UNIVERSITI PUTRA MALAYSIA

EFFECTS OF MICROWAVE FRYING ON PHYSICOCHEMICAL PROPERTIES OF EDIBLE OILS AND QUALITY OF POTATO CHIPS

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By

TAHER A.HOUSSEIN ELFAITOURI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Doctor of Philosophy

September 2017

DEDICATION

Dedicated to whom I love
My mother, my wife and my son

Abstract of thesis presented to the senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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September 2017

Chairman : Professor Chin Ping Tan, PhD
Faculty : Food Science and Technology

Microwave frying is an alternative processing method for producing fried food products with the advantages of saving energy and time and improving both the nutritional quality and acceptability of fried foods by consumers. Thus, the effects of microwave frying on the properties of edible oils and the quality characteristics of fried foods should be studied using different techniques to obtain comprehensive data on the properties of microwave-fried products. In this study, the effects of microwave frying on the physicochemical properties of frying oils, namely, refined, bleached and deodorized (RBD) palm olein and corn oil, which have market acceptability and are widely used in cooking, were evaluated. Changes in physicochemical properties, including free fatty acids, acid value, peroxide value, p-anisidine value, TPM% TOTOX value, color, viscosity, rheological behaviors and thermal properties, were evaluated to monitor the quality and frying performance of frying oil. The experimental data highlighted that both studied frying oils exhibited oil stability against oxidation during the microwave frying process, RBD palm olein showed a comparatively lower degree as compared to corn oil. The studied oils exhibited Newtonian behavior, and there was a significant increase ($P < 0.05$) in the viscosity of both oils as the extent of frying increased. There was a significant ($P < 0.05$) difference in the color of the studied edible oils with increased extent of frying. The thermal properties of the oils were determined by differential scanning calorimetry (DSC). The melting point of RBD palm olein during the heating curve was in the range of -3.25 °C, and during the cooling curve it was in the range of 4.35 °C. A comparison of the average melting point values of corn oil revealed values of -28.0 °C and 26.0 °C during the heating and cooling curves, respectively. The properties of microwaved potato chips, namely, moisture content, oil uptake, bulk density, particle density, porosity values, volumetric shrinkage, hardness, and color development, were also evaluated. The moisture content of potatoes decreased significantly ($P < 0.05$), whereas the oil content values of the potatoes increased significantly ($P < 0.05$), with increasing frying time and microwave power level.

Moreover, the kinetics models gave a good and varied fit for moisture diffusion and oil transfer. Interestingly, the effective moisture diffusivity for potato chips fried in corn oil ranged between $6.36x10^{-9}$ and $12.68x10^{-9}$ m^2/s and between $6.64x10^{-9}$ and $12.84x10^{-9}$ m^2/s. The oil transfer rate constant ranged between $2.02x10^{-2}$ and $1.94x10^{-2}$ s^{-1} and between $1.89x10^{-2}$ and $1.95x10^{-2}$ for potato chips fried in RBD palm olein and in corn oil, respectively. The activation energy obtained from the Arrhenius plot for the effective moisture diffusivity ranged between 58.17 and 58.84 kJ/mol. Scanning electron microscopy images showed the structural changes at the surface of microwaved potato chips, revealing detailed and specific information to elucidate the relation between microwave frying processing conditions and fried food structure. In addition, confocal laser scanning microcopy (CLSM) images were obtained to observe the surface morphology and oil distribution of potato chips. The oil distribution in microwaved potato chips fried under different microwave frying conditions showed that a crust developed during microwave frying. Oil was trapped only in intercellular spaces, which was strongly linked to the microstructure (not only in intercellular spaces but also over some cells). The topographical data acquired by CLSM in reflective mode confirmed that several cells were broken during the cutting operation. CLSM image representation of the reconstructed surface of a microwaved potato chip allowed the oil location on the potato surface to be observed. The macrostructural properties of microwaved potato chips fried in RBD palm olein and corn oil were investigated, and the results showed volumetric shrinkage, thickness expansion and diameter change as a function of the moisture loss effect by the frying process conditions. Moreover, the hardness showed several fluctuations at 160, 170, and 180 °C. The texture of fried potato chips was soggy at 160 °C due to the short microwave frying process, which led to incompletely fried potato chips. The acrylamide content of potato chips was detected during the microwave frying process. The acrylamide levels in potato chips fried in corn oil ranged from 380 to 12,301 ppb. Meanwhile, the acrylamide levels in potato chips fried in RBD palm olein ranged from 282 to 13,230 ppb. Remarkably, 60% of the potato chips had high levels of acrylamide due to the high thermal process during microwave frying. It can be concluded that the microwave frying of potato chips caused the formation of lower amounts of oxidation products in RBD palm olein and corn oil, indicating a lower extent of oxidative degradation of the studied oils. In addition, the physical properties of the studied oils were investigated. Moreover, the quality characteristics of microwaved potato chips were obtained. The levels of acrylamide in microwaved potato chips were determined. In general, the microwave frying is an attractive process for food due to its applicability, convenience and low oxidative degradation.

