DRYING BEHAVIOR OF THAI RED CURRY PASTE BY MICROWAVE AND HOT-AIR DRYING AND THEIR EFFECTS ON QUALITIES

SUDATHIP INCHUEN

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENT FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY IN FOOD SCIENCE

FACULTY OF AGRO-INDUSTRY

KING MONGKUT'S INSTITUTE OF TECHNOLOGY LADKRABANG

2009

KMITL-2009-AI-D-051-065

Dissertation	Drying Behavior of Thai Red Curry Paste by Microwave and Hot-Air Drying and Their Effects on Qualities
Student	Miss Sudathip Inchuen
Student ID.	47063103
Degree	Doctor of Philosophy
Program	Food Science
Year	2009
Major Advisor	Associate Professor Dr.Woatthichai Narkrugsa
Co-Advisor	Assistant Professor Dr.Pimpen Pornchaloempong

ABSTRACT

Thai red curry paste was dried with two different drying methods: microwave and hot-air drying. The microwave drying was carried out in a microwave oven with microwave power of 180, 360 and 540 W, while the hot-air drying was carried out at drying air temperatures of 60, 70 and 80 °C. Drying time of microwave drying process to reduce the moisture content of red curry paste from 2.58 to 0.08 g water/g dry matter was much shorter than that of the hot-air drying process. An increase in the microwave power significantly decreased the drying time. In the hot-air drying, increasing the drying air temperature also significantly decreased the drying time. Microwave drying process of red curry paste consisted of three drying periods, i.e. heating up, constant rate and falling rate periods, while hot-air drying process consisted of two drying periods, i.e. heating up and falling rate periods. To describe the effect of microwave power and drying air temperature on drying kinetics of red curry paste, eleven different mathematical thin-layer equations, i.e. Lewis, Page, Modified Page, Henderson and Pabis, Two term exponential, Wang and Singh, Logarithmic, Approximate of diffusion, Verma et al., Two term and Midilli et al. were used to fit the drying data. The Midilli et al. model provided the best fit to both microwave and hot-air drying experimental data followed by the Page and the Modified Page models.

The sorption isotherms of dried red curry paste at room temperature (30°C) in water activities range of 0.113-0.970 were determined by the static gravimetric method. The sorption isotherm of dried red curry paste exhibited type III behavior. The drying methods did not significant effect on the sorption. The moisture sorption data were fitted to ten sorption models,

i.e. Oswin, Caurie, Smith, Lewicki-2, BET, Haslay, Handerson, GAB, Lewicki-3 and Peleg. The GAB model was found to be the most suitable for fitting the moisture sorption data followed by the Lewicki-3 model. The monolayer moisture contents were taken as the safe minimum moisture level in red curry powder determined using the BET equation. The BET monolayer moisture content values ranged from 0.080 to 0.085 g water/g dry matter.

In addition, the quality attributes of dried red curry paste were evaluated for color properties, proximate compositions, antioxidant properties and sensory evaluation. Color properties were expressed in terms of browning index (BI), color measurements (Hunter **L, a, b),** ratio of color change ($\Delta L/L_0$, $\Delta a/a_0$ and $\Delta b/b_0$) and total color change (ΔE). For antioxidant properties were expressed in terms of total phenolic content (TPC) and antioxidant activities. The Folin-Ciocalteu method was used to determine TPC while the 2,2-diphenyl-1-picrylhydrazyl radical scavenging activity (DPPH-RSA) and the ferric reducing antioxidative power (FRAP) were used to elucidate antioxidant activities. Paired comparison-dependent and selected pair test was used to determine the effect of the drying methods on a color and an aroma including preference. The dried red curry paste was more BI value, lighter and more yellow color of dry-rehydrated red curry paste than the fresh one. The drying processes also increased in the contents of available carbohydrate and phenolic compounds including antioxidant activity while decreased in the content of crude fat. Moreover, sensory evaluation results also showed that the drying process caused a significant decrease in both color and aroma intensities but a significant increase in preference. The drying methods showed no significant effects on the proximate compositions and sensory evaluation of the dried red curry paste, whereas color and antioxidant properties were all affected by the two methods to different extents. The microwave drying resulted in more BI value, slightly darker in color and less yellow color of dry-powdered red curry paste than the hot-air drying, while the rehydrated samples from the microwave drying were lighter and more yellow color than the hot-air drying. Almost all microwave-dried samples had more phenolic content and antioxidant activities than hot-air-dried samples.

ACKNOWLEDGEMENTS

I would like to express my deepest and sincere gratitude to my advisor, Associate Professor Dr. Woatthichai Narkrugsa for his kindness in providing an opportunity to be his advisee. I am also appreciated for his valuable supervision, suggestions, encouragement, supporting, guidance and criticism throughout the course of my study. I would like to express my greatest appreciation and sincere gratitude to my co-advisor, Assistant Professor Dr. Pimpen Pornchaleampong for her valuable advices, kindness useful comment and suggestion. Sincere thanks and appreciation are also due to my graduate committee, Associate Professor Dr. Wanna Tungjaroenchai, Associate Professor Dr. Ratiporn Haruenkit, Assistant Professor Dr. Porjai Thamakorn and Dr. Chitsuda Chaisakdanugul for their helpful suggestions.

I would like to express my sincere gratitude and appreciation to my dear parents, who have been given me a chance to study and have strongly supported me. I deeply thank my brothers and sisters, who took care of me. I also thank to all friends at graduate program (Doctor of Philosophy in Food Science) of Agro-Industry, King Mongkut's Institute of Technology Ladkrabang for their supports and encouragements.

Moreover, I would like to thank Mr. Prasit Niyomsub, Namprick Maesri Limited Partnership, for kindly supplied the Thai red curry paste used in this study and National Center for Genetic Engineering and Biotechnology, Thailand, for the research fund.

This study was supported by the Office of the Higher Education Commission, Thailand and Mahasarakham University, Thailand.

Sudathip Inchuen

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

LIST OF TABLES

LIST OF TABLES (Cont.)

LIST OF TABLES (Cont.)

LIST OF FIGURES

LIST OF FIGURES (Cont.)

FIGURE **PAGE**

LIST OF SYMBOLS

W	=	The moisture content (g water/g dry matter)
W_e	=	The equilibrium moisture content (g water/g dry matter)
$W_{e,exp,i}$	=	The i^{th} experimental equilibrium moisture content(g water/g dry matter)
$W_{e,pre,i}$	=	The i^{th} predicted equilibrium moisture content(g water/g dry matter)
W_0	=	The initial moisture content (g water/g dry matter)
W_t	=	The moisture content (g water/g dry matter) at time t
W_{t+dt}	=	The moisture content (g water/g dry matter) at time t+dt
MR	=	The moisture ratio
$MR_{exp,i}$	=	The i^{th} experimental moisture ratio
$MR_{pre,i}$	=	The i^{th} predicted moisture ratio
DR	=	The drying rate (g water/g dry matter/min)
R^2	=	The coefficient of determination
χ^2	=	The reduced chi-square
RMSE	=	The root mean square error
n	=	The number of replications
N	=	The number of observations
z	=	The number of constants in the model
t	=	Time (min)
k	=	The drying parameter (min^{-1})
a, b, c, n and g	=	The drying constants
L	=	Lightness
a	=	Redness and greenness
b	=	Yellowness and blueness
$\Delta L/L_0$	=	Ratio of lightness change
$\Delta a/a_0$	=	Ratio of red color change
$\Delta b/b_0$	=	Ratio of yellow color change
ΔE	=	Total color change

LIST OF SYMBOLS (Cont.)

A_0	=	The absorbance of the control solution (containing only DPPH)
A_1	=	The absorbance in the presence of the samples extract in DPPH solution
A_S	=	The absorbance of each extract without DPPH solution
a_w	=	The water activity
X_m	=	The monolayer moisture content (g water/g dry matter)
A, *B*, *C*, *D* and *K*	=	The moisture sorption constants

LIST OF ABBREVIATIONS

MW	=	Microwave drying
HA	=	Hot-air drying
BI	=	Browning index
TPC	=	Total phenolic content (mg of gallic acid equivalents/g dry matter)
DPPH-RSA	=	DPPH -radical scavenging activity (mg of trolox equivalents/g dry matter)
FRAP	=	Ferric reducing antioxidative power (mg of trolox equivalents/g dry matter)
S.D.	=	Standard derivation

CHAPTER 1

INTRODUCTION

Thai red curry paste is one of the most famous kinds of curry paste used to enhance several spicy Thai dishes. The paste is prepared from dried red chilli, garlic, shallot, lemon grass, kaffir lime, galangal, coriander seeds, cumin, cardamon and additives such as salt and sugar, all are blended together to obtain a homogeneous orange-red paste providing spicy and authentic fragrance of certain dishes. Moreover, it has been reported that the major ingredients of this product such as chilli (Deepa et al., 2007; Materska and Perucka, 2005), garlic (Leelarungrayub et al., 2006), shallot (Fattorusso et al., 2002), lemon grass, galangal root (Juntachote et al., 2006a; Ly et al., 2003) and coriander seeds (Wangensteen et al., 2004) are good sources of phenolic compounds. The phenolic compounds in these herbs and spices have been found to make a major contribution to human health and multiple positive biological effects, such as antioxidant activity, antimutagenic and/or anticarcinogenic activity and anti-inflammatory action (Surh, 2002; Karakaya, 2004). Fresh Thai red curry paste in a semi-solid form has a short shelf life due to its high moisture content (more than 60%).

The growing popularity of Thai food around the world creates the need to preserve this product. Drying is one of the preservative methods that can extend the shelf-life of the red curry paste. It can be defined as a simultaneous heat and mass transfer operation in which water content of material is lowered by evaporation of water into an unsaturated gas stream (Khraiseheh et al., 1997). Lowering of water activity of product can consequently inhibit the growth of microorganisms and decrease chemical reactions to prolong the shelf life of the product at room temperature. Drying is also provides smaller spaces for storage and lighter weight for transportation.

Hot-air drying is the most widely used method to produce dried foods and agricultural products (Vega-Mercado et al., 2001) because of its low investment and operation cost. However, the disadvantage of hot-air drying is that it takes a long period of time even at high temperatures that may cause serious damage to the product quality attributes such as flavor, color, texture, nutrients and substances beneficial to health. Other disadvantages include reduction in bulk density and rehydration capacity of the dried products (Nijhuis et al., 1998; Tsami et al., 1999). Therefore, there is a need to optimize conditions to obtain high-quality dried products.

Microwave drying is an alternative drying method which offers a considerable reduction of drying time. Microwave application has been reported to improve product qualities resulting in a better aroma, faster and better rehydration with considerable saving in energy (Maskan, 2000). However, it may result in a poor quality product if not properly applied (Nijhuis et al., 1998; Zhang et al., 2006).

It is well-known that the quality of a dried product is strongly dependent on the drying process and the processing conditions. Therefore, a through knowledge of the drying process is needed in order to design the process and to obtain product of desired quality. Knowledge of the influences of the drying on food qualities can be efficiently used to create new quality attributes and new functionality of the product. Moreover, this knowledge may help on the scale up requirement and criteria for industrial use. Therefore, it is necessary to study the effect of microwave and hot-air drying on drying behavior of Thai red curry paste which included moisture sorption properties, color properties, approximate compositions, antioxidant properties and sensory evaluation and of dry product.

Objectives

1. To study the effect of drying methods (microwave and hot-air drying) and drying conditions (microwave power and drying air temperature) on drying behavior of Thai red curry paste.

2. To study the effect of drying methods (microwave and hot-air drying) and drying conditions (microwave power and drying air temperature) on moisture sorption properties of dried Thai red curry paste.

3. To study the effect of drying methods (microwave and hot-air drying) and drying conditions (microwave power and drying air temperature) on color properties, proximate compositions, antioxidant properties and sensory evaluation of dried Thai red curry paste.

CHAPTER 2

LITERATURE REVIEWS

2.1 Ingredients of Thai Red Curry Paste

Thai Red Curry Paste in Thai calls "Nam Prik Kaeng Phet or Nam Phrik Kaeng Daeng". The paste is prepared from mixture of several herbs and spices such as dried red chilli, garlic, shallot, lemon grass, kaffir lime and galangal, and additives such as salt and sugar, all blended together to obtain a homogeneous orange-red paste. It provides the colorful, spicy and authentic fragrance of certain dishes. Moreover, it has been reported that the major ingredients of this product are good sources of phenolic compounds.

2.1.1 Chilli

Chilli peppers (*Capsicum annum* Linn.) are one of the most important spices widely cultivated and employed as a flavoring and coloring ingredients in many foods such as curry paste, curry powder and sauce.

Fresh chilli is a source of vitamins (vitamin A, ascorbic acid, tocopherols) and its also rich sources of flavonoids, phenolic acids and capsaicinoids. The flavonoids and phenolic acid compounds isolated from hot pepper fruit (*Capsicum annum* L.) were *trans-p*-feruloyl-β-D-glucopyranoside, *trans-p*-sinapoyl-β-D-glucopyranoside, quercetin 3-*O*-α-L-rhamnopyranoside-7-*O*-β-D-glucopyranoside, *trans-p*-ferulylalcohol-4-*O*-[6-(2-methyl-3-hydroxypropionyl)] glucopyranoside, luteolin 6-C-β-D-glucopyranoside-8-C-α-L-arabinopyranoside, apigenin 6-C-D-glucopyranoside-8-C-L-arabinopyranoside, lutoeolin7-O-[2-(β-D-apiofuranosyl)-β-D-glucopyranoside], quercetin3-O-α-L-rhamnopyranoside and luteolin 7-*O*-[2-(β-D-apiofuranosyl)-4-(β-D-glucopyranosyl)-6-malonyl]-β-D-glucopyranoside. The main compounds of the fraction isolated from red pepper were sinapoyl and feruloyl glycoside and the main compound from green pepper was quercetin-3-*O*-L-rhamnoside (Materska and Perucka, 2005).

The strong pungency of chilli has been attributed to capsaicinoids that are present in chilli at level up to 1%. The most abundant capsaicinoids are capsaicin and dihydrocapsaicin which constitute more than 80%. Other capsaicinoids are much smaller quantities, including nor-dihydrocapsaicin, homocapsaicin, homodihydrocapsaicin and nonivamin (Goodwin and Hertwig,

2003; Schweiggert et al., 2006a). The natural pattern and contents of individual capsaicinoids in chilli pepper vary with species and variety, growing condition and time of harvest.

Capsicums are often added to food products to enhance color and acceptability. The attractive red-orange color of capsicums is mainly due to the presence of three keto-carotenoids, namely capsanthin, capsorubin and crypto-capsin (Matsufuji et al., 1998; Ahmed et al., 2002).

Chilli is natural antioxidant compound with health benefits. It has been reported that the extracts of chilli have antioxidant properties (Antonella et al., 2002; Materska and Perucka, 2005). Capsaicin, one of the active compounds of red pepper have a variety of reducing blood pressure (Tolan et al., 2004) and anticancer properties (Sánchez et al., 2006).

2.1.2 Garlic

Garlic (*Allium sativum* Liliaceae.) is one of the most important bulb vegetables grown and used as spice and flavoring agent for foods.

In every 100 g of fresh weight, 23 g is carbohydrate accounting for bulk of garlic bulb, apart from its rich content of protein (4.4 g). Among the minerals, garlic is known to contain high levels of phosphorus (44 mg) followed by calcium (5 mg), and iron (0.24 mg). Nicotinic acid (0.91 mg) and vitamin C are important chemical constituents. In addition it contains the minerals selenium and germanium. The essential oil, 0.2% in all, consists of allicin and many kinds of thio-ether compounds. Garlic also contains citral, geraniol, linalool, α-phellandrene, propionic, aldehyde and valeraldehyde (Khanum et al., 2004).

Allicin is considered to be the most important of the biologically active components of crushed bulb. However, allicin does not exist in garlic as such, but is rapidly produced when the precursor alliin is cleaved by the action of allinase upon crushing the tissue. Bakri and Douglas (2005) reported that the garlic extract (57.1% w/v) containing 220 μg/ml allicin. Processed garlic preparations typically contain a range of different sulfur compounds.

Garlic has generally found to be a great antioxidant, antibacterial, antifungal, hypoglycaemic, hyperglycemic, hypolipidaemic, antithrombotic, antihypertensive and anticancer properties (Antri and Mirelman, 1999; Khanum et al., 2004; Oommen et al., 2004; Sallam et al., 2004; Riripongvutikorn et al., 2005; Pedraza-Chaverrí et al., 2006).

The main antimicrobial effect of garlic is due to allicin's chemical reaction with thiol groups of various enzymes, such as alcohol dehydrogenase, thioredoxin reductase and RNA polymerase (Antri and Mirelman, 1999).

2.1.3 Shallot

Shallot (*Allium ascalonicum* L.) is a major component of many Asian diets and is widely belived to be beneficial to health. This bulb is darker than garlic and had a stronger odor that correlates with its sulfide content.

Analysis of shallot extract has shown the presence of flavone and polyphenolic derivatives such as quercetin, quercetin 4'-glucoside, quercetin 7,4'-diglucoside, quercetin 3, 4'-diglucoside, and quercetin mono-D-glucose (Fattorusso et al., 2002).

Leelarungrayub et al. (2006) demonstrated that shallot extracts have an antioxidant activity similar to that associated with garlic.

2.1.4 Galangal

Galangal (*Alpinia galangal* (L.) Swartz), a rhizome closely related to the ginger family, is commonly used for flavoring foods in stir-fries, curries and soups in Southeast Asia, which has gingery notes with slightly sour and peppery notes, is an essential component of Thai curry paste. Galangal has characteristic fragrance as well as pungency, it also used as a medicine for curing stomachache in China and Thailand.

Two phenolic compounds such as p-hydroxycinnamaldehyde and [di-(p-hydroxy-cis-styryl)] methane were isolated from the chloroform extract of the rhizomes of *A. galangal*. The potent antioxidation activity is curcuminoids. Essential oil from rhizomes of galangal comprised 1,8-cineole, β-pinene, α-terpineol, fenchyl acetate, α-pinene, camphene, guaiol, camphor and β-elemene (Juntachote et al., 2006b).

Oonmetta-aree et al. (2006) reported that the major compound of galangal ethanol extracts were essential oil; D,L-1'-ACA (acetoxychavicol acetate) and the minor compounds of crude extract were *p*-coumary diacetate, palmitic acid, acetoxyeugenol acetate, eugenol, β-bisabolene, β-farnesence and sesquiphandrence.

It has been demonstrated that the galangal extracts have antioxidant properties (Ly et al., 2003; Jantachote and Berghofer, 2005; Jantachote et al., 2007), antimicrobial properties (Oonmetta-aree et al., 2006) and anticarcinogenic activity (Zheng et al., 1993).

2.1.5 Lemongrass

Lemongrass (*Cymbopogon citratus* (DC.) stapf (Gramineae)) is an herb. The volatile oil obtained from fresh leaves of this plant is widely used by the perfume and cosmetics industries. It consists of monoterpenes compounds, hydrocarbons, ketones, aldehydes and esters. The GC method can be used to identify a natural mixture. The high percentage of citral (70-85%) in it consists of two isomeric aldehydes, neral and geranial (Nakamura et al., 2003).

It have been demonstrated that the essential oil from lemongrass have antioxidant, antibacterial, antifungal properties (Nguefack et al., 2004; Lertsatitthanakorn et al., 2006) and anticarcinogenic activity (Zheng et al., 1993; Nakamura et al., 2003).

2.1.6 Kaffir Lime

The Kaffir lime (*Citrus hystrix* DC.), also known as *Makrut* (in Thai), is a Southeast Asian citrus plant with very pungent leaves. The green lime fruits are distinguished by their bumpy exterior. The characteristic odor of kaffir lime peel is fruity, tangy and zesty. The volatile oils in the kaffir lime peel are composed of 2.5% α-pinene, 0.2% camphene, 30.6% β-pinene, 22.6% sabinene, 1.4% myrcene, 29.2% limonene, 1.3% cineol, 0.1% γ-terpinene, 0.1% ρ-cymene, 0.1% terpinolene, 0.6% trans-sabinene hydrate, 4.2% citronellal, 0.6% copanene, 0.5% linallol, 0.5% β-cubebene, 4.2% terpinen-4-ol, 0.3% caryophyllene, 0.2% citronellyl acetate, 0.2% α-terpineol, 0.1% geranial, 0.4% citronellol, 0.3% δ-cadinene, 0.1% geraniol, 0.1% nerolidol and 0.3% elemol (Lawrence et al., 1971).

The essential oils of kaffir lime have antioxidant properties (Lertsatitthanakorn et al., 2006).

2.2 Drying

Drying is traditionally defined as the unit operation which converts a liquid, solid or semi-solid feed material into a solid product of significantly lower moisture. In most case, drying involves the application of thermal energy, which causes water to evaporate into the vapor phase.

Drying is one the oldest and the most widely used primary methods of food preservation and is a very important aspect of food processing. Drying can be defined as simultaneous heat and mass transfer operation in which water activity of a material is lowed by the removal of water by evaporation into an unsaturated gas stream (Khraished et al., 1997). The basic objective in drying food products is the removal of water from solids to a certain level at which microbial spoilage is avoided. Longer shelf life and significant reduction in the volume of the product are the major reasons for the popularity of dried food material.

2.2.1 Conventional Drying

Drying method is one of the factors affecting the drying kinetics and the quality of food products. The conventional drying methods normally acquire long processing time and high temperature treatment because of conventional heating occurs by convection followed by conduction where heat must diffuse in from the surface of the material therefore they have high energy consumption and return the product that has unappealing final appearance and texture. This method will degrade the value nutrient in fruits and vegetable.

2.2.1.1 Conventional Drying Behavior

A high moist product dried by hot airflow generally experiences a heating-up, a constant drying rate, and one or several falling rate periods (Mujumdar and Suvachittanont, 2000; Zhange et al., 2006).

(1) A heating-up period, during the first stage of drying of a high moist material, the material heats up due to heat transfer from the air to the material. Once the vapor pressure in the material is higher than that of the environment the material starts to lose moisture, but at a slow rate.

(2) A constant drying rate period, the drying rate is constant because the surface of the material contains free moisture.

(3) A falling rate period, this period can be much extended. Towards the end of the constant rate period, moisture has to be transported from the inside of the material to the surface, and the critical moisture content has been reached. After this time dry spots appear on the

surface, and the drying rate decreases. This is called the first falling rate period. When the surface is completely dry, the moisture is transported from the inner parts of the material as a result of concentration gradients between the interior of the material and the surface. This drying period is called the second falling rate period, and the drying rate is lower than previously.

A fundamental aspect of conventional heat transfer is that the temperature gradients and the moisture gradients are of opposite signs, i.e. the temperature is highest at the surface where the moisture is at its lowest.

When conventional heat transfer methods are used to dry a capillary porous body at atmospheric pressure, the internal movement of moisture is due to liquid flow by capillary action and vapor flow by molecular diffusion. Liquid phase movement is related to moisture gradient and temperature, whereas in the vapor phase it is due to a partial pressure or temperature gradient.

The transition from constant rate to falling rate is often gradual and, for some materials, it may be argued that there is no constant rate in the strict sense.

2.2.1.2 Advantages and Disadvantages of Conventional Drying

Conventional drying is the most widely used method to produce dried foods and agricultural products (Vega-Mercado et al., 2001) because of its low investment and operation cost. However, the disadvantages of hot-air drying are that it takes a long time because heat occurs by convection followed by conduction where heat must diffuse in from the surface of the material therefore they have high energy consumption. Higher temperature and longer drying time in conventional drying may cause serious damage to the quality attributes of the product such as flavor, color, nutrients and substances beneficial to health. Other disadvantages include reduction in bulk density and rehydration capacity of the dried product (Nijhuis et al., 1998; Tsami et al., 1999). Thermal damage incurred by a product during drying is directly proportional to the temperature and time involved. Due to high temperature and long drying time, volatile compounds are vaporized and are lost with water vapor, resulting in significant loss of characteristic flavor in dried products. Case-hardening is a common problem in dried fruits due to rapid drying. As drying proceeds, the rate of water evaporation is faster than the rate of water movement to the product surface, hence making the outer skin dry. Another disadvantage of convectional drying of food is the low energy efficiency. Therefore, there is a search for an alternative efficient drying method for the food industry to process and preserve products of high

quality. To desire to eliminate the existing problems in drying and to achieve fast and effective thermal processing has resulted in the increasing interest in the use of microwave for food drying.

2.2.2 Microwave Heating and Drying

Microwave is defined as electromagnetic waves in the frequency range 300 MHz to 300 GHz, hence the wavelength range from 1 m to 1 mm. There are three frequencies available for microwave technology: (1) 915 MHz, used in certain case due to technological complications; (2) 2.45 GHz, which is already used throughout the world in household microwave ovens; and (3) 28-30 GHz, not feasible on an industrial scale, although it is a low-cost alternative. The energy of microwaves comes from electrical energy that is converted by a power supply to high voltages that in turn are applied to the microwave power tube or generator to produce power at microwave frequencies. The most common power tube used in microwave ovens is the magnetron.

The microwave energy associated with these frequencies is not sufficient to break bonds within the molecules or remove electrons. The electric field component of microwave interacts with food constituent primary through three mechanisms, orientation of permanent dipoles due to asymmetric positive and negative charge as in water molecule, orientation of induced dipoles as in charged polymers, and ionic migration, and ionic migration, as with organic and inorganic salts dissolved in food. Microwave energy is not a form of heat. Heat is a secondary effect of an electromagnetic field interacting with matter, such as food.

The microwave field changes direction millions of time per second in microwave ovens. The conversion of microwave energy into heat is explained by basically two phenomena:

Molecules, with a permanent dipolar moment, rate in the rapidly changing electric field. When molecules rotate in a field that changes polarity at a frequency of many millions of times per second, heat is evolved because of friction forces between the molecules.

Change drift under the action of the field (ionic conduction). Ions, being electrically charged, are influenced by microwave field that cause the ions in solution to flow first in one direction then in the opposite direction as the field is reversed. The effect of ionic conduction can be observed in microwave heating of salted water in that higher temperatures are found at the surface. Ionic conduction also occurs in cellular fluids when animal or vegetable tissues are exposed to microwave energy. When the ions drift, due to the electric field, they collide with other molecules in a billiard ball fashion and heat is evolved because of friction.

Water molecules are polar, i.e. the centre of change is displaced, that can rotate under the influence of an alternating electrical field. Foodstuffs usually contain 50-97% water, thus they are very well suited for heating and drying with microwave energy. In hot air drying, the product surface becomes dry first therefore the dried food layer is a poor conductor of heat through the dehydration process. In contrast microwaves are able to penetrate a dry surface layer and heat the food throughout all high-moisture regions. This promotes mass transport and increases drying rate.

Microwave heating is based on the transformation of alternating electromagnetic field energy into thermal energy by affecting the polar molecules of a material. The most important characteristic of microwave heating is volumetric heating. Volumetric heating means that materials can absorb microwave energy directly and internally and convert it into heat. In microwave heating, heat is generated throughout the material, leading to faster heating rates, compared to conventional heating where heat is usually transferred from the surface to the interior. Microwave drying is caused by water vapor pressure differences between interior and surface regions, which provide a driving force for moisture transfer.

2.2.2.1 Microwave Drying Behavior

In general, a complete microwave drying process consists of three drying periods (Zhange et al., 2006).

(1) A heating-up period in when microwave energy is converted into thermal energy within the moist materials, and temperature of the product increases with time. Once, the moisture vapor pressure in food is above that of the environment, the material starts to lose moisture, but at relatively smaller rates.

(2) Rapid drying period, during which a stable temperature profile is established, the thermal energy converted from microwave energy is used for the vaporization of moisture. In porous food structures, rates of moisture vaporization at different locations in foods depend, to a large extent, upon the local rates of thermal energy conversion from microwave.

(3) Reduced drying rate period, during which the local moisture is reduced to a point when the energy needed for moisture vaporization is less than thermal energy converted from microwave. Local temperature then may rise above the boiling temperature of water. Even though loss factors of food materials decrease with moisture reduction and the conversion of microwave energy into heat is reduced at lower moisture content, product temperature may still continue to rise, resulting in overheating or charring. Development of temperature profiles in the

microwave heating period has been studied for various geometries. During microwave drying processes, the heating period is relatively short and moisture loss is small. Much of the moisture loss takes place during the second period of microwave drying, and moisture distribution in spherical foods is determined at this period through experimental measurements of moisture profiles and computer simulation.

2.2.2.2 Advantages of Microwave Drying

Microwave drying results in a high thermal efficiency, shorter drying time and improved product quality compared to conventional hot air drying. Microwave drying helps to remove the moisture from the food products without the problem of case hardening compared with hot air drying. Combined microwave hot air could greatly reduce the drying time of biological materials without damaging the quality attributes of the finished products (Ren and Chen, 1998).

Microwave drying requires a smaller floor space compared to conventional driers because the increase in processing rate makes it possible to design more compact equipment and hence plant capacity can be increased without additional building space.

In microwave drying, operational cost is lower because energy is not consumed in heating the walls of the apparatus or the environment. Heat generated by microwave energy occurs principally in the product, not in the oven walls or atmosphere. Therefore, heat losses from the oven to the surroundings are much lower, making for more comfortable working temperatures. Fast start-up and shut-down and precise process control are possible in microwave heating.

Other benefits of microwave drying are the inhibition of high surface temperatures, continuation of product respiration, lowered product temperatures when combined with vacuum drying, reduction in the loss of water-soluble components and energy savings. Microwave drying is most effective at product moisture contents below 20%; hence, it has been suggested that microwave energy should be applied in the falling rate period or at low moisture content to finish drying (Maskan, 2000) because at high moisture contents the cost of natural gas heated hot-air process is only 30% of the microwave energy cost. Also, at low moisture content, removal of moisture using hot air is slow but due to volumetric heating it is rapid with microwave. Microwave drying has been reported to improve product quality such as better aroma, faster and better rehydration, considerable saving in energy and much shorter drying times compared with hot air drying alone (Maskan, 2001). Nijhuis et al. (1998) compared the

advantages and disadvantages of various technologies like freeze drying, microwave and radio frequency drying.

Many researchers have successfully dried vegetables with high heat-sensitive compositions, and fruit with high sugar contents. In all cases the drying time is reduced significantly, and in most cases the quality of the dried food products is improved or kept the same as compared with microwave-dried or conventionally dried products.

Microwave drying has positive ratings for drying rate, flexibility, color, flavor, nutritional value, microbial stability, enzyme inactivation, rehydration capacity, crispiness and fresh-like appearance.

2.2.2.3 Disadvantages of Microwave Drying

Microwave drying is known to result in a poor-quality product if not properly applied. Controlling heating uniformity is important to ensure the microbial safety and high quality of microwave-dried foods. The difficulty with microwave heating is the large number of factors that affect the microwave heat transfer behavior such as the thickness, geometry, and the dielectric properties of the food. The heat capacity (Cp) and dielectric properties [dielectric constant (ε'), loss factor (ε'')] change with the moisture content and temperature, which also complicates the microwave drying process.

