UNIVERSITI PUTRA MALAYSIA

MICROWAVE DRYING CHARACTERISTICS OF BANANA FLESH

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PROJECT REPORT SUBMITTED IN PARTIALLY FULFILLMENT OF THE REQUIREMENT FOR THE BACHELOR OF ENGINEERING (PROCESS AND FOOD)

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ABSTRACT

Banana is the low cost of agricultural product with high sugar content and nutritional value. However, the quality of banana deteriorates rapidly after harvesting. Therefore, the microwave drying method is introduced. The purpose of this project is to investigate the effect of different microwave power levels on the drying rate curve of banana flesh, develop the drying rate curve of banana flesh dried by microwave heating and compare the physical properties of fried banana chip and microwave dried banana chip. *Musa acuminate* Colla (AA Group) 'Lakatan' banana slices with 3 mm thickness were dried using microwave at three power levels of 100, 440 and 1000 W. The time required to dry banana flesh at 100, 440 and 1000 W was 30, 7 and 4 min, respectively. The results showed that drying time decreased as microwave power increased. Drying curves obtained from the data were fitted with three different mathematical models for evaluating a suitable thin layer drying model. The page model satisfactorily represented the drying characteristics of banana flesh. Moisture diffusivity obtained varied from 1.080×10^{-6} to 1.572×10^{-6} m^2/s at different power and the activation energy was found to be 10.15 W/g. The results showed that the frying method had higher moisture content than microwave drying method. The hardness of banana sample dried by microwave at a power level of 440W was the highest (1287.26 g). In terms of colour, fried banana had a browner, duller colour than microwave dried banana. For sensory evaluation, dried banana chips using microwave at a power level of 440W were the most preferable. It can be concluded microwave dried banana chips showed better results than fried banana chips in terms of crispness, colour and sensory evaluation.

ABSTRAK

Pisang adalah kos rendah produk pertanian dengan kandungan gula yang tinggi dan nilai pemakanan. Walau bagaimanapun, kualiti pisang berkurangan dengan cepat selepas penuaian. Oleh itu, kaedah pengeringan gelombang mikro diperkenalkan.Tujuan projek ini adalah untuk megenal pasti kesan tahap kuasa ketuhar gelombang mikro yang berbeza terhadap keluk kadar pegeringan pisang, menghasilkan keluk kadar pegeringan pisang yang dikering dengan ketuhar gelombang mikro dan membandingkan sifat fizikal kerepek pisang yang digoreng dengan kerepek pisang yang dikering dengan menggunakan ketuhar gelombang mikro. *Musa acuminate* Colla (AA Group) pisang 'Lakatan' dengan ketebalan 3 mm telah dikering dengan menggunakan ketuhar gelombang mikro pada tahap kuasa 100, 440 dan 1000 W. Masa yang diperlukan untuk mengeringkan pisang pada tahap kuasa 100, 440 dan 1000 W adalah 30, 7 dan 4 minit. Keputusan menunjukkan bahawa masa pengeringan menurun dengan kuasa gelombang mikro meningkat. Keluk pengeringan yang didapati telah disesuaikan dengan tiga model matematik untuk menilai model pengeringan lapisan nipis yang paling sesuai. Model Page merupakan model yang paling sesuai untuk mengenal pasti ciri-ciri pengeringan pisang. Kelembapan pisang yang dikeringkan dengan tahap kuasa yang berlainan adalah dari 1.080 x 10^{-6} ke 1.572 x 10^{-6} m^2/s dan tenaga pengaktifan ialah 10.15 W/g. Keputusan menunjukkan bahawa kaedah penggorengan mempunyai kandungan lembapan yang lebih tinggi daripada kaedah pengeringan gelombang mikro. Keputusan menunjukkan bahawa kekerasan untuk sampel pisang yang dikeringkan oleh gelombang mikro pada tahap kuasa 440W adalah yang tertinggi (1287.26 g). Dari segi warna, kerepek pisang yang digoreng lebih perang dan gelap berbanding dengan kerepek pisang

yang dikering dengan ketuhar gelombong mikro. Untuk penilaian deria, kerepek pisang kering menggunakan ketuhar gelombang mikro pada tahap kuasa 440W adalah yang paling digemari dalam kalangan responden. Secara kesimpulannya, kerepek pisang yang dikeringkan dengan ketuhar gelombong mikro menunjukkan hasil yang lebih baik daripada kerepek pisang yang digoreng dari segi kerangupan, warna dan penilaian deria.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
AOAC	Association of Analytical Communities
DFF	Deep Fat Frying
FAO	Food and Agriculture Organization
MR	Moisture Ratio
RMSE	Root Mean Square Error

CHAPTER 1

INTRODUCTION

Chapter 1 covers on background of banana industries, background of drying process for food, problem statement, objective, scope of work and thesis outline. Section 1.1 discusses on background of banana industries and section 1.2 discusses on background of drying process for food. Section 1.3 explains on the problem that is related to the microwave drying of banana flesh. Section 1.4 detailed on objectives that are needed to achieve throughout the project. Scope of work for this project is explained in Section 1.5 and section 1.6 discusses the outline of thesis.

1.1 Background of Banana Industries

Banana is typically grown in tropical regions, Asia (continent of origin), Latin America, Caribbean countries, and Africa. The biggest producers of banana are India and China, which produced an average of 29 million tonnes and 11 million tonnes per year, respectively between 2010 and 2015 (FAO, 2017). The world production of bananas shows a significant growth between 2000 and 2015. The production grows from 68.2 million tonnes in 2000 to 117.9 million tonnes in 2015 (FAO, 2017). FAOSTAT

(2016) reported that Malaysia produces about 309508 tonnes of banana in 2016. The statistical database shows that banana is the sixth most important food crop in Malaysia after oil palm, rice, rubber, coconut and pineapple.

Banana is a low cost of agricultural product with high sugar content and nutritional value (Monteiro, Carciofi, & Laurindo, 2015). Cultivation of banana in Malaysia is mainly cultivated for consumed raw. However, the quality of bananas deteriorates rapidly after harvesting (Prachayawarakorn, Tia, Plyto & Soponronnarit, 2008). The drying process is introduced to stabilize the product by reducing its moisture content, water activity, slowing down microbial growth, enzymatic activity, and chemical reaction, extending food shelf life and reducing transportation and storage costs (Monteiro et al., 2015). This drying method creates a new range of products and increase value to fresh banana (Prachayawarakorn et al., 2008). Various value-added products are developed to overcome the problem of oversupply of banana during harvesting season.

Banana chips are one value-added products from raw banana, which can be consumed as snack. The demand of snack food in the world, including Malaysia shows an increase trend (Hamir & Mohd Ariff, 2006). Banana chips have nutritional benefits due to its high fiber content, iron and potassium. Therefore, there is market potential for the banana chip industry in Malaysia because there is a growing consumer concern towards ethnic food and healthy food. They found out that there is market potential of the banana chip industry in Malaysia since the survey shows that the banana chip industry will continue to grow in the future.

1.2 Background of Drying Process for Food

Microwave heating is applied to dehydrate the moisture content of food products in the food industry. The entire food products are heated up quickly from inside to outside by microwave penetrate deeply into the food product (Bai-Ngew, Therdthai & Dhamvithee, 2011). Hence, the water is evaporated as vapor rapidly, which results in reduction in drying time and the dried products have better rehydration characteristics as compared to convective air drying (Giri & Prasad, 2007). Their studies reported a reduction of 70-90% in the drying time of mushroom using microwave vacuum drying. The shorter drying time of microwave heating is improving the product quality.

In addition, microwave heating consumes less energy due to short drying time. Sharma and Prasad (2006) reported that the specific energy consumption in microwave drying of garlic cloves is saving about 70% of energy compared to the convective drying process. Dried products by microwave heating is healthier compared to fried products in terms of fat content. Bai-Ngew et al. (2011) found that the fat content of the durian chips is reduced by at least 90% compared with conventional deep fried durian chips. Lower fat content in the food products will extend the shelf life of the product and beneficial to human health.