Abstrak tesis yang dikemukan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

KESAN PENGGORENGAN GELOMBANG MIKRO KE ATAS SIFAT-SIFAT FIZIKOKIMIA MINYAK MAKAN DAN KUALITI KENTANG GORENG

Oleh

TAHER A.HOUSSEIN ELFAITOURI

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Penggorengan gelombang mikro adalah kaedah pemprosesan alternatif untuk menghasilkan produk-produk makanan goreng, dan mempunyai kelebihan dari segi penjimatan tenaga, masa, dan penambahbaikan kualiti pemakanan dan kebolehterimaan pengguna terhadap makanan goreng. Oleh yang demikian, kesan penggorengan gelombang mikro ke atas sifat minyak makan, dan ciri kualiti makanan goreng haruslah dikaji menggunakan teknik-teknik yang berlainan untuk memperoleh data yang menyeluruh berkenaan dengan sifat-sifat produk yang digoreng melalui penggorengan gelombang mikro. Dalam kajian ini, kesan penggorengan gelombang mikro ke atas sifat fizikokimia minyak makan, iaitu olein sawit bertapis, nyahwarna dan nyahbau (RBD) dan minyak jagung, yang mempunyai kebolehterimaan pasaran dan digunakan secara meluas dalam masakan telah dinilai. Perubahan dalam sifat-sifat fizikokimia, termasuk asid lemak bebas, nilai peroksida, nilai p-anisidine, TPM% nilai TOTOX, warna, kelikatan, kelakuan reologi dan sifat-sifat terma, telah dinilai untuk memantau kualiti dan persembahan menggoreng minyak goreng. Data eksperimen menunjukkan bahawa kedua-dua minyak goreng tersebut mempamerkan tahap pengoksidaan yang berbeza semasa proses penggorengan gelombang mikro; olein sawit RBD menunjukkan tahap yang lebih rendah jika dibandingkan dengan minyak jagung. Minyak yang dikaji mempamerkan kelakuan Newtonian, dan terdapat peningkatan yang ketara ($P < 0.05$) dalam kelikatan kedua-dua minyak apabila takat penggorengan ditingkatkan. Terdapat perbezaan yang ketara ($P < 0.05$) dalam warna miyak-minyak makan yang dikaji apabila takat penggorengan ditingkatkan. Sifat terma minyak juga ditentukan menerusi kalorimetri pengimbasan pembezaan (DSC). Takat lebur RBD olein sawit semasa lengkung pemanasan adalah dalam lingkungan -3.25 °C, dan semasa lengkung penyejukan adalah dalam lingkungan 4.35 °C. Perbandingan nilai purata takat lebur minyak jagung semasa lengkung-lengkung pemanasan dan penyejukan masing-masing menunjukkan nilai -28.0 °C dan 26.0 °C. Sifat kentang goreng yang

