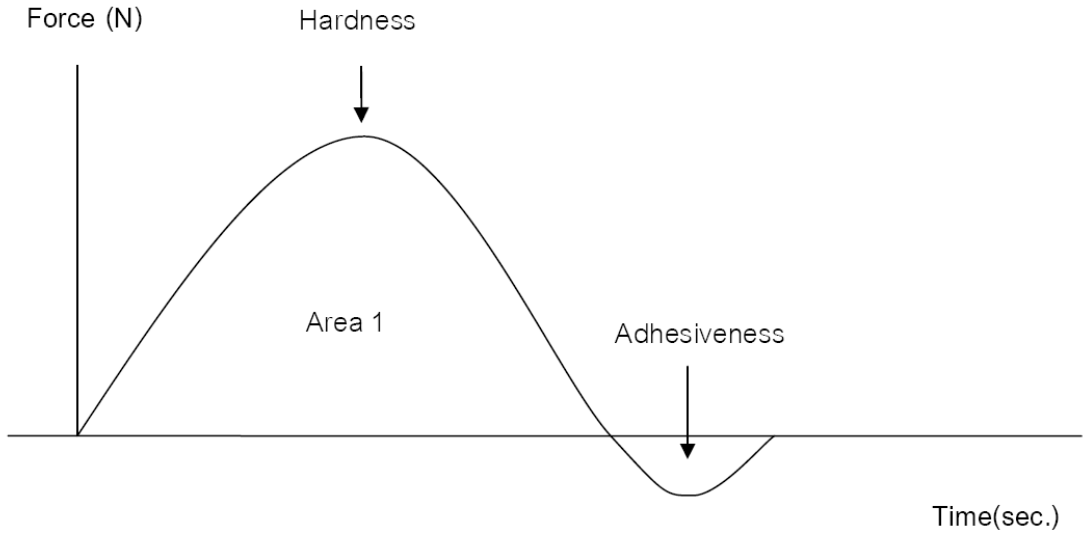


Figure A.1 Typical curve of force-by-time from measuring texture using a texture analyzer and cylinder probe with 2 mm diameter or a HDP/BSK blade cutter

- The texture of OD, VI and dried figs were determined using a texture analyzer and a HDP/BSK blade cutter. The samples were cut along the longitudinal axis from the peel. The test conditions were pre-test speed of 2 mm/s, test speed of 2 mm/s, post-test

speed of 10 mm/s, distance of 50 for OD and VI and 20 mm for dried fig and trigger force of 10 g. Typical cutting work curve is also shown in Figure A.1. The value of hardness is presented by the peak cutting force in N, the value of cutting work is presented as the positive area under force-deformation curve (N.sec) and the adhesiveness is presented as the negative area under the baseline (N.sec).

A.2 Total soluble solids (TSS) analysis, A.O.A.C. Official Methods 932.14C (A.O.A.C., 1995)

A few drops of homogenized sample was directly read with a hand refractometer (Atago model 2210-w06, Tokyo, Japan). The results were reported as Brix degrees (^{o}Brix) at 20ºC.

A.3 Water activity (a_w) analysis

Water activity was determined using a water activity meter (AquaLab, Series 3 TE, Pullman, WA, USA). Five gram of the chopped sample was put inside the close container and left for 1 h to reach the equilibrium. The a_w of the chopped sample was then measured at 25 ± 1^{o}C.

A.4 Moisture content analysis, the modified method of A.O.A.C. Official Methods 925.09B (A.O.A.C., 1995)

Equipments and apparatus

1. Hot air oven (Memmert, model 600, Schwabach, Germany).
2. Aluminum pan
3. Desiccator

Determination

Two grams of sample, accurately weighed, were placed into a preweighed aluminum pan. The sample was heated at 105 ± 2°C for 4 h or until its constant weight was obtained. The sample was then transferred to a desiccator and weighed soon after its temperature reached room temperature. Moisture content of the sample was calculated from the following formula.

$$\text{Moisture content (\% w.b.)} = \frac{\text{weight of sample (g) before drying} - \text{weight of dried sample (g)}}{\text{weight of sample (g) before drying}} \times 100\%$$

A.5 Ash content analysis, A.O.A.C. Official methods 923.03 (A.O.A.C., 1995)

Equipments and apparatus

1. Muffle furnace (Carbolite, model CWF 1200, Germany)
2. Crucible
3. Hot plate
4. Desiccator

Determination

Two grams of sample, accurately weighed, were placed into a preweighed crucible. The sample was heated on a hot plate in a fume-hood cupboard until no smoke was detected. The sample was then ignited in a furnace at 550°C until its gray ash turned into white. The crucible was transferred to a desiccator and weighed soon after its temperature reached room temperature. Ash content of the sample was calculated from the following formula.

$$\text{Ash content (\%w.b)} = \frac{\text{weight of ash (g)}}{\text{weight of sample (g)}} \times 100\%$$

A.6 Crude protein analysis, A.O.A.C. Official Methods 920.152 (A.O.A.C., 1995)

Equipments and apparatus

1. Digestion unit (Buchi, model K-424, Switzerland)
2. Distillation unit (Buchi, model K-324, Switzerland)

Chemical reagents

1. conc. sulfuric acid (A.R. grade, J. T. Baker Neutrasorb, USA)
2. 0.1 N standard hydrochloric acid (A.R. grade, Ajax Finechem, Australia)
3. Sodium hydroxide (A.R. grade, Carlo Erba, France), 45% w/v solution was prepared
4. Boric acid (A.R. grade, Merck, Germany), 4% w/v solution was prepared
5. Selenium reagent mixture (A.R. grade, Merck, Germany)
6. Indicator (dissolved 0.125 g of methyl red (A.R. grade, Fisher Scientific, UK) and 0.0825 g of methylene blue (A.R. grade, Ajex Finechem, Australia) in 100 ml of 90% ethanol)

Determination

One gram of sample was placed into a digestion flask taking care to see that no portion of the sample clings to the neck of the flask. Five grams of selenium mixture and 25 ml of sulfuric acid were added into the flask. In case of blank, one milliliter of distilled water was used instead of the sample. The flask was placed in an inclined position and heated gently until the initial frothing ceased. Continued heating, approximately 20 min, until the color of the digest is pale blue. Cooled the digest and

the digested sample was placed into Buchi distillation with sequential addition of the following chemicals

- 45% (w/v) sodium hydroxide solution 40 ml
- 4% (w/v) boric acid 50 ml
- distilled water 50 ml
- distillation time 3 min

The distilled solution was titrated with 0.1 N hydrochloric acid until reaching the end point. Methyl red/methylene blue was used as an indicator. Crude protein was calculated from the following formula.

$$\% \text{ Nitrogen} = \frac{(V-B) \times N \times 1.4}{\text{weight of sample (g)}}$$

Crude protein (%w.b.) = %Nitrogen x 6.25

where V represents the volume of 0.1 N standard hydrochloric acid titrated with the sample (ml), B represents the volume of 0.1 standard hydrochloric acid titrated with blank (ml), and N represents the exact concentration of standard hydrochloric acid (N).