In this study, microwave drying is presented as a process to produce banana chips. Based on the study of Bai-Ngew et al. (2011), the effective moisture diffusivity and drying rate are increased by increasing the microwave power intensity. A research is to be conducted to investigate the effect of different power levels on the drying rate curve of banana chips in this study. The quality of dried banana chips is affected by the drying process type. Therefore, the physical properties of dried banana chips by microwave heating and deep fat frying are considered in terms of final moisture content, colour and crispness in this study.

1.3 Problem Statement

Banana chips are normally produced by frying thin-sliced bananas with vegetable oil (Prachayawarakorn et al., 2008). Fried banana chips are crispy and highly palatable as an outcome of a crust formation (Monteiro et al., 2015). However, fried banana chips contain high fat content, which will shorten the shelf life of the product due to possible lipid oxidation leading to rancidity (Prachayawarakorn et al., 2008). Therefore, microwave drying is introduced to produce crispy banana chips.

Bananas are starch-rich fruits, which dry slower than other fruits due to their physical, chemical composition and structure (Sankat, Castaigne, & Maharaj, as cited in Pereira, Marsaioli & Ahrné, 2007). The quality of the dried products will be affected as long drying times will increase shrinkage and toughness, reduce the bulk density and rehydration capacity of the products (Pereira et al., 2007). Therefore, the drying rate of banana using microwave heating is very important to be considered. Besides that, different power levels of microwave will also influence the drying rate of the banana. Dried banana chips can have different physical characteristics in terms of crispness and colour depending on different drying method. The physical characteristics of dried products are very important since they affect the acceptability of customer towards the product.

1.4 Objective

The objectives of this research are:

i. To develop the drying rate curve of banana flesh dried by microwave heating.
ii. To investigate the effect of different microwave power levels (100W, 440W & 1000W) on the drying rate curve of banana flesh.
iii. To compare the physical properties of fried banana chip and microwave dried banana chip.

1.5 Scope of Work

The focus was given to the microwave characteristics of banana flesh in this study. Banana flesh with constant thickness of 3mm were dried at 3 different power levels (100, 440 and 1000 W). The drying profile of microwave dried banana chips at varying power levels was determined to investigate the effect of different power levels on the drying profile of banana chips. The physical properties of microwave dried banana chips were compared to fried banana chips by determining final moisture content, crispness and colour. Sensory evaluation of banana chips with different drying treatments were carried out. The physical properties were compared between microwave dried banana and deep-fat fried banana to determine the effect of different drying treatment on physical properties of banana chips.

1.6 Thesis Outline

There are five chapters included in the thesis. The thesis is focused on the microwave drying characteristics of banana flesh. Chapter one is the introduction of the research, which covers the background, problem statements, objectives, scope of work and thesis outline. In chapter two, literature review of previous work about drying methods of fruit and the properties of the fruit that affected by different drying methods are discussed in this chapter. Chapter three consists of the methodology of the research, which included the methods used to prepare banana chips and to carry out physical properties analysis. The results and discussion of the research are presented in chapter four. Last but not least, chapter five covers the conclusion and recommendation.

CHAPTER 2

LITERATURE REVIEW

2.1 Banana

Banana is a very popular fruit in the world that mostly grown in the tropical and subtropical areas and has a center of origin from South-East Asia. Banana fruit is parthenocarpic berries, which consists of peel and edible pulp (Singh et al., 2016). It is the fifth important agricultural crop after coffee, cereals, sugar and cocoa in terms of its economic value (Aurore, Parfait, & Fahrasmane, 2009). There are more than 300 types of bananas are cultivated throughout the world. Bananas are grouped according to the number of chromosome sets present and the proportion of the genomes of *M. acuminata* (A) and *M. balbisiana* (B) (Singh et al., 2016). There are diploid, triploid and tetraploid genome groups. The main genomes groups are AB, AA, AAA, BBB, AAB, ABB and AAAB (Stover & Simmonds, 1987). Dessert banana cultivars are AA or AAA which is usually eaten raw whereas plantains or cooking banana contain the AAB, ABB or BBB genomes (Singh et al., 2016).

2.1.1 Health Nutrition of Banana

Banana is high in nutritional value, which consists several bioactive compounds, such as phenolics, carotenoids, biogenic amines and phytosterols (Singh et al., 2016). Singh's research (2016) found that banana with the presence of bioactive compounds has higher antioxidant activities compared to some berries, herbs and vegetables. Banana pulp contains high antioxidant activities with the presence of dopamine, dopa, carotenes, norepinephrine and ascorbic acid (Singh et al., 2016). These antioxidants retard aging, prevent coronary heart diseases, cancer and neurodegenerative disorders. The uses and health benefits of bioactive compounds present in banana is shown in Table 2.1. In addition, high content of potassium in banana is beneficial for the muscles. Banana also consists of high iron content which beneficial in controlling blood pressure.

Table 2.1: Uses and health benefits of bioactive compounds present in banana.

Compound	Uses and health benefits	Source
Syringic acid	Can be potentially used to ameliorate glycoprotein components abnormalities and has an antidiabetic effect in experimental diabetes.	Muthukumaran, Srinivasan, Venkatesan, Ramachandran, and Muruganathan (2013)
Tannic acid	Applied as medicinal agents for the treatment of burns.	Siang (1983)
Catechol	Used as a a developer for fur dyes, photographic developer, in polymerization inhibitors, and in pharmaceuticals, as an intermediate for antioxidants in lubricating oils and rubber.	USDA (1993)
Catechin	Resistance of LDL to oxidation, brachial artery dilation increased plasma antioxidant activity and fat oxidation.	Williamson and Manach (2005)

Gallic acid	Antioxidant and potential hepatoprotective effects.	Rasool et al. (2010)
Cinnamic acid	Is a precursor to the sweetener aspartame by the means of enzyme catalyzed amination to phenylalanine.	Garbe (2000)
ρ-Coumaric acid	Antioxidant properties and potentially reduce the risk of stomach cancer.	Ferguson, Zhu, and Harris (2005)
Gallocatechin gallate	Cholesterol reduction.	Ikeda et al. (2003)
Quercetin	Promotes overall cardiovascular health by encouraging blood flow.	Perez-Vizcaino and Duarte (2010)
Ferulic acid	Antioxidant, antimicrobial, antiinflammatory, antiallergic, anticarcinogenic, modulation of enzyme activity, antiviral and vasodilatory actions.	Kumar and Pruthi (2014)
Trans-α carotene	Precursor to vitamin A.	Li et al. (2011)
Trans-β carotene	Reduce the risk of CVD and cancer.	Li et al. (2011)
Violaxanthin	Used as a food colorant.	Li et al. (2011)
Neoxanthin	Intermediate in the biosynthesis of the plant hormone abscisic acid.	Bouvier, D'Harlingue, Backhaus, Kumagai, and Camara (2000)
Isolutein	Food colorant and vitamin A precursor.	DeLorenze et al. (2010)
Cryptoxanthin	Food colorant, might reduce the risk of lung cancer.	DeLorenze et al. (2010)
Serotonin	Might contributes to feelings of well-being and happiness.	Young (2007)
Dopamine	Reduce the plasma oxidative stress and enhance the resistance to oxidative modification of LDL.	Yin, Quan, and Kanazawa (2008)
Catecholamines	Increases blood pressure, glucose levels	Kuklin and Conger (1995)

	and heart beat rate.	
β-Sitostero	Potential to reduce blood cholesterol levels and benign prostatic hyperplasia (BPH).	Wilt et al. (1999)
Campesterol and stigmasterol	Reduces the absorption of cholesterol in the human intestines.	Choudhary and Tran (2011)
Cycloartenol	First precursor in biosynthesis of steroids in plants.	Schaller (2003)

2.1.2 Consumption of Bananas and Their Processed Products

Banana can be eaten raw as a dessert and sweet fruit or in other consumption forms such as fried, roasted, dried or juiced. The mature dessert banana is primarily consumed in its natural state, raw while the unripe banana is cooked prior to consumption. Banana can be presented in other forms; so that it can be utilized for other purposes and stored for longer time. For example, banana chip (Monteiro et al., 2016; Pan, Shih, McHugh, & Hirschberg, 2008; Pereira et al, 2007), banana juice (Bora, Handique, & Sit, 2017), banana puree (Yap, Fernando, Brennan, Jayasena, & Coorey, 2017) and banana flour (Bi et al., 2017). The industrial processing of bananas is under-developed and the suitability of different types of processing of banana should be investigated to achieve better use of bananas (Aurore, Parfait & Fahrasmane, 2009).