digoreng menerusi penggorengan gelombang mikro, iaitu kandungan kelembapan, penyerapan minyak, ketumpatan pukal, ketumpatan zarah, nilai keronggaan, pengecutan isi padu, kekerasan, dan perkembangan warna juga telah dinilai. Kandungan kelembapan kentang goreng merosot dengan ketara ($P < 0.05$) manakala kandungan minyak kentang goreng bertambah dengan ketara ($P < 0.05$) dengan peningkatan dalam masa penggorengan dan tahap kuasa gelombang mikro. Tambahan pula, model kinetik memberikan padanan yang bagus dan pelbagai bagi resapan kelembapan dan pemindahan minyak. Yang menariknya, penyerapan kelembapan berkesan bagi kentang goreng yang digoreng menggunakan minyak jagung adalah dalam lingkungan 6.36 $x10^{-9}$ ke 12.68 $x10^{-9}$ m^2/s dan 6.64 $x10^{-9}$ ke 12.84 $x10^{-9}$ m^2/s. Pemalar kadar pemindahan minyak adalah masing-masing dalam lingkungan 2.02 $x10^{-2}$ ke 1.94 $x10^{-2}$ s^{-1} dan 1.89 $x10^{-2}$ ke 1.95 $x10^{-2}$ bagi kentang goreng yang digoreng menggunakan RBD olein sawit dan minyak jagung. Tenaga pengaktifan yang diperoleh melalui plot Arrhenius bagi penyebaran kelembapan berkesan pula adalah dalam lingkungan 58.17 ke 58.84 kJ/mol. Imej-imej mikroskopi elektron pengimbasan menunjukkan perubahan struktur pada permukaan kentang goreng, dan mendedahkan maklumat yang terperinci dan spesifik yang menjelaskan hubungan antara keadaan-keadaan proses penggorengan gelombang mikro dengan struktur makanan goreng. Tambahan pula, imej mikroskopi pengimbasan laser sefokus (CLSM) telah diperolehi untuk memerhati morfologi permukaan dan taburan minyak dalam kentang goreng. Taburan minyak dalam kentang goreng di bawah keadaan penggorengan gelombang mikro yang berlainan menunjukkan pembentukan kerak semasa proses penggorengan gelombang mikro. Minyak hanya terperangkap di dalam ruang antara sel, dan ini boleh dikait rapat dengan struktur mikro (bukan sahaja ruang-ruang antara sel, tetapi juga ke atas sesetengah sel). Data topografi yang diperolehi melalui CLSM dalam mod pantulan mengesahkan bahawa terdapat sel-sel yang pecah ketika operasi pemotongan. Imej CLSM yang mewakili permukaan bentuk-semula kentang goreng telah membolehkan pemerhatian lokasi minyak pada permukaan kentang goreng. Sifat struktur makro kentang goreng yang digoreng dalam olein sawit RBD dan minyak jagung telah dikaji, dan hasil kajian menunjukkan pengecutan isi padu, perkembangan ketebalan dan perubahan diameter sebagai fungsi kepada kesan kehilangan kelembapan akibat keadaan proses penggorengan. Tambahan pula, kajian menunjukkan bahawa terdapat beberapa turun naik dari segi kekerasan pada suhu 160, 170 dan 180 °C. Tekstur kentang goreng adalah lebih lembik pada 160 °C kerana proses penggorengan gelombang mikro yang singkat, yang mengakibatkan penggorengan kentang goreng yang tidak lengkap. Kandungan akrilamid kentang goreng telah dikesan semasa proses penggorengan gelombang mikro. Tahap akrilamid dalam kentang goreng yang digoreng menggunakan minyak jagung adalah dalam lingkungan 380 ke 12,301 ppb, manakala tahap akrilamid dalam kentang goreng yang digoreng menggunakan olein sawit RBD adalah dalam lingkungan 282 ke 13,230 ppb. Yang menakjubkan, 60% kentang goreng mempunyai tahap akrilamid yang tinggi akibat daripada proses terma yang tinggi semasa penggorengan gelombang mikro. Ianya boleh disimpulkan bahawa penggorengan kentang goreng menggunakan gelombang mikro mengakibatkan pembentukan jumlah produk pengoksidaan yang lebih rendah dalam olein sawit RBD dan minyak jagung, dan ini menunjukkan takat penguraian pengoksidaan yang lebih rendah dalam minyak-minyak yang dikaji. Tambahan lagi, ciri-ciri kualiti kentang goreng juga telah diperolehi. Tahap akrilamid dalam kentang goreng yang digoreng menggunakan gelombang mikro juga telah ditentukan. Secara amnya, penggorengan gelombang mikro adalah satu proses pemprosesan makanan yang menarik kerana kebolehgunaannya, kemudahannya dan degradasi pengoksidaannya yang rendah.