A.7 Crude fat analysis, A.O.A.C. Official methods 920.39C (A.O.A.C., 1995)

Equipments and apparatus

1. Soxhlet (Gerhardt, model HC61, Germany)
2. Rotary evaporator (Eyela, model SB-651, Japan)

Chemical reagent

1. Petroleum ether (A.R. grade, Fisher Scientific, UK)

Determination

Two grams of dried sample, accurately weighed, were placed into a porous thimble. The thimble was placed into a Soxhlet apparatus and 250 ml of petroleum ether was added. Crude fat extraction was conducted for 4 hours. The solvent was evaporated from the extraction using a rotary evaporator. The crude fat residue in the preweighed rounded-bottom flask was dried at 105±2°C for 30 min or until its constant weight was obtained. The sample was then transferred to desiccators and weighed soon after its temperature reached room temperature. Crude fat was calculated from the following formula.

$$\text{Crude fat (\%d.b.)} = \frac{\text{weight of crude fat residue (g)} \times 100}{\text{weight of dried sample (g)}}$$

A.8 Crude fiber analysis, A.O.A.C. Official methods 930.10 (A.O.A.C., 1995)

Equipments and apparatus

1. Hot plate
2. Buchner funnel
3. Suction flask
4. Crucible
5. Whatman No.43 filter paper
6. Muffle furnace (Carbolite, model CWF 1200, Germany)

Chemical reagents

1. Sodium hydroxide (A.R. grade, Carlo Erba, France), 1.25% w/v solution was prepared.
2. conc. sulfuric acid (A.R. grade, J. T. Baker Neutrasorb, USA), 1.25% v/v solution was prepared.

3. Ethyl alcohol absolute (A.R. grade (J.T. Baker, NJ), 95% v/v solution was prepared.

Determination

Two grams of residue from crude fat were digested with 200 ml of the sulphuric acid solution and boiled on a hot plate. (Content of the flask must come to boiling within 1 min and boiling must continue briskly for exactly 30 min.) During digestion, took care to keep the material from remaining on the sides of the beaker without contact with the solution. After 30 min, the residue was immediately filtered through a filter paper in Buchner funnel using vacuum and washed with boiling water until the washings were no longer acid and transferred back into the beaker. Added 200 ml of the sodium hydroxide solution and boiled for exactly 30 min. After digestion, the residue was immediately filtered and washed with boiling water until the washings were no longer alkaline and washed with approximately 25 ml of alcohol for 2 times. The residue in the preweighed crucible was dried at 105±2°C until its constant weight was obtained and then transferred to desiccators and weighed soon after its temperature reached room temperature. The contents of the preweighed crucible were ignited in a furnace at 550°C until carbonaceous matter is destroyed. Cool in a desiccator and weigh. The loss in weight represents crude fiber.

$$\text{Crude fiber (\%)} = \frac{\text{Loss in weight (g)}}{\text{weight of sample taken (g)}} \times 100$$

A.9 Calculation of carbohydrate content (A.O.A.C. 1995)

The carbohydrate content was calculated from the following formula.

Carbohydrate content (%w.b.) = 100 – (%moisture + %ash + %protein + %lipid + % crude fiber)

A.10 pH value analysis, A.O.A.C. Official Methods 981.12 (A.O.A.C., 1995)

Prior to use, the pH meter (Eutech Model pH 2700, Singapore) was standardized with standard buffer solution of pH 4 and 7. The homogenized sample was let to reach the equilibrium and gently stirred before testing. After electrodes were rinsed and blotted, they were immersed in the sample and read pH, letting meter stabilized 1 min. Electrodes were rinsed and blotted and repeated on fresh portion of sample. Two pH values were determined on each sample. Readings in close agreement indicate that sample is homogeneous. Values were reported to 2 decimal places.

A.11 Determination of TP contents, Folin-Ciocalteu assay (Waterhouse, 2005)

1. Preparation of gallic acid standard solution

a) To prepare a stock solution, 0.500g of gallic acid (Fluka, Spain) was dissolved in 10 ml of ethanol (A.R. grade, VWR Prolabo, France) and diluted to 100 ml with water in a volumetric flask.

b) A 0, 1, 2, 3, 5, 10 and 15 ml aliquot of gallic acid stock solution was added to a volumetric flask and diluted to 100 ml with water. The final concentration of gallic acid will be 0, 50, 100, 150, 250, 500 and 750 mg/l.

2. Preparation sodium carbonate solution

The 200 g of sodium carbonate (A.R. grade, Ajax Finechem, Australia) was dissolved in 800 ml of water and boiled. After the solution was cooled down, a few crystals of sodium carbonate was added. After 24 hours, the solution was filtered with

Whatman no. 1 filter paper and the volume of the solution was made up to 1,000 ml in a volumetric flask.

3. Folin-Ciocalteu assays

One ml of sample or standard solution was added to 100 ml volumetric flask and approximately 70 of ml water were added. Five ml of Folin-Ciocalteu reagent (Carlo Erba, France) was added, then swirled to mixed and incubated 1-8 minutes at room temperature. Fifteen ml of sodium carbonate solution was subsequently added and made up the final volume with water to 100 ml. The solution was mixed and incubated at room temperature for 2 h. The absorbance was measured by a spectrophotometer (Lambda 25 UV-VIS Spectrometer, Perkin Elmer instrument, USA) at 765 nm. The standard curve was shown in Figure A.2

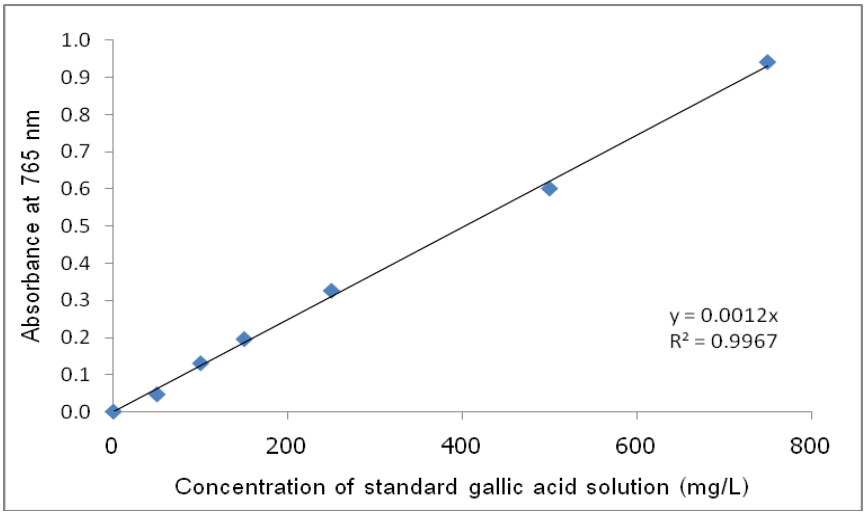


Figure A.2 Gallic acid standard curve for TP content determination

4. Calculation of total phenolic content

The amounts of TP in crude extract were calculated using gallic acid standard curve. The value was expressed as mg gallic acid/ 100 g sample.