2.2 Drying Methods

Dehydration process has been widely used in chemical and food processing industries in order to preserve the final products for a long period. The objective of drying process is to remove the water from solids to a level at which microbial spoilage is prevented.

2.2.1 Microwave Drying

Microwaves are electromagnetic waves with the frequency varies from 300 MHz to 300 GHz (Chandrasekaran, Ramanathan, & Basak, 2013). The lower the frequency of the electromagnetic waves indicates the better the penetration of the wave into the product. Microwave drying is widely used in the food industry because of its significant reduction in drying time and energy consumption (Guo, Sun, Cheng, & Han, 2017). In addition, microwave drying technology is suitable for drying heat-sensitive materials, for example, fruit and vegetable (Hu et al., 2006). Several research reported that microwave drying technology is applied on banana (Mui, Durance, & Scaman, 2002; Pereira et al., 2007), durian (Bai-Ngew et al., 2011; Paengkanya, Soponronnarit, & Nathakaranakule, 2015), garlic cloves (Sharma et al., 2006) and apple (Sham, Scaman, & Durance, 2001; Zarein, Samadi & Ghobadian, 2015).

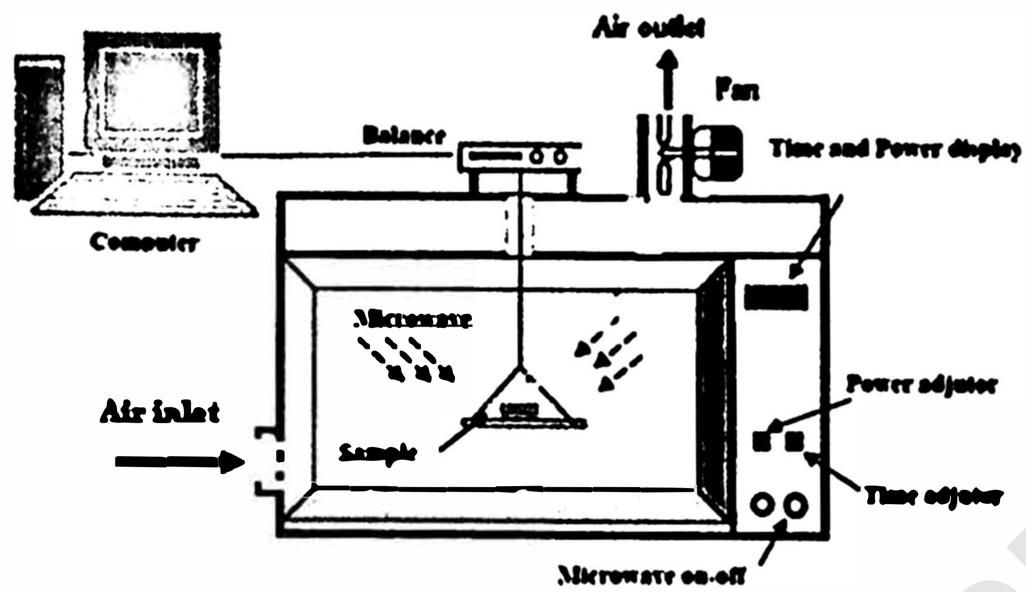

Figure 2.1: A schematic diagram of microwave–convective oven dryer (Zarein et al., 2015).

2.2.2 Effect of Power Level on Drying Rate

Zarein's (2015) research investigated the microwave dryer effect on energy efficiency during drying of apple slices. The drying experiments were carried out at 200, 400 and 600 W. Their results showed that the microwave drying period of samples lasted between 25 and 4.25 min at 200 and 600W respectively. Their research reported that the highest energy efficiency was recorded for the samples dried at 600 W as 54.34% and lowest at 200 W as 17.42%.

Based on study of microwave drying characteristics of spinach, Spinach leaves (*Spinacia oleracea* L. cv. ''Meridian'') with 50 g weight and 9.01 humidity on dry basis were dried in microwave oven using eight different microwave power levels ranging between 90 and 1000 W, until the humidity fell down to 0.1 on dry basis (Ozkan, Akbudak & Akbudak, 2007). The study showed that microwave drying period of spinach leaves lasted between 290 and 430 s at the microwave powers at 1000 and 500 W, respectively, while the energy consumption was constant (0.12 kWh).

There is study conducted on convective and microwave drying characteristics of sorbus fruit (Lüle, & Koyuncu, 2015). Samples of sorbus fruit were dehydrated at three different microwave power levels of 90, 160 and 350W. The results showed that the microwave drying period lasted between 200 and 1000 min for different power levels ranging from 90 to 350 W.

The effective moisture diffusivity of foods increased as microwave power levels increased (Guo et al., 2017). Several studies have been conducted as shown in Table 2.2. Hence, the higher the microwave power level results in shorter microwave drying period. Microwave drying technology consumes less energy compared to other drying methods.

Table 2.2: Effective moisture diffusivity of foods during microwave drying.

Material	Power (W)	D_{eff} (m^2/s)	Change	Simulation model	R^2	References
Bamboo shoot slices	140-350	4.153×10^{-10}-22.835×10^{-10}	↑	Wang and Singh model	0.985	Bal et al. (2010)
Sardine fish	200-500	7.158×10^{-8}-3.408×10^{-7}	↑	Midilli et al. model	0.999	Darvishi et al. (2013)
Purslane leaves	180-900	5.913×10^{-11}-1.872×10^{-10}	↑	Midilli et al. model	0.997	Demirhan and Ö zbek (2010)
Onion slices	328-557	2.59×10^{-7}-2.27×10^{-6}	↑	Page model	0.995	Demiray, Seker, and Tulek (2016)
Apple slices	200-600	3.93×10^{-7}-2.27×10^{-6}	↑	Midilli et al. model	0.999	Zarein et al. (2015)
Green Bean Slices	180-800	1.387×10^{-8}-3.724×10^{-8}	↑	Midilli et al. model	0.999	Doymaz, Kipcak, and Piskin

						(2016)
Olive pomace	170-510	3.55×10^{-9}- 20.47×10^{-9}	↑	Midilli et al. model	0.999	Sadi and Meziane (2015)

'↑' means that with the increase in microwave power, D_{eff} increases accordingly.

2.2.3 Mathematical Modelling

In mathematical modelling of fruit drying, the mathematical equation is used to predict the behavior of the operation (Wang et al., 2007). Semi-theoretical equations are used for the models under the concept of thin layers.

2.2.3.1 Newton Model

The Newton model is initially used to fit the experimental date of the drying kinetics due to its simplicity. It is assumed that there occurs negligible internal resistance, there is no resistance to moisture movement from within the interior of the material out to the surface of the material (Lewis, 1921). The drying rate of the material is proportional to the difference in the moisture content between the drying material and equilibrium moisture content at the drying air condition. This model is represented in (Eq. (1)).

$$MR = \exp(-kt) \tag{1}$$

where, k is the constant of the model following an Arrhenius expression and t is the time.

2.2.3.2 Page Model

The Page model is the modification of the Newton model by introducing a new coefficient affecting time (Avhad & Marchetti, 2016). The modifications were suggested to correct some shortcomings. Two empirical constants were suggested in this model. The Page model is written in (Eq. (2)).

$$MR = \exp(-kt^n) \tag{2}$$

where, k and n are the constants of the model. k follows an Arrhenius expression and t is the time.