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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

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LIST OF SYMBOLS AND ABBREVIATIONS

M	Instantaneous, initial and equilibrium moisture content (g/g, db)
M_e	Equilibrium moisture content (g/g, db)
M_0	Initial moisture content (g/g, db)
M_r	Moisture ratio $\left(\frac{M-M_e}{M_0-M_e}\right)$ dimensionless
L	Thickness of the sample (m)
K	Rate constant (s^{-1})
D_{eff}	Effective diffusivity (m^2/s)
D_0	Effective diffusivity at high liquid concentration (m2/s)
T	Time (s)
FC	Oil content (g/g)
Co	Equilibrium oil content (g/g)
exp	Exponential sign
R	Universal gas constant (0.0083143 kJ/mol K)
Ea	Activation energy (kJ/mol)
T	Absolute temperature (k)
Π	Pi (22/7)
%	Precent
g	Gram
kg	Kilogram
L	Litter
mL	Milliliter
W	Wight
V	Volume
Hz	Hertz

W	Watts
SEM	Scanning electron microscopy
CLSM	Confocal Scanning electron microscopy
AFM	Atomic force microscopy
ESEM	Environmental scanning electron microscopy
IM	Immune microscopy
LM	Light microscopy
TEM	Transmission electron microscopy
FAO	Food and Agriculture Organization
WHO	World Health Organization
FDA	Food and Drug Administration
HPLC	High performance liquid chromatography
UV	Ultraviolet
IMPI	International Microwave Power Institute
EC	European Commission
S_v	Volumetric shrinkage
V_0	Initial volume
V_t	Volume at (t) time
L	Thickness
l_0	Initial thickness
l_t	Thickness at time(t)
D	Diameter
D_0	Initial diameter
D_t	Diameter at time (t)
ρ_b	Bulk Density
ρ_p	Particle Density
ρ_w	Density of water

Ɛ	Porosity
T_m	Milting point
T_g	Transition temperature
Pa	Pascal
H	Hour
min	Minutes
s	Seconds
Σ	Stress
μ	Viscosity
ΔE	Color difference
c_p	Centipoise
mJ	Millijoule
J	Joule

CHAPTER 1

INTRODUCTION

Deep-fat frying is a food thermal processing that can be used to produce fried food products. Deep fat frying is a cooking and drying process performed by dipping food in vegetable oils at temperatures above 100 °C (Barutcu et al., 2009). Fried foods are preferred by customers due to their crispy porous structure, flavor, golden color, and distinctive taste. During the frying process, the food is fried at high temperatures (180-190 °C), leading to heavily vaporization of the water from the food, which is then removed through the surface. Consequently, the heat converts moisture within the food to steam and melts the fat within the food. The steam and fat then migrate from the interior of the food to its outer and into the oil. On the other hand, some of the frying oil is absorbed into the food that is being fried (Datta, 1999).