An inherent problem associated with microwave heating is the non-uniformity in heating caused by an uneven spatial distribution of the electromagnetic field inside the drying cavity. Temperature distribution during microwave heating was determined that temperature difference of up to 60–80°C was found on the food samples depending on the time and power level. To achieve uniform heating, the product is kept in constant movement within the microwave cavity so that different parts of the product receive an average of electromagnetic field intensity over a period of time. Many factors influence the uniformity of electromagnetic field. These factors can be divided into two groups: cavity effects, and workload or product interaction. Cavity effects are due to design limitation, location of the microwave inlet point, shape of the cavity, hanging parts such as mixer, which are sometimes used for stirring of the product to assure more uniform electromagnetic field distribution. Workload interactions include loss factor, penetration depth, thickness, shape and size of the product that are different from product to product.

The microwave heating is that there is no common method to monitor or control the electromagnetic field distribution and its effect after the microwave is switched on.

Microwave drying sometimes may cause excessive heating, which may result in physical damages to the product such as scorching, off-color and non-uniform temperature distribution in the final product. One more drawback is that too rapid mass transport by microwave power may cause quality damage or undesirable changes in the food texture by "puffing". However, this may or may not be a limitation, depends upon the desired quality attributes of the final products.

Another major drawback is the penetration depth of the microwave field into the products. Although microwave power at 915 MHz penetrate to a greater depth than does at 2450 MHz, in large-scale drying applications, the penetration depth is still much smaller compared to that attained in radio frequency heating at 10-300 MHz.

Due to the high cost associated with microwave drying, it was used only in cases where drying of final products has to meet high-quality specifications or as a supplementary drying method for further product-quality improvement (Drouzas and Schubert, 1996). Microwave energy is only applied in the falling rate period or at low moisture content to finish drying of the product. Hence, microwaves can be advantageous in the last stages of air drying (Funebo and Ohlsson, 1998). High start-up costs have prevented many potential users of microwave energy from investing in new technology. Previously, operational costs were considerable, with expensive magnetrons needing to be replaced too frequently.

2.3 Quality Characteristics of Dried Products

In term of food quality includes three principal areas; nutritional value, acceptability and safety. Processing raw food will have an adverse effect on some of its nutrients and acceptable attributes like visual appeal, aroma, flavor and texture. The overall quality of products is judged by a number of parameters. The quality changes that happen in any product during drying are color (color and appearance), sensorial (odor, taste and flavor), structural (density, porosity and specific volume), textural and rehydration properties (rehydration rate and rehydration capacity) and nutritional characteristics (vitamins and proteins). Food safety is the protecting of food from microbial, physical (drying out and infestation) and chemical (rancidity and browning) hazards or contamination that may occur during all stages of food production, growing, harvesting, processing, transporting, distribution and storage.

2.3.1 Color Properties

The color of food is important for its acceptability. Factors such as non-enzymatic (Maillard reactions) and enzymatic browning, and process conditions like pH, acidity, oxidation, time and temperature, are responsible for the loss of pigments and color during processing of foods.

Color changes are related to browning reactions taking place during drying of fruits and vegetables. The browning of fruits and vegetables during drying is due to both enzymatic and non-enzymatic browning reactions. The color of the products is measured by lightness **L**, redness or greenness **a** and yellowness or blueness **b**, during or after drying. The increase of **a** value denotes a more red chroma, which is indicative of the browning reaction. Microwave drying causes a smaller increment of redness **a**, which means the final products are less brown than conventional air-dried ones.

Prabhanjan et al. (1995) studied the thin-layer drying of carrot (*Daucus carota*) and showed that product dried by conventional air drying and microwave drying at half the power level retained good color while those dried at maximum microwave power were dull.

Oduro and Clarke (1999) performed quality assessment of gari (a fermented form of cassava) (*Manihot esculenta*) produced using microwave energy and compared with the commercially available products. They measured values of **L** and **b** which indicates lightness and yellowness. The **L** value increased slightly with time, producing pale colors and the values of **b** value also increased with time producing more yellowness. The acceptable range of color values

is 80–85 for **L** and 17–21 for **b**. Cooking times greater than 15 min gave color properties that fell beyond the accepted range but the samples cooked between 12 and 15min were regarded as high-quality gari. The **L** and **b** values for gari purchased from commercial market ranged between 77.5–85.8 and 18–27.5, respectively. Hence, gari produced using microwave energy exhibited lower variation compared to that of commercial gari.

Sharma and Prasad (2001) studied the drying of garlic (*Allium sativum*) and the results showed that garlic was lighter in color for combined microwave-hot-air drying compared to hot-air drying alone.

Velu et al. (2006) studied the dry milling characteristics of microwave-dried maize (*Zea mays* L.) and showed that the flour of the microwave-dried sample was brighter than the control and the convective-dried samples.

In the case of chilli products, an important reaction is the degradation of orange-red color pigment. The orange-red color of chilli is mainly due to the profuse synthesis of various carotenoid pigments. These include oxygenated carotenoids, such as capsanthin, capsorubin and crypto-capsin. Capsanthin amount was 35% of total carotenoids. Some of other minor pigments responsible for chilli color are violaoxanthin, capsanthin-5,6-epoxides, zeaxanthin, lutein, β-cryptoxanthin and β-carotene (Ahmed et al., 2002).

Carotenoids are compounds constituted by eight isoprenoid units. The isoprenoid units are joined in a head-to-tail pattern, but the order is inverted at the molecule center. Carotenoids are very stable when they are present in intact plant tissue, but after processing carotenoids are isolated and are vulnerable to the effects of heat, light and high oxygen tension.

Ramesh et al. (2001) reported the loss of red color is caused by autoxidation of carotenoids. It is shown that the stability of the quality of paprika, during storage is dependent on drying conditions and the degradation rate of quality increases as the drying temperature increases.

Ahmed et al. (2002) reported the kinetics of thermal degradation of color during the treatment of red chilli puree at 60, 70, 80 and 90°C (up to 20 min) and storage of red chilli paste at 5, 25 and 37°C (up to 6 months) resulted in the degradation of visual color (**L•a•b** and **ΔE**) of chilli puree which followed the first-order reaction kinetics and the dependence of rate constants for both **L•a•b** and **ΔE** on temperature following the Arrhenius relationship. The activation energies for the degradation of **L•a•b** and **ΔE** during the thermal treatment were 24.8 and 24.2 kJ/mol, and during storage were 24.1 and 25.0 kJ/mol.

Pérez-Gálvez et al. (2005) reported the slow drying at mild temperatures of red pepper for paprika production, the carotenoid content went through different stages either decreased or increased which are reflect of the processing conditions.

Schweiggert et al. (2006b) reported the thermal treatment prior mincing fresh chilli and paprika pods resulted in a 25-34% loss of the initial carotenoid contents in chilli and 20-53% in paprika.

Antioxidants are used to prevent lipid oxidation which occurs during processing and storage. Marie-Elisabeth and Claudette (2005) used phenolic compounds and plant extracts to protect paprika carotenoids against discoloration. This result showed that BHT and α-tocopherol were good protectors of carotenoid photooxidation. The results obtained with extracts of rosemary and tea confirms their potential as natural protectors. Mixtures containing α-tocopherol and rosemary extract showed strong synergistic effects. Ladrón de Guevara et al. (2005) has also been reported that the adding a natural antioxidant (rosemary extract at 1%) to the heat-treated paprika product, color stability increased and, in the lower the humidity the greater the increase in stability.

2.3.2 Rehydration Characteristics

Most of the dehydrated products are rehydrated prior to their final use therefore the rehydration characteristics of the dried product are used as a quality index. There indicate the physical and chemical changes during drying and are influenced by processing conditions, sample compositions, sample preparation and the extent of structural and chemical disruptions induced by drying. In a microwave drying system, the microwaves can easily penetrate the inert dry layers to be absorbed directly by the moisture at the water front. The quick energy absorption causes rapid evaporation (boiling) of water creating an outward flux of rapidly escaping vapor. In addition to improving the rate of drying, this outward flux can help to prevent the collapse (shrinkage) of tissue structure, which prevails in most conventional air drying techniques. Hence, better rehydration characteristics may be expected in microwave-dried products. Studies on thin-layer drying of carrot by Prabhanjan et al. (1995) by conventional and microwave-assisted convective drying found that product shrinkage was minimal at the highest power level of microwave application. Rehydration properties were improved by drying with higher microwave power levels as indicated by higher values of coefficient of rehydration and rehydration ratio (ratio of mass of the rehydrated sample to that of dehydrated sample).

Funebo and Ohlsson (1998) studied the microwave-assisted hot-air dehydration of apple (*Golden delicious*) and mushroom (*Agaricus bisporus*) was performed with low-power microwave energy. The microwave energy was supplied by either microwave applicators with transverse magnetic (TM) modes as dominant modes, or by a multimode cavity microwave oven. They found that the rehydration capacity was not better for the microwave-dried apples and mushrooms when compared to hot air-dried products. Rehydration capacity was 20-50% better for TM applicator-dried apples and mushroom than for multimode cavity dried ones.

Tsami et al. (1999) studied the sorption characteristics of freeze, microwave, vacuum and conventional dried pectin-sugar gel. Freeze-dried gel adsorbed more water vapor than microwave-dried gel, which had a higher sorption capacity than vacuum-and conventional-dried product.

Maskan (2000) studied hot-air, microwave and hot-air followed by microwave drying of banana slices. He found that the rehydration ratio of sample dried with the microwave finish method had the highest value. He suggested that product shrinkage seemed to be minimum in the microwave finish dried sample. However, from ANOVA results showed that the drying conditions did not influence ($p > 0.05$) the rehydration capacity of bananas.

Maskan (2001) studied the shrinkage and rehydration characteristics of kiwi fruits (*Actinidia deliciosa*) during hot-air and microwave drying. The shrinkage was 81% and 85% for hot-air and microwave drying, respectively. Higher and rapid shrinkage of samples dried by microwave was observed and this may be because of extensive heat generation and accelerated removal of water from the tissues in the sample dried by microwave. Microwave-dried kiwi fruit slices exhibited lower rehydration capacity and faster water absorption rate than the air dried samples.

Garau et al. (2007) studied hot-air drying of orange peel and pulp remaining after juice extraction. Dehydration around 50-60°C apparently promoted the minor disruption of cell wall polymers, in particular of pectin substance. Pulp samples exhibited higher values of swelling and fat adsorption capacity than those derived from orange peel. Although, significant decreased in water retention capacity, fat adsorption capacity and solubility values were detected for both samples as the air-drying temperature increased.

2.3.3 Structural Properties

Structural properties are important for the characterization of the quality of a dehydrated product. The structure of a food material may be characterized by its bulk density, true density, porosity and specific volume. Bulk density is determined by the mass of the sample and its bulk volume. It is the density of a material including air pores, and thus it is a function of water content, solid type and air volume proportion. True density is the density excluding all pores and it is determined by the mass of sample and its true volume. Porosity characterizes the overall open structure of a dehydrated material. It is the fraction of the empty volume and is estimated from the bulk density and the true density. Porosity is strongly affected by drying method and conditions.

Tsami et al. (1999) reported the porosity of the dehydrated pectin-sugar gels depended on the drying method, ranging between 0.2 and 0.5. Freeze- and vacuum-dried pectin developed the highest porosity, whereas the lowest porosity was obtained using conventional and microwave drying.

Kratchanova et al. (2004) studied microwave heating of fresh orange peels. Scanning electron micrographs showed that microwave heating led to destruction of the parenchyma cells. The changes resulted in an increase in the capillary-porous characteristics and the water absorption capacity of the plant materials. The capillary-porous characteristic was improved as the result of the increase in the pressure and temperature in the inside of the tissue. The damage to the plant tissue increased with the rise in the intensity of microwave field.

Sundaram and Durance (2008) studied the air, vacuum, freeze and microwave vacuum dried locust bean gum-pectin-starch composite gel. The porosity of the dried gels varied with different drying methods and ranged between 68 and 87%. Freeze-dried gel developed the highest porosity, whereas the lowest porosity was obtained from air drying method. Air and microwave vacuum-dried gels had narrow pore size distribution where as freeze and vacuum-dried gels had wider pore size distribution. Also, the freeze-dried gels had pore structural collapse and low bulk density.

2.3.4 Textural Properties

Texture is one of the important characteristics indicating product quality. Textural properties are usually related to mechanical tests, which examine the viscoelastic behaviour of the material. Textural properties of dehydrated products are normally measured as a puncture force, which is a measure of the hardness of the product surface and is an indicator of the extent of case hardening that has occurred during drying.

Funebo et al. (2002) studied the microwave convective dehydration of apple slices. The firmness of dehydrated apple pieces increased linearly with temperatures during dehydration and the apples were almost twice as firm when dehydrated at 70°C compared with 50°C. These dehydrated samples were 5–9 times harder than fresh apples.

2.3.5 Nutritional Characteristics

Walde et al. (2002) studied the microwave drying of wheat and determined that the total protein content of microwave-dried samples of wheat did not change and remained the same as that of the control (9.9%), but the structural and functional characteristics of wheat protein--gluten were changed. The functionality of gluten was altered, which was observed by the absence of elasticity and stretchability of the dough.

Hsu et al. (2003) studied the effects of freeze, hot-air and drum drying on proximate composition of yam flour. The drying methods showed significant effects on the moisture contents of yam flours, they had no marked effects on other components of yam flours.

Velu et al. (2006) studied the dry milling characteristics of microwave-dried maize (*Zea mays* L.). The microwave drying did not alter the protein content as measured by Kjeldahl's method. However, some structural changes in the starch and protein were noticed. The protein and starch content of microwave dried samples were 10.48% and 65.66%, respectively, whereas for the control sample protein and starch were 10.06% and 60.57%, respectively.

Kratchanova et al. (2004) studied the quality of extracted pectin of microwave-heated orange peels. In this work it is shown that the microwave heating inactivated the pectinmethylesterase activity in the orange. Further, increase in the power of the microwave treatment lead to a complete suppression of the pectolitic activity in the peels. The inactivation of the pectinmethylesterase by microwave treatment leads to an increase extractability of pectin from the material and the pectin obtained after a microwave pretreatments have a higher degree of esterification molecular mass and gel strength.

Garau et al. (2007) studied the physico-chemical properties of dietary fiber of air dried orange by-products. The modifications on the dietary fiber components were observed when either extent drying periods, i.e. at lower temperatures, or elevated drying temperatures were applied.

Karatas and Kamisli (2007) conducted a study to determine the variation of vitamins (A, C and E) and malondialdehyde in apricot (*Prunus armeniaca*) using infrared and microwave drier. Vitamin A, C and E of apricot samples dried in microwave drier are higher than those of the infrared drier. Also the values of malondialdehyde are higher in microwave dried than in infrared-dried apricot samples. Hence, they concluded that using a microwave drier for apricot was much more effective than infrared drier in terms of retention of vitamin A, C and E and malondialdehyde values.

Arslan and Özcan (2008) studied the mineral content of fresh, sun dried, oven dried and microwave oven dried rosemary leaves. Fresh and dried herbs had high amounts of K, Ca, Na, Mg and P minerals. Al, B, Ba, Cu, Fe and P values of the fresh and dried samples were not statistically significant. The highest mineral values were determined in oven dried samples. The microwave oven drying method led to the lowest increase in mineral values in comparison to other drying methods. The convective style of energy and wave strength of the oven drying method could cause more increase in the solubility of the elements than the microwave drying.

2.3.6 Antioxidant Properties

Processing methods are generally believed to be responsible for a depletion of naturally occurring antioxidants in raw material of plant origin. Particularly, intense and/or prolonged thermal treatment may be responsible for a significant loss of natural antioxidants, due to the fact that most of the compounds are relatively unstable. However, food processing can have many effects, not all of which result in a loss of quality and health properties.

2.3.6.1 Fate of the Antioxidant Compounds

In the case for some vegetables, the antioxidant activities, this was found to be lost in stored vegetables at ambient or chill temperature, blanching, freezing and prolonged boiling of vegetables in water (Hunter and Fletcher, 2002). Ewald et al. (1999) have been reported that the peeling and blanching of onions at the pilot scale reduced flavonoid content to approximately half the starting level. While, during the cooking the β-carotene contents were lost during pressure cooking and open pan boiling (Gayathri et al., 2004).

Thermal treatments associated with food processing alter the polyphenolic content of vegetables. Roy et al. (2007) have been reported that heating vegetables juice at a cooking temperature strongly effect their polyphenolic content, antioxidant and anti-proliferation activity. This is due to the fact that most of the compounds are relatively unstable. A large amount of literature deals with ascorbic acid chemical oxidation and/or thermal degradation as a consequence of blanching, cooking, pasteurization, sterilization and dehydration (Burg and Fraile, 1995).

Larrauri et al. (1997) studied the effect of drying temperatures (60, 100 and 140°C) on stability of polyphenols and antioxidant activity of red grape pomace peels. When drying temperature was 100 and 140°C, a significant reduction in both total extractable polyphenols (18.6 and 32.6%) and condensed tannins (11.1 and 16.6%) was observed, as well as decrease of 28 and 50% in the antioxidant activity of the samples, respectively.

Piga et al. (2003) studied the polyphenols and antioxidant of prunes, which are obtained by dehydrating fresh plum at air temperature 60-85°C. Drying destroyed anthocyanins, and there was a significant decrease in flavonols. Ascorbic acid was drastically reduced in relation to process temperature. The most striking result was that drying at 85°C doubled antioxidant activity. They suggested that this behavior could be the result of two factors: (i) the polyphenols in an intermediate stage of oxidation have greater antioxidant power than the initially stage even though this is temporary; and (ii) high temperature stabilization procedures may lead to the formation of new compounds with higher antioxidant activity.

Lim and Murtijaya (2007) studied the total phenolic content and antioxidant activity of fresh, oven and microwave dried *Phyllanthus amarus* plants. They showed that different drying treatments led to significant reduction in antioxidant properties of plant methanolic extracts, with microwave drying causing the highest decrease in total phenolic content and antioxidant activity exhibited by the reduction in both radical scavenging activity and ferric reducing antioxidant power.

In some cases processing causes little or no change to the content and activity of naturally occurring antioxidants. This is the case for tomato puree carrot, holy basil, galangal and garlic (Zanoni et al., 2003; Mayer-Miebach et al., 2005; Jantachote and Berghofer, 2005; Pedraza-Chaverrí et al., 2006).

In the case tomato puree and carrot, which was found that lycopene content and antioxidant activity of lipophilic fraction in tomato puree, remained stable even after

sterilization process (Zanoni et al., 2003) and lycopene in carrot also remained stable even after convectional drying at temperature in the range of 50-90°C and microwave vacuum drying with a microwave power 400 W (Mayer-Miebach et al., 2005).

In the case of holy basil and galangal, the antioxidant activities of holy basil and galangal extracts, which were found to be heat stable ever after heating at 80°C for 60 min (Jantachote and Berghofer, 2005).

In the case of garlic, the scavenging activity of garlic extracts, which was found to be essentially heat stable even after heating extraction (Pedraza-Chaverrí et al., 2006).

2.3.6.2 Increasing of Antioxidant Compounds

Generally, the outer layers of plant such as peel, shell and hull contain large amount of polyphenol compounds to protect inner materials. A number of phenolic acids are linked to various cell wall components such as arabinoxylans and proteins. It has been reported that heat treatment might disrupt the cell wall and liberate antioxidant compounds from insoluble portion of plant (Choi et al., 2006).

Lee et al. (2006) have been reported that the total polyphenol contents and antioxidant activities of peanut hulls increased even after far-infrared radiation or heated treatment. There were slight difference in the kinds of polyphenol compounds between non-heated and heat-treated or far-infrared radiated. Likewish, the total polyphenol contents and antioxidant activities of grape seed extracts and Shiitake mushroom even after heat-treated (Kim et al., 2006; Choi et al., 2006).

2.3.6.3 Formation of Novel Compounds Having Pro and Antioxidant Activity

Maillard reaction products (MRPs), which can be occur in food during processing and storage. The antioxidant activities of MRPs have been reported to be strongly affected by the physico-chemical properties of the system and by the processing conditions. Polyphenols, ascorbic acid and other carbonyl compounds even if formed during oxidative reactions can take part in the Maillard reaction itself (Manzocco et al., 2001). Turkman et al. (2006) have been reported that increased heat treatment leads to development of antioxidant activity which has positive effects on human health-in honey due to formation of Maillard reaction products.

Beyond their well-documented antioxidant properties, MRPs may also exhibit pro-oxidant properties. Highly reactive radicals are formed in the early stages of the Maillard reaction just prior to the Amadori rearrangement and their disappearance is accompanied by a gradual development of browning. A reduction in original antioxidant properties through the

formation of compounds with pro-oxidant properties would appear to be of considerable interest with regard to low temperature or short-time heat treatments (Nicoli et al., 1999).

The formation of pro-oxidants during the early phases of the Maillard reaction may depend upon the intensity and duration of the heat treatment, when low-temperature heating is applied, the phases that contribute to the formation of compounds with pro-oxidant properties last longer than in the case of high temperature treatments. In all cases, during the formation of pro-oxidants no changes in color were detected (Nicoli et al., 1999).

It has been reported that both antioxidant and pro-oxidant activity can be observed during milk samples heated at 80, 90, and 120°C for increasing lengths of time. At each heating temperature, samples showed an initial increase and a subsequent decrease in pro-oxidant activity. The latter was associated with an increase in the antioxidant properties. The increase in antioxidant properties during the advanced stages of heating can be accounted for the formation of Maillard reaction products. In the case of milk, its reducing properties were shown to be strongly affected by heating. In particular, heat treatment of milk can promote an increase in its pro-oxidant activity, probably as a consequence of both the loss of natural antioxidants and the formation of novel oxidative molecules in the early stages of Maillard reaction (Calligaris et al., 2004).

2.3.6.4 Interaction among Antioxidant Species

These are mainly represented by redox reactions, such as those occurring between different natural antioxidants or synthetic antioxidants. These events, which mainly take place when different food matrices are mixed together (e.g. aqueous phase and lipid phase), have almost unpredictable consequences on the overall antioxidant properties and food stability. Processing can promote or enhance these reactions.

The antioxidant spices such as, turmeric and onion generally improved the retention of β-carotene in vegetables during cooking (Gayathri et al., 2004).

The seasoning, such as soy sauce, rice soybean paste, barley soybean paste and consommé, which was found that heating around the boiling point enhanced the radical scavenging and anti-mutagenic activities of catechin, epicatechin, naringenin and naringing with seasoning addition (Bao et al., 2004).

The spice essential oils such as, clove, thyme, cinnamon, basil, oregano and nutmeg, which was appeared able to prevented α-tocopherol loss following oil heating at 180°C

for 10 min (Tamaino et al., 2005). This is due to ability of these compounds to reduce the radical forms of α-tocopherol contained in the lipid matrix.

It has been observed that when sunflower oil was added in homogenates prior thermal treatment, the antioxidant properties of the methanol-soluble compounds raised after heat treatment at 130°C for 0.5 h (Mayer-Miebach et al., 2005).

2.3.7 Sensory Characteristics

The properties of dry products are influenced by chemical and physical changes. Heat treatment of fruits and vegetables often reduces the original volatile flavor compounds, while introducing additional volatile flavor compounds through the autoxidation of unsaturated fatty acids and thermal decomposition, and/or initiation of Maillard reactions. With respect to the introduction of new compounds during drying, two major chemical reactions are important; autoxidation and the Maillard reaction. The flavor characteristics of food products containing unsaturated fatty acids can be drastically affected when these lipids are in direct contact with oxygen. Initiators such as light, metallic ions and heat can initiate autoxidation reactions. The Millard reaction is also an important source of volatile flavor compounds, which can have a considerable effect on the flavor of dried vegetables and fruits.

Sharma and Prasad (2001) conducted a study to explore the possibility of drying garlic by combined hot-air-microwave and hot-air drying alone. The retention of volatile components responsible for flavor was more in hot-air-microwave drying compared to conventional hot-air drying alone. The flavor strength of garlic dried by hot-air alone is 3.27 mg/g dry matter whereas the flavor strength of the garlic dried by microwave-drying is 4.06 mg/g dry matter. The loss of volatile flavor compounds after drying may be due to the inactivation of volatile-forming enzymes as well as loss of the precursors.

2.4 Moisture Sorption Isotherm

2.4.1 General Aspect and Meaning

Controlling the moisture content during the processing of foods is an ancient method of preservation. This is achieved by either removing water or binding it, such that the food becomes stable to both microbial and chemical deterioration. For this reason much attention has been given to the sorption properties of foods. Sorption characteristics have, and are currently being examined in light of their influence on the storage stability of dehydrated products, as well as their effect on the diffusion of water vapor.

Walter in 1924 was probably the first researcher to relate the relative water vapor pressure to microbial growth, the main cause of food spoilage. A decade afterwards, Scott in 1957 and Salwin in 1959 independently applied this relationship and introduced the concept of water activity (a_w). This is a term indicating the 'quality' of the water content of food. It describes the degree of 'boundness' of water and hence, its availability to participate in physical, chemical, and microbiological reactions. Since then, experimental and theoretical studies of the water associated with foods have been intensified in an attempt to understand and interpret water behavior. Such endeavors have been fraught with difficulties because foods are heterogeneous mixtures of soluble organic and inorganic materials (Al-Muhtaseb et al., 2002).

The concept of water activity that is used most commonly by researchers in the food industry can be defined as:

$$a_w = \frac{P}{P_0} = \frac{\text{Relative Humidity}}{100} \qquad (2.1)$$

where **P** is the partial pressure of water in the food (atm), and $\mathbf{P_0}$ is the vapor pressure of pure water at the same temperature (atm).

The relationship between total moisture content and the water activity of the food, over a range of values, and at a constant temperature, yields a moisture sorption isotherm when expressed graphically (Figure 2.1).

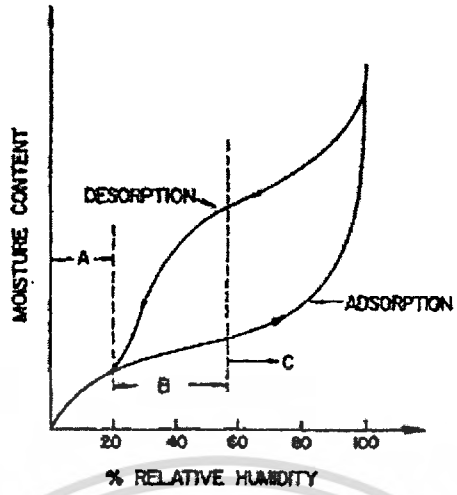

Figure 2.1 Generalized sorption isotherm for food products.

Source: Al-Muhtaseb et al. (2002).

This isotherm curve can be obtained in one of two ways;

(1) an adsorption isotherm is obtained by placing a completely dry material into various atmospheres of increasing relative humidity and measuring the weight gain due to water uptake;

(2) a desorption isotherm is found by placing an initially wet material under the same relative humidities, and measuring the loss in weight.

The adsorption and desorption processes are not fully reversible, therefore a distinction can be made between the adsorption and desorption isotherms by determining whether the moisture levels within the product are increasing indicating wetting, or whether the moisture is gradually lowering to reach equilibrium with its surroundings, implying that the product is being dried.

On the basis of the van der Waals adsorption of gases on various solid substrates, Brunauer et al. classified adsorption isotherms into five general types (Figure 2.2) (Al-Muhtaseb et al. 2002). Type I is the Langmuir, and Type II the sigmoid shaped adsorption isotherm; however, no special names have been attached to the other three types. Types II and III are closely related to Types IV and V, except that the maximum adsorption occurs at a pressure lower than the vapor pressure of the gas. If, however, the solid is porous so that it has an internal surface, then the thickness of the adsorbed layer on the walls of the pores is necessarily limited by

the width of the pores. The form of the isotherm is modified correspondingly; instead of Type II and III, Type IV and V exist.

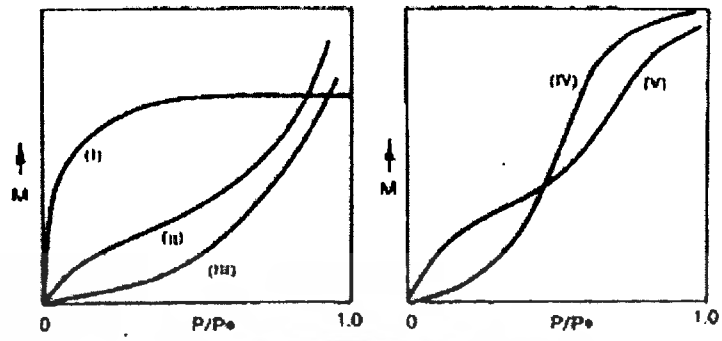

Figure 2.2 Five types of van der Waals adsorption isotherm.
Source: Al-Muhtaseb et al. (2002).

Moisture sorption isotherms of most foods are nonlinear, generally sigmoidal in shape, and have been classified as Type II isotherms. Most of the water in fresh food exerts a vapor pressure very close to that of pure water, i.e. unity. This vapor pressure level is maintained until the moisture content of the food decreases to about 22%. The moisture level is then no longer able to sustain the vapor pressure of the food at unity, and therefore, begins to show a lowered vapor pressure, as if in solution. The changes with atmospheric humidity of this last fraction (22%) of water in dehydrated foods result in the characteristic sigmoid shape of water sorption isotherms. The direct plasticizing effect of increasing moisture content at constant temperature is equivalent to the effect of increasing temperature at constant moisture and leads to increased segmental mobility of chains in amorphous regions of glassy and partially crystalline polymers. Foods rich in soluble components, such as sugars, however, have been found to show Type III behavior, this is due to the solubility of sugars in water (Al-Muhtaseb et al., 2002). The sorption isotherm characteristics of many food products have been determined experimentally (Table 2.1).

Table 2.1 Types of van der Waals adsorption isotherms observed for different food materials.

Adsorption isotherm	Food materials
Type II	Starch gel, Corn, Potato, Macadamia nuts, Carrot, Tomato, Green pepper, Lentil seeds, Onion, Chestnut, Hazelnut, Cocoa beans.
Type III	Pineapple, Banana, Sugars, Apples, Sugar alcohol, Sucrose-Starch, Raisins, Apricot, Cured beef

Source: Al-Muhtaseb et al. (2002).

For interpretation purposes, the generalized moisture sorption isotherm for a hypothetical food system may be divided into three main regions, as detailed in Figure 2.1. Region A represents strongly bound water with an enthalpy of vaporization considerably higher than that of pure water. A typical case is sorption of water onto highly hydrophilic biopolymers such proteins and polysaccharides. The moisture content theoretically, represents the adsorption of the first layer of water molecules. Usually, water molecules in this region are unfreezable and are not available for chemical reactions or as plasticizers. Most dried food products are empirically observed to display their greatest stability at moisture contents comparable to the monolayer moisture content. The sigmoidal shape with a distinct point of inflection indicates strong interactive forces between the surface and the first layer of water.

Region B, represents water molecules which are less firmly bound, initially as multilayer above the monolayer. In this region, water is held in the solid matrix by capillary condensation. This water is available as a solvent for low-molecular weight solutes and for some biochemical reactions. The quality of water present in the material that does not freeze at the normal freezing point usually is within this region. In region C or above, excess water is present in macro-capillaries or as part of the fluid phase in high moisture materials. This exhibits nearly all the properties of bulk water, and thus is capable of acting as a solvent. Microbial growth becomes a major deteriorative reaction in this region.