2.2.3.3 Henderson and Pabis Model

The Henderson and Pabis model is also considered as a bi-parametric exponential model (Iguaz et al., 2003). This model is derived from a general series solution of Fick's second law. Coefficient k is related to the effective moisture diffusivity when the drying process occurs only in the falling rate period and liquid diffusion control process (Avhad et al., 2016). The Henderson and Pabis Model is represented in (Eq. (3)).

$$MR = a \cdot \exp(-kt) \tag{3}$$

where, k is the constant of the model following an Arrhenius expression and t is the time.

2.2.4 Deep-Fat Frying

Deep-fat frying is one of the most popular methods to prepare foods due to its short, easy preparation and the attractive taste of the products (Koerten et al., 2015). In deep-fat frying process, the surface temperature of the food increases rapidly when the addition of the food to the hot oil (Mellema, 2003). The increase of surface temperature results the water at the surface starts to boil quickly. As the boiling process starts, the convetion will be further intensified by the turbulent water vapour. Hence, surface drying will occur due to evaporation. The food will become heated and will be cooked as water deep inside the food.

2.3 Physical Properties of Dried Banana

The quality of dried product will be affected by the drying process. Therefore, physical properties of dried banana are evaluated in this study.

2.3.1 Moisture Content

The rates of shrinkage and colour change will be affected by the moisture content in the food (Amjad, Crichton, Munir, Hensel, & Sturm, 2017). Hence, exact estimation of the moisture content is very important to develop effective relationship between quality attributes and moisture content of the product during the drying process in order to achieve optimization of the drying process (Amjad et al., 2017).

2.3.2 Crispness

Szczesniak and Skinner (1973) described that "Crispness appears to be the most versatile single texture. It is particularly good as an appetizer and as a stimulant to active eating. It is not notable as a relaxing or satiable texture. It appears to be universally liked and is often used as a very popular accent-contributing or dramatizing characteristic. Crispness is very prominent in texture combinations that mark excellent cooking and is nearly synonymous with freshness and wholesomeness."

Zhang et al. (2007) found that increased microwave power could increase the expansion ratio and crispness of the fish slices, and then improve the sensory quality of the finished products. Bai-Ngew et al. (2011) reported that the hardness of microwave vacuum-durian chips was in the same range as that of conventionally fried durian chips.

2.3.3 Colour

The colour measurement is carried out by measuring CIE chromaticity coordinates (L*, a* and b*) to give an indication of the degree of discolouration occurring (Pereira et al., 2007). The study reported that there is no effects were observed on the colour of the dried banana (Pereira et al., 2007). The results indicated that product quality in terms of colour was not strongly affected by processing parameters such as microwave power. Bai-Ngew et al. (2011) reported that using different levels of microwave power had no significant effect on lightness (L* value) and yellowness (b* value) of the microwave vacuum-dried durian chips, however redness (positive a* value) of dried durian chips was clearly observed when the levels of microwave powers was increased.

CHAPTER 3

METHODOLOGY

In this chapter, materials, equipment and methodology used for experimental research were discussed. Section 3.1 introduced the methodology of the experimental research. Section 3.2 explained the preparation of banana slices. Section 3.3 explained the microwave drying method to dry banana slices and Section 3.4 described the drying characteristics of banana flesh. Drying profile, mathematical modelling and effective moisture diffusivity were included in this section. Section 3.5 explained the step to deep-fat fry banana chips. The methods used to determine the physical properties of banana chips were presented in Section 3.6, 3.7 and 3.8. Last but not least, Section 3.9 described the statistical analysis used to analyze results from sensory evaluation test.

3.1 Introduction

The bananas (*Musa acuminate* Colla (AA Group) 'Lakatan') were purchased from the local market and sliced into constant thickness of 3mm. Banana slices were dried using microwave heating at three different power levels. The physical properties of microwave dried banana and deep-fat fried banana in terms of moisture content, colour and crispness were measured and compared.

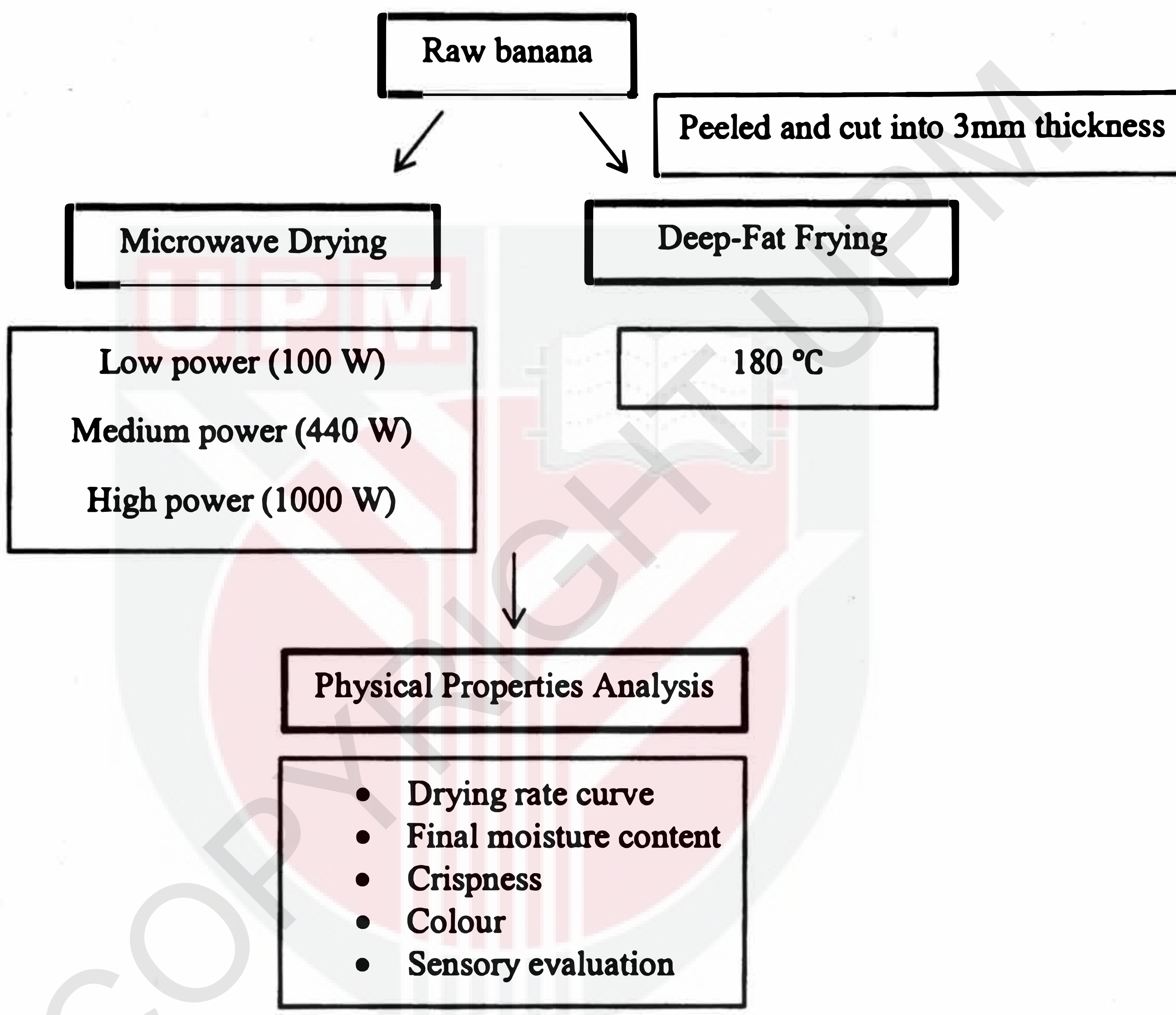

Figure 3.1: Flow Chart of Project Work.