A.12 Determination of TMA contents: pH differential method (Giusti and Wrolstad, 2005)

1. Preparation of pH 1.0 and 4.5 buffer solutions

Potassium chloride buffer at the concentration of 0.025 M, pH 1.0, was prepared by dissolving 1.86 g of potassium chloride (Ajax Finechem, Australia) in 980 ml of water, adjust pH 1.0 g of concentrated HCI (J.T. Baker, USA), and made up volume to 1,000 ml with water in a volumetric flask. Sodium acetate buffer at the concentration of 0.4 M, pH 4.5, was prepared by dissolving 54.43 g of sodium acetate (Sigma-Aldrich, Germany) in 960 ml of water in a volumetric flask.

2. Anthocyanin measurement

To start the measurement, the spectrophotometer was set zero with distilled water at both 520 nm and 700 nm. One ml of crude extract was diluted to 6 ml with pH 1.0 potassium chloride buffer and with pH 4.5 sodium acetate buffer to 6 ml in a tube (dilution factor was 6) and let them equilibrate for 15 minutes.

a) The absorbance was calculated by:

$$A = (A_{\lambda\ vis\text{-}max} - A_{700})_{pH\ 1.0} - (A_{\lambda\ vis\text{-}max} - A_{700})_{pH\ 4.5}$$

Where: A = absorbance

$A_{\lambda\ vis\text{-}max}$ = absorbance at 520 nm

A_{700} = absorbance at 700 nm

b) The concentration of monomeric anthocyanin pigment was calculated by: monomeric anthocyanin pigment (mg/L) = $(A \times MW \times DF \times 100) / (\varepsilon \times 1)$

Where: A = absorbance

MW = molecular weight cyanidin-3-rutinoside = 595.2

DF = dilution factor = 6

ε = molar absorptivity of cyanidin-3-rutinoside= 28,800 $M^{-1}cm^{-1}$

A.13 FRAP assay (the modified method of Benzi and Strain, 1996)

1. Preparation of trolox standard curve

To prepare trolox solution, trolox (Fluka, Denmark) was diluted with methanol (J.T. Baker, Phillipsburg, NJ, USA) and mixed well. The final concentration will be 0, 0.050, 0.075, 0.100, 0.125, 0.150 and 0.175 µM

2. Solution preparation

a) Acetate buffer pH 3.6: Forty grams of $CH_3COONa{\cdot}3H_2O$ (Fisher Scientific, UK) was added to 700 ml of distilled water, adjust pH 3.6 of concentrated CH_3COOH and made volume up to 1,000 ml of distilled water in a volumetric flask.

b) Tripyridyltriazine (TPTZ) solution: a 0.312 g portion of TPTZ (Fluka, Switzerland) was added to 100 ml of 40 m M HCl (J.T. Baker, USA)

c) $FeCl_3$ solution: a 0.3244 g portion of $FeCl_3$ (POCH S.A., Poland) was added to 100 ml of H_2O.

d) FRAP solution: a 25 ml aliquot acetate buffer was added with 2.5 ml of ferric chloride solution and followed with 2.5 ml of TPTZ solution (the solution must be added in this order).

3. FRAP assay

FRAP solution was warmed at 37°C in a hot water bath (DT-1 Heto-Holten, Heto Lab Equipment, Japan) for 30 min. To prepare a standard curve, 400 µl of trolox solution was added to 4,000 µl of FRAP solution in a tube. For the analysis of extract, 400 µl of sample was added to 4,000 µl of FRAP solution in a tube. The mixture was held for 30 min at 37°C in a hot water bath before measuring the absorbance. The color of the mixture was changed from golden brown to deep blue purple. The absorbance was measured at 593 nm. Distilled water was used as blank. The corrected absorbance was calculated as followed:

$$A_{corrected} = A_{final} - A_{initial}$$

Where: $A_{corrected}$ = corrected absorbance

A_{final} = absorbance of the sample after 30 min holding time

$A_{initial}$ = absorbance of 1,000 µl FRAP solution

The corrected absorbance of the sample was compared with the corrected absorbance in trolox standard curve. The trolox standard curve is shown in Figure A.3. The antioxidant activity was calculated as µmol trolox/ 100 g sample.

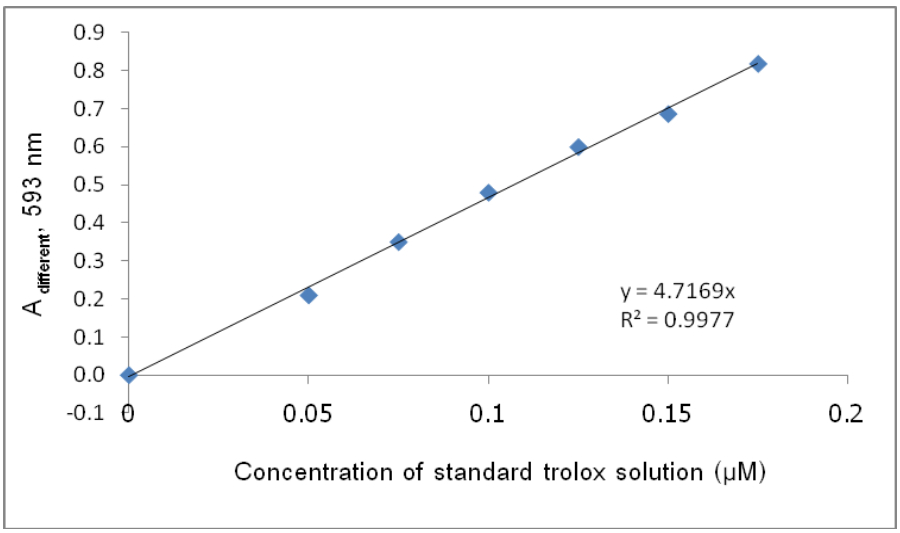


Figure A.3 Trolox standard curve for FRAP assay

A.14 Microstructure analysis

The microstructure of the sample was analyzed using SEM technique as described by the modified method of Moreno *et al*. (2004). The samples were cut into slabs (5 mm x 3 mm x 3 mm). For the fresh sample, Sample fixation was done by immersion in 2.5 % w/w glutaraldehyde in phosphate buffer (0.2 M, pH 7.2) for 2 hour, and sample were then cleaned from glutaraldehyde by soaking it with phosphate buffer (0.2 M, pH 7.2) 2 times (each times 10 minutes) and distilled water for 10 min. Samples

were dehydrated by immersion in ethanol solutions (30, 50, 70 and 90%) for 30 min each. After that, they were immersion in absolute ethanol 3 times (each time for 1 h).