The variation in sorption properties of foods is caused by biological variation in foods, pretreatment of food, and differences in experimental techniques adopted (gravimetric, manometric or hygrometric).

2.4.2 Application of Sorption Isotherm

Sorption isotherms are important for more than one reason. From the point of view of thermodynamics, they are informative on sorption and desorption enthalpies and the type of binding of water to dry matter. On structural level, they can help in understanding the role of particle size, amorphous state or specific are in water vapor pressure sorption. Concerning the technological aspect, water vapor isotherms are useful in the prediction of shelf life, the control of drying and the prevention of such accidents as caking and sticking of food powder.

2.4.2.1 Usefulness of the Monolayer Value

It is well accepted today that the optimum point for the stability of dehydrated biological products is at the monolayer, which in general is the water activity range between 0.2 and 0.3 to 0.4. The completion of monolayer may easily be calculated and in principle it serves to describe the point where the polar groups of a surface are saturated with water on a molecular 1:1 basis. Covering the polar groups provides a protective action against lipid auto-oxidation as it prevents exposure to oxygen. Possible mechanisms for this protection include hydrogen bounding of water of lipid hydroperoxides, hydration of trace mineral catalysts, formation of insoluble metal hydroxides and the effect of free radical formation. This moisture content corresponds fairly well with monolayer value as determined from the BET or GAB isotherm equation. The GAB equation utilizes all the moisture sorption data unlike the BET equation which is dependent upon data below water activity 0.5. The monolayer moisture content is of significant importance to the physical and chemical stability of dehydrated materials with regard to lipid oxidation, enzymatic activity, non-enzymatic browning and structure characteristics (Kaleemullah and Kailappan, 2007). Table 2.2 presents some calculated monolayer moisture values for various foods.

Table 2.2 Monolayer moisture content values (X_m) in g water/100 g solids for dehydrated foods at 20-30°C.

Food Product	X_m
Almond	2-3
Apples	8
Apricots	15
Bananas	4-7
Beef, dried	2-4
Cheeses	3-5
Coffee	2-5
Corn flour	6-8
Figs	12
Gelatin	7-11
Lentil	6
Milk, nonfat dry	3-7
Milk, spray dried	4.3
Peas	4-7
Potato	5-7
Prunes	13
Raisins	12
Starch	7-11
Wheat	7
Wheat flour	6-8

Source: Bell and Labuza (2000).

2.4.2.2 Storage Stability of Sugar

If sugar for example, if crystalline is stable when a_w is maintained below 0.83. Stability can be reached easily at ordinary temperature and relative humidity for pure sucrose well crystallized. If some impurities are remaining at the surface in the thin film of saturated syrup surrounding the crystals, the behavior of sugar towards water vapor may change. As a general rule, impurities in sugar syrup increase sugar solubility, which leads to a lowered water activity of saturated solution. This means that problem such as caking or stickiness may occur at relative humidity below 80%. The same type of instability occurs when the size of crystals is small or when amorphous sugar obtained by the breakage of crystals or by a rapid drying at high temperature is present at the surface of sugar crystals. Recrystallisation of amorphous sugar may occur at relative humidity as low as 38% at 20°C with release of water which dissolves more sugar initiating a caking process. If the impurities at the surface of sucrose crystals involve other sugars more hygroscopic like glucose or fructose, then the instability of sugar is observed at lower relative humidity (Mathlouthi, 2001).

2.4.2.3 Shelf Life and Water Activity of Intermediate Moisture Foods

Water availability for microbial spoilage in intermediate moisture foods (IMF) can be minimized through formulation. For sponge cake, taken as example of IMF, usually water activity is around 90%. Adding water activities depressors to the formula of the cake combined with modified atmosphere packaging (MAP) (less than 1% of O_2) proves to be an efficient method for extending the shelf life from few days to several months(Mathlouthi, 2001).

Mathlouthi (2001) reported that change in water availability during storage of sponge cake may be manifested by a hysteresis between adsorption and desorption isotherms. To minimize sorption hysteresis and depress significantly (from 0.90 to 0.84) the value of a_w of sponge cake, the addition of 0.5-1% of soya protein was found efficient. Moreover, efficiency of water retention is increased if additive is added to "creaming" which is treated thermally by heating at 45°C for 10 min. Such a treatment allows the globular structure of protein to unfold and sites of fixation of water molecules by H-bonds to become available. Combining this formulation modification with MAP (50% CO_2 + 50% N_2) and storing the product at 4°C allows the increase of shelf life of sponge cake up to 10 weeks without microbial spoilage. Water activity depressors prove to be useful in increasing the stability of baked goods.

CHAPTER 3

MATERIALS AND METHODS

3.1 Raw Materials

3.1.1 Thai red curry paste will be supported from NAMPRICK MAESRI, PART. (Nakornpathum, Thailand). Ingredients of this product are dried red chilli 35%, garlic 23%, shallot 20%, salt 7%, lemon grass 6%, sugar 3%, kaffir lime 2%, galangal 1% and spice (coriander seed, cumin and cardamom) 1%. About 500 g of Thai red curry paste were packed in retort pouch (PETsioX12/DL/Ny15/DL/cpp70μ) size 150X190 mm. The paste samples were stored at -60 ℃ until experiment.

3.2 Chemicals

3.2.1 2,2-Diphenyl-1-picryl-hydrazyl (DPPH) from Sigma-Aldrich Chemical Co., USA.

3.2.2 2,4,6-Tris (2-pyridyl)-s-triazine (TPTZ) from Sigma-Aldrich Chemical Co., USA.

3.2.3 Folin-Ciocalteu from Sigma-Aldrich Chemical Co., USA.

3.2.4 Gallic acid from Sigma-Aldrich Chemical Co., USA.

3.2.5 Iron (III) chlorides from Sigma-Aldrich Chemical Co., USA.

3.2.6 95% Ethanol from Italmar Co., LTD, Thailand.

3.2.7 Trolox (6-hydroxy-2,5,7,8-tetramethyl chroman-2-carboxylic acid) from Sigma-Aldrich Chemical Co., USA.

3.3 Equipments

3.3.1 Microwave oven (HITACHI, MR-30A, Thailand)

3.3.2 Hot-air oven (Path OV663, Thailand)

3.3.3 Digital balance (Shimadzu, BL-200H, Japan)

3.3.4 Infrared thermometer (Chino, Japan)

3.3.5 Anemometer (Testo 425, GmbH&Co, Germany)

3.3.6 UV-visible spectrophotometer (SHIMADZU 1700, Japan)

3.3.7 Thermoconstanter (NOVOSINA, Switzerland)

3.3.8 pH meter (INOLAB, Germany)

3.3.9 Benchtop Centrifuges (Allegra X-12R, Beckman Coulter, Inc. USA)

3.3.10 Colorimeter (Minolta CR 300, Konica-Minolta, Japan)

3.3.11 Analytical mill (Retsch, ZM1000, Germany)

3.4 Experimental Procedures

3.4.1 Microwave and Hot-Air Drying of Thai Red Curry Paste

3.4.1.1 Drying Process

Prior to each of drying experiments, the paste samples were taken out of storage and thawed to 20°C at room temperature. The moisture content of samples was measured individually according to the hot-air oven method (AOAC, 1990). The initial moisture content of the red curry was determined as 258% dry basis. In each of drying experiments, 55±1 g paste material were uniformly spread on the translucent plastic sheet with thickness of 1 mm on a surface area 180 mm x 180 mm. Each sample was placed at the center of drying equipments.

A microwave oven (HITACHI, MR-30A, Thailand) with maximum output of 900 W at 2450 MHz was used for the microwave drying experiments. The dimension of microwave cavity was 520(W) x 376(D) x 292(H) mm. The oven had a carrousel in the cavity with a digital panel to regulate the microwave power and the processing time. The paste samples were dried at three different levels of microwave power (180, 360 and 540 W). Moisture loss was periodically measured at 1 min intervals during drying by removing the plastic sheet from the drying equipment and weighing on the digital balance (0.001g accuracy). The final temperatures of dried curry paste were measured by infrared thermometer.

A hot-air oven (Path OV663, Thailand) was used for the hot-air drying experiments. The dimension of the oven cavity was 800(W) x 900(D) x 1500(H) mm with a 3 kW-heater and a fixed air velocity. The air velocity was measured with an anemometer and was found to be 9.02 m/s. The paste samples were dried at three different drying air temperatures (60, 70 and 80°C). The oven was switch on 1 h before drying process to equilibrate the temperature. Moisture loss was periodically measured at 10 min intervals during drying.

The drying procedure was continued till the weight of the paste samples was reduced to a level corresponding to moisture content of about 8% dry basis. All weighing process was completed in less than 10 s during the drying process to avoid loss or gain of moisture to or from the environment.

3.4.1.2 Drying Kinetics

The moisture ratio during drying was calculated using the equation:

$$MR = \frac{W - W_e}{W_0 - W_e} \quad (3.1)$$

where: MR is the moisture ratio, dimensionless, W is the experimental moisture content, W_e is the equilibrium moisture content and W_0 is the initial moisture content, both in dry matter.

It was assumed that the equilibrium moisture content is zero for microwave and hot air drying. Then the expression can be reduced to:

$$MR = \frac{W}{W_0} \quad (3.2)$$

The drying rate of red curry paste during the drying experiment was calculated using the following equation.

$$DR = \frac{W_{t+dt} - W_t}{dt} \quad (3.3)$$

where: DR is drying rate (g water/g dry matter/min), W_t is the moisture content (g water/g dry matter) at time t, W_{t+dt} is the moisture content at time t+dt and t is drying time (min).

For mathematical modelling, the equations in Table 3.1 were tested to select the best model for describing the drying curve of Thai red curry paste during drying.

Table 3.1 Drying models (Celma et al., 2007).

Model name	Model equation	
One parameter		
Lewis	$MR = \exp(-kt)$	(3.4)
Two parameters		
Page	$MR = \exp(-kt^n)$	(3.5)
Modified Page	$MR = \exp(-(kt)^n)$	(3.6)
Henderson and Pabis	$MR = a\exp(-kt)$	(3.7)
Two term exponential	$MR = a\exp(-kt)+(1-a)\exp(-kat)$	(3.8)
Wang and Singh	$MR = 1+at+bt^2$	(3.9)
Three parameters		
Logarithmic	$MR = a\exp(-kt)+c$	(3.10)
Approximate of diffusion	$MR = a\exp(-kt)+(1-a)\exp(-kbt)$	(3.11)
Verma et al.	$MR = a\exp(-kt)+(1-a)\exp(-gt)$	(3.12)
Four parameters		
Two term	$MR = a\exp(-k_0t)+ b\exp(-k_1t)$	(3.13)
Midilli et al.	$MR = a\exp(-kt^n)+bt$	(3.14)

where: k, k_0 and k_1 are drying parameter (min^{-1}), a, b, c, n and g are drying constants (dimensionless) and t is drying time (min).

A non-linear regressions analysis was used to calculate the best fitted values of constants in the equations in Table 3.1 using the software Statistica for windows 5.0 (StatSoft, Inc. 1984-1995). The fitness the tested mathematical model to the experimental data was evaluated with the coefficient of determination (R^2), the reduced chi-square (χ^2) and the root mean square error (RMSE). The higher R^2 values and the lower χ^2 and RMSE values, the better is the fitness. The χ^2 and RMSE were calculated as follows:

$$\chi^2 = \frac{\sum (MR_{exp,i} - MR_{pre,i})^2}{N - z} \quad (3.15)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})^2} \quad (3.16)$$

where: $MR_{exp,i}$ is the i^{th} experimental moisture ratio, $MR_{pre,i}$ is the i^{th} predicted moisture ratio, N is the number of observations, z is the number of constants in the drying model.

3.4.2 Moisture Sorption of Dried Thai Red Curry Paste

3.4.2.1 Moisture Sorption Isotherms Determination

Sorption isotherm was determined by static, gravimetric method using air-tight glass jars containing saturated salt solution. The salt solution used is $LiCl_2$, CH_3COOK, $MgCl_2$, K_2CO_3, KI, NaCl, KCl and K_2SO_4, which give water activity (a_w) values at 30°C of 0.113, 0.216, 0.324, 0.432, 0.679, 0.751, 0.836 and 0.970, respectively (Bell and Labuza, 2000). Dried red curry paste in powdered form is used in the sorption experiments. To determine the sorption values, triplicate samples each of 0.5 g (±0.001 g) is accurately weighed into the previously weighed aluminum pans. The pan was placed inside the jar over saturated salt solutions, which were then tightly closed and placed in an electric oven at a desired constant temperature. At high water activities ($a_w \geq 0.751$) a small of toluene was placed in a capillary tube fixed in the jar to prevent microbial spoilage of sample (Maskan and Göğüş, 1997). The sample was weighed every week until two consecutive weight changes $\leq \pm 0.001$ g was achieved, at which time the sample was assumed to be at equilibrium. After the equilibrium of samples had been reached, the moisture content was determined using the oven method at 105°C until reaching constant weight (AOAC, 1990).

3.4.2.2 Moisture Sorption Models

The experimental data of all samples were fitted to ten sorption models as shown in Table 3.2. The parameters of the sorption models were estimated from experimental results using a non-linear regression analysis (Statistica for windows 5.0). The regression work was done based on the Quasi-Newton method.

Table 3.2 Moisture sorption models (Shivhare et al., 2004; Arslan and Toğrul., 2005; Martinelli et al., 2007).

Model name	Model equation	
Two parameters		
Oswin	$W_e=A(a_w/1-a_w)^B$	(3.17)
Caurie	$W_e=\exp(A+Ka_w)$	(3.18)
Smith	$W_e=A+(B\ln(1-a_w))$	(3.19)
Lewicki-2	$W_e=A((1/a_w)-1)^{B-1}$	(3.20)
BET*	$W_e= X_mCa_w/[(1-a_w)(1-a_w+Ca_w)]$	(3.21)
Haslay	$a_w=\exp(-A/W_e^B)$	(3.22)
Henderson	$(1-a_w)=\exp(-AW_e^B)$	(3.23)
Three parameters		
GAB	$W_e=X_mCKa_w/[(1-Ka_w)(1- Ka_w +CKa_w)]$	(3.24)
Lewicki-3	$W_e=A[(1/(1-a_w)^B)-(1/(1+a_w^C))]$	(3.25)
Four parameters		
Peleg	$W_e=A(a_w)^C+ B(a_w)^D$	(3.26)

Where: a_w is the water activity, W_e is the equilibrium moisture content (g water/g dry matter), X_m is the monolayer moisture content (g water/g dry matter), A, B, C, D and K are the moisture sorption constants (dimensionless). *Sorption data fitted for water activity ≤ 0.432.

The fitness the tested mathematical model to the experimental data was evaluated with the coefficient of determination (R^2), the reduced chi-square (χ^2) and the root mean square error (RMSE). The χ^2 and RMSE can be calculated as follows:

$$\chi^2 = \frac{\sum_{i=1}^{N} (W_{e,exp,i} - W_{e,pre,i})^2}{N - z} \quad (3.27)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(W_{e,exp,i} - W_{e,pre,i})^2} \quad (3.28)$$

where: $W_{e,exp,i}$ is the i^{th} experimental equilibrium moisture content, $W_{e,pre,i}$ is the i^{th} predicted equilibrium moisture content, N is the number of observations, z is the number of constants in the sorption model.

3.4.3 The Effects of Microwave and Hot-Air Drying on Qualities of Dried Thai Red Curry Paste

3.4.3.1 Sample Preparation

Thai red curry paste was dried follow procedure 3.4.1.1 and the final moisture content of dried red curry paste was fixed at approximately 0.08 g water/g dry matter. Dried paste product were sealed in aluminum foil bags to prevent moisture absorption and stored at -4°C used for further studies.

Prior to qualities and moisture sorption property determination, the dried paste product were divided into two portions, the fist portion was blend into small pieces and milled using an analytical mill through sieve sizes of 0.25 mm to obtain dry-powdered Thai red curry paste and used for browning index, color measurements, approximate compositions, antioxidant properties and moisture sorption properties determinations. Another portion of the dried sample was hydrated to initial moisture content (2.58 g water/g dry matter) using distilled water to obtain dry-rehydrated Thai red curry paste used for color measurements and sensory evaluation.

3.4.3.2 Color Properties

1) Browning Index (BI) Determination

The extent of brown pigment was evaluated as BI followed the method of Kim et al. (2006) and Vega-Gálvez et al. (2008) with some modifications. Fresh and dry-powdered Thai red curry paste samples (1 g dry matter) were suspended in 50 mL of distilled water, and water-soluble pigments were extracted at room temperature for 24 h with intermittent stirring, and then filtered with No.1 Whatman paper. The filtrate was diluted with an equal volume of 95% ethanol and then centrifuged at 4,000 rpm, 4°C for 15 min. The absorbance of supernatant was measured at 420 nm using a spectrophotometer. The BI was expressed in terms of the absorbance (Abs)/g dry matter.

2) Color Measurements

The color of fresh, dry-powdered and dry-rehydrated Thai red curry paste was measured using a Minolta CR 300 colorimeter (Konica-Minolta, Japan). The color system used was Hunter **Lab** (considering standard illuminant D_{65} and observer 2°). The color brightness coordinate **L** measured the whiteness value of a color and ranged from black at 0 to white at 100. The chromaticity coordinate **a** measured red when positive and green when negative, and the chromaticity coordinate **b** measured yellow when positive and blue when negative (Arslan and Özcan, 2008). The colorimeter was calibrated against a standard calibration white plate (**L**=96.98, **a** = 0.03 and **b** = 1.84) prior to each color measurement. The average of three readings was then reported.

The changes of color of dried paste after rehydration (dry-rehydrated Thai red curry paste) with fresh one were expressed in term of ratio of color change ($\Delta L/L_0$, $\Delta a/a_0$ and $\Delta b/b_0$) and total color change (ΔE). The color change and total color change were calculated as;

$$\Delta L / L_0 = \frac{L_R - L_0}{L_0} \quad (3.29)$$

$$\Delta a / a_0 = \frac{a_R - a_0}{a_0} \quad (3.30)$$

$$\Delta b / b_0 = \frac{b_R - b_0}{b_0} \quad (3.31)$$

$$\Delta E = \sqrt{(L_R - L_0)^2 - (a_R - a_0)^2 - (b_R - b_0)^2} \quad (3.32)$$

Where: L_R, a_R and b_R are Hunter **L**, **a** and **b** values of the rehydrated samples, L_0, a_0 and b_0 represent the initial Hunter **L**, **a** and **b** values of the paste sample before drying.

3.4.3.3 Proximate Composition Determination

Moisture, crude protein (N X 6.25), crude fat, ash and crude fiber contents of Thai red curry powder were determined by method of the AOAC (1990). The available carbohydrate was obtained by subtraction, i.e. 100 - (crude protein + crude fat + crude fiber + ash) (Hsu et al., 2003).

3.4.3.4 Antioxidant Properties

1) Phenolic Extraction

Fresh and dry-powdered samples (250 mg dry matter) were extracted with 25 mL of 80% ethanol for 24 hr at room temperature and then centrifuged at 6,000 rpm, 4°C for 15 min. After centrifugation, the supernatant was separated from the residue and stored at -4°C until analysis.

2) Total Phenolic Content Determination

Total phenolic content (TPC) in Thai red curry product extracts was determined using the Folin-Ciocalteu method described by Choi et al. (2006) with some modifications. The extract (0.5 mL) was added to test tubes followed by 9.5 mL of distilled water, 0.5 mL of Folin-Ciocalteu reagent and 2 mL of 10% sodium carbonate solution. The content of test tubes was mixed thoroughly. After standing for 1 hr at room temperature, the absorbance was measured at 730 nm using a spectrophotometer. The concentration of total phenolic compounds expressed as mg of gallic acid equivalents/g dry matter, using the linear equation (Figure D1), which was determined from known concentrations of gallic acid standard prepared similarly.

3) Antioxidant Activities Determination

3.1) DPPH-Radical Scavenging Activity Determination

The scavenging activity of the extracts on 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical was determined according to the method described by Choi et al. (2006) with some modifications. The extract (0.4 mL) was mixed with 5 ml of 40% ethanol solution and 0.6 mL of 0.8 $mmolL^{-1}$ of DPPH solution. The mixture was vigorously shaken and left to stand for 30 min under subdued light. The absorbance of each extract containing DPPH (A_1) was measured at 517 nm using a spectrophotometer. The absorbance of each extract without DPPH (A_s), and only DPPH solution without extract (A_0, called control) were also recorded, to determine the DPPH radical scavenging activity (DPPH-RSA). The percentage of DPPH-RSA of each extract was calculated using the following equation:

$$DPPH - RSA(\%) = \left[\frac{A_0 - (A_1 - A_S)}{A_0}\right] X100 \qquad (3.33)$$

where: A_0 is the absorbance of the control solution (containing only DPPH), A_1 is the absorbance in the presence of the samples extract in DPPH solution and A_s, which is used for error correction arising from unequal color of the sample solutions, is the absorbance of the sample extract solution without DPPH.

The DPPH-radical scavenging activity expressed as 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (trolox) equivalents in mg/g dry matter was determined using the linear equation from standard curve of trolox standard (Figure D2).

3.2) Ferric Reducing Antioxidative Power Determination

Ferric reducing antioxidative power (FRAP) of the extracts was determined according to the method of Wong et al. (2006) with some modifications. The FRAP reagent consists of 10 $mmolL^{-1}$ 2,4,6-tripyridyl-S-triazine(TPTZ) in 40 $mmolL^{-1}$ HCl, 20 $mmolL^{-1}$ $FeCl_3.6H_2O$, 0.1m $molL^{-1}$ sodium acetate buffer, pH 3.6 in the ratio of 1:1:10. The extracts (0.1 mL) was added to 3 mL of FRAP reagent and mixed thoroughly. After standing for 8 min at room temperature, the absorbance was measured at 593 nm with spectrophotometer. The FRAP expressed as mg 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (trolox) equivalents/g dry matter was determined using the linear equation from standard curve of trolox standard (Figure D3).

3.4.3.5 Sensory Evaluation

1) Sample Preparation

The dried red curry paste was rehydrated with distilled water as moisture content as fresh sample. After that, the fresh and the dry-rehydrated samples were prepared following directions: 10 g oil was heated in a pan then added 100 g ground pork and stirred until cooked. Added 30 g of the red curry samples and 15 g of non-diary creamy and stirred until oil appears on top. The prepared samples of 20 g were presented in pair in plastic cups labeled with a random three-digit code.

2) Panelist

Untrained panel of 26 people were recruited from employees and students in agro-industry faculty (aged 20-50) selected according to consumption criteria, availability and interest in participating in the test.

3) Sensory Test

For paired comparisons-dependent and selected pairs tests based on attribute of color, aroma and preference. The fresh red curry paste (A) was compared with the dry-rehydrated samples (Ai) where Ai = A1, A2 and A3 were microwave dried samples at 180, 360 and 540 W, respectively while Ai = A4, A5 and A6 were hot-air dried sample at 60, 70 and 80°C, respectively. Therefore, 6 selected pairs were A-A1, A-A2, A-A3, A-A4, A-A5 and A-A6. Each panelist evaluated all 6 selected pairs but one pair at a time in a balanced and randomized order for a single attribute. For each pair, each panelist indicated which of the two samples is more in color and aroma intensities and preferred. The color and aroma attributed were considered both before and after cooking while the preference was considered only after cooking. The test was used in forced-choice method. "No difference" response was not allowed.

4) Data Analysis

For step (1), compare A-A1, A-A2, A-A3, A-A4, A-A5 and A-A6.

- Null, H_0: the sensory attribute intensity for A < 50% (i.e., there was no difference)

- Alternative, H_a: the sensory attribute intensity for A ≥ 50%

- Panel responses for each test pair were significant differences between samples judged against tabulated critical numbers of correct answers (one-sided paired comparison test for difference) (Meilgaard et al., 2007). In this study, N=26 at α=0.05, the critical value was 18. If the observer response (pick the high number along with it's identify) ≥ the critical value (18), then reject H_0, saying that one sample is more sensory attribute intensity over another.

For step (2), to determine if all Ai are different, when differences among A and Ai exist.

- Null, H_0: all Ai samples are not difference,

- Alternative, H_a: not all Ai samples are same

- The Cochran's Q test is performed (Appendix E).

- Q statistics follow asymptotic χ^2 distributions with df of (m-1), where: m is the total number of pairs of samples (Meilgaard et al., 2007). In this study, the 2-tailed tabled χ^2 at df = 5 was 9.24.

- Compare Q statistic with the tabled χ^2 value. Reject H_0 (all Ai samples are not different) if calculated Q is greater than table χ^2, 2-tailed at α=0.05 level (9.24).

- The (1-α) level simultaneous confidence intervals (SCI) for difference of any two true proportions (samples) are calculated. If zero is included in SCI, the 2 samples are not significantly different.

3.4.4 Statistical Analysis

The Data were reported as a mean±standard derivation for three replications. The statistical analysis of the data was carried out using SPSS (Statistical Package for Social Science) software version 11, SPSS Inc., 1989-2001, for the analysis of variance (ANOVA) in determining significant differences between drying methods at a confidence level at 95% ($p \leq 0.05$). Variable mean was compared by Duncan's multiple rang test.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Microwave and Hot-Air Drying of Thai Red Curry Paste

4.1.1 Drying Behavior

Thai red curry paste was dried with two different drying methods: microwave and hot-air drying, to reduce the moisture content of red curry paste from 2.58 to 0.08 g water/g dry matter. The final dried product temperature for microwave drying was 83.8, 95.4 and 96.6°C at a microwave power of 180, 360 and 540 W, respectively. The influence of microwave power and drying air temperature on the moisture content versus drying time curve are shown in Figure 4.1.

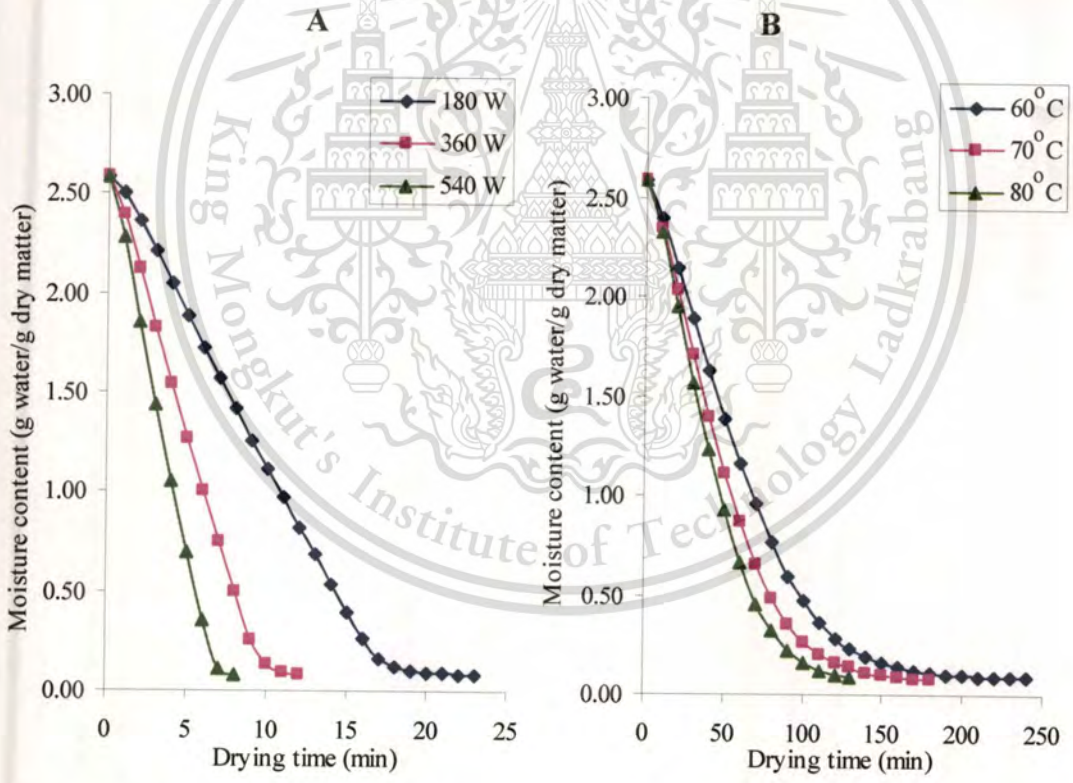

Figure 4.1 Moisture content versus drying time curves during microwave drying (A) and hot-air drying (B).

The drying time to reach the final moisture content for microwave drying was 23, 12 and 8 min at microwave powers of 180, 360 and 540 W, respectively, while that for hot-air drying was 240,

180 and 130 min at drying air temperatures of 60, 70 and 80°C, respectively. The time required for microwave drying of red curry paste was much shorter than for hot-air drying. This phenomenon indicated that the mass transfer of drying sample was rapid during microwave heating because the microwave penetrated directly into the sample. The heat was generated inside the sample and provided fast and uniform heating throughout the entire product, thus creating a large vapor pressure differential between the center and the surface of product and allowing rapid transport and evaporation of water. An increase in microwave power significantly shortened the drying time. Similar results were found by Sumnu et al. (2005), Ozkan et al. (2007) and Wang et al. (2007) on the study of microwave drying of carrot, spinach and apple pomace, respectively. Varith et al. (2007) also found that drying time for combined microwave-hot air drying of peeled longan was shortened by increasing the microwave power. In hot-air drying, increasing of drying air temperature also shortened the drying time significantly. Similar results were found by Doymaz (2005), Abalone et al. (2006) and Vega et al. (2007b) for hot-air drying of okra, amaranth seeds and aloe vera, respectively.

The drying rate was calculated as the quantity of moisture removed per unit time per unit dry matter. The drying rate plotted against moisture content during microwave and hot-air drying is shown in Figure 4.2.

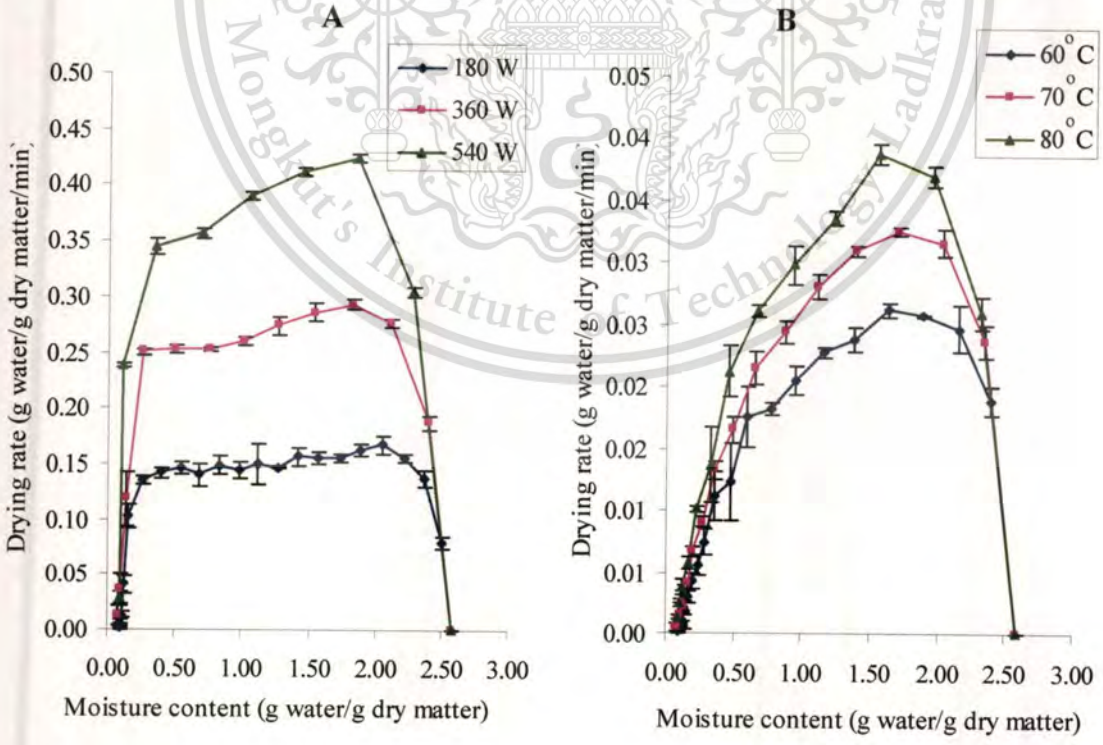

Figure 4.2 Drying rate versus moisture content curves during microwave drying (A) and hot-air drying (B).