3.2 Material Preparation

Ripe but firm *Musa acuminate* Colla (AA Group) 'Lakatan' bananas were purchased from the local market. They were chosen on the basis of their peel colour (yellow but still green on the stem) (Pereira et al., 2007). These bananas were hand peeled and cut into slices of 3mm of thickness with a two fixed blades cutter, rejecting fruit ends, where the diameter were smaller (Monteiro et al., 2016). The initial weight of banana slice was measured using an electronic balance model AY220 (Shimadzu, Japan).

Figure 3.2: Musa acuminate Colla (AA Group) 'Lakatan' bananas.

Figure 3.3: Electronic balance model AY220 (Shimadzu, Japan).

3.3 Microwave Drying

Banana slice was dried at three different level of microwave power 100W (low level), 440W (medium level) and 1000W (high level) using commercial microwave oven model NN-C2003S (Panasonic, Malaysia). The weight loss of the banana slice was measured every 5 minutes, 1 minute and 20 second intervals for low, medium and high power level respectively using an analytical balance model AY220 (Shimadzu, Japan). Drying process was continued until the weight does not change between the two weighing intervals. All measurements were carried out in triplicate. The drying characteristics examined were detailed in the following Section 3.4.

Figure 3.4: Microwave oven model NN-C2003S (Panasonic, Malaysia).

3.4 Drying Characteristics

The drying characteristics of the banana flesh were studied using drying profiles, established semi-theoretical drying models, moisture diffusivities and activation energies.

3.4.1 Drying Profile

The drying profile used in this study was drying curve and drying rate curve plotted against the free moisture content, X and time. Free moisture content, X, (Eq. (3)) refered to the water loss at a particular time in dry solids.

$$X = X_t - X^* \tag{3}$$

where X_t was the moisture content at time (t) in drying time was calculated using (Eq.(4)) and X^* was equilibrium moisture content (kg equilibrium moisture kg dry solid^{-1}):

$$X_t = \frac{W - W_s}{W_s} \tag{4}$$

where W is weight of the wet solid in (kg) and W_s is weight of dry solid in (kg).

3.4.2 Mathematical Modeling

Three thin layer drying models (Table 3.1) were investigated to find the most suitable one to describe the drying characteristics of banana flesh. In these models, the moisture ratio was simplified to M/M_0 instead of $(M - M_e)/(M_0 - M_e)$ since the values of M_e are relatively small compared to M_t and M_0 (Akgun and Doymaz, 2005).

Table 3.1: Mathematical models applied to the moisture ratio values.

No.	Model name	Model	References
1	Newton	$MR = \exp(-kt)$	Motevali et al. (2010)
2	Page	$MR = \exp(-kt^n)$	Motevali et al. (2010)
3	Henderson and Pabis	$MR = a \cdot \exp(-kt)$	Chhinnan (1984)

The statistical parameters used to select the best model were correlation coefficient (R^2) and root mean square error ($RMSE$) between the experimental and predicted moisture ratio values. These parameters were calculated as given below (Ertekin and Yaldiz, 2004):

$$R^2 = 1 - \frac{\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2}{\sum_{i=1}^{N}(\overline{MR}_{pre,i} - MR_{exp,i})^2} \quad (5)$$

$$RMSE = \left(\frac{\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2}{N}\right)^{\frac{1}{2}} \quad (6)$$

where MR_{exp} is the experimental dimensionless moisture ratio, MR_{pre} is the predicted dimensionless moisture ratio, N is the number of experimental data points, and z is the number of parameters in the model. The model was said to be good if R^2 value was high and RMSE values were low (Ertekin and Yaldiz, 2004).

3.4.3 Effective Moisture Diffusivity

The diffusion coefficients are typically determined by plotting experimental drying data in terms of ln(MR) versus drying time (t), because the plot gives a straight line with a slope as (Tü tü ncü and Labuza, 1996):

$$k = \frac{\pi^2 D_{eff}}{4L^2} \quad (7)$$

where D_{eff} is the effective diffusivity (m^2/s), and L is the half-thickness of samples (m).

Activation energy is assumed as related to effective moisture diffusion and the ratio of microwave output power to sample weight (m/p) since temperature is not precisely measurable inside the microwave oven as activation energy is modified from the revised Arrhenius equation (Zarein et al., 2013). Activation energy of the material is determined as follows (Özbek and Dadali, 2007):

$$D_{eff} = D_0 \exp(-\frac{E_a m}{P}) \quad (8)$$

where E_a is the activation energy (W/g), m is the mass of raw sample (g), D_0 is the pre-exponential factor (m^2/s) and P is the microwave power (W).

3.5 Deep-fat Frying

Deep fat frying (DFF) was performed in a deep fryer model FDF 1002 (Faber, Italy). The unit was filled with Daisy corn oil, made from pure corn oil. The oil temperature for frying was 180 °C and samples were fried between 45 and 120 s (Xu & Kerr, 2012). Six pieces were fried per batch and the temperature was maintained within 5 °C during frying (Xu & Kerr, 2012). The fried samples were cooled at 20 °C and packaged in sealed bags.

Figure 3.5: Deep fryer model FDF 1002 (Faber, Italy).

3.6 Final Moisture Content

The final moisture contents of the banana slices were determined according to the oven drying method to dry samples at 105 °C for 3h (AOAC, 1995; Zhang, Ding, & Gu, 1998). The initial weight and final weight of the sample were measured by using an analytical balance model AY220 (Shimadzu, Japan). The measurements were carried out in triplicate. The final moisture content was calculated as in (Eq.(8)).

$$X = \frac{W - W_s}{W_s} \quad (9)$$

where W is initial weight of the sample before drying in (kg) and W_s is final weight of sample after drying in (kg).

3.7 Crispness

The texture characteristics of the banana chips were measured using a texture analyser model TA.XT Plus (Stable Micro Systems, UK) fitted with a spherical probe (P/ 0.25). The pre-test speed was 1.0mm/s, test speed was 1.0 mm/s, post-test speed was 10.0 mm/s with a travel distance of 3 mm. Each sample was randomly selected from the bag just prior to testing, and placed centrally on the sample holder. A force–displacement curve was recorded and analysed by the software of Texture Exponent 32 (Surrey, UK) to calculate the peak force, which reflects the firmness of the material. Test results were obtained from three replicate samples of each treatment group of microwave drying and deep-fat frying respectively.

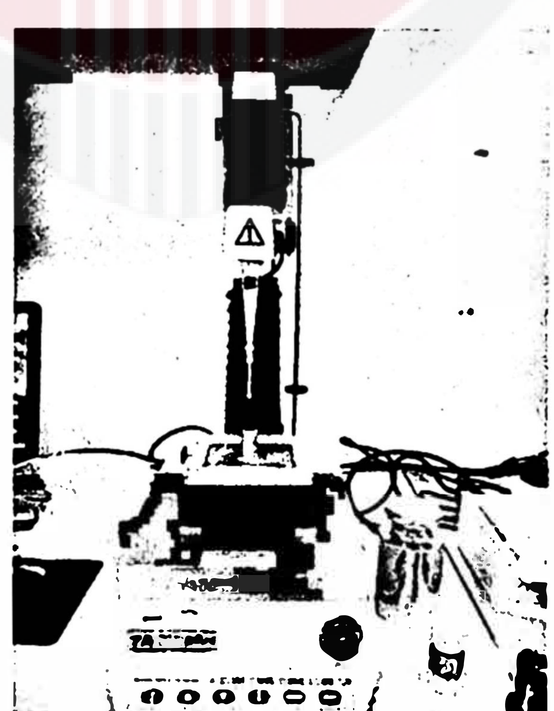

Figure 3.6: Texture analyzer model TA-XT Plus (Stable Micro Systems, UK).

3.8 Colour

A color spectrophotometer model UltraScan PRO (HunterLab, United States) was used to measure the color of chips. Six samples from each treatment group were used for evaluation. The color was measured from samples of microwave drying and deep-fat frying. Color was reported as lightness (L*), redness (a*) and yellowness(b*).