For OD and VI samples, they were prepared beginning from dehydration steps by immersion in 50% ethanol solution until absolute ethanol.

For dried samples, they were dehydrated with absolute ethanol 3 times (each time for 1 h).

The samples (fresh, OD, VI and dried) were then critical point dried in a dryer (Balzers Model CPD 020, Vaduz, Liechtenstein) at a temperature of 31^{o}C and pressure 73.8 Bar and were put on the stub. 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 50x zoom level.

APPENDIX B

QUESTIONNAIRES FOR SENSORY EVALUATION

B.1 Descriptive sensory test

QUESTIONNAIRE FOR SENSORY EVALUATION OF DRIED FIG

Date……..... Name…….....

Have you ever tried dried fruit product before?

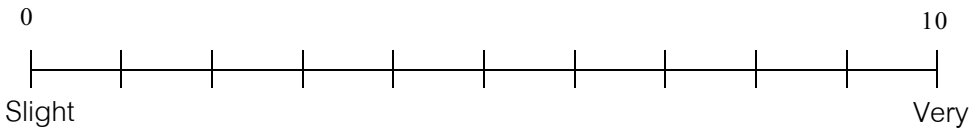
Yes……..... No…….....

Descriptive sensory test

Please indicate the intensity of each following sensory attribute by putting a vertical line (with the coding number) on the line scale at the point which represents the intensity that you have perceived for each sample.

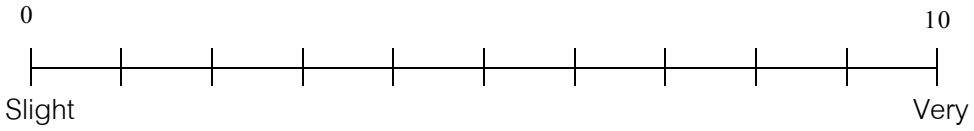
1. **Color**

Brown color

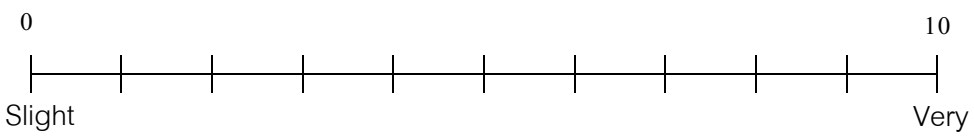


2. **Texture**

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

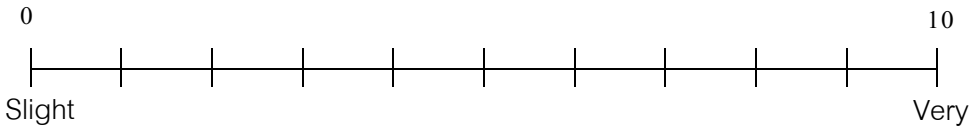


Chewiness (The energy required to chew a solid food to the point required for swallowing it)

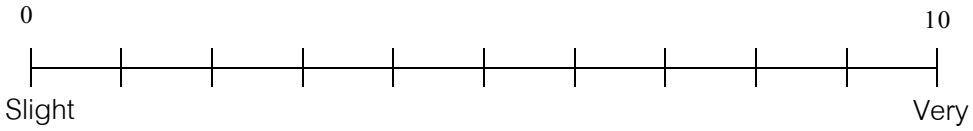


3. **Flavor**

Natural flavor of fig



Cooked flavor



B.2 **Affective sensory test**

Please evaluate the dried fig samples and indicate how much you like or dislike them by putting the number, from 1 to 9, for each coded sample.

1.-Dislike extremely

2.-Dislike very much

3.-Dislike moderately

4.-Dislike slightly

5.-Neither like nor dislike

6.-Like slightly

7.-Like Moderately

8.-Like very much

9.-Like extremely

Attributes	Samples
Color	
Flavor	
Texture	
Overall	

Comments……………………………………………………………………………………………

………………………………………………………………………………………………………

………………………………………………………………………………………………………

APPENDIX C

ADDITIONAL DATA

a

b

c

Figure C.1 Examples of a) Hot-air dried fig b) Multistage dried fig and c) MWVD fig

APPENDIX D

STATISTICAL ANALYSIS

Table D.1 The ANOVA table showing the effects of OD and VI on color values of figs at $p \leq 0.05$

		Sum of Squares	df	Mean Square	F	Sig.
*L**	Between Groups	1.721	2	.860	.126	.883
	Within Groups	61.430	9	6.826		
	Total	63.151	11			
*a**	Between Groups	1.994	2	.997	4.457	.045
	Within Groups	2.013	9	.224		
	Total	4.006	11			
*b**	Between Groups	2.743	2	1.372	.174	.843
	Within Groups	70.805	9	7.867		
	Total	73.548	11			
Hue angle	Between Groups	31.592	2	15.796	2.744	.117
	Within Groups	51.817	9	5.757		
	Total	83.409	11			
Chroma	Between Groups	2.433	2	1.216	.152	.861
	Within Groups	72.099	9	8.011		
	Total	74.532	11			

Table D.2 The ANOVA table showing the effects of OD and VI on textural property of figs at $p \leq 0.05$

		Sum of Squares	df	Mean Square	F	Sig.
Hardness	Between Groups	.966	2	.483	.375	.698
	Within Groups	11.592	9	1.288		
	Total	12.558	11			
Cutting work	Between Groups	1644.331	2	822.166	.942	.425
	Within Groups	7851.982	9	872.442		
	Total	9496.313	11			
Adhesiveness	Between Groups	.172	2	.086	.583	.578
	Within Groups	1.329	9	.148		
	Total	1.501	11			

Table D.3 The ANOVA table showing the effects of OD and VI on compositions, a_w and pH of figs at $p \leq 0.05$

		Sum of Squares	df	Mean Square	F	Sig.
Moisture content	Between Groups	70.066	3	23.355	13.715	.000349
	Within Groups	20.435	12	1.703		
	Total	90.501	15			
a_w	Between Groups	.000	3	.000	1.401	.290
	Within Groups	.000	12	.000		
	Total	.000	15			
TSS	Between Groups	15.224	3	5.075	26.220	.000015
	Within Groups	2.322	12	.194		
	Total	17.546	15			
pH	Between Groups	.692	3	.231	3.006	.072
	Within Groups	.921	12	.077		
	Total	1.613	15			

Table D.4 The ANOVA table showing the effects of OD and VI on WL, SG and WR of figs at $p \leq 0.05$

		Sum of Squares	df	Mean Square	F	Sig.
WL	Between Groups	88.280	2	44.140	27.138	.000154
	Within Groups	14.638	9	1.626		
	Total	102.918	11			
SG	Between Groups	.187	2	.094	37.781	.000042
	Within Groups	.022	9	.002		
	Total	.209	11			
WR	Between Groups	204.831	2	102.416	120.431	.0000003
	Within Groups	7.654	9	.850		
	Total	212.485	11			