It can be seen that the thin-layer microwave drying process of red curry paste consisted of three drying periods: heating up, constant rate, and falling rate periods, while the hot-air drying process exhibited only two drying periods: heating up and falling rate periods. The microwave drying results agreed with the study of parsley and mint leaves microwave drying as reported by Soysal (2004) and Özber and Dadali (2007). Those researchers found that after a short heating up period, a constant rate and falling rate periods were observed. However, Maskan (2000) and Maskan (2001) reported only falling rate period in microwave drying of banana and kiwi fruit. In hot-air drying, similar results were reported for red bell pepper (Vega et al., 2007a) and strawberry (Doymaz, 2008). Vega et al. (2007a) also reported that in the hot-air drying process of products of vegetal origin, the constant rate period was not observed, and there was a marked falling rate period due to the quick moisture removal from the samples. However, opposite observation was reported by Maskan (2000) who states that a short constant rate period during the drying of high moisture content products was observed by using lower drying temperatures such as 40-50°C.

At the beginning of drying rate period in microwave drying, the microwave energy is converted into thermal energy within the moist samples, resulting in increased paste temperature with time. For hot-air drying, the paste heats up due to heat transfer from the air to the paste. Once the vapor pressure in paste is higher than that of the environment, the paste starts to lose moisture, but at a slow rate. As the microwave power and drying air temperature increase, the drying rate during the heating up period significantly increases, the mass transfer rapidly occurring in the higher microwave power and drying air temperature.

After a short heating up period, a constant rate period was observed only during microwave drying, but not during conventional hot-air drying. This was because the air in the microwave oven was saturated and formed a thick film around the paste, preventing effective evaporation of moisture from the paste. Thus, a constant rate period was observed. In this period, thermal energy that was converted from microwave energy was used for moisture vaporisation, the rate of which depends on the microwave power.

The final period was the falling rate period in which the moisture content decreased to 0.08 g water/g dry matter for all drying conditions. In microwave drying, this period started at moisture content of 0.25-0.35 g water/g dry matter, while in hot-air drying it started at moisture content of 1.50-1.63 g water/g dry matter. Results showed that in hot-air drying, this period started at high moisture content. It was possible that in this case the paste surface became dry and prevented effective moisture removal from the surface. Meanwhile, the microwave remained heating the moisture inside

the product so that its temperature increased continuously. After this period, therefore, the paste burned and become non-usable as the dried product temperature reached 83.8, 95.4 and 96.6°C at the microwave powers of 180, 360 and 540 W, respectively. The results suggested that microwave drying should not be continued after the constant rate period.

4.1.2 Drying Models

To describe the effect of microwave power and drying air temperature on the kinetic of red curry paste drying, eleven different drying models, i.e. Lewis, Page, Modified Page, Handerson and Pabis, Wang and Sigh, Two term exponential, Logarithmic, Approximate of diffusion, Verma et al., Two term and Midilli et al. were used. The coefficient of determination (R^2), the reduced chi-square (χ^2) and the root mean square error (RMSE) were used to assess the best model characterizing the drying curves. The statistic analysis of the models for a given drying condition is presented in Table 4.1.

Among the eleven models, the Midilli et al. model provided the best explanation for microwave and hot-air drying behavior due to a higher coefficient of determination (R^2 = 0.99626 - 0.99987), lower reduced chi-square (χ^2 = 0.00003 - 0.00080) and lower root mean square error (RMSE = 0.00446 - 0.02043) than those from other models, followed by the Page, the Modified Page models. The coefficient of determination, reduced chi-square and root mean square error values of the Page, the Modified Page models were 0.99473 - 0.99946, 0.00007 - 0.00096 and 0.00749 - 0.02279, respectively. The Midilli et al. model was exhibited a better suitability with the experimental data is probably due to the high number of coefficients and form of the model equation (Hacihafizoğlu et al., 2008). Comparison between experimental and predicted results from the Midilli et al., the Page and the Modified Page models is illustrated in Figure 4.3, Figure 4.4 and Figure 4.5, respectively. Several authors reported good results when applying these models in drying kinetics of foods. For the Midilli et al. model was applied for red chilli peppers and leech lime leaves (Waewsak et al., 2006), apples (Menges and Ertekin, 2006), rough rice (Hacihafizoğlu et al., 2008) and sludge of olive oil extraction (Celma et al., 2007). The Page model was applied for red peppers (Doymaz and Pala, 2002), bay leaves (Demir et al., 2004), okra (Doymaz, 2005), amaranth seed (Abalone et al., 2006), nettle leaves (Alibas, 2007), sultana grapes (Margaris and Ghiaus, 2007), avocado and banana (Ceylan et al., 2007) and rosemary leaves (Arslan and Özcan, 2008). The Modified Page model was applied for kale (Mwithiga and Olwal, 2005), red bell peppers (Vega et al., 2007a) and aloe vera (Vega et al., 2007b).

Table 4.1 Statistical results of eleven thin-layer drying models at different drying methods.

Models	Microwave drying			Hot-air drying		
	180 W	360 W	540 W	60 °C	70 °C	80 °C
One parameter model						
Lewis						
R^2	0.92854	0.93129	0.93540	0.97742	0.97685	0.96954
χ^2	0.00834	0.00846	0.00844	0.00269	0.00245	0.00352
RMSE	0.08939	0.08835	0.08662	0.05058	0.04800	0.05715
Two parameters model						
Page						
R^2	0.99473	0.99515	0.99551	0.99751	0.99876	0.99946
χ^2	0.00064	0.00065	0.00067	0.00026	0.00014	0.00007
RMSE	0.02425	0.02342	0.02279	0.01520	0.01115	0.00749
Modified Page						
R^2	0.99473	0.99515	0.99551	0.99761	0.99876	0.99946
χ^2	0.00064	0.00065	0.00067	0.00096	0.00014	0.00007
RMSE	0.02425	0.02342	0.02279	0.02503	0.01114	0.00749
Henderson-Pabis						
R^2	0.95087	0.94858	0.94829	0.98560	0.98476	0.97893
χ^2	0.00599	0.00690	0.00772	0.00205	0.00171	0.00264
RMSE	0.07412	0.07643	0.07750	0.04271	0.03894	0.04753
Two term exponential						
R^2	0.92854	0.96863	0.97088	0.97699	0.97642	0.96903
χ^2	0.00872	0.00421	0.00433	0.00286	0.00264	0.00388
RMSE	0.06207	0.05495	0.05344	0.05100	0.04845	0.05763
Wang and Sign						
R^2	0.98522	0.98903	0.99157	0.99194	0.99462	0.99478
χ^2	0.00180	0.00147	0.00126	0.00181	0.00060	0.00071
RMSE	0.04065	0.03529	0.03120	0.03710	0.02319	0.02359
Three parameters model						
Logarithmic						
R^2	0.98681	0.99019	0.99217	0.98793	0.98906	0.98958
χ^2	0.00169	0.00145	0.00136	0.00197	0.00130	0.00142
RMSE	0.03838	0.03338	0.03007	0.04040	0.03301	0.03341
Approximate of diffusion						
R^2	0.98862	0.98929	0.97228	0.99805	0.99903	0.99935
χ^2	0.00145	0.00158	0.00484	0.00095	0.00012	0.00009
RMSE	0.02427	0.03484	0.05010	0.02384	0.00983	0.00835
Verma et al.						
R^2	0.92854	0.96944	0.95365	0.98560	0.98476	0.97893
χ^2	0.00913	0.00452	0.00807	0.00095	0.00205	0.00264
RMSE	0.08939	0.05280	0.06883	0.02384	0.03654	0.00836
Four parameters model						
Two-term model						
R^2	0.95087	0.94858	0.94829	0.98560	0.98476	0.97893
χ^2	0.00659	0.00844	0.01081	0.00224	0.00194	0.00316
RMSE	0.07412	0.07643	0.07750	0.04271	0.03894	0.04753
Midilli et al.						
R^2	0.99626	0.99730	0.99806	0.99962	0.99979	0.99987
χ^2	0.00050	0.00044	0.00040	0.00080	0.00003	0.00004
RMSE	0.02043	0.01749	0.01497	0.01845	0.00446	0.00516

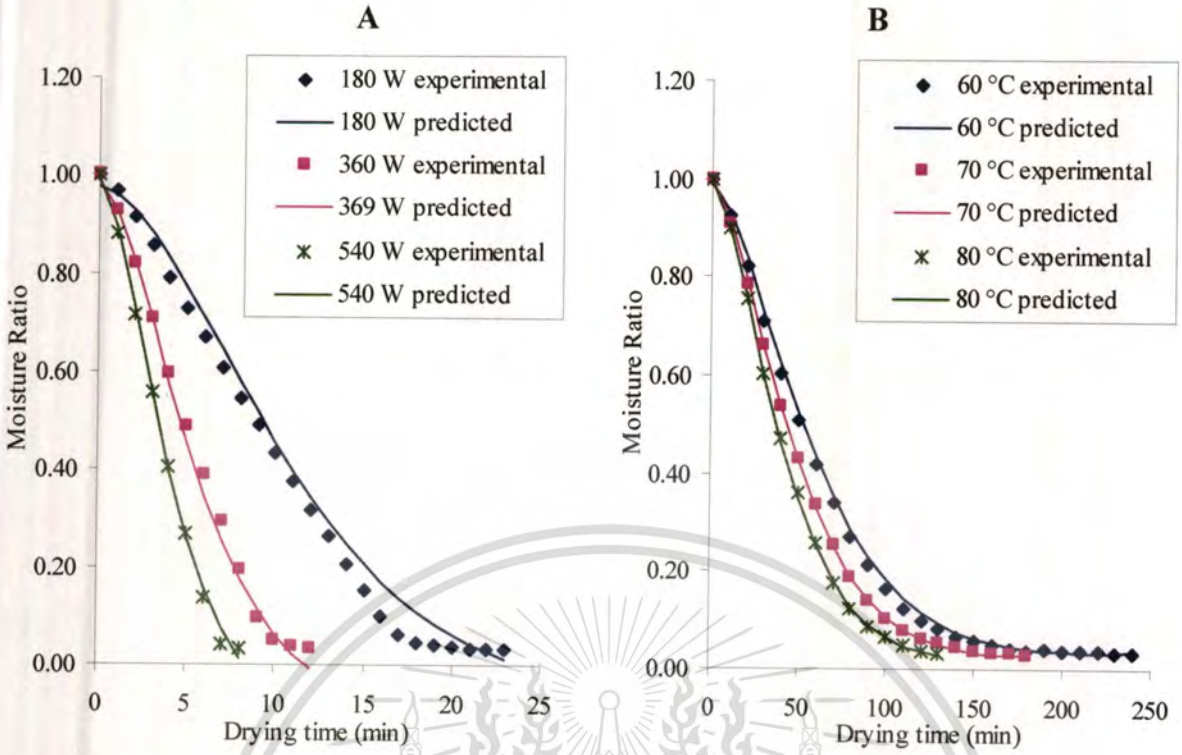

Figure 4.3 Comparison between experimental and predicted cures of moisture ratio versus time by Midilli et al. model for red curry paste during microwave drying (A) and hot-air drying(B).

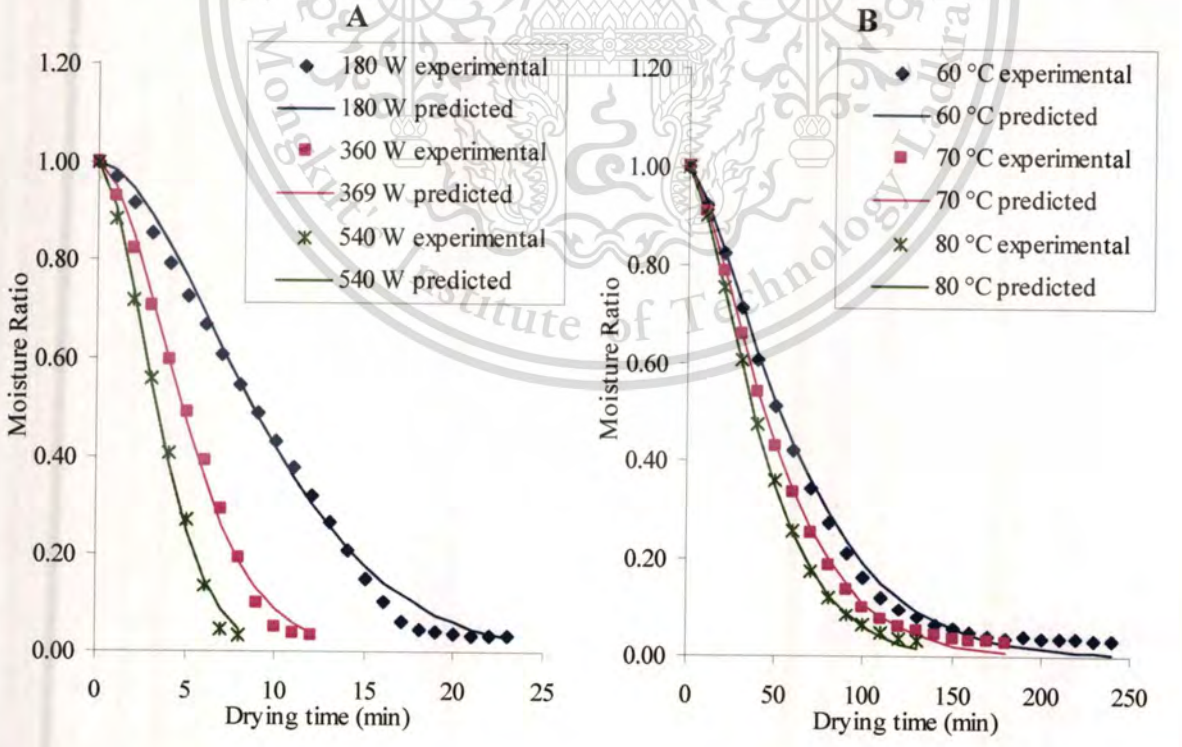

Figure 4.4 Comparisons between experimental and predicted curves of moisture ratio versus time by Page model for red curry paste during microwave drying (A) and hot-air drying (B).

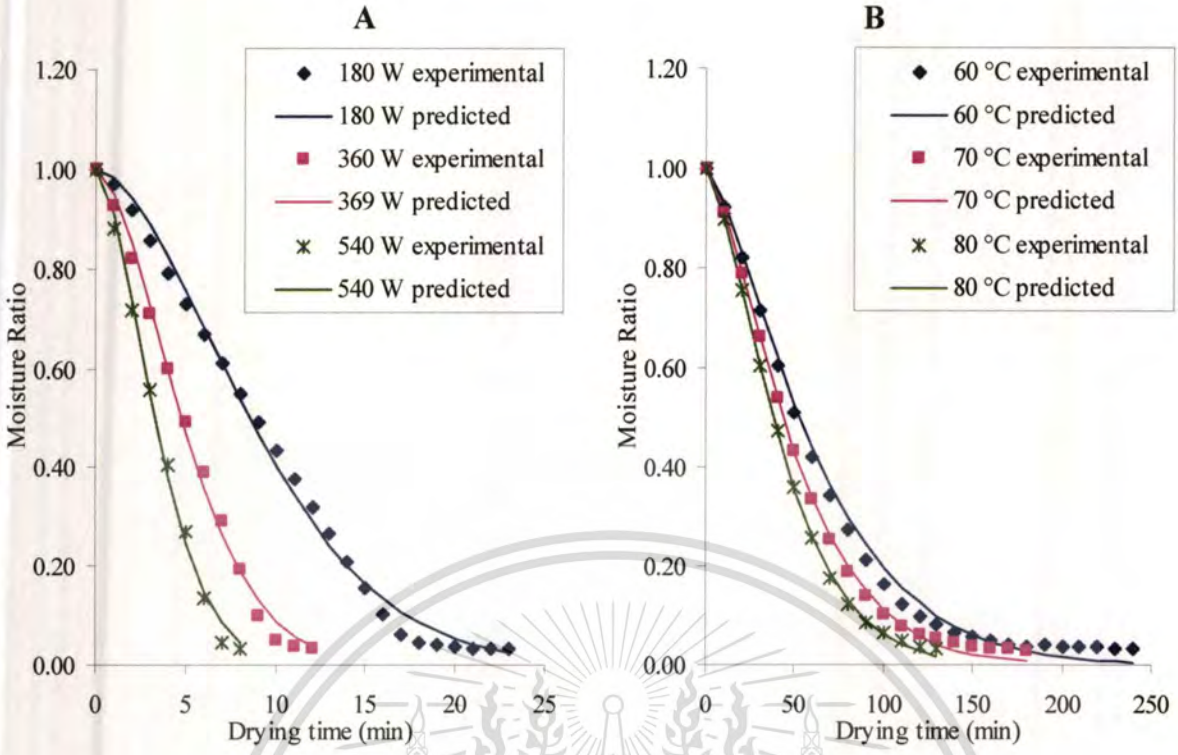

Figure 4.5 Comparisons between experimental and predicted curves of moisture ratio versus time by Modified Page model for red curry paste during microwave drying (A) and hot-air drying(B).

4.1.3 Drying Parameters

The drying parameters k_p and n_p in the Page equation, k_{mp} and n_{mp} in the Modified Page equation and k_m, n_m, a and b in the Midilli et al. equation were estimated for each drying condition. The estimated parameters and statistical analysis of these models for a given drying condition were presented in Table 4.2. The analysis of variance (ANOVA) at 95% confidence level indicated that microwave power and air drying temperature significantly affected ($p<0.05$) the drying parameters k_p, k_{mp} and k_m. However, k_p and k_m showed no statistical difference ($p>0.05$) with respect to drying air temperature. Azzouz et al. (2002), Mwithiga and Olwal (2005), Vega et al. (2007a) and Vega et al. (2007b) reported that drying parameter k of the Page and the Modified Page models was a function of drying temperature of the product. The drying parameters were much higher in microwave drying than in hot-air drying. As microwave power increased, the drying parameters significantly increased. Similar resulted were obtained by Maskan (2000), Soysal (2004) and Wang et al. (2007) on the study of banana, parsley and apple pomace, respectively.

Table 4.2 Estimated coefficients and statistical analysis of three thin-layer models.

Drying methods	Models	Model constants				R^2	χ^2	*RMSE*
	Page $MR = \exp(-k_p t^n)$	k_p (min^{-1})*	n_p*					
Microwave drying								
180 W		0.0186 ^{c}	1.6896 ^{a}			0.99473	0.00064	0.02425
360 W		0.0503 ^{b}	1.6842 ^{a}			0.99515	0.00065	0.02342
540 W		0.0950 ^{a}	1.6743 ^{a}			0.99551	0.00067	0.02279
Hot-air drying								
60°C		0.0032 ^{d}	1.3520 ^{c}			0.99751	0.00026	0.01520
70°C		0.0041 ^{d}	1.3652 ^{c}			0.99876	0.00014	0.01115
80°C		0.0039 ^{d}	1.4279 ^{b}			0.99946	0.00007	0.00749
	Modified Page $MR = \exp(-(k_{mp} t)^n)$	k_{mp} (min^{-1})*	n_{mp}*					
Microwave drying								
180 W		0.0946 ^{c}	1.6897 ^{a}			0.99473	0.00064	0.02425
360 W		0.1694 ^{b}	1.6842 ^{a}			0.99515	0.00065	0.02342
540 W		0.2451 ^{a}	1.6743 ^{a}			0.99551	0.00067	0.02279
Hot-air drying								
60°C		0.0143 ^{f}	1.3532 ^{c}			0.99761	0.00096	0.02503
70°C		0.0178 ^{e}	1.3662 ^{c}			0.99876	0.00014	0.01114
80°C		0.0205 ^{d}	1.4293 ^{b}			0.99946	0.00007	0.00749
	Midilli et al. $MR = a\exp(-k_m t^n) + bt$	k_m (min^{-1})*	n_m*	a*	b*			
Microwave drying								
180 W		0.0169 ^{c}	1.6937 ^{a}	0.9765 ^{d}	-0.0014 ^{a}	0.99626	0.00050	0.02043
360 W		0.0512 ^{b}	1.6009 ^{b}	0.9866 ^{c}	-0.0051 ^{b}	0.99730	0.00044	0.01749
540 W		0.0980 ^{a}	1.5375 ^{c}	0.9929 ^{ab}	-0.0102 ^{c}	0.99806	0.00040	0.01497
Hot-air drying								
60°C		0.0022 ^{d}	1.4515 ^{d}	0.9911 ^{b}	0.0001 ^{a}	0.99962	0.00080	0.01845
70°C		0.0031 ^{d}	1.4450 ^{d}	0.9938 ^{ab}	0.0002 ^{a}	0.99979	0.00003	0.00446
80°C		0.0033 ^{d}	1.4763 ^{cd}	0.9957 ^{a}	0.0001 ^{a}	0.99987	0.00004	0.00516

*Column (mean ± S.D., n=3) having different superscripts are significantly different (p<0.05).

Parameters n_p, n_{mp} and n_m were greater than 1.0 which mean that the relationship between moisture ratio and time were unlikely a first-order kinetic. Therefore, the Page, the modified Page and the Midilli et al. models offered improved predictability of drying kinetics over other model. Vega et al. (2007a) reported that the good fit of experimental data using the Page and the Modified Page models may be due to theirs incorporation of the n parameter.

The parameter n_p, n_{mp} and n_m of different drying methods were significantly different (p<0.05). Results showed that the microwave drying parameters were higher than those of hot-air drying. Parameters n_p and n_{mp} were constant with microwave power and increased as drying air temperature increased. On the other hand, parameter n_m decreased as microwave power increased and was constant with drying air temperature. Alibas (2007), Wang et al. (2007) and Vega et al. (2007a)

reported that the drying parameter, n, of the Page and the Modified Page models was dependent on the microwave power and drying temperature. However, some studies showed different results, in which the parameter of beans, potatoes, pears (Senadeera et al., 2003) and aloe vera (Vega et al., 2007b) was constant with temperature.

Parameters a and b of the Midilli et al. model in hot-air drying was significantly higher than in microwave drying at microwave powers of 180 and 360 W. Microwave power significantly affected ($p<0.05$) on the drying parameters. Microwave power increased, parameter a significantly increased while parameter b decreased. However, both parameters showed no statistical difference ($p>0.05$) with respect to drying air temperature.

4.2 Moisture Sorption of Dried Thai Red Curry Paste

4.2.1 Moisture Sorption Isotherms

The initial moisture content of microwave and hot-air dry-powdered Thai red curry paste were found in the range of 0.082 to 0.086 g water/g dry matter. Moisture sorption isotherms of these samples are shown in Figure 4.6. As the initial moisture contents of the powdered were low, adsorption was dominant. The values for equilibrium moisture content (W_e) of the powdered increased with water activity (a_w). This may be due to the fact that vapor pressure of water present in samples increase with that of the surroundings. The moisture content increased very slowly with increase in water activity up to 0.432. From this point on there was a gradual increase in moisture content with increase in water activity up to 0.851, beyond which there was a steep rise in moisture in all samples.

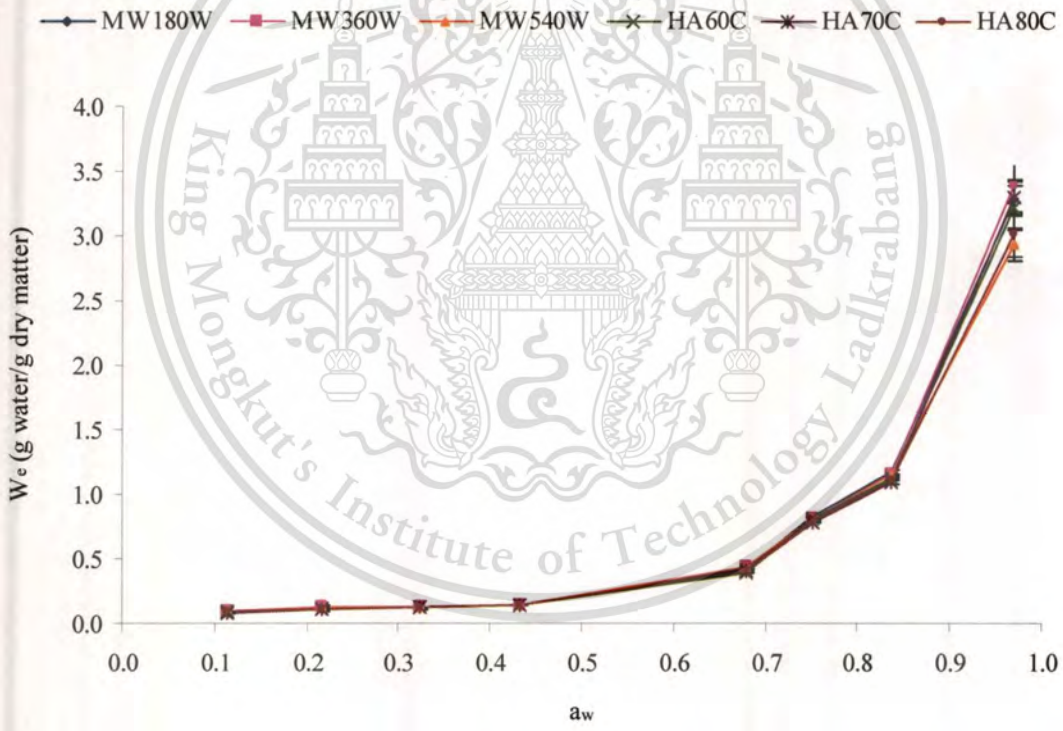

Figure 4.6 Moisture adsorption isotherm of dry- powdered Thai red curry paste from microwave drying (MW) and hot-air drying (HA).

The shape of all isotherms followed the type III behavior according to Brunauer et al.'s classification (Al-Muhtaseb et al., 2002), which adsorbs small amounts of water at low water activity level and large amounts at high water activity level and once the bulk moisture point has reached, the

powdered rapidly adsorbs large amounts of water vapor, causing it to deliquesce lading to the steep rise in the third part of the curve corresponding to the formation of hydrate. The linear shape at the first part of the isotherms is caused by the water adsorption on to the biopolymers such as proteins and polysaccharides. The shape increase in water content at high water activity is due to the gradual dissolution of solutes such as salts and sugars. These results suggested that dry-powdered red curry paste is characterized by high hygroscopicity, as a result of high solutes content (salts and sugars) mostly in the amorphous state, which promotes undesirable effects (i.e. caking).

Al-Muhtaseb et al. (2002) reported that foods rich in soluble components have been found to show Type III behavior, this is due to the solubility of the component in water. A similar isotherm behavior has been found in crushed chillies (Arslan and Toğrul, 2005), pistachio nut paste (Maskan and Göğüş, 1997), model fruit powder (Tsami et al., 1999; Drouzas et al., 1999), pineapple pulp powder (Gabas et al., 2007), fruit rich in sugar such as grapes, apricots and apples (Kaymak-Ertekin and Gedik, 2004) and salted alligator's meat (Lopes Filho et al., 2002).

It is known that the shape and position of the isotherm are influenced by sample composition, physical structure (crystalline or amorphous), pretreatment and food processing (Gabas et al., 2007). According to Figure 4.6, the effect of drying methods on shape and position of the powdered isotherm was negligible. It means that the state of adsorbed water of dry-powdered red curry paste during sorption process will not be very different among the methods of drying. Moreover, all the powdered samples had slightly difference in amount of equilibrium moisture content over entire water activity level, which indicated that the drying methods also did not significantly affect on adsorption capacity of the samples. Similar results were obtained by Debnath et al. (2002) on freeze-dried, vacuum shelf-dried and through flow-dried onions, but contrast with the results obtained from several researchers. Tsami et al. (1999) found freeze-dried had a higher adsorption capacity than microwave-dried, vacuum-dried and conventionally-dried pectin-sugar gels, respectively. Lee and Lee (2008) and Giri and Prasad (2009) also found freeze-dried had a higher adsorption capacity than microwave-dried and air-dried mushrooms, respectively. However, Sundaram and Durance (2008) found convective air-dried had a higher adsorption capacity among all up to 0.8 a_w level than freeze-dried and microwave-vacuum-dried locust bean gum-pectin-starch composite gels. These researchers suggested that moisture sorption capacity of the dry products in accordance with the result of structural properties such as shrinkage and porosity (total pore area and pore size distribution), which mainly depends on the drying methods. Moreover, the effect of drying methods on the sorption capacity from different materials may not be same.

4.2.2 Moisture Sorption Models

The experimental equilibrium moisture content data at any water activity of dry-powdered red curry paste from microwave and hot-air drying methods were fitted against the water activity on ten different sorption models listed in Table 3.2. The statistical test methods, the coefficient of determination (R^2), the reduced chi-square (χ^2) and the root mean square error (RMSE) were used to select the best fitting equation for the dry-powdered red curry paste. The estimated parameters and statistical analysis of the models are presented in Table 4.3. The results show that the highest values for R^2 and the lowest values for χ^2 and RMSE were obtained with the GAB model for all the powered samples. Mathematical comparison of the observed and predicted results gave R^2 values ranging from 0.99639 to 0.99753 (average 0.99696), χ^2 values ranging from 0.00451 to 0.00580 (average 0.00504) and RMSE values ranging from 0.05308 to 0.06022 (average 0.05608). The fitted sorption isotherms for the model with the experimental data are illustrated in Figure 4.7.

Normally, parameters in the GAB equation have physical meaning, X_m is the monolayer content; C is the total heat of sorption of the first layer; K is a factor correcting the properties of multilayer molecules with respected to the bulk liquid (Maskan and Göğus, 1997). However, there are some other limit values for parameters C and K suggested by Lewicki (1997), based on the mathematical analysis of the model. In order to guarantee a relatively good description of the isotherm and to fulfill the requirements of the BET model, as well as assuring the estimated the X_m values differ by not more than ± 15% from the true monolayer capacity, the author stated that the parameters should assume values in the ranges $5.67 \leq C \leq \infty$ and $0.24 \leq K \leq 1$. Here the estimated C results are not in accordance with the limit values were considered as not fulfilling theoretical requirements so the values of GAB's parameters obtained in the work lack any physical meaning. Similar results were found by Lewicki (1997) for apple cellular fiber, carrot, coffee, mushroom, wheat bran flour and yeast's isotherms. The physically impossible values of the GAB parameters have been reported by several researchers. The high value of X_m has been reported by Arslan and Toğrul (2005) on the study of crushed chilies. Furthermore, the negative value of C and the higher value than unity of K have been fond by Maskan and Göğus (1997) on the study of pistachio nut paste.