Figure 3.7: Color spectrophotometer model UltraScan PRO (HunterLab, United States).

3.9 Sensory Evaluation

Untrained panelists (40) were recruited from students at the University Putra Malaysia (UPM). In sensory trials, panelist were asked to determine consumer likability of select chips. They were asked to evaluate 4 samples: microwave dried banana chips (3 samples at 3 different power levels) and deep-fat fried banana chips. Crispness, appearance, aroma and overall acceptability were assessed using a 9-point hedonic scale (Xu & Kerl, 2012). (Scale 1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like or dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, 9 = like extremely). During preparation, four banana chips from each of the four drying treatments were placed in a lid-closed small plastic container by labelling three random digit code (Mui, Durance, & Scaman, 2002). Panelists were asked to bring the container to their noses, remove the container lid, take three sniffs, and evaluate and record the aroma intensity of the chip samples using the sensory score sheet (Mui et al., 2002). After that, the panelists were asked to take a bite through the samples with their front teeth to evaluate the crispness (Sham, Scaman, & Durance, 2001). Panelists were provided spring water to cleanse their palates between samples (Mui et al., 2002).

3.10 Statistical Analysis

Sensory evaluation was statistically analyzed by an analysis of variance (ANOVA) and followed by Tukey's test to determine differences amongst the treatment groups (Xu et al., 2012). Statistical significance was expressed at the $p < 0.05$ level (Xu et al., 2012).

CHAPTER 4

RESULTS AND DISCUSSION

This chapter shows the results obtained from experiment and discussion on the microwave drying characteristics of banana flesh. Section 4.1 discusses on the drying characteristics of banana chips at varying power levels. Section 4.2 discusses on the final moisture content of banana chips. Next, Section 4.3 shows the crispness of banana chips at different drying treatments and Section 4.4 shows the colour of banana chips. Lastly, sensory evaluation is discussed in Section 4.5.

4.1 Drying Characteristics

4.1.1 Drying Profile

Figure 4.1 shows the drying curve for banana flesh under microwave drying, where the moisture content of the samples at varying microwave power levels (100W, 440W, 1000W). The moisture content of banana samples decreased exponentially with the drying time for all different microwave power levels. The time required to dry the moisture content of banana samples to obtain a constant weight between the two weighing intervals was 30, 7 , 4 min at 100, 440 and 100W, respectively. The results showed that drying time significantly affected by microwave power level. The highest power level of 1000W consumed the shortest drying time, which was 4 min. At higher power level, due to quick removal of moisture, the drying time was less. The results indicated that mass transfer within the sample was more rapid for higher microwave power heating. This is due to more heat was generated within the sample creating a large vapor pressure difference between the center and the surface of the product due to characteristic of microwave volumetric heating (Zarein et al., 2013). This agreed with other studies, including those on durian (Bai-Ngew et al., 2010), apple (Zarein et al., 2013), sorbus fruit (Lüle et al., 2015) and mushroom (Giri et al., 2005).

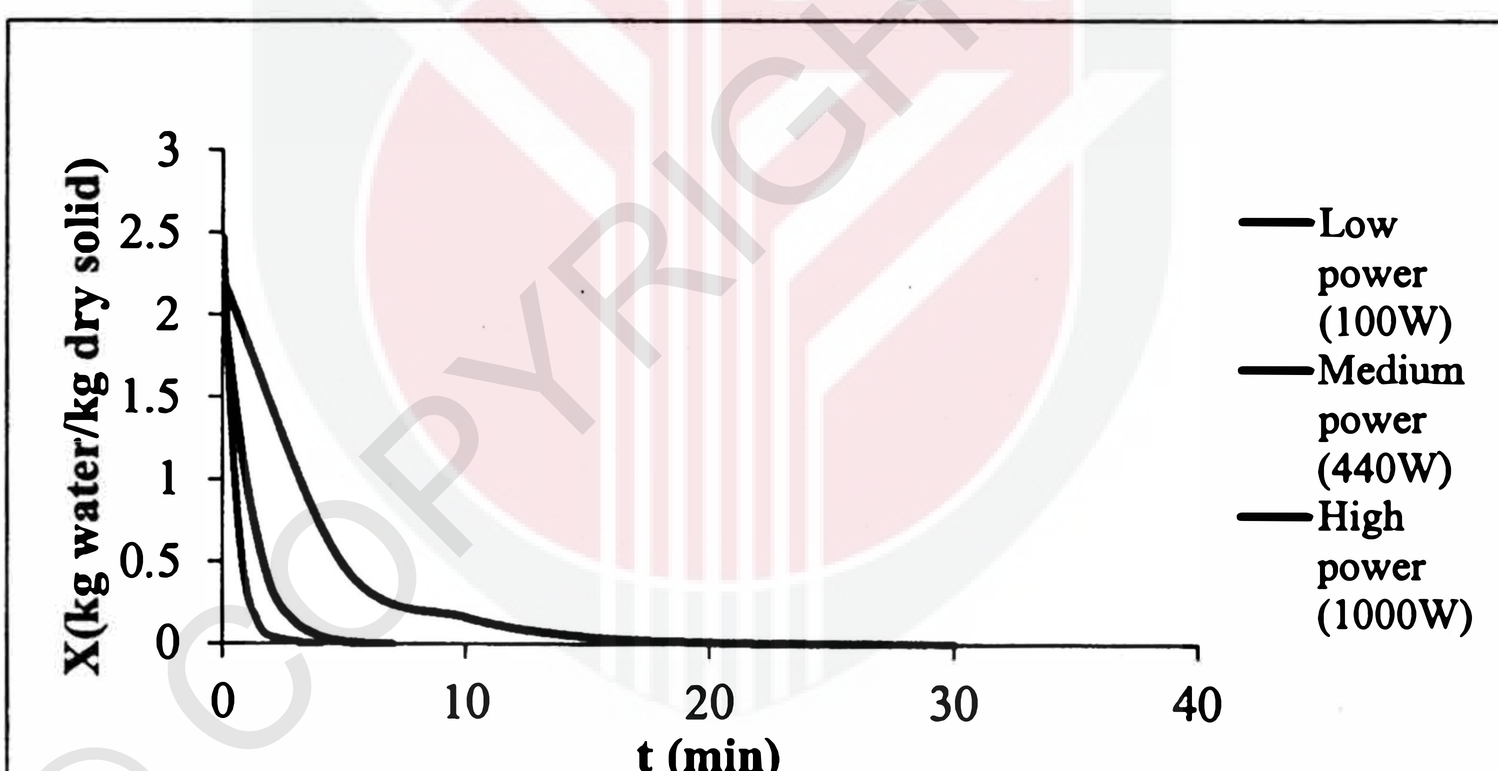

Figure 4.1: Drying curve for banana flesh at varying power levels (100W, 440W, 1000W).

Figure 4.2 showed the drying rate curve of banana flesh at different microwave power levels. The results indicated that there were no constant rates drying oberseved in this study because of the thin layer thickness of the banana sample and too rapid heating by microwaves. The highest drying rate for banana samples was 0.0946, 0.975 and 4.270 kg water/ kg dry solid.min for 100, 440 and 1000W, respectively. It can be seen that the higher drying rates were obtained with higher microwave power. After reaching the maximum drying rate, the drying rate started to decrease. The amount of microwave energy absorbed by the sample depended on its dielectric properties and the electric field strength (Mudgett, 1990). The sample absorbed more microwave power and drying process was faster for sample with higher moisture content as the values of dielectric constant and loss factors were higher. The drying rate experienced falling rate period as drying progresses due to the loss of moisture in the product which resulted decreasing of absorption of microwave power (Kharaisheh, Cooper, & Magee, 1995; Sharma & Prasad, 2001).