Table D.5 The ANOVA table showing the effects of OD and VI on TP, TMA contents and FARP value of figs at $p \leq 0.05$

		Sum of Squares	df	Mean Square	F	Sig.
TP (d.b.)	Between Groups	2480.702	2	1240.351	8.345	.009
	Within Groups	1337.726	9	148.636		
	Total	3818.428	11			
TMA (d.b.)	Between Groups	11.842	2	5.921	1.749	.228
	Within Groups	30.477	9	3.386		
	Total	42.320	11			
FRAP value (d.b.)	Between Groups	230388.799	2	115194.400	36.847	.000046
	Within Groups	28136.420	9	3126.269		
	Total	258525.219	11			

Table D.5 The ANOVA table showing the effects of OD and VI on TP, TMA contents and FARP value of figs at $p \leq 0.05$ (Continued)

TP (w.b.)	Between Groups	51.081	2	25.541	5.374	.029
	Within Groups	42.775	9	4.753		
	Total	93.856	11			
TMA (w.b.)	Between Groups	.184	2	.092	.860	.455
	Within Groups	.965	9	.107		
	Total	1.149	11			
FRAP value (w.b.)	Between Groups	5302.703	2	2651.351	26.613	.000166
	Within Groups	896.620	9	99.624		
	Total	6199.323	11			

Table D.6 The ANOVA table showing effects of temperature and shape on a_w of VI figs at $p \leq 0.05$

Dependent Variable: a_w					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.091[a]	11	.008	13.563	.000040
Intercept	4.066	1	4.066	6630.530	10^{-13}
Temperature	.077	3	.026	41.607	.000001
Shape	.010	2	.005	8.050	.006
Temp * Shape	.005	6	.001	1.378	.299
Error	.007	12	.001		
Total	4.164	24			
Corrected Total	.099	23			

a. R Squared = .926 (Adjusted R Squared = .857)

Table D.7 The ANOVA table showing effects of temperature and shape on moisture content of VI figs at $p \leq 0.05$

Dependent Variable: Moisture content					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	295.921[a]	11	26.902	19.820	.000005
Intercept	4865.523	1	4865.523	3584.619	10^{-13}
Temperature	234.609	3	78.203	57.615	.0000002
Shape	40.573	2	20.287	14.946	.001
Temp * Shape	20.739	6	3.456	2.546	.079
Error	16.288	12	1.357		
Total	5177.732	24			
Corrected Total	312.209	23			

a. R Squared = .948 (Adjusted R Squared = .900)

Table D.8 The ANOVA table showing effect of shape on TP contents and FARP value of VI figs at $p \leq 0.05$

		Sum of Squares	df	Mean Square	F	Sig.
TP (d.b.)	Between Groups	138.856	2	69.428	.672	.574
	Within Groups	310.175	3	103.392		
	Total	449.032	5			
FRAP value (d.b.)	Between Groups	23323.140	2	11661.570	10.418	.045
	Within Groups	3358.013	3	1119.338		
	Total	26681.153	5			

Table D.9 The ANOVA table showing effects of drying methods on color values of dried figs from various treatments at $p \leq 0.05$

		Sum of Squares	df	Mean Square	F	Sig.
*L**	Between Groups	19.384	2	9.692	1.993	.192
	Within Groups	43.756	9	4.862		
	Total	63.140	11			
*a**	Between Groups	2.941	2	1.471	5.562	.027
	Within Groups	2.380	9	.264		
	Total	5.321	11			
*b**	Between Groups	84.778	2	42.389	15.255	.001
	Within Groups	25.008	9	2.779		
	Total	109.786	11			
Hue angle	Between Groups	61.978	2	30.989	2.272	.159
	Within Groups	122.765	9	13.641		
	Total	184.743	11			
Chroma	Between Groups	81.564	2	40.782	13.501	.002
	Within Groups	27.186	9	3.021		
	Total	108.750	11			

Table D.10 The ANOVA table showing effects of drying methods on textural property of dried figs from various treatments at $p \leq 0.05$

		Sum of Squares	df	Mean Square	F	Sig.
Hardness	Between Groups	87.481	2	43.740	9.179	.007
	Within Groups	42.888	9	4.765		
	Total	130.369	11			
Cutting work	Between Groups	53743.188	2	26871.594	875.436	$5x\ 10^{-11}$
	Within Groups	276.256	9	30.695		
	Total	54019.444	11			
Adhesiveness	Between Groups	.284	2	.142	31.302	.00009
	Within Groups	.041	9	.005		
	Total	.325	11			

Table D.11 The ANOVA table showing effects of drying methods on TP, TMA contents and FRAP value of dried figs at $p \leq 0.05$

		Sum of Squares	df	Mean Square	F	Sig.
TP (d.b.)	Between Groups	914.318	2	457.159	.879	.448
	Within Groups	4678.751	9	519.861		
	Total	5593.069	11			
TMA (d.b.)	Between Groups	16.167	2	8.084	95.769	.000001
	Within Groups	.760	9	.084		
	Total	16.927	11			
FRAP value (d.b.)	Between Groups	68181.564	2	34090.782	24.620	.000224
	Within Groups	12462.085	9	1384.676		
	Total	80643.649	11			

Table D.11 The ANOVA table showing effects of drying methods on TP, TMA contents and FRAP value of dried figs at $p \leq 0.05$ (Continued)

TP (w.b.)	Between Groups	1108.386	2	554.193	1.929	.201
	Within Groups	2585.701	9	287.300		
	Total	3694.088	11			
TMA (w.b.)	Between Groups	10.046	2	5.023	101.934	.000001
	Within Groups	.443	9	.049		
	Total	10.489	11			
FRAP value (w.b.)	Between Groups	52452.208	2	26226.104	34.324	.000061
	Within Groups	6876.664	9	764.074		
	Total	59328.873	11			

Table D.12 The ANOVA table showing effects of drying methods on brown color of dried figs as tested by a line scale at $p \leq 0.05$

Dependent Variable: Brown color

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	22.042[a]	21	1.050	2.262	.014
Intercept	1904.067	1	1904.067	4103.825	10^{-3}
panelist	11.080	19	.583	1.257	.267
Trt	10.962	2	5.481	11.814	.000102
Error	17.631	38	.464		
Total	1943.740	60			
Corrected Total	39.673	59			

a. R Squared = .556 (Adjusted R Squared = .310)

Table D.13 The ANOVA table showing effects of drying methods on hardness of dried figs as tested by a line scale at $p \leq 0.05$

Dependent Variable: Hardness

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	16.200[a]	21	.771	1.344	.209
Intercept	2541.504	1	2541.504	4428.994	10^{-3}
panelist	13.566	19	.714	1.244	.276
Trt	2.634	2	1.317	2.295	.115
Error	21.806	38	.574		
Total	2579.510	60			
Corrected Total	38.006	59			

a. R Squared = .426 (Adjusted R Squared = .109)

Table D.14 The ANOVA table showing effects of drying methods on chewiness of dried figs as tested by a line scale at $p \leq 0.05$