Table 4.3 Statistic results and estimated values of sorption model parameters.

Models	Parameters	Microwave drying			Hot-air drying		
		180 W	360 W	540 W	60°C	70°C	80°C
Two parameters							
Oswin	*A*	0.33648	0.32630	0.34232	0.35039	0.34215	0.35615
	B	0.65178	0.66792	0.62815	0.64678	0.66175	0.61036
	R^2	0.98892	0.99200	0.98801	0.98878	0.99145	0.98526
	χ^2	0.01565	0.01184	0.01480	0.01662	0.01334	0.01746
	RMSE	0.10835	0.09425	0.10537	0.11164	0.10004	0.11443
Caurie							
	A	-5.58930	-5.82891	-5.32475	-5.48757	-5.70087	-5.06514
	B	6.95845	7.23285	6.61666	6.87698	7.12712	6.32436
	R^2	0.99335	0.99274	0.99290	0.99413	0.99344	0.99440
	χ^2	0.00939	0.01075	0.00877	0.00869	0.01025	0.00662
	RMSE	0.08392	0.08978	0.08108	0.08074	0.08766	0.07049
Smith							
	A	-0.30889	-0.32477	-0.26495	-0.31367	-0.33029	-0.24857
	B	-0.92524	-0.94499	-0.86580	-0.94819	-0.97144	-0.85031
	R^2	0.94904	0.94273	0.95534	0.95187	0.94578	0.96288
	$\chi 2$	0.06775	0.07996	0.05165	0.06701	0.07975	0.04109
	RMSE	0.22542	0.24488	0.19681	0.22418	0.24456	0.17555
Lewicki-2							
	A	0.33648	0.32630	0.34232	0.35039	0.34215	0.35615
	B	0.34822	0.33208	0.37185	0.35322	0.33825	0.38964
	R^2	0.98823	0.99152	0.98720	0.98806	0.99093	0.98422
	χ^2	0.01565	0.01184	0.01480	0.01662	0.01334	0.01746
	RMSE	0.10835	0.09425	0.10537	0.11164	0.10004	0.11443
BET							
	X_m	0.08017	0.08339	0.08464	0.08356	0.08321	0.08287
	C	429.62592	145.333057	1333229.36	107.06766	1326.3384	618734.8
	R^2	0.96880	0.91936	0.89922	0.95998	0.87758	0.84921
	χ^2	0.00002	0.00006	0.00006	0.00003	0.00009	0.00010
	RMSE	0.00328	0.00566	0.00570	0.00418	0.00666	0.00723
Haslay							
	A	0.17562	0.17495	0.17492	0.18406	0.18449	0.18302
	B	0.91551	0.92786	0.94602	0.90163	0.91205	0.91593
	R^2	0.96782	0.97037	0.96476	0.97085	0.96589	0.96384
	χ^2	2.12845	1.79900	1.86518	2.76614	2.43855	2.87668
	RMSE	1.26346	1.16157	1.18274	1.44035	1.35237	1.46885
Henderson							
	A	1.86038	1.89811	1.87708	1.80529	1.82196	1.82029
	B	0.78050	0.80097	0.81029	0.77582	0.79150	0.79160
	R^2	0.93792	0.94151	0.93691	0.94296	0.94013	0.94008
	χ^2	0.16648	0.23175	0.13049	0.15781	0.21300	0.08008
	RMSE	0.35335	0.41691	0.31283	0.34403	0.39968	0.24507

Table 4.3 Continued.

Models	Parameters	Microwave drying			Hot-air drying		
		180 W	360 W	540 W	60°C	70°C	80°C
Three parameters							
GAB							
	X_m	0.51270	0.36958	0.45741	0.58185	0.42026	0.70660
	C	0.36373	0.55482	0.45222	0.32846	0.48915	0.28460
	K	0.91039	0.93380	0.90986	0.90335	0.92692	0.87733
	R^2	0.99658	0.99726	0.99639	0.99714	0.99753	0.99683
	χ^2	0.00580	0.00487	0.00535	0.00509	0.00463	0.00451
	RMSE	0.06022	0.05517	0.05781	0.05638	0.05379	0.05308
Lewicki-3							
	A	0.70377	0.62745	0.80473	0.75473	0.67691	0.96289
	B	0.46590	0.50227	0.41554	0.45390	0.48925	0.36552
	C	6.71382	6.71161	6.89649	6.75285	6.68133	7.03462
	R^2	0.99552	0.99672	0.99571	0.99595	0.99682	0.99576
	χ^2	0.00759	0.00582	0.00635	0.00720	0.00596	0.00603
	RMSE	0.06887	0.06033	0.06302	0.06706	0.06102	0.06140
Four parameters							
Peleg							
	A	1.91516	1.98273	1.77474	1.95455	2.02753	1.71775
	B	1.91516	1.98273	1.77474	1.95455	2.02753	1.71775
	C	6.06913	6.32743	5.76744	5.99412	6.22799	5.49316
	D	6.06913	6.32743	5.76744	5.99412	6.22799	5.49316
	R^2	0.98904	0.98822	0.98782	0.98978	0.98893	0.98933
	χ^2	0.02322	0.02617	0.02256	0.02269	0.02594	0.01896
	RMSE	0.10776	0.11440	0.10621	0.10651	0.11388	0.09737

For the second best model to describe the experimental data was the Lewicki-3 model for all the powdered samples. Statistic data for the Lewicki-3 correlation were: R^2 ranging from 0.99552 to 0.99682 (average0.99608), χ^2 ranging from 0.00582 to 0.00759 (average 0.00649) and RMSE ranging from 0.06033 to 0.06362 (average 0.06362). On the other hand, the Henderson, Haslay and Smith equations provided the worst representation of the data. Lewicki (1998) theorized that the Lewicki-3 model consists of two functions subtracted from each other assumes two processes occurring in parallel. The first process prevails at high water activities, and the second plays a major role at low water activities. He also found that the equation gives higher probability of good fit to experimental data than the GAB and Peleg equations. Nevertheless no physical significance can be assigned to the parameters of the equation.

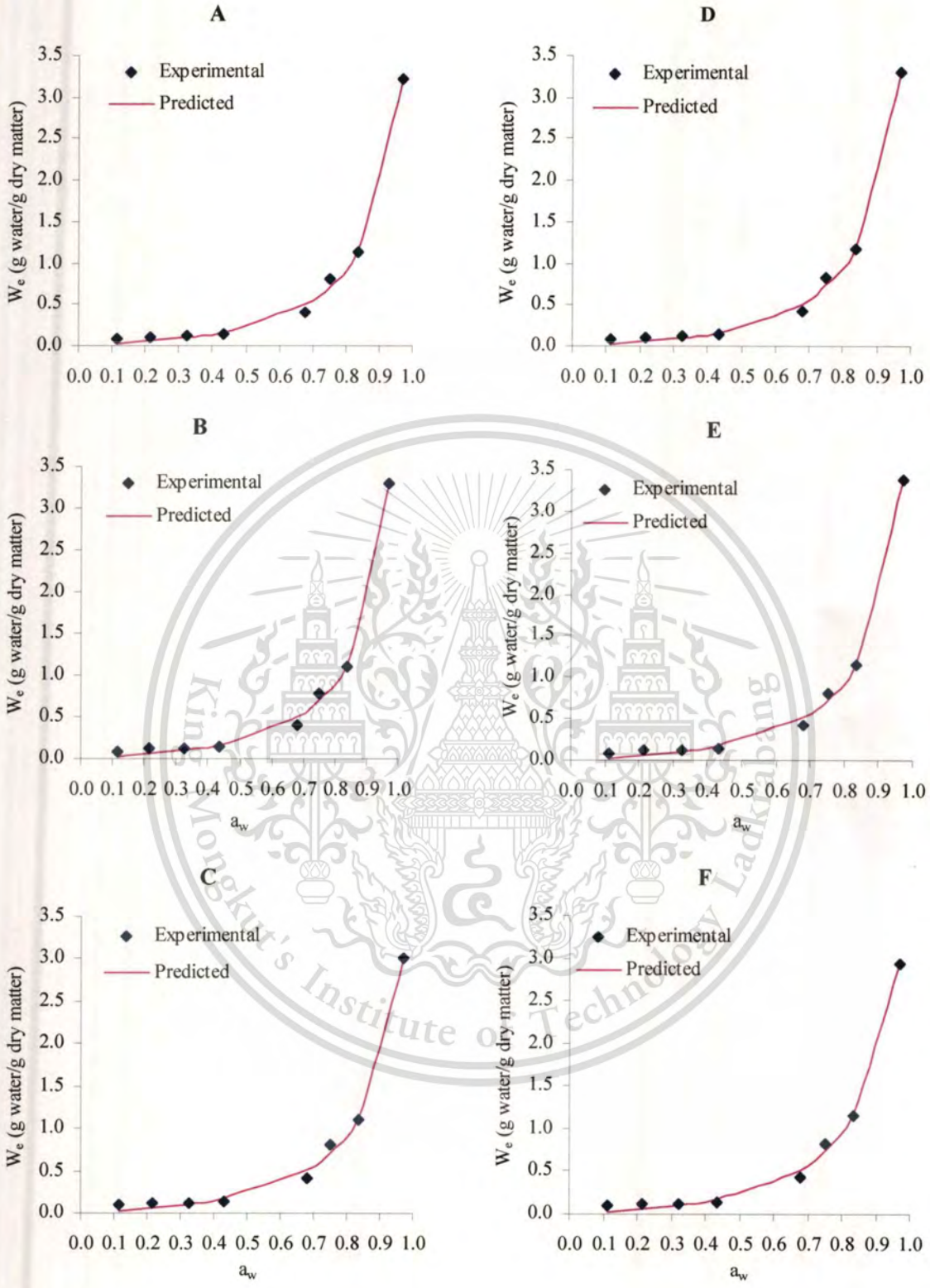

Figure 4.7 Comparison of experimental and predicted adsorption equilibrium moisture contents from GAB model of dry-powdered Thai red curry paste from microwave drying at microwave powers of 180 W (**A**), 360 W (**B**) and 540 W (**C**) and hot-air drying at air temperatures of 60°C (**D**), 70°C (**E**) and 80°C (**F**).

4.2.3 Monolayer Moisture Content (X_m)

The value of X_m is of particular interest, since it indicates the amount of water that is strongly adsorbed to specific sites at the food surface. It is considered as the optimum value to assure food stability. For most dry foods, the rate of quality loss due to chemical reaction is negligible below monolayer value. Therefore, this value is important in storage of dry-powdered red curry paste, since at this level the water does not act as a solvent, being biologically inert.

The X_m value in this study was determined using the BET equation. The results showed X_m values in the range of 0.080 to 0.085 g water/g dry matter, the values at which the powdered samples keep very well, on storage for a long period of time. Tsami et al. (1999) found X_m values for model fruit powder between 0.060 and 0.097 following adsorption at temperature 25°C, which is in agreement with the magnitude order of X_m estimated in the present work. Whereas, the results for lemon juice and pineapple powder were found in range of 0.146 to 0.166 g water/g dry matter following adsorption at temperature in the range of 20 to 50°C (Martinelli et al., 2007; Gabas et al., 2007). Kaymak-Ertekin and Gedik (2004) found X_m of grapes, apricots and apples between 0.095 and 0.220 g water/g dry matter, potato between 0.067 and 0.073 g water/g dry matter following adsorption and desorption at temperature in the range of 30 to 60°C. The results indicated that the value of X_m for dry-powdered red curry paste is lower than for the high sugar fruits and fruit powder while higher than for the starchy foods.

4.3 The Effects of Microwave and Hot-Air Drying on Qualities of Dried Thai Red Curry Paste

4.3.1 Color Properties

4.3.1.1 Browning Index (BI)

Browning reaction occurs during food processing and storage, and important factor on food quality. The causes of food browning can be classified as enzymatic and non-enzymatic browning. The non-enzymatic browning is mainly caused by maillard reaction, caramelisation, and ascorbic acid degradation, and is favored by heat treatment (Chen et al., 2009). According to a report by Turhan et al. (1997) and Maskan (2000), a major color change during drying was due to the large increase in the content of brown pigments. Moreover, the brown pigments formation is closely related to drying temperature and relative humidity of food materials (Vega-Gálvez et al., 2008). Therefore, the influence of the drying methods on the brown pigments formation should be considered. The extent of browning was evaluated as BI, measured as absorbance at 420 nm (Kim et al., 2006 and Vega-Gálvez et al., 2008). The extent of browning of fresh and dried red curry paste was expressed in term of the Abs/g dry matter as shown in Figure 4.8.

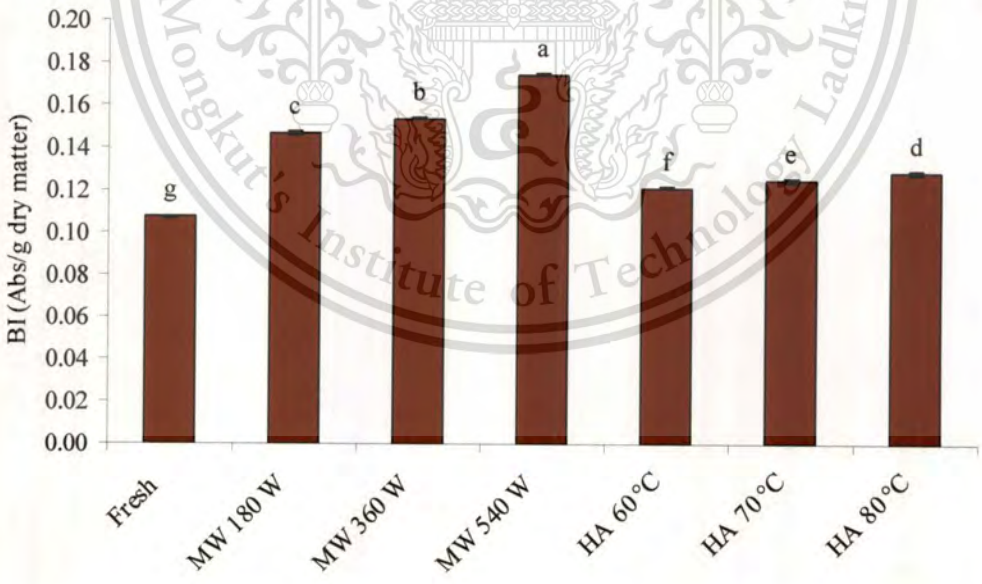

Figure 4.8 Browning index (BI) value of fresh and dried Thai red curry paste from microwave drying (MW) and hot-air drying (HA).

Bars (mean ± S.D., n=3) having different letters are significantly different (p<0.05).

The BI value of fresh red curry paste (0.107 Abs/g dry matter) was significantly less than the dried samples (0.121-0.175 Abs/g dry matter), which indicated that brown pigments formation occurred during drying process. Microwave drying caused the formation of brown pigments more hot-air drying. Moreover, as the microwave power and drying air temperature increased, the formation increased. Similar results were found by Vega-Gálvez et al. (2009) and Miranda et al. (2009) for hot-air drying of red bell peppers and aloe vera.

4.3.1.2 Color Measurements

From a consumer-acceptance viewpoint, color is an important attribute of the dried product. It can be a measurement of reactions extension in the product, since formed and/or degraded compounds may contribute to a specific colorant (Francis, 1995). A mix of red and yellow makes up the major color of Thai red curry product due to the presence of carotenoid from the red chilli. Color components are represented by Hunter **a** and **b** values, while any change in **a** and **b** values is accompanied by a simultaneous change in **L** values (Ahmed et al., 2002). Hence, color measurements (Hunter **L**, **a** and **b**) should be used to evaluate the effect of drying methods on the color quality of dried Thai red curry paste in both powdered and rehydrated form.

1) Dry-Powdered Red Curry Paste

Color measurement results for dry-powdered red curry paste (Figure 4.9) were: **L** value in the range of 56.827 to 59.364, **a** value in the range of 23.072 to 24.103, and **b** value in the range of 30.432 to 31.652. According to the results of the ANOVA analysis, the overall color parameters of the powdered are affected by different drying methods. The **L** and **b** values of powdered from the microwave drying were slightly lower than the hot-air drying, which indicated that the powdered from the microwave drying was slightly darker in color and less yellow than the hot-air drying. The **a** value of powdered from microwave drying at a microwave power of 540 W was not significantly different from hot-air drying at air temperature of 60°C, but had significantly more red color than from hot-air drying at air temperatures of 70 and 80°C.

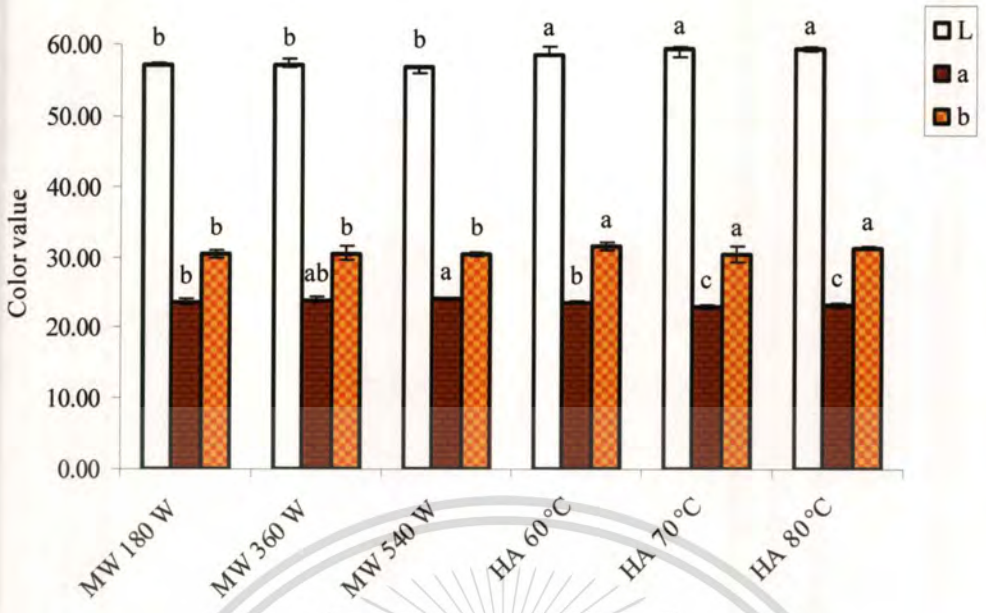

Figure 4.9 Color measurements of dry-powdered Thai red curry paste from microwave drying (MW) and hot-air drying (HA).

Bars (mean ± S.D., n=3) having different letters are significantly different (p<0.05).

The discoloration of sample during drying was related to pigment destruction, enzymatic browning and non-enzymatic browning. Therefore, the color became darker and redder, implying that more browning of the product occurred while less yellow color could imply that pigment destruction had occurred. These results indicated that the microwave-dried products were more influenced by the browning reactions, causing more pigment destruction than for the hot-air-dried products. Similar results were obtained by Funebo and Ohlsson (1998) when drying of mushrooms and apples. However, Arslan and Özcan (2008) and Sumnu et al. (2005) found that microwave drying prevented color damage during drying of rosemary leaves and carrots.

Sharma and Prasad (2001) and Vega-Gálvez et al. (2008) reported that browning and carotenoid pigment destruction increased with an increase in the drying temperature and/or time. Therefore, the undesirable browning and reduced yellow color of the microwave-dried product occurred in samples because of the high temperature generated by microwaves (Drouzas et al., 1999). The final temperature of microwave-dried paste was 83.8, 95.4 and 96.6°C at a microwave power of 180, 360 and 540 W, respectively. In contrast, hot-air drying was performed at lower drying temperatures than the microwave drying, resulting in a lighter and yellower color of the dry-powdered

red curry paste. These results revealed that the microwave drying technique strongly affected the color quality of powdered red curry product and produced more brown compounds.

The differences among color **L**, **a** and **b** values of microwave-dried samples were not significant, which indicated that the change in color values was not dependent on the microwave power. The results are in agreement with Maskan (2000) who studied microwave-dried banana, Soysal (2004) for microwave-dried parsley and Pereira et al. (2007), for microwave/hot-air-dried, osmotically dehydrated banana. Hot-air-dried samples at an air temperature of 60°C had slightly higher **a** value than other hot-air-dried samples but were significantly different, especially for a long time process while **L** and **b** values were not significantly different.

2) Dry-Rehydrated Red Curry Paste

For the effect of drying method on color measurements of dried red curry paste, their betters describe by the dry-rehydrated product and compare with the fresh product. Figure 4.10 shows the results of color measurements of fresh and dry-rehydrated samples of red curry paste.

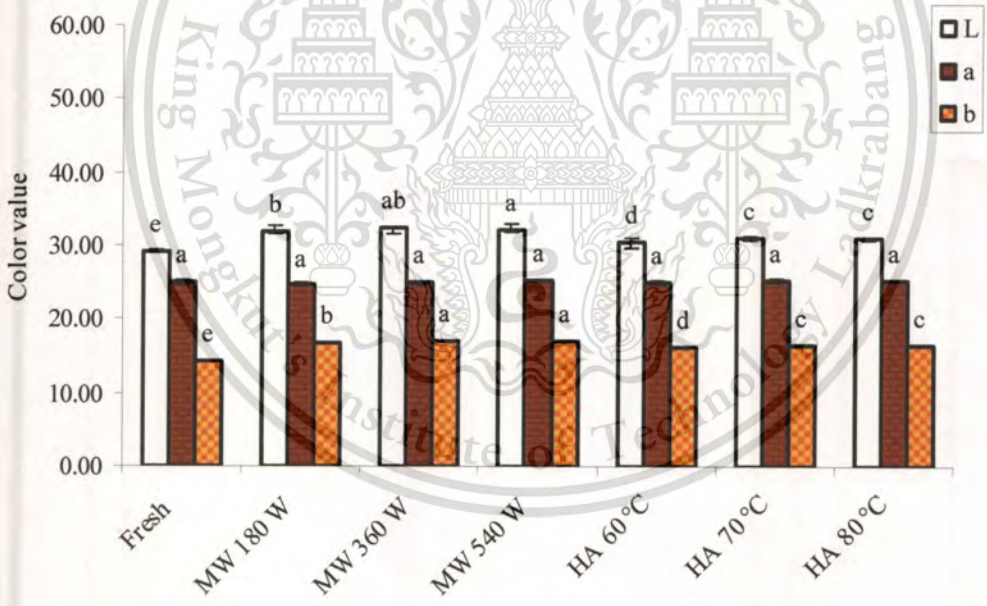

Figure 4.10 Color measurements of fresh and dry-rehydrated Thai red curry paste from microwave drying (MW) and hot-air drying (HA).
Bars (mean ± S.D., n=3) having different letters are significantly different (p<0.05).

The Hunter **L**, **a** and **b** values of the fresh sample were 29.073, 25.101 and 14.415, respectively, while the dry-rehydrated samples were found 30.660-32.407, 24.787-25.380, and

16.127-17.350, respectively. It was found that the **L** and **b** values of the fresh sample differed significantly from the values of the rehydrated samples ($p<0.05$) while the **a** value showed not significant different ($p>0.05$). The **L** and **b** values of the rehydrated samples were slightly higher than the fresh sample, which indicate that the rehydrated samples was slightly lighter in color and more yellow color than the fresh one.

The **L** and **b** values of microwave drying were slightly higher than hot-air drying, which indicated that dry-rehydrated red curry paste from the microwave drying was slightly lighter in color and more yellow color than the hot-air drying and still had same the red color. The differences among color **L** and **a** values of microwave-dried sample were not significant. However, microwave-dried at microwave powers of 360 W and 540 W had significantly higher the **b** value than microwave-dried at a microwave power of 180 W. Hot-air-dried samples at air temperatures of 70°C and 80°C had significantly higher **L** and **b** values than hot-air-dried samples at an air temperature of 60°C.

Therefore, the lighter in color of the rehydrated samples could be implied that pigment destruction occurred and more yellow color of the samples implying that more browning of the product occurred.

4.2.1.3 Color Change

The changes of color of dried paste after rehydration with fresh one were expressed in term of the ratio of color change ($\Delta L/L_0$, $\Delta a/a_0$ **and** $\Delta b/b_0$) as shown in Figure 4.11 and total color change (ΔE) was calculated using **L**, **a** and **b** values, which taken into account changes in red and yellow color was also compared as shown in Figure 4.12. It was found that drying method affected $\Delta L/L_0$, $\Delta b/b_0$ and ΔE values significantly while $\Delta a/a_0$ value did not significantly different. The $\Delta L/L_0$, $\Delta b/b_0$ and ΔE values of microwave-dried sample was higher than hot-air-dried, which indicated that a greater discoloration occurred during microwave drying. In addition, microwave power and drying air temperature significantly affected ($p<0.05$) on the change of lightness, yellow color and total color change values. Microwave power and drying air temperature increased, the change of lightness, yellow color and total color change significantly increased.

Discoloration of sample during drying was related to pigment destruction, enzymatic browning and non-enzymatic browning. From the results can be seen that the effect of the drying methods on the change of yellow color ($\Delta b/b_0$) was consistently higher than the change of lightness ($\Delta L/L_0$), which indicated that a major color change during drying was due to the large increase in the content of brown pigments. Similar results were found by Vega-Gálvez et al. (2009) and Miranda et al. (2009) for hot-air drying of red bell pepper and aloe vera.

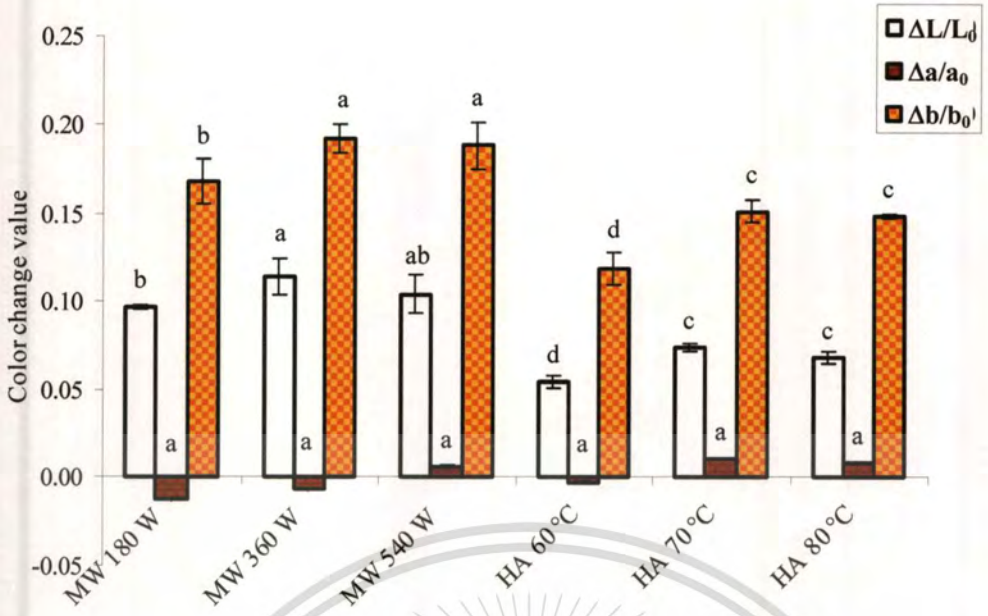

Figure 4.11 The change of lightness ($\Delta L/L_0$), red color ($\Delta a/a_0$) and yellow color ($\Delta b/b_0$) values of dry-rehydrated Thai red curry paste from microwave drying (MW) and hot-air drying (HA).

Bars (mean ± S.D., n=3) having different letters are significantly different ($p<0.05$).

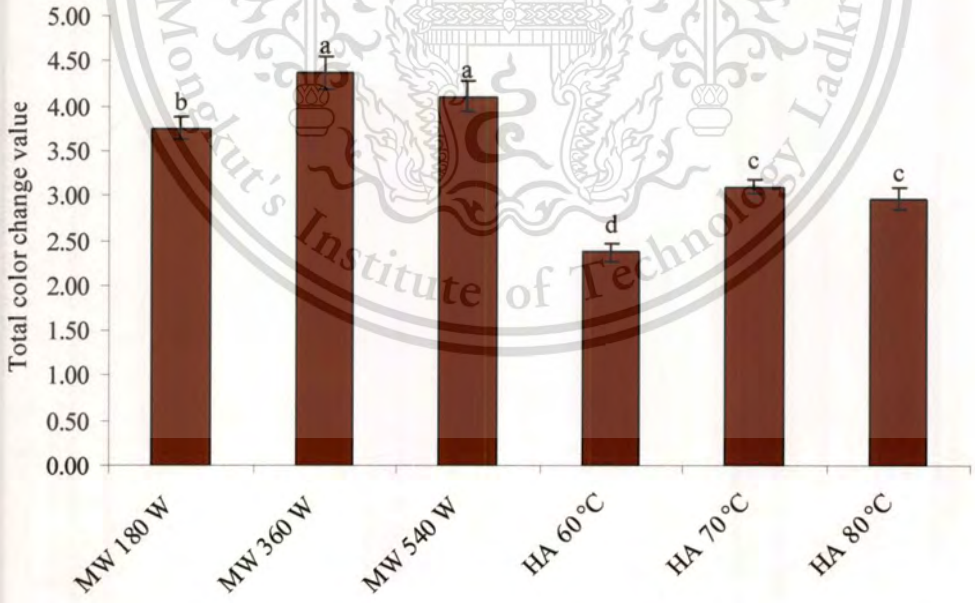

Figure 4.12 Total color change (ΔE) value of dry-rehydrated Thai red curry paste from microwave drying (MW) and hot-air drying (HA).

Bars (mean ± S.D., n=3) having different letters are significantly different ($p<0.05$).

4.3.2 Proximate Composition

The proximate composition of fresh and dried Thai red curry paste samples obtained from microwave and hot-air drying are presented in Table 4.4.

Table 4.4 Proximate compositions (% dry matter) of fresh and dried Thai red curry paste from microwave drying and hot-air drying.

Drying methods	Moisture	Crude Protein	Crude Fat	Crude Fiber	Ash	Available Carbohydrate
Fresh	257.61±1.68 [a]	11.49±0.14 [a]	4.28±0.03 [a]	29.75±0.09 [a]	27.43±0.19 [a]	27.04±0.04 [c]
Microwave drying						
180 W	8.37±0.17 [b]	10.94±0.12 [ab]	3.34±0.07 [b]	29.41±0.23 [a]	27.96±0.11 [a]	28.36±0.30 [ab]
360 W	8.23±0.12 [b]	11.17±0.39 [ab]	3.24±0.09 [b]	29.50±0.14 [a]	27.95±0.25 [a]	28.15±0.15 [ab]
540 W	8.37±0.12 [b]	10.81±0.25 [b]	3.28±0.10 [b]	29.37±0.26 [a]	27.93±0.31 [a]	28.61±0.65 [a]
Hot-air drying						
60°C	8.46±0.10 [b]	11.01±0.23 [ab]	3.46±0.23 [b]	29.80±0.18 [a]	27.66±0.27 [a]	28.08±0.42 [ab]
70°C	8.34±0.10 [b]	11.36±0.43 [ab]	3.54±0.14 [b]	29.83±0.24 [a]	27.53±0.29 [a]	27.73±0.08 [b]
80°C	8.61±0.17 [b]	11.26±0.34 [ab]	3.22±0.10 [b]	29.72±0.17 [a]	28.05±0.26 [a]	27.75±0.39 [b]

Mean (± S.D., n=3) with different superscripts in each column are significantly different ($p<0.05$).