Frying is a complex operation that includes various physical-chemical changes, such as gelatinization of starch, crust formation, protein denaturation and moisture evaporation. The frying process affects the oxidative and hydrolytic degradation and polymerization of the oil (Suzan, 2003). Deep-fat frying has two types of processes: "traditional" atmospheric frying and vacuum frying (Armado et al., 2008). During the deep-fat frying process, heat transfer occurs through convection (in the oil mass) and conduction (inside the food) (Armando et al., 2008). The food receives the same heat treatment over its entire surface, which confers a uniform flavor and appearance. The food product is cooked in the fryer and attached to a thin layer of oil. The temperature of the fried product reduces by natural movement, and the steam pressure within the pores of the fried product decreases. This decrease in steam pressure pushes the oil to flow within the surface of the fried food product (Moreira et al., 1995, Armando et al., 2008). The advantages of deep-fat frying are an increase in palatability and acceptance by the consumer and destruction of bacteria and toxins by the heat (Tan & Che Man, 2002).

Microwave ovens are household equipment around the world, and the utilization of microwave ovens have become a necessary kitchen tool for meal preparation. Microwave heating has some advantages, including reduced energy consumption, a shorter cooking time, improved product quality, the production of distinctive microstructures and properties, and the synthesis of new material abilities (Clark et al., 2000). During microwave heating, uniform heating of the product causes moisture vaporization to occur (Ngadi et al., 2007).

Microwave frying of food products is a new method of enhancing the feature of fried foods, with less degradation of frying oils and a reduction in oil uptake (Oztop et al., 2007). During microwave frying, there is heat generation within the food because of dipolar rotation and an ionic conduction. Microwave frying is generally performed in a vessel of material that transmits microwaves. To perform frying in a microwave oven, oil at room temperature is heated to frying temperatures using microwaves. Then, the food product is put in heated oil, and frying is carried out at the wanted power level for a specified frying time (Sumnu et al., 2008).

Food safety is a matter of public concern. During the deep frying process, the chemistry that occurs in frying oil and in fried foods includes thermal and oxidative reactions involving lipids, proteins, carbohydrates and minor food constituents. Moreover, there has been an increased interest in reducing the oil amount of fried food products as a result of health concerns, as the consumption of high-fat food is a major cause for obesity. In addition, there are different studies about the toxicity of by-products that are produced during the frying process, such as acrylamide, which is formed during the heating of food products containing carbohydrates and asparagine (FAO/WHO, 2002).

Acrylamide has been categorized as a likely carcinogenic substance to humans, and national and international regulatory agencies have focused their attention on the detection of acrylamide in food items (US EPA (US Environmental Protection Agency 1994), (European Commission 2001). Since the world realised the importance of acrylamide in foods subjected to high temperatures, the studies of levels of acrylamide in microwaved-fried food products should be considering.

The most important problem in microwave frying is caused by a variety of changes in the quality of edible oils, which affect the quality of fried products at the macro and micro scales. In addition, toxic compounds that are hazardous to human health are produced during microwave frying.

In aiming to evaluate the above problems, the following information is needed. First, estimates of how different edible oils affect the quality of potato chips during microwave frying are needed. In addition, estimates of the levels of the acrylamide that pose a hazard to the health of the consumer are needed.

There is a need to understand and characterize the transfer processes that occur during microwave frying and to predict quality changes. As a consequence, the primary target of this research was to investigate the effect of microwave frying on the physicochemical properties of edible oils and the quality attributes of potato chips.

The specific purposes of this work were as follows:

i. To determine the effect of microwave frying on the physicochemical properties of edible oils.
ii. To provide the relationship between moisture loss and oil adsorption on potato chip structure and to evaluate the sensory characteristics of microwaved-potato chips.
iii. To determine the macrostructure properties and physical changes that occurs in potato chips.
iv. To study the morphological changes in microwaved-potato chips.
v. To determine the acrylamide formation that occurs in potato chips prepared by microwave frying.

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