Dependent Variable: Chewiness

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	44.312[a]	21	2.110	3.909	.00013
Intercept	2047.504	1	2047.504	3792.722	10^{-3}
panelist	8.939	19	.470	.872	.616
Trt	35.372	2	17.686	32.761	$5x10^{-9}$
Error	20.514	38	.540		
Total	2112.330	60			
Corrected Total	64.826	59			

a. R Squared = .684 (Adjusted R Squared = .509)

Table D.15 The ANOVA table showing effects of drying methods on natural flavor of dried figs as tested by a line scale at $p \leq 0.05$

Dependent Variable: Natural flavor

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	11.722[a]	21	.558	1.779	.060
Intercept	1822.708	1	1822.708	5810.484	10^{-3}
panelist	2.875	19	.151	.482	.954
Trt	8.846	2	4.423	14.100	.000026
Error	11.920	38	.314		
Total	1846.350	60			
Corrected Total	23.642	59			

a. R Squared = .496 (Adjusted R Squared = .217)

Table D.16 The ANOVA table showing effects of drying methods on cooked flavor of dried figs as tested by a line scale at $p \leq 0.05$

Dependent Variable: Cooked flavor

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	73.545[a]	21	3.502	9.496	$2x10^{-9}$
Intercept	1269.600	1	1269.600	3442.369	10^{-3}
panelist	7.320	19	.385	1.045	.439
Trt	66.225	2	33.113	89.781	10^{-3}
Error	14.015	38	.369		
Total	1357.160	60			
Corrected Total	87.560	59			

a. R Squared = .840 (Adjusted R Squared = .751)

Table D.17 The ANOVA table showing effects of drying methods on color of dried figs as tested by affective test

Dependent Variable: Color

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	215.520[a]	51	4.226	1.719	.011
Intercept	4139.627	1	4139.627	1684.359	10^{-13}
panelist	201.707	49	4.116	1.675	.016
Trt	13.813	2	6.907	2.810	.065
Error	240.853	98	2.458		
Total	4596.000	150			
Corrected Total	456.373	149			

a. R Squared = .472 (Adjusted R Squared = .198)

Table D.18 The ANOVA table showing effects of drying methods on flavor of dried figs as tested affective test

Dependent Variable: Flavor

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	169.827[a]	51	3.330	1.557	.031
Intercept	4570.560	1	4570.560	2136.863	10^{-13}
panelist	168.107	49	3.431	1.604	.024
Trt	1.720	2	.860	.402	.670
Error	209.613	98	2.139		
Total	4950.000	150			
Corrected Total	379.440	149			

a. R Squared = .448 (Adjusted R Squared = .160)

Table D.19 The ANOVA table showing effects of drying methods on texture of dried figs as tested by affective test

Dependent Variable: Texture

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	157.513[a]	51	3.088	1.091	.350
Intercept	4320.167	1	4320.167	1526.671	10^{-13}
panelist	137.500	49	2.806	.992	.502
Trt	20.013	2	10.007	3.536	.033
Error	277.320	98	2.830		
Total	4755.000	150			
Corrected Total	434.833	149			

a. R Squared = .362 (Adjusted R Squared = .030)

Table D.20 The ANOVA table showing effects of drying methods on overall preference as tested by affective test

Dependent Variable: Overall

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	150.678[a]	51	2.954	1.544	.033
Intercept	4565.042	1	4565.042	2385.613	10^{-13}
panelist	136.375	49	2.783	1.454	.059
Trt	14.303	2	7.152	3.737	.027
Error	187.530	98	1.914		
Total	4903.250	150			
Corrected Total	338.208	149			

a. R Squared = .446 (Adjusted R Squared = .157)

Table D.21 The ANOVA table showing effect of storage time on physicochemical and antioxidant properties of hot-air dried figs at $p \leq 0.05$

		Sum of Squares	df	Mean Square	F	Sig.
Moisture content	Between Groups	4.528	4	1.132	.374	.819
	Within Groups	15.122	5	3.024		
	Total	19.650	9			
a_w	Between Groups	.001	4	.000	.229	.911
	Within Groups	.004	5	.001		
	Total	.004	9			
*L**	Between Groups	26.448	4	6.612	1.369	.363
	Within Groups	24.147	5	4.829		
	Total	50.595	9			
*a**	Between Groups	.710	4	.177	1.251	.397
	Within Groups	.709	5	.142		
	Total	1.418	9			
*b**	Between Groups	14.346	4	3.587	3.126	.121
	Within Groups	5.737	5	1.147		
	Total	20.083	9			
Hue angle	Between Groups	5.326	4	1.332	.394	.806
	Within Groups	16.892	5	3.378		
	Total	22.219	9			
Chroma	Between Groups	24.408	4	6.102	6.161	.036
	Within Groups	4.953	5	.991		
	Total	29.361	9			
Hardness	Between Groups	23.073	4	5.768	9.947	.013
	Within Groups	2.900	5	.580		
	Total	25.973	9			
Cutting work	Between Groups	2261.801	4	565.450	3.723	.091
	Within Groups	759.312	5	151.862		
	Total	3021.113	9			

Table D.21 The ANOVA table showing effect of storage time on physicochemical and antioxidant properties of hot-air dried figs at $p \leq 0.05$ (Continued)

Adhesiveness	Between Groups	.372	4	.093	.635	.660
	Within Groups	.731	5	.146		
	Total	1.103	9			
TP (d.b.)	Between Groups	13527.689	4	3381.922	32.003	.001
	Within Groups	528.381	5	105.676		
	Total	14056.071	9			
FRAP value (d.b.)	Between Groups	44859.491	4	11214.873	11.331	.010
	Within Groups	4948.647	5	989.729		
	Total	49808.139	9			

Table D.22 The ANOVA table showing effect of storage time on physicochemical and antioxidant properties of multistage dried figs at $p \leq 0.05$

		Sum of Squares	df	Mean Square	F	Sig.
Moisture content	Between Groups	19.952	4	4.988	6.162	.036
	Within Groups	4.047	5	.809		
	Total	24.000	9			
a_w	Between Groups	.006	4	.001	1.492	.331
	Within Groups	.005	5	.001		
	Total	.010	9			
L^*	Between Groups	45.431	4	11.358	2.781	.146
	Within Groups	20.421	5	4.084		
	Total	65.852	9			
a^*	Between Groups	1.344	4	.336	.526	.723
	Within Groups	3.196	5	.639		
	Total	4.540	9			

Table D.22 The ANOVA table showing effect of storage time on physicochemical and antioxidant properties of multistage dried figs at $p \leq 0.05$ (Continued)