The dried red curry paste showed decreased levels of moisture and fat contents while increased available carbohydrates compared to fresh sample. The drying operation induced reductions of 17-25% in fat. The decreased lipid content may be due to enzymatic hydrolysis (Miranda et al., 2009) and lipid oxidation (Leite et al., 2007). In addition, crude protein level of microwave dried at a microwave power of 540 W slightly lower than the fresh sample, it could be due to the Maillard reaction. Similar results found by Leite et al. (2007), they reported that air drying promoted a reduction in lipids and proteins of banana, notably at higher temperature. However, opposite observation was reported by Walde et al. (2002) and Velu et al. (2003), they found that microwave drying did not alter the protein content of dried wheat and maize, but some structural and functional characteristics of protein were changed.

The drying methods showed no significant effects ($p>0.05$) on the moisture, crude protein, crude fat, crude fiber, ash and available carbohydrate of the dried red curry paste. Similar results were obtained by Hsu et al. (2003) and Faustino et al. (2007) from freeze, hot-air and drum drying of yam flour and hot-air drying of green bell peppers. The largest component in red curry product was the fiber, followed by available carbohydrate, ash, protein and fat, respectively. The carbohydrate was mainly contributed by sugar in the red curry paste. Major component in ash was

salts (sodium chloride) and the minor component was found potassium and magnesium in red chilli (Wangcharoen and Morasuk, 2009), phosphorus, calcium, iron, selenium and germanium in garlic (Khanum et al., 2004). In the proximate analysis, the carbohydrate content (dry matter) of red curry product was obtained by subtraction, i.e. 100 - (crude protein + crude fat + crude fiber + ash). Therefore, the decreased lipid and protein caused increased available carbohydrate in dried products.

4.3.3 Antioxidant Properties

4.3.3.1 Total Phenolic Content (TPC)

In addition to color and chemical composition, a health benefit is an important attribute which enhances the quality of dried Thai red curry paste. The ingredients of Thai red curry product are a mixture of herbs and spices, which are good sources of phenolic compounds. Therefore, it is important to consider the effect of the drying methods on the TPC of fresh and dried red curry paste extracts. Folin-Ciocalteu reagent is used to obtain a crude estimate of the amount of phenolic compound present in an extract. The principle of this assay is the reduction of the Folin-Ciocalteu reagent in the presence of phenolates, resulting in the production of molybdenum-tungsten blue, which absorbs at 730 nm. Generally, the outer layers of a plant such as the peel, shell and hull, contain large amount of phenolic compounds to protect the inner material. A number of phenolic acids are linked to various cell wall components, such as arabinoxylans and proteins (Lee et al., 2006). Choi et al. (2006) and Jeong et al. (2004) reported that heat treatment might disrupt the cell wall and liberate phenolic compounds from the insoluble portion of the plant.

The effects of drying method on TPC are shown in Figure 4.13. Drying method had a significant effect on TPC ($p<0.05$). The fresh sample contained 7.043 mg gallic acid equivalents/g dry matter. After drying were found 6.963-8.333 mg gallic acid equivalents/g dry matter. When the paste dried by hot-air oven did not significant different from fresh one, it had a significant when the paste dried by microwave oven at microwave powers of 180, 360 and 540 W, resulting TPC increased by 4.74, 11.00 and 18.316%, respectively.

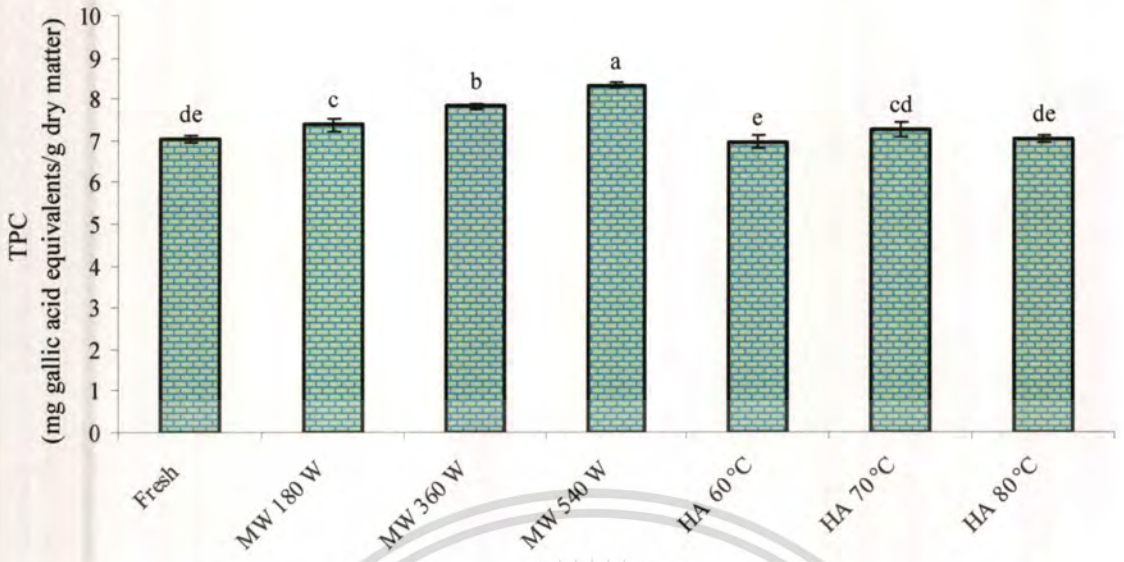

Figure 4.13 Total phenolic contents (TPC) of fresh and dried Thai red curry paste from microwave drying (MW) and hot-air drying (HA).
Bars (mean ± S.D., n=3) having different letters are significantly different (p<0.05).

The TPC in almost microwave-dried products was significantly (p<0.05) higher than hot-air-dried products. Microwave heating is based on the transformation of alternating electromagnetic field energy into thermal energy by affecting the polar molecules of a material. The materials can be absorb microwave energy directly and internally and convert it into heat. Kratchanova et al. (2004) found that microwave heating led to destruction of parenchyma cells of orange peels, while Garau et al. (2007) found that hot-air drying of orange peel around 50-60ºC apparently promoted the minor disruption of cell wall polymers. Therdthai and Zhou (2009) also reported that microstructure of microwave vacuum dried mint leaves was more porous and open than that of hot-air-dried ones. The intense heat generated from the microwaves creates a high vapor pressure and temperature inside plant tissue, resulting in the disruption of plant cell wall polymers. Consequently, cell wall phenolics or bond phenolics to be extracted. In contrast to the results obtained in this investigation, Lim and Murtijaya (2007) reported that microwave drying caused a greater decrease in the TPC of *Phyllanthus amarus* than hot-air drying. Thus, the effect of drying methods on phenolic compounds from different materials may not be the same.

Among microwave-dried samples, an increase in microwave power significantly (p<0.05) increased the TPC, which indicated that the disruption to plant tissue increased with a rise in the intensity of the microwave field, causing more phenolic compounds to be liberated and released.

Hot-air-dried samples showed no statistical difference (p>0.05) with respect to drying temperatures. This might be attributed to a minor disruption of cell wall polymers during hot-air drying.

4.3.3.2 Antioxidant Activities; DPPH-Radical Scavenging Activity (DPPH-RSA) and Ferric Reducing Antioxidative Power (FRAP)

Several analytical methods have been developed to determine the antioxidant capacity of natural substances *in vitro*. However, the antioxidant activity of plant extracts can't be evaluated by using only one method, due to the complex composition of phytochemical and oxidative processes. Therefore, at least two methods should be employed in order to evaluate the total antioxidant activity. In this study, DPPH-RSA and FRAP methods were used to evaluate the antioxidant activity. Both methods, which have been established and widely used to measure the antioxidant activity of fruit and vegetable juices or extracts, are simple assays that give fast, reproducible results (Kaur and Kapoor, 2001). The DPPH-RSA assay is based on the reduction of DPPH radicals in ethanol, which causes an absorbance drop at 517 nm. In this study, the radical scavenging activity was expressed as trolox equivalents per g dry matter as it is a more meaningful and descriptive expression than expressing antioxidant activity as the percentage decrease in absorbance (Wong et al., 2006). As such, the results provide a direct comparison of the antioxidant activity with trolox. The FRAP assay determines the ability of the extracts to reduce ferric ions. An antioxidant capable of donating a singlet electron to the ferric-TPTZ (Fe(III)-TPTZ) complex causes the reduction of this complex into the blue ferrous-TPTZ (Fe(II)-TPTZ) complex which absorbs strongly at 593 nm.

The antioxidant activities of fresh and dried red curry paste determined using the DPPH-RSA and FRAP assays are shown in Figure 4.14. Drying method had a significantly affected on radical scavenging and ferric reducing activities (p<0.05). DPPH-RSA and FRAP values of fresh sample was 1.364 and 4.607 mg trolox equivalents/g dry matter. After drying they were found 1.476-2.003 and 4.916-6.108 mg trolox equivalents/g dry matter. All dried samples had significantly increased both radical scavenging and ferric reducing activities comparing with fresh sample. Microwave drying resulted in higher DPPH-RSA than hot-air drying. The reduction of DPPH radical potential depends on microwave power and drying air temperature. The DPPH-RSA values increased as the microwave power and drying air temperature increased. Almost all of the microwave-dried samples possessed stronger ferric ion-reducing activity than hot-air-dried samples. The FRAP values of microwave-dried samples depended on the microwave power, while the drying air temperature did not have a significant effect on the FRAP values among hot-air-dried samples.

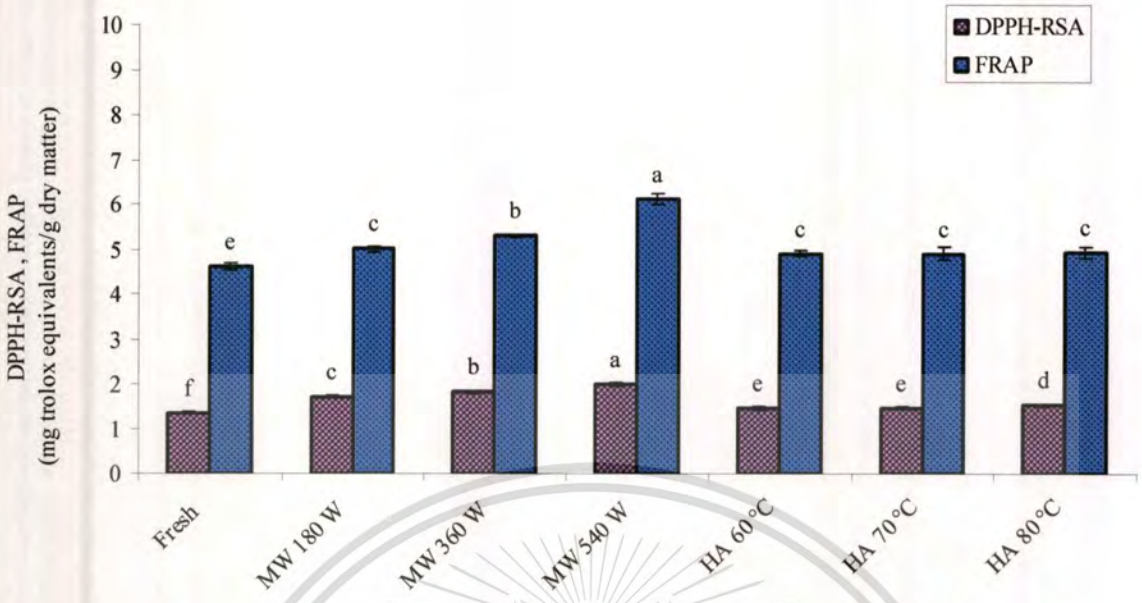

Figure 4.14 DPPH-radical scavenging activity (DPPH-RSA) and Ferric reducing antioxidative power (FRAP) of fresh and dried Thai red curry paste from microwave drying (MW) and hot-air drying (HA).

Bars (mean ± S.D., n=3) having different letters are significantly different (p<0.05).

4.3.2.3 Correlations between Total Phenolic Content, Browning Index and Antioxidant Activities

The correlations between results of TPC and antioxidant activity analysis were highly significant (p<0.01) as presented in Table 4.5. These correlations indicated that the level of TPC contribute to the antioxidant activity of Thai red curry product. Phenolic compounds have been reported to be responsible for the antioxidant activities of botanical extracts (Karakaya, 2004). Maisuthisakul et al. (2007) also found a high positive relationship between total phenolic and flavonoid contents in Thai indigenous plant extracts and antiradical activity. Velioglu et al. (1998) indicated that the relationship between TPC and the antioxidant activity of plant materials, such as flaxseed products and cereal products, was positive but the relationship between phenolic and antioxidant activity for anthocyanin-rich materials and for medical plants was not significant.

Table 4.5 Bivariate correlation coefficients for relationship between total phenolic content and antioxidant activities.

Results	Correlation coefficients	Sign (2-tailed)
TPC	1.000	-
DPPH-RSA	0.905	<0.01
FRAP	0.923	<0.01

Another reason for the improved antioxidant activity of dried red curry paste could be the formation of novel compounds having antioxidant activity during drying (Nicoli et al., 1999). In this study, non-enzymatic browning reaction products might have been formed. Table 4.6 shows the high correlation between the antioxidant activity and the brown pigment formation. The results indicated that drying of Thai red curry paste probable favor the non-enzymatic browning reaction and increase the concentration of phenolic compounds, explaining the increased antioxidant activity of the dried product. Similar results were found by Moreno et al. (2007) for off-vine grape drying process.

Table 4.6 Bivariate correlation coefficients for relationship between browning index (BI) and antioxidant activities.

Results	Correlation coefficients	Sign (2-tailed)
BI	1.000	-
DPPH-RSA	0.991	<0.01
FRAP	0.917	<0.01

Ambiguous connections between the content of particular antioxidants and antioxidant activity are difficult to explain based on only quantitative analysis. Zheng and Wang (2001) suggested that not only the level of antioxidants, but also a synergy occurring between them and the other plant constituents, might influence the difference in the antioxidant ability of plant extracts.

The FRAP values were consistently higher than those obtained for the DPPH-RSA. A similar result was reported by Wong et al. (2006), who found that the DPPH-RSA of 25 edible tropical plants, expressed as trolox equivalents, were lower than their corresponding ferric reducing activities. They suggested that the lower DPPH-RSA values of plant extracts could be due to the presence of antioxidant compounds not reactive towards DPPH. Antioxidant compounds such as

polyphenols, may be more efficient as reducing agents for ferric ions but some may not scavenge DPPH radicals as efficiently due to steric hindrance.

4.3.4 Sensory Evaluation

The color and aroma of food is very important for its acceptability and a slight change in the color and aroma of processed food may affect the overall quality of the product. Therefore, paired comparison-dependent and selected pair test was used to determine effect of drying method on color and aroma including preference. Microwave and hot-air-dried red curry paste were rehydrated with distilled water to moisture content as fresh sample. Color and aroma intensities of the dry-rehydrated samples were compared with the fresh sample are presented in Table 4.7 and 4.8. It can be found that microwave and hot-air drying had a significant effect ($p<0.05$) on the color and aroma intensities of dry-rehydrated red curry paste, the drying caused a significant decrease in color and aroma of the product. In the case of color intensity test, the results was corresponded the color measurements which fond that the rehydrated paste was lighter in color and more yellow color than the fresh paste. So, almost panelists perceived as more color intensity in fresh red curry paste than the rehydrated samples. For aroma intensity, the aroma of Thai red curry paste is related to volatile compounds consists in lemongrass, kaffir lime and galangal. The major chemical composition of these volatile compounds is composed of monoterpene and sesquiterpene. Lorjaroenphon (2004) found that the major volatile compound of fresh lemongrass, kaffir lime and galangal were citral (geranial and neral), citronellal and 1,8-cineole, respectively. She also reported that the aroma of Tom Yum soup prepared from oven dried lemom grass, kaffir lime and galangal, the drying process reduced citral, citronellal and 1,8-cineole, caused the reduction in green, lemon-like, cool, camphoraceous and fresh odor. However, the drying increased the concentration of trans-β-caryophyllene, (-)-caryophyllene oxide and δ-cadinene that caused dry, woody and smoky odor note. Therefore, in this study the drying process might be reduced the major volatile compound of Thai red curry paste while some new chemicals might be formed.

Table 4.7 Results of paired comparisons-dependent and selected pairs test for color intensity of fresh and dry-rehydrated Thai red curry paste from microwave drying (MW) and hot-air drying (HA).

Sample pair	More intense in fresh red curry paste	More intense in dry-rehydrated red curry paste	Outcome/significant
Fresh-MW 180 W	19	7	Perceived as more color intensity in fresh red curry paste than dry-rehydrated sample ($p<0.05$)
Fresh-MW 360 W	18	8	Perceived as more color intensity in fresh red curry paste than dry-rehydrated sample ($p<0.05$)
Fresh-MW 540 W	19	7	Perceived as more color intensity in fresh red curry paste than dry-rehydrated sample ($p<0.05$)
Fresh-HA 60°C	19	7	Perceived as more color intensity in fresh red curry paste than dry-rehydrated sample ($p<0.05$)
Fresh-HA 70°C	18	8	Perceived as more color intensity in fresh red curry paste than dry-rehydrated sample ($p<0.05$)
Fresh-HA 80°C	18	8	Perceived as more color intensity in fresh red curry paste than dry-rehydrated sample ($p<0.05$)

Test statistic = one-sided paired comparison test for difference. For N=26 at $\alpha=0.05$, the critical value = 18.

Table 4.8 Results of paired comparisons-dependent and selected pairs test for aroma intensity of fresh and dry-rehydrated Thai red curry paste from microwave drying (MW) and hot-air drying (HA).

Sample pair	More intense in fresh red curry paste	More intense in dry-rehydrated red curry paste	Outcome/significant
Fresh-MW 180 W	20	6	Perceived as stronger aroma intensity in fresh red curry paste than dry-rehydrated sample ($p<0.05$)
Fresh-MW 360 W	21	5	Perceived as stronger aroma intensity in fresh red curry paste than dry-rehydrated sample ($p<0.05$)
Fresh-MW 540 W	21	5	Perceived as stronger aroma intensity in fresh red curry paste than dry-rehydrated sample ($p<0.05$)
Fresh-HA 60°C	21	5	Perceived as stronger aroma intensity in fresh red curry paste than dry-rehydrated sample ($p<0.05$)
Fresh-HA 70°C	23	3	Perceived as stronger aroma intensity in fresh red curry paste than dry-rehydrated sample ($p<0.05$)
Fresh-HA 80°C	22	4	Perceived as stronger aroma intensity in fresh red curry paste than dry-rehydrated sample ($p<0.05$)

Test statistic = one-sided paired comparison test for difference. For N=26 at $\alpha=0.05$, the critical value = 18.

Normally, Thai red curry paste has been used as ingredient in many kind of Thai dishes. Therefore, the effect of drying methods on color and aroma of red curry paste after cooking could be determined. Fresh and dry-rehydrated red curry pastes were stirred with ground pork before sensory test. The difference of color and aroma intensities including preference test of the dish prepared from the rehydrated paste was compared with the dish prepared from the fresh paste are presented in Table 4.9, 4.10 and 4.11, respectively. Microwave and hot-air drying had a significant effect ($p<0.05$) on all the evaluated sensory attributes. The color and aroma of the dish prepared from the fresh sample more significantly intensity than the rehydrated samples; it indicated that the drying methods caused decrease of color and aroma intensities of dried red curry paste which contributed to the sensory attributes of food after cooking. For preference test, the results contrast with color and aroma attribute, the dishes prepared from the rehydrated samples was more preferred than the fresh one.

Table 4.9 Results of paired comparisons-dependent and selected pairs test for color intensity of stirred ground pork with fresh and dry-rehydrated Thai red curry paste from microwave drying (MW) and hot-air drying (HA).

Sample pairs	More intense in fresh red curry paste	More intense in dry-rehydrated red curry paste	Outcome/significant
Fresh-MW 180 W	21	5	Perceived as more color intensity in fresh red curry paste than dry-rehydrated sample ($p<0.05$)
Fresh-MW 360 W	18	8	Perceived as more color intensity in fresh red curry paste than dry-rehydrated sample ($p<0.05$)
Fresh-MW 540 W	21	5	Perceived as more color intensity in fresh red curry paste than dry-rehydrated sample ($p<0.05$)
Fresh-HA 60°C	20	6	Perceived as more color intensity in fresh red curry paste than dry-rehydrated sample ($p<0.05$)
Fresh-HA 70°C	18	8	Perceived as more color intensity in fresh red curry paste than dry-rehydrated sample ($p<0.05$)
Fresh-HA 80°C	18	8	Perceived as more color intensity in fresh red curry paste than dry-rehydrated sample ($p<0.05$)

Test statistic = one-sided paired comparison test for difference. For N=26 at $\alpha=0.05$, the critical value = 18.

Table 4.10 Results of paired comparisons-dependent and selected pairs test for aroma intensity of stirred ground pork with fresh and dry-rehydrated Thai red curry paste from microwave drying (MW) and hot-air drying (HA).

Sample pair	More intense in fresh red curry paste	More intense in dry-rehydrated red curry paste	Outcome/significant
Fresh-MW 180 W	19	7	Perceived as stronger aroma intensity in fresh red curry paste than dry-rehydrated sample (p<0.05)
Fresh-MW 360 W	21	5	Perceived as stronger aroma intensity in fresh red curry paste than dry-rehydrated sample (p<0.05)
Fresh-MW 540 W	20	6	Perceived as stronger aroma intensity in fresh red curry paste than dry-rehydrated sample (p<0.05)
Fresh-HA 60°C	19	7	Perceived as stronger aroma intensity in fresh red curry paste than dry-rehydrated sample (p<0.05)
Fresh-HA 70°C	18	8	Perceived as stronger aroma intensity in fresh red curry paste than dry-rehydrated sample (p<0.05)
Fresh-HA 80°C	19	7	Perceived as stronger aroma intensity in fresh red curry paste than dry-rehydrated sample (p<0.05)

Test statistic = one-sided paired comparison test for difference. For N=26 at α=0.05, the critical value = 18.

Table 4.11 Results of paired comparisons-dependent and selected pairs test for preference of stirred ground pork with fresh and dry-rehydrated Thai red curry paste from microwave drying (MW) and hot-air drying (HA).

Sample pair	More prefer in fresh red curry paste	More intense in dry-rehydrated red curry paste	Outcome/significant
Fresh-MW 180 W	7	19	Perceived as more prefer in dried red curry than fresh one (p<0.05)
Fresh-MW 360 W	4	22	Perceived as more prefer in dried red curry than fresh one (p<0.05)
Fresh-MW 540 W	8	18	Perceived as more prefer in dried red curry than fresh one (p<0.05)
Fresh-HA 60°C	5	21	Perceived as more prefer in dried red curry than fresh one (p<0.05)
Fresh-HA 70°C	4	22	Perceived as more prefer in dried red curry than fresh one (p<0.05)
Fresh-HA 80°C	6	20	Perceived as more prefer in dried red curry than fresh one (p<0.05)

Test statistic = one-sided paired comparison test for difference. For N=26 at α=0.05, the critical value = 18.

The effect of drying methods on the sensory attributes was evaluated using Cochran's Q test as presented in Table 4.12. According to Cochran's Q test, it can be found that the drying methods did not significant on color and aroma intensities of dry-rehydrated red curry paste both before and after cooking including preference test.

Table 4.12 Results of Cochran's Q test for the color, aroma intensities and preference attributes.

Attribute	Calculated Q	Outcome/significant
Before cooking		
Color	0.338	No significant differences among dry-rehydrated samples
Aroma	2.500	No significant differences among dry-rehydrated samples
After cooking		
Color	2.429	No significant differences among dry-rehydrated samples
Aroma	1.290	No significant differences among dry-rehydrated samples
Preference	3.226	No significant differences among dry-rehydrated samples

Test statistic = Q statistics follow asymptotic χ^2 distributions with df at 5.
The 2-tailed tabled χ^2 at df_5 was 9.24.

CHAPTER 5

CONCLUSIONS

5.1 Conclusions

5.1.1 Microwave and Hot-Air Drying of Thai Red Curry Paste

The effects of microwave and hot-air drying methods on drying behavior of Thai red curry paste were examined in this study. It was found that the time required for microwave drying to reduce the moisture content from 2.58 to 0.08 g water/g dry matter was 23, 12 and 8 min at microwave powers of 180, 360 and 540 W respectively. This was much shorter than that for hot-air drying, which was 240, 180 and 130 min at drying air temperatures of 60, 70 and 80°C respectively. An increase in microwave power and drying air temperature shortened the drying time for both processes. The drying behavior showed that microwave drying of red curry paste showed three drying periods, i.e. heating up, constant rate and falling rate periods, while in the hot air drying only heating up and falling rate period were observed. The Midilli et al. model provided an excellent prediction for both microwave and hot-air drying processes followed by the Page and the Modified Page models. Drying parameters k_m, n_m, a and b in the Midilli et al. equation were estimated. The parameters k_m and a increased with an increase the microwave power while the parameters n_m and b decreased. The k_m, n_m, a and b values for microwave drying were 0.0169, 0.0512 and 0.980 min^{-1}, 1.6937, 1.6009 and 1.5375, 0.9765, 0.9866 and 0.9929 and -0.0014, -0.0051 and -0.0102 at microwave powers of 180, 360, and 540 W, respectively. However, there were no differences between these parameter values of hot-air drying at various drying air temperatures. The k_m, n_m, a and b values for the hot air drying were 0.0022, 0.0031 and 0.0033 min^{-1}, 1.4515, 1.4450 and 1.4763, 0.9911, 0.9938 and 0.9957 and 0.0001, 0.0002 and 0.0001 at drying air temperatures of 60, 70 and 80°C, respectively.

5.1.2 Moisture Sorption of Dried Thai Red Curry Paste

Due to hygroscopicity characteristics of this kind of product, it is essential to know its water activity in different ambient conditions. This study presented the data on moisture adsorption of dry-powdered Thai red curry paste prepared by microwave and hot-air drying methods over a range of water activities 0.113-0.970. It was found that all the dry-powdered red curry paste exhibited type III sorption isotherms. The GAB model was found to be the most

suitable for fitting the moisture sorption data followed the Lewicki-3 model. The X_m value for microwave drying was 0.0802, 0.0834 and 0.0846 g water/g dry matter at microwave powers of 180, 360, and 540 W, respectively. The X_m value for the hot air drying was 0.0836, 0.0832 and 0.0829 g water/g dry matter at drying air temperatures of 60, 70 and 80°C, respectively. The moisture sorption data give useful guidance for processing, handling for package, transportation and storage of the product.

5.1.3 The Effects of Microwave and Hot-Air Drying on Qualities of Dried Thai Red Curry Paste

The drying process significantly produced a profound impact on color properties, approximate compositions, antioxidant properties and sensory evaluation of the dried-product. The results indicated that the formation brown pigment occurred during both microwave and hot-air drying. The color of dry-rehydrated red curry paste was lighter and more yellow color than the fresh one. The drying processes increased in the contents of available carbohydrate and phenolic compounds while decreased in the content of crude fat. Moreover, this study also showed that the drying processes enhance the antioxidant activity of Thai red curry paste. For sensory evaluation, the drying process caused a significant decrease in both color and odor intensities but a significant increase the preference.

Microwave drying caused the formation of brown pigment more than that of hot-air drying. Moreover, as the microwave power and drying air temperature increased, the formation increased. Microwave drying resulted in darker and less yellow color of dry-powdered red curry paste than hot-air drying. However, after rehydration, the rehydrated sample of microwave drying became lighter, and more red and less yellow color than hot-air drying, while the same a red color. There were no differences between the color values of microwave dry- powdered samples at various microwave powers. However, there were found the difference among red color value of hot-air dry-powdered, hot-air-dried samples at an air temperature of 60°C had higher red color value than at air temperatures of 70 and 80°C. In the rehydrated sample, the microwave-dried at microwave powers of 360 W and 540 W had higher yellow color value than at a microwave power of 180 W, while hot-air-dried at air temperatures of 70 and 80°C had higher lightness and yellow color values than at an air temperature of 60°C. In terms of ratio of color change ($\Delta L/L_0$, $\Delta a/a_0$ and $\Delta b/b_0$) and total color change (ΔE) of dried red curry paste after rehydration the results showed that the $\Delta L/L_0$, $\Delta b/b_0$ and ΔE values of microwave-dried sample was higher than

the hot-air-dried. The higher microwave power and drying air temperature, the more color changed of in terms of $\Delta L/L_0$, $\Delta b/b_0$ and ΔE.

The effect of both drying methods on chemical composition and sensory evaluation was not significant. However, the antioxidant properties were affected by the drying method. The TPC, DPPH-RSA and FRAP values for almost all microwave-dried samples were higher than for hot-air-dried samples. These values increased with an increase in microwave power. However, there was no difference between the TPC and FRAP values from hot-air drying at various drying air temperature. The level of TPC and BI contributed to DPPH-RSA and FRAP of red curry products.

5.2 Suggestions

5.2.1 The results from this study showed an opportunity to dry Thai red curry paste. However, this research is limited in its scope as it was studied the effects of the drying methods only on final qualities of the end product and conducted only under microwave and hot-air drying. Therefore, further study is necessary to study the qualities change during processing and storage, compare with other drying methods (vacuum- drying, freeze-drying and combination drying) and investigate the suitable drying method and optimal drying conditions.

5.2.2 Microwave drying technique strongly affected the color properties of dried Thai red curry paste due to produced brown compounds. Therefore, to save energy and improve the color property, microwave energy should be combined with hot-air drying. It has been suggested that microwave energy should be applied in the falling rate period or at low moisture content to finish drying (Maskan, 2000) because at low moisture content, removal of moisture using hot-air is slow but due to volumetric heating it is rapid with microwave. Applying microwave drying in the last stage of hot-air drying process can also be very efficient in removing bound water from the product. Maskan (2000) also reported that combined microwave hot-air could greatly reduce the drying time of biological materials without damaging the quality attributes of the finished products. In the study case, drying of red curry paste, microwave energy should be applied at moisture content of 1.50-1.63 g water/ g dry matter.

5.2.3 Drying of Thai red curry paste with high solutes (salts and sugars) content presents technical difficulties because of their thermoplasticity at high temperature and humidity, and caking or stickiness may occur at relative humidities below 80%. Moreover, the moisture sorption isotherms result indicates that dried red curry paste is characterized by high hygroscopicity, as a result of high amorphous state solutes content, which promotes undesired effects such as caking during storage. To avoid all these problems, Herbs and spices ingredients have been dried and ground to small particle size and the solutes in crystalline state should be mixed with later.