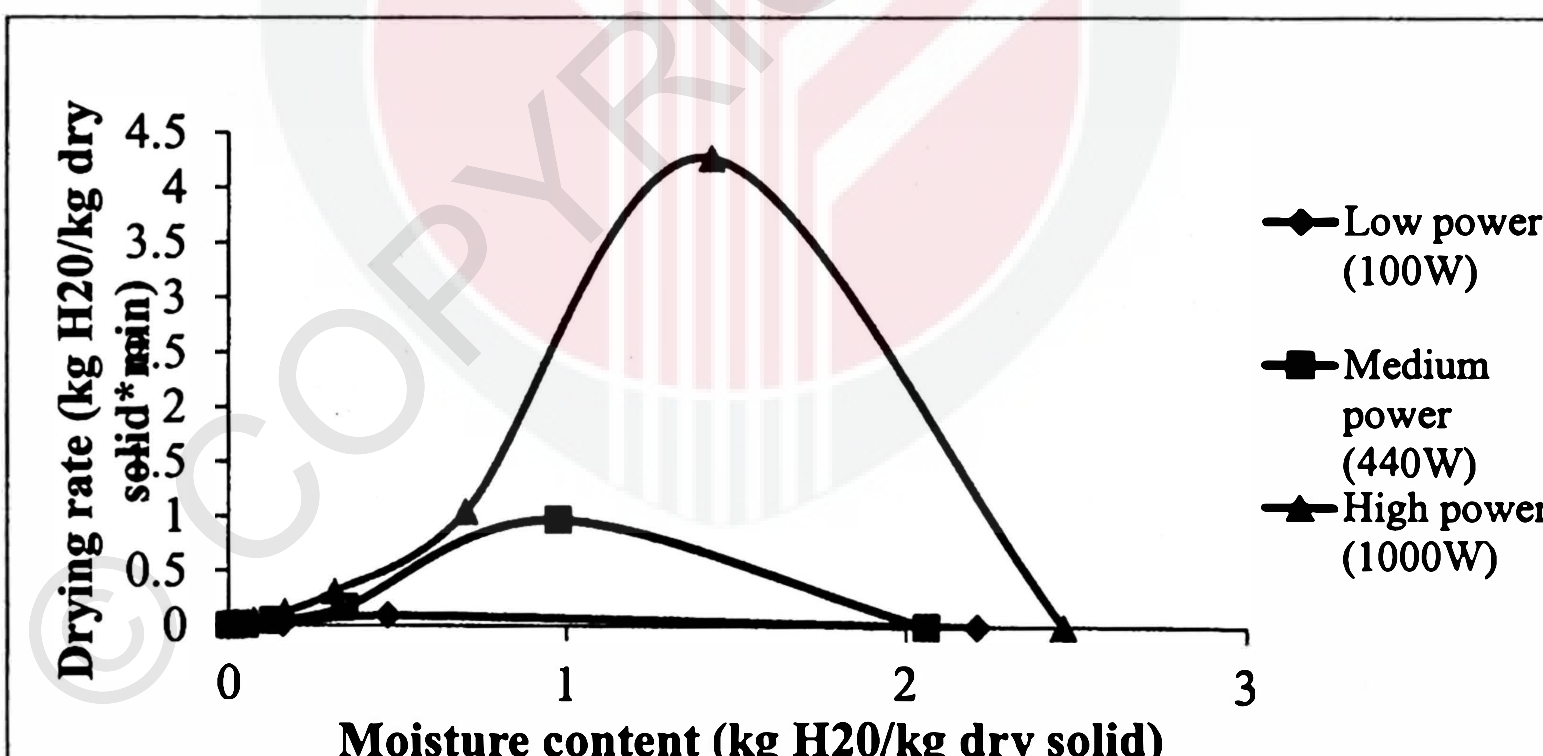

Figure 4.2: Drying rate curve of banana flesh at varying power levels (100W, 440W, 1000W).

4.1.2 Mathematical Modeling

The moisture ratio of banana flesh was fitted in three models and the results of statistical analysis were shown in Table 4.1. From the results, the drying rate, *k* increased as the microwave power levels increased. This can be observed in Newton, Page and Henderson and Pabis models. The drying rate constant increased from 0.298, 0.4211 and 0.2977 min^{-1} to 1.8717, 1.9956 and 1.8936 min^{-1} in Newton, Page and Henderson and Pabis models respectively as the microwave power levels increased. Similar observations were reported for apple slices (Zarein et al., 2013), rambutan seed (Ahmad et al., 2018) and spinach leaves (Ozkan et al., 2005).

In all cases, the value of R^2 was greater than 0.90 which indicated a good fit. (Madamba et al., 1996). The model was said to be good if R^2 value was high and RMSE values were low (Ertekin and Yaldiz, 2004). In all microwave power levels, Page model was concluded to be the best model based on its highest values of R^2 and lowest values of $RMSE$. As it was seen, the R^2 and $RMSE$ values for Page model ranged from 0.9910 to 0.9965 and 0.0028 to 0.0055, respectively. It may be assumed that Page model represented the thin layer drying behavior of banana flesh. Similar results were obtained for microwave-vaccum and convective hot-air dried mushroom (Giri et al., 2005), microwave drying of spinach leaves (Ozkan et al., 2005), microwave vacuum-dried durian chips (Bai-Ngew et al., 2010) and microwave drying of rambutan seed (Ahmad et al., 2018).

Table 4.1: Values of parameters for respective models at different microwave power levels.

Power (W)	Models	Constant parameters			R^2	$RMSE$
		$k\ (min^{-1})$	n	a		
100	Newton	0.2980			0.9941	0.0109
	Page	0.4211	0.8046		0.9910	0.0028
	Henderson and Pabis	0.2977		0.9986	0.9941	0.0109
440	Newton	0.8304			0.9855	0.0190
	Page	0.7546	1.2080		0.9937	0.0043
	Henderson and Pabis	0.8362		1.0092	0.9855	0.0187
1000	Newton	1.8717			0.9879	0.0218
	Page	1.9956	1.1613		0.9965	0.0055
	Henderson and Pabis	1.8936		1.0139	0.9879	0.0149

4.1.3 Effective Moisture Diffusivity

The determined values of effective moisture diffusivity (D_{eff}) for different microwave power levels were represented in Figure 4.3. The results showed that the moisture diffusivity increased from 1.080 x 10^{-6} to 1.572 x 10^{-6} m^2/s as microwave power levels increased. This can be explained that the activity of the water molecules increased by increased heating energy which leading to higher moisture diffusivity when banana samples were dried at higher power level (Zarein et al., 2013). Similar trends showed in microwave vacuum-dried durian chips (Bai-Ngew et al., 2010) and microwave drying of apple slices (Zarein at al., 2013) from previous studies. However, the moisture diffusivity decreased slightly to 9.995×10^{-7} m^2/s at power level of 440W. This was due to the bound water molecules presented inside the banana flesh structure which lead to the low moisture diffusivity.

The activation energy was calculated by plotting $\ln(D_{eff})$ versus m/P as presented in Figure 4.4. Hence, the dependence of the effective diffusivity of banana samples on microwave power can be represented by the following equation:

$$D_{eff} = 1.317 \, x \, 10^{-6} \exp(-10.15 \frac{m}{P}) \qquad (10)$$

The activation energy for banana samples was found to be 10.15 W/g.