*b**	Between Groups	24.465	4	6.116	4.449	.067
	Within Groups	6.874	5	1.375		
	Total	31.339	9			
Hue angle	Between Groups	26.569	4	6.642	3.253	.114
	Within Groups	10.210	5	2.042		
	Total	36.779	9			
Chroma	Between Groups	19.779	4	4.945	6.271	.035
	Within Groups	3.943	5	.789		
	Total	23.721	9			
Hardness	Between Groups	134.903	4	33.726	3.615	.096
	Within Groups	46.644	5	9.329		
	Total	181.547	9			
Cutting work	Between Groups	3794.547	4	948.637	3.660	.094
	Within Groups	1295.824	5	259.165		
	Total	5090.371	9			
Adhesiveness	Between Groups	.752	4	.188	30.014	.001
	Within Groups	.031	5	.006		
	Total	.783	9			
TP (d.b.)	Between Groups	26795.931	4	6698.983	27.980	.001
	Within Groups	1197.103	5	239.421		
	Total	27993.033	9			
FRAP value (d.b.)	Between Groups	7704.924	4	1926.231	5.125	.051
	Within Groups	1879.232	5	375.846		
	Total	9584.156	9			

Table D.23 The ANOVA table showing effect of storage time on physicochemical and antioxidant properties of MWVD figs at $p \leq 0.05$

		Sum of Squares	df	Mean Square	F	Sig.
Moisture content	Between Groups	39.680	4	9.920	6.793	.030
	Within Groups	7.302	5	1.460		
	Total	46.981	9			
a_w	Between Groups	.016	4	.004	4.860	.057
	Within Groups	.004	5	.001		
	Total	.020	9			
*L**	Between Groups	18.961	4	4.740	12.584	.008
	Within Groups	1.883	5	.377		
	Total	20.844	9			
*a**	Between Groups	1.834	4	.458	3.312	.111
	Within Groups	.692	5	.138		
	Total	2.526	9			
*b**	Between Groups	9.659	4	2.415	2.428	.178
	Within Groups	4.972	5	.994		
	Total	14.631	9			
Hue angle	Between Groups	20.921	4	5.230	1.982	.236
	Within Groups	13.197	5	2.639		
	Total	34.118	9			
Chroma	Between Groups	26.698	4	6.675	8.553	.018
	Within Groups	3.902	5	.780		
	Total	30.600	9			
Hardness	Between Groups	155.408	4	38.852	8.866	.017
	Within Groups	21.912	5	4.382		
	Total	177.320	9			
Cutting work	Between Groups	23546.521	4	5886.630	27.240	.001
	Within Groups	1080.517	5	216.103		
	Total	24627.038	9			

Table D.23 The ANOVA table showing effect of storage time on physicochemical and antioxidant properties of MWVD figs at $p \leq 0.05$ (Continued)

Adhesiveness	Between Groups	.244	4	.061	8.582	.018
	Within Groups	.036	5	.007		
	Total	.280	9			
TP (d.b.)	Between Groups	20618.415	4	5154.604	13.939	.006
	Within Groups	1848.964	5	369.793		
	Total	22467.379	9			
FRAP value (d.b.)	Between Groups	56596.255	4	14149.064	67.561	.00015
	Within Groups	1047.139	5	209.428		
	Total	57643.394	9			

Table D.24 The ANOVA table showing effect of storage time for 0 week on physicochemical and antioxidant properties of dried figs from various treatments at $p \leq 0.05$

		Sum of Squares	df	Mean Square	F	Sig.
Moisture content	Between Groups	3.213	2	1.607	2.529	.227
	Within Groups	1.906	3	.635		
	Total	5.119	5			
a_w	Between Groups	.016	2	.008	2.218	.256
	Within Groups	.011	3	.004		
	Total	.027	5			
*L**	Between Groups	14.175	2	7.087	103.617	.002
	Within Groups	.205	3	.068		
	Total	14.380	5			
*a**	Between Groups	.526	2	.263	3.825	.150
	Within Groups	.206	3	.069		
	Total	.732	5			

Table D.24 The ANOVA table showing effect of storage time for 0 week on physicochemical and antioxidant properties of dried figs from various treatments at $p \leq 0.05$ (Continued)

*b**	Between Groups	22.965	2	11.482	63.957	.003
	Within Groups	.539	3	.180		
	Total	23.504	5			
Hue angle	Between Groups	2.663	2	1.331	6.315	.084
	Within Groups	.632	3	.211		
	Total	3.295	5			
Chroma	Between Groups	29.611	2	14.806	20.136	.018
	Within Groups	2.206	3	.735		
	Total	31.817	5			
Hardness	Between Groups	16.378	2	8.189	1.089	.441
	Within Groups	22.560	3	7.520		
	Total	38.938	5			
Cutting work	Between Groups	10627.962	2	5313.981	21.274	.017
	Within Groups	749.357	3	249.786		
	Total	11377.319	5			
Adhesiveness	Between Groups	.174	2	.087	21.895	.016
	Within Groups	.012	3	.004		
	Total	.186	5			
TP (d.b.)	Between Groups	5137.900	2	2568.950	42.823	.006
	Within Groups	179.969	3	59.990		
	Total	5317.869	5			
FRAP value (d.b.)	Between Groups	16977.185	2	8488.592	54.773	.004
	Within Groups	464.936	3	154.979		
	Total	17442.121	5			

Table D.25 The ANOVA table showing effect of storage time for 2 week on physicochemical and antioxidant properties of dried figs from various treatments at $p \leq 0.05$

		Sum of Squares	df	Mean Square	F	Sig.
Moisture content	Between Groups	18.790	2	9.395	1.917	.291
	Within Groups	14.702	3	4.901		
	Total	33.492	5			
a_w	Between Groups	.009	2	.005	2270.333	.00002
	Within Groups	.000	3	.000		
	Total	.009	5			
*L**	Between Groups	12.527	2	6.263	1.800	.306
	Within Groups	10.440	3	3.480		
	Total	22.967	5			
*a**	Between Groups	.065	2	.032	.204	.826
	Within Groups	.475	3	.158		
	Total	.540	5			
*b**	Between Groups	7.207	2	3.603	4.002	.142
	Within Groups	2.701	3	.900		
	Total	9.908	5			
Hue angle	Between Groups	6.743	2	3.372	1.171	.421
	Within Groups	8.640	3	2.880		
	Total	15.383	5			
Chroma	Between Groups	3.718	2	1.859	4.116	.138
	Within Groups	1.355	3	.452		
	Total	5.073	5			
Hardness	Between Groups	21.047	2	10.523	1.514	.351
	Within Groups	20.855	3	6.952		
	Total	41.901	5			
Cutting work	Between Groups	1197.005	2	598.502	6.276	.085
	Within Groups	286.096	3	95.365		
	Total	1483.101	5			

Table D.25 The ANOVA table showing effect of storage time for 2 week on physicochemical and antioxidant properties of dried figs from various treatments at $p \leq 0.05$ (Continued)