However, in the dry ingredient mixing, moisture is exchanged because of the chemical potential difference between ingredients until a final equilibrium water activity is reached. Thus, to predict the final equilibrium water activity, the moisture sorption isotherm of each component is required, preferably at the temperature of product storage. These equations can be used to design the food so that the amount of each ingredient is such that no ingredient crosses the critical water activity that leads to an unacceptable product. If this cannot be accomplished, then ingredient modification is the next possible solution.

REFERENCES

Abalone, R., Gastón, A., Cassinera, A. and Lara, M.A. 2006. Thin layer drying of amaranth seeds. **Biosyst Eng.** 93(2): 179-188.

Ahmed, J., Shivhare, U.S. and Ramaswamy, H.S. 2002. A fraction conversion kinetic model for thermal degradation of color in red chilli puree and paste. **LWT-Food Sci Technol.** 35: 497-503.

Alibas, I. 2007. Energy consumption and colour characteristics of nettle leaves during microwave, vacuum and convective drying. **Biosyst Eng.** 96(4): 495-502.

Al-Muhtaseb, A.H., McMinn, W.A.M. and Magee, T.R.A. 2002. Moisture sorption isotherm characteristics of food products: A Review. **Trans IChemE.** 80: 118-128.

Ankri, S. and Mirelman, D. 1999. Antimicrobial properties of allicin from garlic. **Microbes and Infect.** 2: 125-129.

Antonella R., Monica D., Viviana C., Stefania P., Giovanni A., Mauro B. and Dessi, M.A. 2002. Antioxidant activity of capsinoids. **J. Agric. Food Chem.** 50: 7396-7401.

AOAC. 1990. Official methods of analysis. Washington, DC: Association of Official Analytical Chemists.

Arslan, D. and Özcan, M.M. 2008. Evaluation of drying methods with respect to drying kinetics mineral content and colour characteristics of rosemary leaves. **Energ Convers Manage.** 49: 1258-1264.

Arslan, N. and Toğrul, H. 2005. Moisture sorption isotherms of crushed chillies. **Biosyst Eng.** 90: 47-61.

Azzouz, S., Guizani,A., Jomaa, W. and A. Belghith, A. 2002. Moisture diffusivity and drying kinetic equation of convective drying of grapes. **J. Food Eng.** 55(4): 323-330.

Bakri, I.M. and Douglas, C.W.I. 2005. Inhibitory effect of garlic extract on oral bacteria. **Arch Oral Biol.** 50: 645-651.

Bao,H., Ren, H., Endo, H.,Takagi, Y. and Haysshi, T. 2004. Effects of heating and the addition of seasonings on the anti-mutagenic and anti-oxidative activities of polyphenols. **Food Chem.** 86: 517-524.

Bell, L.N. and Labuza, T.P. 2000. **Moisture sorption: practical aspects of isotherm measurement and use**. 2nd ed. St. Paul: American Association of Cereal Chemists, Inc. 122 p.

Burg, P. and Fraile, P. 1995. Vitamin C destruction during the cooking of a potato dish. **LWT-Food Sci Technol.** 28: 506-514.

Calligaris, S., Manzocco, L., Anese, M. and Nicoli, M.N. 2004. Effect of heat-treatment on the antioxidant and pro-oxidant activity of milk. **Int Dairy J.** 14: 421-427.

Celma, A.R., Rojas, S., López, F., Montero, I. and Miranda, T. 2007. Thin-layer drying behaviour of sludge of olive oil extraction. **J. Food Eng.** 80(4): 1261-1271.

Ceylan, İ., Mustafa Aktaş, M. and Doğan, H. 2007. Mathematical modeling of drying characteristics of tropical fruits. **Appl Therm Eng.** 27(11-12): 1931-1936.

Chen, S-L., Yang, D-J., Chen, H-Y. and Liu, S-C. 2009. Effect of hot acidic fructose solution on caramelisation intermediates including colour, hydroxymethyfurfural and antioxidative activity changes. **Food Chem.** 114: 582-588.

Choi, Y., Lee, S.M., Chun, J., Lee, H.B. and Lee, J. 2006. Influence of heat treatment on the antioxidant activities and polyphenolic compounds of shitake (*Lentinus edodes*) mushroom. **Food Chem.** 99: 381-387.

Debnath, S., Hemavathy, J. and Bhat, K.K. 2002. Moisture sorption studies on onion powder. **Food Chem.** 78: 479-482.

Deepa, N., Kaur, C., George, B., Singh, B. and Kapoor, H.C. 2007. Antioxidant constituents in some sweet pepper (*Capsicum annuum* L.) genotypes during maturity. **LWT-Food Sci Technol.** 40: 121-129.

Demir, V., Gunhan, T., Yagcioglu, A.K. and Degirmencioglu, A. 2004. Mathematical modelling and the determination of some quality parameters of air-dried bay leaves. **Biosyst Eng.** 88(3): 325-335.

Doymaz, İ. and Pala, M. 2002. Hot-air drying characteristics of red pepper. **J. Food Eng.** 55(4): 331-335.

Doymaz, İ. 2005. Drying characteristics and kinetics of okra. **J. Food Eng.** 69(3): 275-279.

Doymaz, İ. 2008. Convective drying kinetics of strawberry. **Chem Eng Process.** 47(5): 914-919.

Drouzas, A.E. and Schubert, H. 1996. Microwave application in vacuum drying of fruits. **J. Food Eng.** 28(2): 203-209.

Drouzas, A.E., Tsami, E. and Saravacos, G.D. 1999. Microwave/vacuum drying of model fruit gels. **J. Food Eng.** 39: 117-122.

Ewald, C., Fjelkner-Modig, S., Johansson, K., Sjoholm, I. and Akesson, B. 1999. Effect of processing on major flavonoids in processed onions green beans and peas. **Food Chem.** 64: 231-235.

Fattorusso, E., Iorizzi, M., Lanzotti, V. and Taglialatel, O. 2002. Chemical composition of shallot (*Allium ascalonicum* Hort.). **J. Agric. Food Chem.** 50: 5686-5690.

Faustino, J.M.F., Barroca, M.J. and Guiné, R.P.F. 2007. Study of the drying kinetics of green bell pepper and chemical characterization. **Food Bioprod Process.** 85(3): 163-170.

Funebo, T. and Ohlsson, T. 1998. Microwave assisted air dehydrated air dehydration of apple and mushroom. **J. Food Eng.** 38(3): 353-367.

Fenebo, T, Ahrne, L., Prothon, F, Kidman, S., Langton, M. and Skjoldeb-rand, C. 2002. Microwave and convection dehydration of ethanol treated and frozen apple-physical properties and drying kinetics. **Int. J. Food Sci. Tech.** 37(6): 603-614.

Gabas, A.L., Telis, V.R.N., Sobral, P.J.A. and Telis-Romero, J. 2007. Effect of maltodextrin and arabic gum in water vapor sorption thermodynamic properties of vacuum dried pineapple pulp powder. **J. Food Eng.** 82: 246-252.

Garau, M.C., Simal, S., Rosslló, C. and Femenia, A. 2007. Effect of air-drying temperature on physico-chemical properties of dietary fibre and antioxidant capacity of orange (*Citrus anrantium* v. Canoneta) by-products. **Food Chem.** 104: 1014-1024.

Gayathri, G.N., Platel, K., Prakash, J. and Srinivasan, K. 2004. Influence of antioxidant spices on the retention of β-carotene in vegetables during domestic cooking processes. **Food Chem.** 84: 35-43.

Giri, S.K. and Prasad, S. 2009. Quality and moisture sorption characteristics of microwave vacuum, air and freeze-dried button mushroom (*Agaricus bisporus*). **J. Food Process Pres.** 33: 237-251.

Goodwin, D.C. and Hertwig, K.M. 2003. Peroxidase-catalyzed oxidation of capsaicinoids: steady-state and transient-state kinetic studies. **Arc Biochem Biophys.** 417: 18-26.

Hacihafizoğlu, O., Cihan, A. and Kahveci, K. 2008. Mathematical modelling of drying of thin layer rough rice. **Food Bioprod Process.** In Press, Corrected Proof, Available online 20 February.

Hsu, C-L., Chen, W., Weng, Y-M. and Tseng, C-Y. 2003. Chemical composition, physical properties and antioxidant activities of yam flours as affected by different drying methods. **Food Chem.** 83: 85-92.

Hunter, K.J. and Fletcher, J.M. 2002. The antioxidant activity and composition of fresh, frozen, jarred and canned vegetables. **Innov Food Sci Emerg.** 2: 399-406.

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

Juntachote, T., Berghofer, E., Siebenhandl, S. and Bauer, F. 2007. The effect of dried galangal powder and its ethanolic extract on oxidative stability in cooked ground pork. **LWT-Food Sci Technol.** 40(2): 324-330.

Juntachote, T. and Berghofer, E. 2005. Antioxidative properties and stability of ethanolic extracts of holy basil and galangal. **Food Chem.** 92: 193-202.

Juntachote, T., Berghofer, E., Bauer, F. and Siebenhandl, S. 2006a. The application of response surface methodology to the production of phenolic extracts of lemon grass, galangal, holy basil and rosemary. **Int J. Food Sci Technol.** 41: 121-133.

Juntachote, T., Berghofer, E., Siebenhandl, S. and Bauer. F. 2006b. The antioxidative properties of holy basil and galangal in cooked ground pork. **Meat Sci.** 72: 446-456.

Kaleemullah, S. and Kailappan, R. 2007. Monolayer moisture, free energy change and fraction of bound water of red chillies. **J. Stor Prod Res.** 43: 104-110.

Karakaya, S. 2004. Bioavailability of phenolic compounds. **Cri Rev Food Sci Nut.** 44: 453-464.

Karatas, F. and Kamisli, F. 2007. Variations of vitamins (A, C and E) and MAD in apricots dried in IR and microwave. **J. Food Eng.** 78(2): 662-668.

Kaur, C. and Kapoor, H.C. 2001. Antioxidant in fruits and vegetables-the millennium's health. **Int J. Food Sci Technol.** 36: 703-725.

Kaymak-Ertekin, F. and Gedik, A. 2004. Sorption isotherms and isosteric heat of sorption for grapes, apricots, apples and potatoes. **LWT-Food Sci Technol.** 37: 429-438.

Khanum, F., Anilakumar, K.R. and Viswanathan, K.R. 2004. Anticarcinogenic properties of garlic: a review. **Food Sci Nut.** 44(6): 479-488.

Khraisheh, M.A.M., Cooper, T.J.R. and Magee, T.R.A. 1997. Microwave and air drying: fundamental considerations and assumptions for the simplified thermal calculations of volumetric power absorption. **J. Food Eng.** 33(2): 207-219.

Khraisheh, M.A.M., McMinn, W.A.M. and Magee, T.R.A. 2004. Quality and structure changes in starchy foods during microwave and convective drying. **Food Res Int.** 37(5): 497-503.

Kim, S.Y., Jeong, S.M., Park, W.P., Nam, K.C., Ahn, D.U. and Lee, S.C. 2006. Effect of heating conditions of grape seeds on the antioxidant activity of grape seed extracts. **Food Chem.** 97: 472-479.

Kratchanova, M., Pavlova, E. and Panchev, I. 2004. The effect of microwave heating of fresh Orange peels on the fruit tissue and quality of extracted pectin. **Carb Polym.** 56: 181-185.

Ladrón de Guevara, R.G., Bernabeu, R., Picazo, M.I., González, M. and Varón, R. 2005. The effect of a natural antioxidant on the stability of heat-treated paprika. **Int J. Food Sci Technol.** 40: 1005-1010.

Larrauri, J.A., Rupérez, P. and Saura-Calixto, F. 1997. Effect of drying temperature on the stability of polyphenols and antioxidant activity of red grape pomace peels. **J. Agric. Food Chem.** 45: 1390-1393.

Lawrence B.M., Hogg J.W., Terhune S.J. and Podimuang V. 1971. Constituents of the Leaf and Peel Oil of *Citrus hystrix*, D.C. **Phytochem.** 10(6): 1401-1405.

Lee, J.H. and Lee, M.J. 2008. Effect of drying method on the moisture sorption isotherms for *Inonotus obliquus* mushroom. **LWT-Food Sci Technol.** 41: 1478-1484.

Lee, S.C., Jeong, S.M., Kim, S.Y., Park, H. R., Nam, K.C. and Ahn, D.U. 2006. Effect of far-infrared radiation and heat treatment on the antioxidant activity of water extracts from peanut hulls. **Food Chem.** 94: 489-493.

Leelarungrayub, N., Rattanapanone, V., Chanarat, N. and Gebicki, J. M. 2006. Quantitative evaluation of the antioxidant properties of garlic and shallot preparation. **Nutr.** 22: 266-274.

Leite, J.B., Mancini, M.C. and Borges, S.V. 2007. Effect of drying temperature on the quality of dried banana cv. *prata* and *d' água*. **LWT-Food Sci Technol.** 40: 319-323.

Lertsatitthanakorn, P., Taweechaisupapong, S., Aromdee, C. and Khunkitti, W. 2006. In vitro bioactivities of essential oils used for acne control. **Int J. Aromather.** 16: 43-49.

Lewicki, P.P. 1997. The application of the GAB model to food water sorption isotherms. **Int J. Food Sci Technol.** 32: 553-557.

Lewicki, P.P. 1998. A three parameter equation for food moisture sorption isotherms. **J. Food Process Eng.** 21: 127-144.

Lim, Y.Y. and Murtijaya, J. 2007. Antioxidant properties of *Phyllanthus amarus* extracts as affected by different drying methods. **LWT-Food Sci Technol.** 40: 1664-1669.

Lopes Filho, J.F., Romanelli, P.F., Barboza, S.H.R., Gabas, A.L. and Telis-Romero, J. 2002. Sorption isotherms of alligator's meat (*Caiman crocodiles yacare*). **J. Food Eng.** 52: 201-206.

Lorjaroenphon, Y. 2004. **Effect of Processing on Aroma Compounds of Tom Yum Soup Bases.** Master of Science Thesis, Food Science Program, Department of Food Science and Technology, Faculty of Agro-Industry, Kasetsart University, 143 p.

Ly, T.N., Shimoyamada, M., Kato, K. and Yamauchi, R. 2003. Isolation and characterization of some antioxidative compounds from the rhizomes of smaller galanga (*Alpinia officinarum* Hance). **J. Agric. Food Chem.** 51: 4924-4929.

Maisuthisakul, P., Suttajit, M. and Pongsawatmanit, R. 2007. Assessment of phenolic content and free radical-scavenging activity of some Thai indigenous plants. **Food Chem.** 100(4): 1409-1418.

Manzocco, L., Calligaris, S., Mastrocola, D., Nicoli, M.C. and Lerici, C.R. 2001. Review of non-enzymatic browning and antioxidant capacity in processed foods. **Trends in Food Sci Tech.** 10: 94-100.

Margaris, D.P. and Ghiaus, A.G. 2007. Experimental of hot air dehydration of sultana grapes. **J. Food Eng.** 79(4): 1115-1121.

Marie-Elisabeth, C. and Claudette, B. 2005. Phenolic compounds and plant extracts protect paprika against UV-induced discoloration. **Int J. food Sci Technol.** 40(1): 67-73.

Martinelli, L., Gobas, A.L. and Telis-Romero, J. 2007. Thermodynamic and quality properties of lemon juice powder as affected by moltodextrin and arabic gum. **Dry Technol.** 25: 2035-2045.

Maskan, M. 2000. Microwave/air and microwave finish drying banana. **J. Food Eng.** 44(2): 71-78.

Maskan, M. 2001. Drying, shrinkage and rehydration characteristics of kiwi fruits during hot air and microwave drying. **J. Food Eng.** 48(2): 177-182.

Maskan, M. and Göğüş, F. 1997. The fitting of various models to water sorption isotherms of pistachio nut paste. **J. Food Eng.** 33: 227-237.

Materska, M. and Perucka, I. 2005. Antioxidant activity of the main phenolic compounds isolated from hot pepper fruit (*Capsicum annuum* L.). **J. Agric. Food Chem.** 53: 1750-1756.

Mathlouthi, M. 2001. Water content, water activity, water structure and the stability of foodstuffs. **Food Cont.** 12: 409-417.

Matsufuji, H., Nakamura, H., Chino, M. and Takeda, M.1998. Antioxidant activity of capsanthin and the fatty acid esters in paprika (*Capsicum annuum*). **J. Agric. Food Chem.** 46: 3468-3472.

Mayer-Miebach, E., Behsnilian, D., Regier, M. and Schuchmann, H.P. 2005. Thermal processing of carrots: lycopene stability and isomerisation with regard to antioxidant potential. **Food Res Int.** 38: 1103-1108.

Meilgaard, M., Civille, G.V. and Carr, B.T. 2007. **Sensory Evaluation Techniques.** 4th ed. FL: CRC Press. 448p

Menges, H.O. and Ertekin, C. 2006. Mathematical modeling of thin layer drying of golden apples. **J. Food Eng.** 77 (1): 119-125.

Miranda, M., Maureira, H., Rodrìguez, K. and Vega-Gálvez, A. 2009. Influence of temperature on the drying kinetics, physicochemical properties and antioxidant capacity of *Aloe Vera* (*Aloe Barbadensis* Miller) gel. **J. Food Eng.** 91: 297-304.

Moreno, J., Peinado, J. and Peinada, R.A. 2007. Antioxidant activity of musts from Pedro Ximénez grapes subjected to off-vine drying process. **Food Chem.** 104: 224-228.

Mujumdar, A.S. and Suvachittanont, S. 2000. **Developments in Drying Volume II: Drying of Foods and Agro-Product.** Bangkok: Kasetsart University Press. 244 p.

Mwithiga, G. and Olwal, J.O. 2005. The drying kinetics of kale (*Brassica oleracea*) in a convective hot-air dryer. **J. Food Eng.** 71: 373-378.

Nakamura, Y., Miyamoto, M., Murakami, A., Ohigashi, H., Osawa, T. and Uchida, K. 2003. A phase II detoxification enzyme inducer from lemongrass: identification of citral and involvement of electrophilic reaction in the enzyme inducer. **Biochem Biophys Res Comm.** 302: 593-600.

Nicoli, M.C., Anese, M. and Parpinel, M. 1999. Influence of processing on antioxidant properties of fruit and vegetables. **Trends Food Sci Technol.** 10: 94-100.

Nijhuis, H.H., Torringa, H.M., Muresan, S. Yuksel, D., Leguijt, C. and Kloek, W. 1998. Approaches to improving the quality of dried fruit and vegetables. **Trends Food Sci Technol.** 9: 13-20.

Nguefack, J., Leth, V., Amvam Zolllo, P.H. and Mathur, S.B. 2004. Evaluation of five essential oils from aromatic plants of cameroon for controlling food spoilage and mycotoxin producing fungi. **Int J. Food Microb.** 94: 329-334.

Oduro, I. and Clarke, B. 1999. The quality assessment of gari produced by using microwave energy. **Int J. Food Sci Technol.** 34(4): 365-370.

Oommen, S., John Anto, R., Srinivas, G. and Karunagaran, D. 2004. Allicin from garlic induces caspase-mediated apoptosis in cancer cells. **Eur J. Pharm.** 485(1-3, 6): 97-103

Oonmetta-aree, J., Susuki, T., Gasaluck, P. and Eumkeb, G. 2006. Antimicrobial properties and action of galangal (*Alpinia galanga* Linn.) on *Staphylococcus aureus*. **LWT-Food Sci Technol.** 39: 1214-1220.

Özber, B. and Dadali, G. 2007. Thin-layer drying characteristics and modelling of mint leaves undergoing microwave treatment. **J. Food Eng.** 83(4): 541-549.

Ozkan, I.A., Akbudak, B. and Akbudak, N. 2007. Microwave drying characteristics of spinach. **J. Food Eng.** 78(2): 577-583.

Pedraza-Chaverrí, J., Medina-Campos, O.N., Ávila-Lombardo, R., Zúñiga-Bustos, A.B. and Orozco-Ibarra, M. 2006. Reactive oxygen species scavenging capacity of different cooked garlic preparations. **Life Sci.** 78(7): 761-770.

Pereira, N.R., Marsaioli Jr., A. and Ahmé, L.M. 2007. Effect of microwave power, air velocity and temperature on the final drying of osmotically dehydrated banana. **J. Food Eng.** 81(1): 79-87.

Pérez-Gálvez, A., Hornero-Méndez, D. and Mínguez-Mosquera, M.I. 2005. Dependence ofcarotenoid content and temperature-time regimes during the traditional slow drying of red pepper for paprika production at La Vera county. **Eur. Food Res. Technol.** 221: 645-652.

Piga, A., Caro, A.D. and Corda, G. 2003. From plums to prunes: influence of drying parameters on polyphenols and antioxidant activity. **J. Agric. Food Chem.** 51: 3675-3681.

Prabhanjan, D.G., Ramaswamy, H.S. and Raghavan, G.S.V. 1995. Microwave assisted convective air drying of thin layer drying of thin layer carrots. **J. Food Eng.** 25(2): 283-293.

Ramesh, M.N., Wolf, W., Tevini, D. and Jung, G. 2001. Influence of processing parameters on the drying of spice paprika. **J. Food Eng.** 49(1): 63-72.

Rayavara K. Kempaiah and Krishnapura Srinivasan. 2006. Beneficial influence of dietary curcumin,capsaicin and garlic on erythrocyte integrity in high-fat fed rats. **J. Nutr Biochem.** 17: 471-478.

Ren, G. and Chen, F. 1998. Drying of american gingseng (*Panax quinquefolium*) roots by microwave-hot air combination. **J. Food Eng.** 35(4): 433-445.

Riripongvutikorn, S., Thummaratwasik, P. and Hung, Y-W. 2005. Antimicrobial and antioxidant effect of Thai seasoning tom-yum. **LWT-Food Sci Technol.** 38: 347-352.

Roy, M.K., Takenaka, M., Isobe, S. and Tsushida, T. 2007. Antioxidant potential, anti-proliferativeactivities and phenolic content in water-soluble fractions of some commonly consumed vegetables: effects of thermal treatment. **Food Chem.** 103(1): 106-114.

Sallam, Kh.I., Ishioroshi, M. and Samejima, K. 2004. Antioxidant and antimicrobial effects of garlic in chicken sausage. **LWT-Food Sci Technol.** 37: 849-855.

Sànchez, A.M., Sànchez, M.G., Malagarie-Cazenave, S., Olea, N. and Diaz-Laviada, I. 2006. Induction of apoptosis in prostate timor PC-3 cells and inhibition of xenograft prostate tumor growth by the vanilloid capsaicin. **Apoptosis.** 11: 89-99.

Schweiggert, U., Schieber, A. and Carle, R. 2006. Effects of blanching and storage on capsaicinoid stability and peroxidase activity of hot chilli peppers (*Capsicum frutescens* L.). **Innov Food Sci Emerg Technol.** 7: 217-224.

Schweiggert, U., Carle, R. and Schieber, A. 2006. Characterization of major and minor capsaicinoids and related compounds in chilli pods (*Capsicum frutescens* L.) by high-performance liquid chromatography/atmospheric pressure chemical ionization mass spectrometry. **Anal Chimica Act.** 557: 236-244.

Senadeera, W., Bhandari, B.R., Young, G. and Wijesinghe, B. 2003. Influence of shapes of selected vegetable materials on drying kinetics during fluidized bed drying. **J. Food Eng.** 58(3): 277-283.

Sharma, G. P. and Prasad, S. 2001. Drying of garlic (*Allium sativum*) cloves by microwave-hot air combination. **J. Food Eng.** 50(2): 99-105.

Shivhare, U.S., Arora, S., Ahmed, J. and Raghavan, G.S.V. 2004. Moisture adsorption isotherms for mushroom. **LWT-Food Sci Technol.** 37: 133-137.

Soysal, Y. 2004. Microwave drying characteristics of parsley. **Biosys Eng.** 89(2): 167-173.

Sumnu, G., Turabi, E. and Oztop, M. 2005. Drying of carrots in microwave and halogen lamp-microwave combination ovens **LWT-Food Sci Technol.** 38: 549-553.

Sundaram, J. and Durance, T.D. 2008. Water sorption and physical properties of locust bean gum-pectin-starch composite gel dried using different drying methods. **Food Hydroc.** 22: 1352-1361.

Surh, Y. J. 2002. Anti-tumor promoting potential of selected spices ingredients with antioxidative and anti-inflammatory activities. **Food Chem Toxic.** 40: 1091-1097.

Therdthai, N. and Zhou, W. 2009. Characterization of microwave vacuum drying and hot air drying of mint leaves (*Mentha cordifolia* Opiz ex Fresen). **J. Food Eng.** 91: 482-489.

Toğrul, H. 2006. Suitable drying model for infrared drying of carrot. **J. Food Eng.** 77(3): 610-619.

Tolan, I., Ragoobirsingh D. and Morrison EY. 2004. Isolation and purification of the hypoglycaemic principle present in *Capsicum frutescens*. **Photother Res.** 18(1): 95-96.

Tsami, E., Krokida, M.K. and Drouzas, A.E. 1999. Effect of drying method on sorption characteristics of model fruit powders. **J. Food Eng.** 38: 381-392.

Turkman, N., Sari, F., Poyrazoglu, E.S. and Velioglu, Y.S. 2006. Effects of prolonged heating on antioxidant activity and color of honey. **Food Chem.** 95: 653-657.

Varith, J., Dijkanarukkul, P., Achariyaviriya, A. and Achariyaviriya, S. 2007. Combined microwave-hot air drying of peeled longan. **J. Food Eng.** 81(2): 459-468.

Velu, V., Nagender, A., Prabhakara Rao, P.G. and Rao, D.G. 2006. Dry milling characteristics of microwave dried maize grains. **J. Food Eng.** 74(1): 30-36.

Vega, A., Fito, P., Andrés, A. and Lemus, R. 2007a. Mathematical modeling of hot-air drying kinetics of red bell pepper (var. Lamuyo). **J. Food Eng** 79: 1460-1466.

Vega, A., Uribe, E., Lemus, R. and Miranda, M. 2007b. Hot-air drying characteristics of aloe vera (*Aloe barbadensis* Miller) and influence of temperature on kinetic parameters. **LWT-Food Sci Technol.** 40: 1698-1707.

Vega-Gálvez, A., Lemus-Mondaca, R., Bilbao-Sáinz, C., Fito, P. and Andrés, A. 2008. Effect of air drying temperature on the quality of rehydrated dried red bell pepper (var. Lamuyo). **J. Food Eng.** 85: 42-50.

Vega-Gálvez, A., Scala, K.D., Rodrìguez, K., Lemus-Mondaca, R., Miranda, M., López, J. and Perez-Won, M. 2009. Effect of air-drying temperature on physico-chemical properties, antioxidant capacity, color and total phenolic content of red pepper (*Capsicum annuum*, L. var. Hungarian). **Food Chem.** 117: 647-653.

Vega-Mercado, H., Góngora-Nieto, M.M. and Barbosa-Cánovas, G.V. 2001. Advances in dehydration of foods. **J. Food Eng.** 49: 271-289.

Velioglu, Y.S., Mazza, G., Gao, L. and Oomah, B.O. 1998. Antioxidant activity and total phenolics in selected fruits, vegetables and grain products. **J. Agric. Food Chem.** 46: 4113-4117.

Waewsak, J., Chindaruksa, S. and Punlek, C. 2006. A mathematical modeling study of hot air drying for some agricultural products. **Thammasat Int. J. Sc. Tech.** 11(1): 14-20.

Walde, S.G., Balaswamy, K., Velu, V. and Rao, D.G. 2002. Microwave drying and grinding characteristics of wheat (*Triticum aestivum*). **J. Food Eng.** 55(3): 217-276.

Wang, Z., Sun, J., Chen, F., Liao, X. and Hu, X. 2007. Mathematical modelling on thin layer microwave drying of apple pomace with and without hot air pre-drying. **J. Food Eng.** 80(2):536-544.

Wangcharoen, W. and Morasuk, W. 2009. Antioxidant capacity changes of bird chili (*Capsicum frutescens* Linn.) during hot air drying. **Kasetsart J. (Nat. Sci.).** 43: 12-20.

Wangensteen, H., Samuelsen, A. B. and Malterud, K.E. 2004. Antioxidant activity in extract from coriander. **Food Chem.** 88: 293-297.

Wong, S.P., Leong, L.P. and William Koh, J.H. 2006. Antioxidant activities of aqueous extracts of selected plants. **Food Chem.** 99: 775-783.

Wu, T. and Mao, L. 2008. Influences of hot-air drying and microwave drying on nutritional and odorous properties of grass carp (*Ctenopharyngodon idellus*) fillets. **Food Chem.** 110: 647-653.

Zanoni, B., Pagliarini, E., Giovanelli, G. and Lavelli, V. 2003. Modelling the effects of thermal sterilization on the quality of tomato puree. **J. Food Eng.** 56: 203-206.

Zhang, M., Tang, J., Mujumdar, A.S. and Wang, S. 2006. Trends in microwave-related drying of fruits and vegetables. **Trends Food Sci Technol.** 17: 524-534.

Zheng, G.-Q., Kenney, P.M. and Lam, L.K.T. 1993. Potential anticarcinogenic natural product isolated from lemongrass oil and galanga root oil. **J. Agric. Food Chem.** 41(2): 153-156.

Zheng, W. and Wang, S.Y. 2001. Antioxidant activity and phenolic compounds in selected herbs. **J. Agric. Food Chem.** 49: 5165-5170.

APPENDIX A

Experimental Data of Microwave and Hot-Air Drying

Table A1 Data of microwave drying at a microwave power of 180 W (n=3).

Time (min)	Moisture content (g water/g dry matter)		Drying rate (g water/g dry matter/min)		Moisture ratio	
	Average	SD	Average	SD	Average	SD
0	2.5818	0.0000	0.0000	0.0000	1.0000	0.0000
1	2.5031	0.0053	0.0787	0.0053	0.9695	0.0020
2	2.3658	0.0129	0.1374	0.0076	0.9163	0.0050
3	2.2108	0.0117	0.1550	0.0037	0.8563	0.0045
4	2.0434	0.0193	0.1674	0.0076	0.7915	0.0075
5	1.8813	0.0161	0.1621	0.0056	0.7287	0.0062
6	1.7265	0.0148	0.1547	0.0038	0.6687	0.0057
7	1.5711	0.0119	0.1554	0.0053	0.6085	0.0046
8	1.4147	0.0090	0.1565	0.0080	0.5479	0.0035
9	1.2612	0.0065	0.1469	0.0114	0.4910	0.0025
10	1.1178	0.0135	0.1500	0.0071	0.4329	0.0052
11	0.9732	0.0192	0.1445	0.0071	0.3770	0.0074
12	0.8248	0.0178	0.1484	0.0082	0.3195	0.0069
13	0.6848	0.0283	0.1400	0.0105	0.2653	0.0110
14	0.5388	0.0262	0.1461	0.0056	0.2087	0.0102
15	0.3969	0.0222	0.1419	0.0040	0.1537	0.0086
16	0.2612	0.0257	0.1356	0.0036	0.1012	0.0099
17	0.1582	0.0147	0.1030	0.0111	0.0613	0.0057
18	0.1171	0.0066	0.0411	0.0083	0.0454	0.0026
19	0.1037	0.0046	0.0135	0.0020	0.0402	0.0018
20	0.0950	0.0023	0.0087	0.0026	0.0368	0.0009
21	0.0891	0.0045	0.0059	0.0028	0.0345	0.0018
22	0.0856	0.0031	0.0035	0.0019	0.0332	0.0012
23	0.0837	0.0016	0.0020	0.0017	0.0324	0.0006

Table A2 Data of microwave drying at a microwave power of 360 W (n=3).

Time (min)	Moisture content (g water/g dry matter)		Drying rate (g water/g dry matter/min)		Moisture ratio	
	Average	SD	Average	SD	Average	SD
0	2.5818	0.0000	0.0000	0.0000	1.0000	0.0000
1	2.3949	0.0067	0.1869	0.0067	0.9276	0.0026
2	2.1180	0.0099	0.2768	0.0036	0.8204	0.0038
3	1.8249	0.0115	0.2931	0.0044	0.7068	0.0045
4	1.5390	0.0140	0.2859	0.0075	0.5961	0.0054
5	1.2652	0.0213	0.2738	0.0076	0.4900	0.0083
6	1.0053	0.0195	0.2599	0.0043	0.3894	0.0075
7	0.7532	0.0187	0.2521	0.0020	0.2917	0.0072
8	0.5005	0.0160	0.2527	0.0039	0.1939	0.0062
9	0.2497	0.0145	0.2508	0.0028	0.0967	0.0056
10	0.1314	0.0152	0.1183	0.0024	0.0509	0.0059
11	0.0951	0.0012	0.0363	0.0049	0.0369	0.0045
12	0.0823	0.0030	0.0128	0.0009	0.0319	0.0011

Table A3 Data of microwave drying at a microwave power of 540 W (n=3).

Time (min)	Moisture content (g water/g dry matter)		Drying rate (g water/g dry matter/min)		Moisture ratio	
	Average	SD	Average	SD	Ave	SD
0	2.5818	0.0000	0.0000	0.0000	1.0000	0.0000
1	2.2769	0.0115	0.3049	0.0115	0.8819	0.0044
2	1.8529	0.0100	0.4240	0.0015	0.7177	0.0039
3	1.4417	0.0086	0.4112	0.0068	0.5584	0.0033
4	1.0520	0.0103	0.3897	0.0044	0.4075	0.0040
5	0.6952	0.0105	0.3568	0.0064	0.2693	0.0040
6	0.3504	0.0186	0.3449	0.0126	0.1357	0.0072
7	0.1121	0.0039	0.2383	0.0213	0.0434	0.0015
8	0.0837	0.0139	0.0284	0.0103	0.0324	0.0054

Table A4 Data of hot-air drying at an air temperature of 60°C (n=3).

Time (min)	Moisture content (g water/g dry matter)		Drying rate (g water/g dry matter/min)		Moisture ratio	
	Average	SD	Average	SD	Average	SD
0	2.5818	0.0000	0.0000	0.0000	1.0000	0.0000
10	2.3933	0.0043	0.0188	0.0004	0.9270	0.0017
20	2.1463	0.0102	0.0247	0.0006	0.8313	0.0039
30	1.8887	0.0099	0.0258	0.0000	0.7316	0.0038
40	1.6263	0.0113	0.0262	0.0004	0.6299	0.0044
50	1.3880	0.0145	0.0238	0.0004	0.5376	0.0056
60	1.1601	0.0156	0.0228	0.0003	0.4493	0.0061
70	0.9552	0.0194	0.0205	0.0004	0.3700	0.0075
80	0.7724	0.0183	0.0183	0.0003	0.2992	0.0071
90	0.5967	0.0180	0.0176	0.0011	0.2311	0.0108
100	0.4736	0.0162	0.0123	0.0014	0.1834	0.0063
110	0.3623	0.0171	0.0111	0.0014	0.1403	0.0066
120	0.2877	0.0106	0.0075	0.0009	0.1115	0.0041
130	0.2316	0.0073	0.0056	0.0003	0.0897	0.0028
140	0.1891	0.0051	0.0042	0.0003	0.0733	0.0020
150	0.1592	0.0037	0.0030	0.0003	0.0617	0.0014
160	0.1390	0.0028	0.0020	0.0002	0.0539	0.0011
170	0.1215	0.0077	0.0018	0.0006	0.0470	0.0030
180	0.1115	0.0005	0.0010	0.0007	0.0432	0.0002
190	0.1054	0.0030	0.0006	0.0003	0.0408	0.0012
200	0.0983	0.0008	0.0007	0.0002	0.0381	0.0003
210	0.0948	0.0009	0.0003	0.0002	0.0367	0.0004
220	0.0938	0.0006	0.0001	0.0000	0.0363	0.0002
230	0.0888	0.0020	0.0005	0.0002	0.0344	0.0008
240	0.0864	0.0021	0.0002	0.0001	0.0335	0.0008

Table A5 Data of hot-air drying at an air temperature of 70°C (n=3).

Time (min)	Moisture content (g water/g dry matter)		Drying rate (g water/g dry matter/min)		Moisture ratio	
	Average	SD	Average	SD	Average	SD
0	2.5818	0.0000	0.0000	0.0000	1.0000	0.0000
10	2.3455	0.0137	0.0236	0.0014	0.9085	0.0053
20	2.0295	0.0243	0.0316	0.0011	0.7861	0.0094
30	1.7045	0.0244	0.0325	0.0004	0.6602	0.0095
40	1.3945	0.0215	0.0310	0.0004	0.5401	0.0083
50	1.1137	0.0270	0.0281	0.0010	0.4314	0.0105
60	0.8694	0.0195	0.0244	0.0009	0.3367	0.0076
70	0.6542	0.0152	0.0215	0.0013	0.2534	0.0059
80	0.4890	0.0161	0.0165	0.0011	0.1894	0.0063
90	0.3566	0.0168	0.0132	0.0008	0.1381	0.0065
100	0.2656	0.0165	0.0091	0.0005	0.1029	0.0064
110	0.1990	0.0166	0.0067	0.0004	0.0771	0.0064
120	0.1587	0.0120	0.0040	0.0005	0.0615	0.0047
130	0.1381	0.0201	0.0021	0.0018	0.0535	0.0078
140	0.1129	0.0134	0.0025	0.0009	0.0437	0.0052
150	0.0973	0.0048	0.0016	0.0009	0.0377	0.0019
160	0.0879	0.0056	0.0009	0.0002	0.0340	0.0022
170	0.0834	0.0063	0.0004	0.0004	0.0323	0.0024
180	0.0785	0.0063	0.0005	0.0003	0.0304	0.0025

Table A6 Data of hot-air drying at an air temperature of 80°C (n=3).

Time (min)	Moisture content (g water/g dry matter)		Drying rate (g water/g dry matter/min)		Moisture ratio	
	Average	SD	Average	SD	Average	SD
0	2.5818	0.0000	0.0000	0.0000	1.0000	0.0000
10	2.3220	0.0134	0.0260	0.0013	0.8994	0.0052
20	1.9530	0.0067	0.0369	0.0007	0.7565	0.0026
30	1.5650	0.0035	0.0388	0.0007	0.6062	0.0014
40	1.2294	0.0061	0.0336	0.0005	0.4762	0.0024
50	0.9312	0.0059	0.0298	0.0011	0.3607	0.0023
60	0.6699	0.0060	0.0261	0.0002	0.2595	0.0023
70	0.4574	0.0264	0.0213	0.0021	0.1772	0.0102
80	0.3204	0.0010	0.0137	0.0027	0.1241	0.0004
90	0.2194	0.0013	0.0101	0.0001	0.0850	0.0005
100	0.1615	0.0030	0.0058	0.0002	0.0625	0.0012
110	0.1236	0.0028	0.0038	0.0003	0.0479	0.0011
120	0.0992	0.0028	0.0024	0.0001	0.0384	0.0011
130	0.0861	0.0015	0.0013	0.0001	0.0333	0.0006

APPENDIX B

Experimental Data of Moisture Sorption Properties

Table B1 Equilibrium moisture content (EMC, g water/g dry matter) of dry-powdered Thai red curry paste from microwave and hot-air drying (n=3).

a_w		Microwave drying			Hot-air drying		
		180 W	360 W	540 W	60°C	70°C	80°C
0.113	Ave.	0.0868	0.0852	0.0931	0.0849	0.0888	0.0890
	SD	0.0017	0.0017	0.0013	0.0011	0.0033	0.0010
0.216	Ave.	0.1049	0.1120	0.1169	0.1105	0.1176	0.1185
	SD	0.0026	0.0055	0.0015	0.0033	0.0023	0.0268
0.324	Ave.	0.1213	0.1246	0.1269	0.1196	0.1211	0.1205
	SD	0.0013	0.0048	0.0042	0.0030	0.0014	0.0040
0.432	Ave.	0.1367	0.1395	0.1426	0.1433	0.1423	0.1412
	SD	0.0013	0.0026	0.0003	0.0011	0.0029	0.0018
0.679	Ave.	0.3965	0.4046	0.4109	0.4221	0.4308	0.4342
	SD	0.0015	0.0136	0.0037	0.0156	0.0112	0.0066
0.751	Ave.	0.8145	0.7889	0.8024	0.8318	0.8144	0.8126
	SD	0.0045	0.0057	0.0037	0.0034	0.0119	0.0034
0.836	Ave.	1.1298	1.1008	1.1103	1.1772	1.1543	1.1493
	SD	0.0198	0.0235	0.0317	0.0171	0.0259	0.0308
0.97	Ave.	3.2151	3.3036	3.0095	3.2884	3.3884	2.9363
	SD	0.2722	0.3279	0.3708	0.2336	0.3532	0.3264

APPENDIX C

Experimental Data of Color Properties

Table C1 Browning index (BI) of fresh and dried Thai red curry paste from microwave and hot-air drying.

Drying methods	NEB (Abs at 420 nm /g dry matter)
Fresh	0.107±0.001^{g}
Microwave drying	
180 W	0.147±0.001^{c}
360 W	0.154±0.001^{b}
540 W	0.175±0.001^{a}
Hot-air drying	
60°C	0.121±0.001^{f}
70°C	0.125±0.001^{e}
80°C	0.129±0.001^{d}

Mean (± S.D., n=3) with different superscripts in each column are significantly different (p<0.05).

Table C2 Color measurements of dry-powdered Thai red curry paste from microwave and hot-air drying.

Drying methods	Color		
	L	**a**	**b**
Microwave drying			
180 W, 23 min	57.114 ± 0.280^{b}	23.636 ± 0.348^{b}	30.442 ± 0.455^{b}
360 W, 12 min	57.171 ± 0.752^{b}	23.950 ± 0.346^{ab}	30.550 ± 0.997^{b}
540 W, 8 min	56.827 ± 0.146^{b}	24.103 ± 0.077^{a}	30.432 ± 0.313^{b}
Hot-air drying			
60°C, 240 min	58.687 ± 1.050^{a}	23.653 ± 0.040^{b}	31.570 ± 0.445^{a}
70°C, 180 min	59.324 ± 0.318^{a}	23.072 ± 0.259^{c}	31.652 ± 1.092^{a}
80°C, 130 min	59.364 ± 0.243^{a}	23.168 ± 0.246^{c}	31.429 ± 0.278^{a}

Mean (± S.D., n=3) with different superscripts in each column are significantly different (p<0.05).

Table C3 Color measurements of fresh and dry-rehydrated Thai red curry paste from microwave and hot-air drying.

Drying methods	Hunter color		
	L	**a**	**b**
Fresh	29.073±0.003^{e}	25.101±0.506^{a}	14.415±0.079^{e}
Microwave drying			
180 W	31.880±0.036^{b}	24.787±0.133^{a}	16.847±0.099^{b}
360 W	32.407±0.302^{ab}	24.923±0.162^{a}	17.350±0.240^{a}
540 W	32.113±0.306^{a}	25.273±0.439^{a}	17.133±0.256^{a}
Hot-air drying			
60°C	30.660±0.089^{d}	25.040±0.095^{a}	16.127±0.078^{d}
70°C	31.223±0.064^{c}	25.380±0.053^{a}	16.597±0.006^{bc}
80°C	31.060±0.110^{c}	25.313±0.087^{a}	16.557±0.106^{c}

Mean (± S.D., n=3) with different superscripts in each column are significantly different (p<0.05).

Table C4 Ratio of color change ($\Delta L/L_0$, $\Delta a/a_0$ and $\Delta b/b_0$) and total color change values of dry-rehydrated Thai red curry paste from microwave and hot-air drying.

Drying methods	$\Delta L/L_0$	$\Delta a/a_0$	$\Delta b/b_0$	ΔE
Microwave drying				
180 W	0.097±0.001^{b}	-0.012±0.001^{a}	0.169±0.013^{b}	3.754±0.132^{b}
360 W	0.115±0.010^{a}	-0.007±0.001^{a}	0.193±0.008^{a}	4.375±0.185^{a}
540 W	0.105±0.011^{ab}	0.007±0.001^{a}	0.189±0.013^{a}	4.108±0.371^{a}
Hot-air drying				
60°C	0.055±0.003^{d}	-0.002±0.000^{a}	0.119±0.009^{d}	2.368±0.104^{d}
70°C	0.074±0.002^{c}	0.011±0.000^{a}	0.151±0.006^{c}	3.103±0.073^{c}
80°C	0.068±0.004^{c}	0.008±0.000^{a}	0.149±0.001^{c}	2.963±0.122^{c}

Mean (± S.D., n=3) with different superscripts in each column are significantly different (p<0.05).

APPENDIX D

Experimental Data of Antioxidant Properties

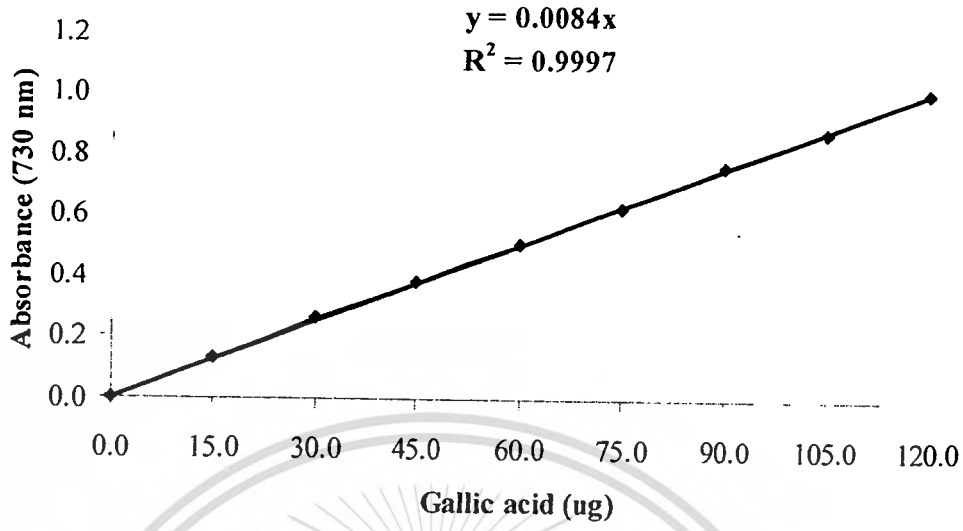

Figure D1 Standard curve of gallic acid standard for total phenolic content calculation.

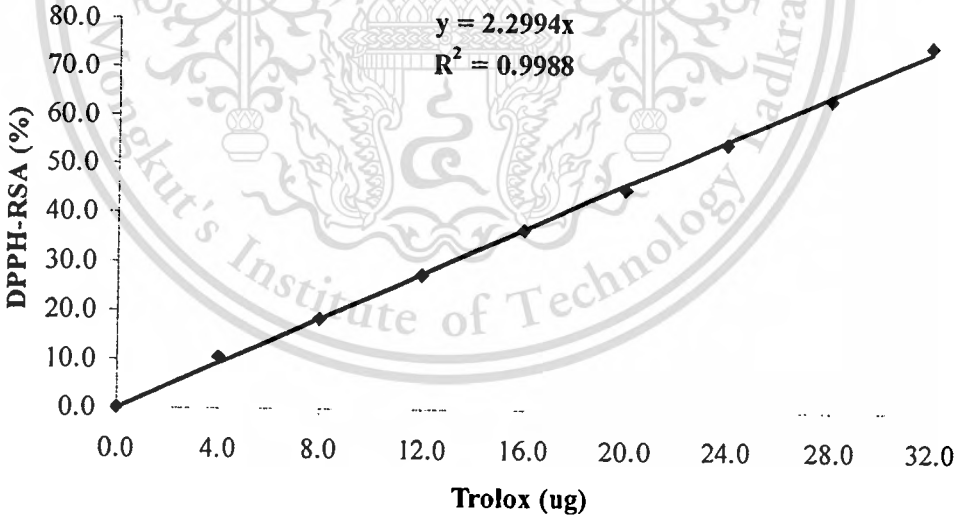

Figure D2 Standard curve of trolox standard for DPPH-RSA calculation.

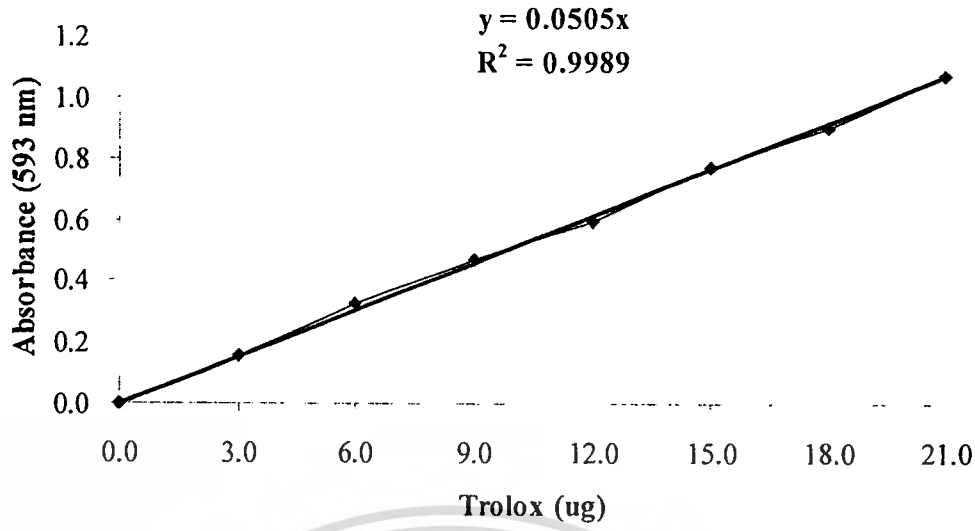

Figure D3 Standard curve of trolox standard for FRAP calculation.

Table D1 Total phenolic content and antioxidant activity of fresh and dried Thai red curry paste from microwave and hot-air drying.

Samples	TPC*	DPPH-RSA**	FRAP**
Fresh	7.043± 0.075 ^{de}	1.364 ± 0.024 ^{f}	4.607 ± 0.075 ^{d}
Microwave drying			
180 W, 23 min	7.377 ± 0.157 ^{c}	1.725 ± 0.010 ^{c}	5.017± 0.059 ^{c}
360 W, 12 min	7.818 ± 0.069 ^{b}	1.822 ± 0.011 ^{b}	5.297± 0.025 ^{b}
540 W, 8 min	8.333 ± 0.067 ^{a}	2.003 ± 0.032 ^{a}	6.108± 0.120 ^{a}
Hot-air drying			
60 °C, 240 min	6.963 ± 0.153 ^{e}	1.476 ± 0.032 ^{e}	4.918 ± 0.057 ^{c}
70 °C, 180 min	7.252 ± 0.164 ^{cd}	1.477± 0.014 ^{e}	4.916 ± 0.140 ^{c}
80 °C, 130 min	7.035 ± 0.100 ^{de}	1.542± 0.027 ^{d}	4.943 ± 0.119 ^{c}

*mg gallic acid equivalents/ g dry matter.
**mg trolox equivalents /g dry matter.
Mean (± S.D., n=3) with different superscripts in each column are significantly different (p<0.05).

APPENDIX E

Experimental Data of Sensory Evaluation

Data Analysis

1) Simplifying sample codes. A=fresh, A1=microwave drying at 180 W, A2= microwave drying at 360 W, A3= microwave drying at 540 W, A4=hot-air drying at 60 °C, A5=hot-air drying at 70 °C, A4=hot-air drying at 80 °C.

2) For each pair, assigned a value of 1= Ai more sensory attribute intensity than A

0 = Ai less sensory attribute intensity than A

3) Calculation of the Cochran's Q test, using the following equation:

$$Q = (m-1) \times \frac{m\sum_{i=1}^{m} T_i^2 - T^2}{mT - \sum_{j=1}^{N} S_j^2} \qquad \text{(E.1)}$$

where: m = the total no. of pairs of samples

T_i (i=1,2,...m) = the total no. of correct responses from the N panelists from sample i (column)

S_j (i=1,2,...N) = the total no. of correct responses from the m samples for panelist j (row)

T = the total no. of correct responses from the N panelists for all m samples

4) Q statistics follow asymptotic χ^2 distributions with df of (m-1), where: m is the total number of pairs of samples (Meilgaard et al., 2007). In this study, as I expected that Ai samples would be more sensory attribute intensity than A, I used the 1-tailed table χ^2 at df =5, α=0.05 was 9.24.

5) Compare Q statistic with the tabled χ^2 value. Reject H_0 (all Ai samples are not different) if calculated Q is greater than table χ^2, 2-tailed at α=0.05 level (4.35).

Table E1 Results of paired comparisons-dependent and selected pairs test for color intensity of fresh and dry-rehydrated Thai red curry paste.

Panelist	A1	A2	A3	A4	A5	A6	Sj	Sj^2
1	0	0	0	0	0	1	1	1
2	0	1	0	0	1	1	3	9
3	0	0	0	0	0	0	0	0
4	0	1	1	1	1	1	5	25
5	1	0	0	0	0	0	1	1
6	0	0	0	0	0	0	0	0
7	0	1	0	0	0	0	1	1
8	0	0	0	0	0	0	0	0
9	0	0	1	0	0	0	1	1
10	1	0	0	1	1	0	3	9
11	0	0	0	0	0	0	0	0
12	1	0	0	0	1	0	2	4
13	0	1	1	0	1	1	4	16
14	0	1	0	0	0	0	1	1
15	1	1	1	0	0	0	3	9
16	1	1	0	1	0	1	4	16
17	0	0	0	1	1	0	2	4
18	1	1	1	0	0	1	4	16
19	0	0	0	0	0	0	0	0
20	0	0	0	1	0	0	1	1
21	1	0	1	0	1	1	4	16
22	0	0	0	0	0	1	1	1
23	0	0	0	1	1	0	2	4
24	0	0	0	1	0	0	1	1
25	0	0	1	0	0	0	1	1
26	0	0	0	0	0	0	0	0
Ti	7	8	7	7	8	8	T=45 T^2=2025	ΣSj^2=137
Ti^2	49	64	49	49	64	64	ΣTi^2=339	
Pci	0.304	0.348	0.304	0.304	0.348	0.348		

The Cochran's Q test is calculated using equation E.1

$$Q = (6-1) \times \frac{(6 \times 339) - 2025}{(6 \times 45) - 137} = 0.338$$

The Cochran's Q test was lower than the table χ^2 (9.24) therefore, accept H_0, i.e., saying that no significant differences among the dried samples.

Table E2 Results of paired comparisons-dependent and selected pairs test for aroma intensity of fresh and dry-rehydrated Thai red curry paste.

Panelist	A1	A2	A3	A4	A5	A6	Sj	Sj^2
1	0	0	0	0	0	0	0	0
2	1	0	0	0	0	0	1	1
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0
12	0	1	0	1	1	0	3	9
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	1	1	1	0	1	1	5	25
16	0	1	1	1	0	1	4	16
17	0	0	0	0	0	0	0	0
18	1	1	1	0	0	0	3	9
19	1	0	1	1	0	1	4	16
20	1	1	0	1	1	1	5	25
21	1	0	0	0	0	0	1	1
22	0	0	1	0	0	0	1	1
23	0	0	0	0	0	0	0	0
24	0	0	0	1	0	0	1	1
25	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
Ti	6	5	5	5	3	4	T=28 T^2=784	ΣSj^2=104
Ti^2	36	25	25	25	9	16	ΣTi^2=136	
Pci	0.261	0.217	0.217	0.217	0.130	0.174		

The Cochran's Q test is calculated using equation E.1

$$Q = (6-1) \times \frac{(6 \times 136) - 784}{(6 \times 28) - 104} = 2.500$$

The Cochran's Q test was lower than the table χ^2 (9.24) therefore, accept H_0, i.e., saying that no significant differences among the dried samples.

Table E3 Results of paired comparisons-dependent and selected pairs test for color intensity of stirred ground pork with fresh and dry-rehydrated Thai red curry paste.

Panelist	A1	A2	A3	A4	A5	A6	Sj	Sj^2
1	0	0	0	0	1	0	1	1
2	0	1	1	0	1	0	3	9
3	0	0	1	0	1	1	3	9
4	0	1	0	0	1	0	2	4
5	0	1	0	0	1	0	2	4
6	1	1	1	1	0	1	5	25
7	0	0	0	0	0	0	0	0
8	1	0	0	0	0	1	2	4
9	1	1	0	0	0	0	2	4
10	0	0	1	0	0	0	1	1
11	0	1	0	0	0	0	1	1
12	1	0	0	1	1	0	3	9
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	1	0	1	2	4
16	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
18	0	0	0	1	0	1	2	4
19	0	0	0	1	0	0	1	1
20	0	0	0	0	0	1	1	1
21	0	0	0	0	0	0	0	0
22	0	0	0	1	1	0	2	4
23	1	1	1	0	0	0	3	9
24	0	1	0	0	0	0	1	1
25	0	0	0	0	0	1	1	1
26	0	0	0	0	1	1	2	4
Ti	5	8	5	6	8	8	T=40 T^2=1600	ΣSj^2=100
Ti^2	25	64	25	36	64	64	ΣTi^2=278	
Pci	0.200	0.320	0.200	0.240	0.320	0.320		

The Cochran's Q test is calculated using equation E.1

$$Q = (6-1) \times \frac{(6 \times 278) - 1600}{(6 \times 40) - 100} = 2.429$$

The Cochran's Q test was lower than the table χ^2 (9.24) therefore, accept H_0, i.e., saying that no significant differences among the dried samples.

Table E4 Results of paired comparisons-dependent and selected pairs test for aroma intensity of stirred ground pork with fresh and dry-rehydrated Thai red curry paste.

Panelist	A1	A2	A3	A4	A5	A6	Sj	Sj^2
1	0	0	1	0	0	1	2	4
2	0	1	0	0	0	0	1	1
3	0	1	0	0	1	0	2	4
4	1	0	1	0	0	0	2	4
5	0	1	0	0	1	0	2	4
6	0	0	1	1	1	1	4	16
7	0	0	0	0	1	1	2	4
8	0	0	0	1	1	0	2	4
9	1	0	0	0	0	1	2	4
10	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0
12	1	1	1	1	1	1	6	36
13	0	0	0	1	0	0	1	1
14	0	0	0	0	0	0	0	0
15	0	0	0	1	0	0	1	1
16	1	0	0	0	0	0	1	1
17	0	0	1	0	1	1	3	9
18	1	0	0	0	1	0	2	4
19	0	0	0	1	0	0	1	1
20	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0
24	1	1	1	0	0	1	4	16
25	0	0	0	1	0	0	1	1
26	1	0	0	0	0	0	1	1
Ti	7	5	6	7	8	7	T=40 T^2=1600	ΣSj^2=116
Ti^2	49	25	36	49	64	49	ΣTi^2=272	
Pci	0.269	0.192	0.231	0.269	0.308	0.269		

The Cochran's Q test is calculated using equation E.1

$$Q = (6-1) \times \frac{(6 \times 272) - 1600}{(6 \times 40) - 116} = 1.290$$

The Cochran's Q test was lower than the table χ^2 (9.24) therefore, accept H_0, i.e., saying that no significant differences among the dried samples.

Table E5 Results of paired comparisons-dependent and selected pairs test for preference of stirred ground pork with fresh and dry-rehydrated Thai red curry paste.

Panelist	A1	A2	A3	A4	A5	A6	Sj	Sj^2
1	0	1	1	1	1	0	4	16
2	1	0	0	1	1	1	4	16
3	1	1	0	1	1	1	5	25
4	1	1	1	0	1	0	4	16
5	1	1	1	1	1	1	6	36
6	1	1	1	1	1	1	6	36
7	1	1	1	1	1	1	6	36
8	1	0	0	0	0	1	2	4
9	0	0	1	1	1	1	4	16
10	1	1	0	1	1	1	5	25
11	0	1	1	1	0	1	4	16
12	1	1	0	1	1	1	5	25
13	0	1	1	0	0	0	2	4
14	0	1	1	1	1	1	5	25
15	1	1	1	1	1	0	5	25
16	1	1	1	1	1	1	6	36
17	1	1	0	0	1	1	4	16
18	1	1	1	1	1	1	6	36
19	1	0	0	1	1	1	4	16
20	0	1	1	1	1	1	5	25
21	1	1	0	1	1	1	5	25
22	0	1	1	1	1	0	4	16
23	1	1	1	1	1	1	6	36
24	1	1	1	1	1	1	6	36
25	1	1	1	1	1	1	6	36
26	1	1	1	0	0	0	3	9
Ti	19	22	18	21	22	20	T=122 T^2=14884	ΣSj^2=608
Ti^2	361	484	324	441	484	400	ΣTi^2=2494	
Pci	0.731	0.846	0.692	0.808	0.846	0.769		

The Cochran's Q test is calculated using equation E.1

$$Q = (6-1) \times \frac{(6 \times 2494) - 14884}{(6 \times 122) - 608} = 3.226$$

The Cochran's Q test was lower than the table χ^2 (9.24) therefore, accept H_0, i.e., saying that no significant differences among the dried samples.

AUTHOR BIOGRAPHY

Name Miss Sudathip Inchuen

Date of Birth May, 22nd, 1976

Place of Birth Surin Province, Thailand.

Address 78, Moo 24, Sawai Sub-district, Muang district, Surin Province, Thailand 32000.

Education

2000-2002 Master Degree of Science (Food Science)
King Mongkut's Institute of Technology Lardkrabang, Bangkok, Thailand.
Thesis: "Study on Physico-chemical properties of Banana Flour"

1996-1999 Bachelor Degree of Science (Food Technology and Nutrition).
Mahasarakham University, Mahasarakham, Thailand.

Publication

Sudathip Inchuen, Woattichai Narkrugsa, Pimpen Pornchaloempong, Pipat Chanasinchana and Teerapon Swing. 2008. Microwave and hot-air drying of Thai red curry paste. **Maejo International Journal of Science and Technology.** 1(Special Issue), 38-49.

Sudathip Inchuen, Woattichai Narkrugsa, and Pimpen Pornchaloempong. 2010. Effect of drying methods on chemical composition, color and antioxidant properties of Thai red curry powder. **Kasetsart Journal (Nat. Sci.).** 44:1, 1-10.