Adhesiveness	Between Groups	.060	2	.030	3.078	.188
	Within Groups	.029	3	.010		
	Total	.090	5			
TP (d.b.)	Between Groups	3128.588	2	1564.294	2.963	.195
	Within Groups	1583.749	3	527.916		
	Total	4712.337	5			
FRAP value (d.b.)	Between Groups	15734.792	2	7867.396	6.900	.075
	Within Groups	3420.446	3	1140.149		
	Total	19155.238	5			

Table D.26 The ANOVA table showing effect of storage time for 4 week on physicochemical and antioxidant properties of dried figs from various treatments at $p \leq 0.05$

		Sum of Squares	df	Mean Square	F	Sig.
Moisture content	Between Groups	7.293	2	3.646	1.598	.337
	Within Groups	6.845	3	2.282		
	Total	14.138	5			
a_w	Between Groups	.011	2	.005	1105.897	.00005
	Within Groups	.000	3	.000		
	Total	.011	5			
L^*	Between Groups	12.629	2	6.315	8.330	.060
	Within Groups	2.274	3	.758		
	Total	14.903	5			
a^*	Between Groups	.551	2	.276	.867	.504
	Within Groups	.953	3	.318		
	Total	1.505	5			

Table D.26 The ANOVA table showing effect of storage time for 4 week on physicochemical and antioxidant properties of dried figs from various treatments at $p \leq 0.05$ (Continued)

*b**	Between Groups	18.551	2	9.275	5.070	.109
	Within Groups	5.489	3	1.830		
	Total	24.039	5			
Hue angle	Between Groups	.385	2	.193	.026	.975
	Within Groups	22.648	3	7.549		
	Total	23.034	5			
Chroma	Between Groups	9.649	2	4.825	5.360	.102
	Within Groups	2.700	3	.900		
	Total	12.349	5			
Hardness	Between Groups	61.388	2	30.694	7.444	.069
	Within Groups	12.370	3	4.123		
	Total	73.759	5			
Cutting work	Between Groups	44.649	2	22.325	.061	.942
	Within Groups	1092.366	3	364.122		
	Total	1137.015	5			
Adhesiveness	Between Groups	.052	2	.026	5.350	.102
	Within Groups	.015	3	.005		
	Total	.067	5			
TP (d.b.)	Between Groups	3860.147	2	1930.073	84.542	.002
	Within Groups	68.489	3	22.830		
	Total	3928.636	5			
FRAP value (d.b.)	Between Groups	47791.909	2	23895.955	40.660	.007
	Within Groups	1763.113	3	587.704		
	Total	49555.022	5			

Table D.27 The ANOVA table showing effect of storage time for 6 week on physicochemical and antioxidant properties of dried figs from various treatments at $p \leq 0.05$

		Sum of Squares	df	Mean Square	F	Sig.
Moisture content	Between Groups	24.534	2	12.267	34.731	.008
	Within Groups	1.060	3	.353		
	Total	25.593	5			
a_w	Between Groups	.005	2	.003	540.448	.000146
	Within Groups	.000	3	.000		
	Total	.005	5			
*L**	Between Groups	8.313	2	4.156	1.409	.370
	Within Groups	8.850	3	2.950		
	Total	17.163	5			
*a**	Between Groups	1.673	2	.836	4.150	.137
	Within Groups	.605	3	.202		
	Total	2.277	5			
*b**	Between Groups	13.948	2	6.974	6.658	.079
	Within Groups	3.142	3	1.047		
	Total	17.091	5			
Hue angle	Between Groups	8.444	2	4.222	3.068	.188
	Within Groups	4.128	3	1.376		
	Total	12.572	5			
Chroma	Between Groups	22.067	2	11.034	19.493	.019
	Within Groups	1.698	3	.566		
	Total	23.765	5			
Hardness	Between Groups	98.327	2	49.163	14.996	.027
	Within Groups	9.835	3	3.278		
	Total	108.162	5			

Table D.27 The ANOVA table showing effect of storage time for 6 week on physicochemical and antioxidant properties of dried figs from various treatments at $p \leq 0.05$ (Continued)

Cutting work	Between Groups	28.998	2	14.499	.184	.840
	Within Groups	235.769	3	78.590		
	Total	264.766	5			
Adhesiveness	Between Groups	.828	2	.414	1.693	.322
	Within Groups	.734	3	.245		
	Total	1.563	5			
TP (d.b.)	Between Groups	5092.350	2	2546.175	13.407	.032
	Within Groups	569.735	3	189.912		
	Total	5662.086	5			
FRAP value (d.b.)	Between Groups	31155.659	2	15577.830	42.094	.006
	Within Groups	1110.228	3	370.076		
	Total	32265.887	5			

Table D.28 The ANOVA table showing effect of storage time for 8 week on physicochemical and antioxidant properties of dried figs from various treatments at $p \leq 0.05$

		Sum of Squares	df	Mean Square	F	Sig.
Moisture content	Between Groups	17.974	2	8.987	13.765	.031
	Within Groups	1.959	3	.653		
	Total	19.932	5			
a_w	Between Groups	.001	2	.000	.981	.470
	Within Groups	.002	3	.001		
	Total	.002	5			
*L**	Between Groups	41.891	2	20.945	2.546	.226
	Within Groups	24.682	3	8.227		
	Total	66.573	5			
*a**	Between Groups	.443	2	.222	.282	.772
	Within Groups	2.357	3	.786		
	Total	2.800	5			
*b**	Between Groups	32.046	2	16.023	8.414	.059
	Within Groups	5.713	3	1.904		
	Total	37.759	5			
Hue angle	Between Groups	.717	2	.359	.253	.792
	Within Groups	4.251	3	1.417		
	Total	4.968	5			
Chroma	Between Groups	34.833	2	17.416	10.800	.043
	Within Groups	4.838	3	1.613		
	Total	39.671	5			
Hardness	Between Groups	145.341	2	72.671	37.360	.008
	Within Groups	5.835	3	1.945		
	Total	151.176	5			

Table D.28 The ANOVA table showing effect of storage time for 8 week on physicochemical and antioxidant properties of dried figs from various treatments at $p \leq 0.05$ (Continued)

Cutting work	Between Groups	152.913	2	76.456	.297	.763
	Within Groups	772.067	3	257.356		
	Total	924.979	5			
Adhesiveness	Between Groups	.364	2	.182	67.870	.003
	Within Groups	.008	3	.003		
	Total	.372	5			
TP (d.b.)	Between Groups	6418.353	2	3209.177	8.211	.061
	Within Groups	1172.505	3	390.835		
	Total	7590.858	5			
FRAP value (d.b.)	Between Groups	101474.754	2	50737.377	136.355	.001
	Within Groups	1116.295	3	372.098		
	Total	102591.048	5			

VITA

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She entered the Graduate School at Chulalongkorn University in 2011, presented some parts of her research at 51st Kasetsart University Annual Conference organized by Kasetsart University, Bangkok on February 2013, and now is working towards her M.Sc. in Food Technology. During her graduate study, she was a teaching assistant for the course of Food Processing Laboratory in Department of Food Technology, Faculty of Science, Chulalongkorn University.