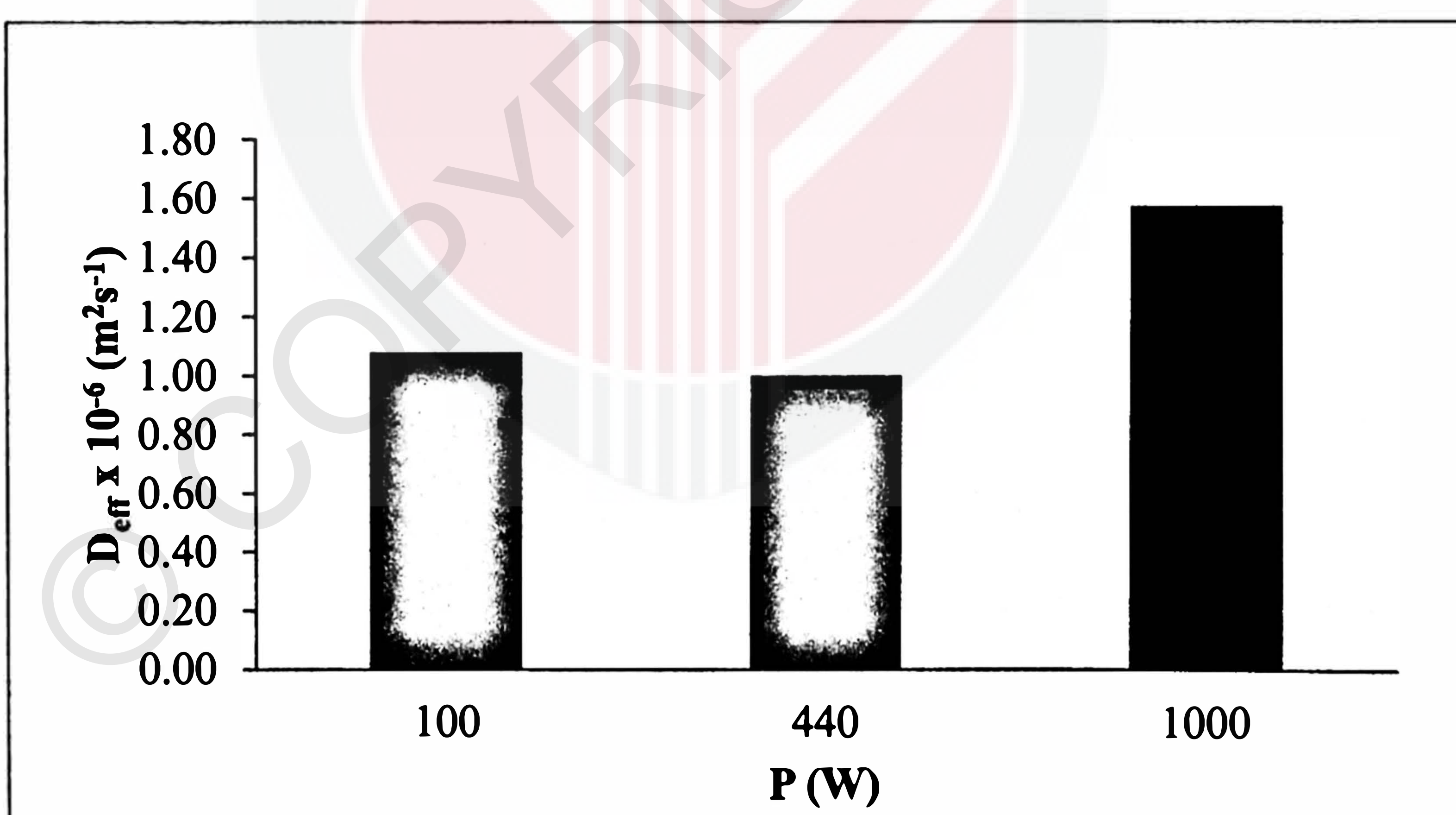

Figure 4.3: Moisture diffusivity at different power (100, 440 and 1000W).

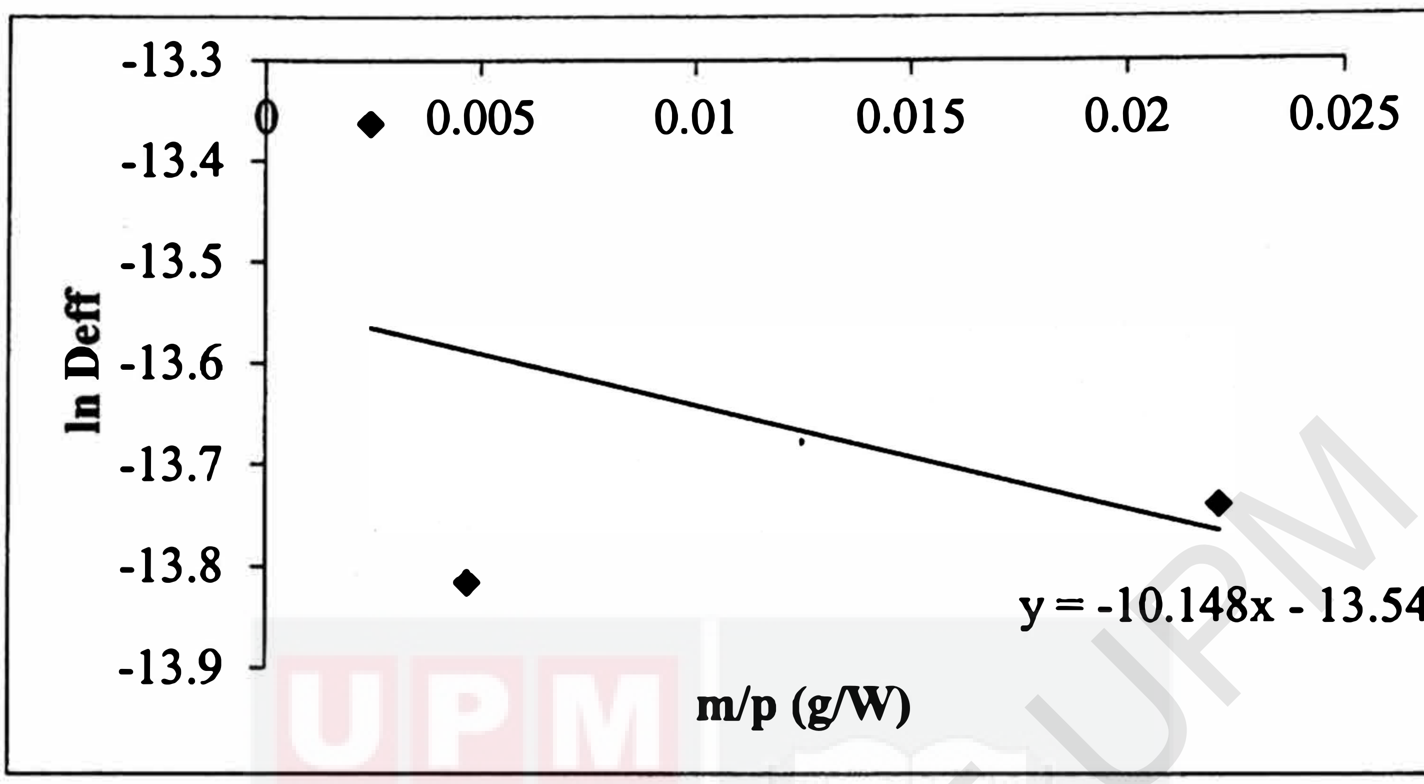

Figure 4.4: Arrhenius-type relationship the values of ln (D_{eff}) versus sample amount/power.

4.2 Final Moisture Content

Figure 4.5 showed the final moisture content at different power levels and drying treatment. For microwave drying method, the final moisture content of banana samples decreased with increasing power levels. The final moisture content of the samples were 0.005942, 0.002459, 0.004306 kg water/ kg dry solid for power level of 100, 440 and 1000W, respectively. Power level at 440W had the lowest final moisture content among three different power levels. The highest power level will increase the water evaporation by increasing the collision between the molecules and thus giving a lower value of final moisture content. However, the highest power level did not gave lowest final moisture content in this study. This may due to the shortest drying time for the highest power level. The water molecules in the sample did not absorb enough energy to evaporate from the sample in this case.

The frying method showed the highest final moisture content if compared to microwave drying method. During frying, heat and moisture transfer process were occurring simultaneously, where moisture leaves the food in the form of vapour; while oil was absorbed simultaneously (Liu-Peng et al. 2005). The evaporation of water molecules in frying process was slower if compared to microwave drying process. Hence, the final moisture content of banana sample was 0.03662 kg water/kg dry solid in which the highest final moisture content.

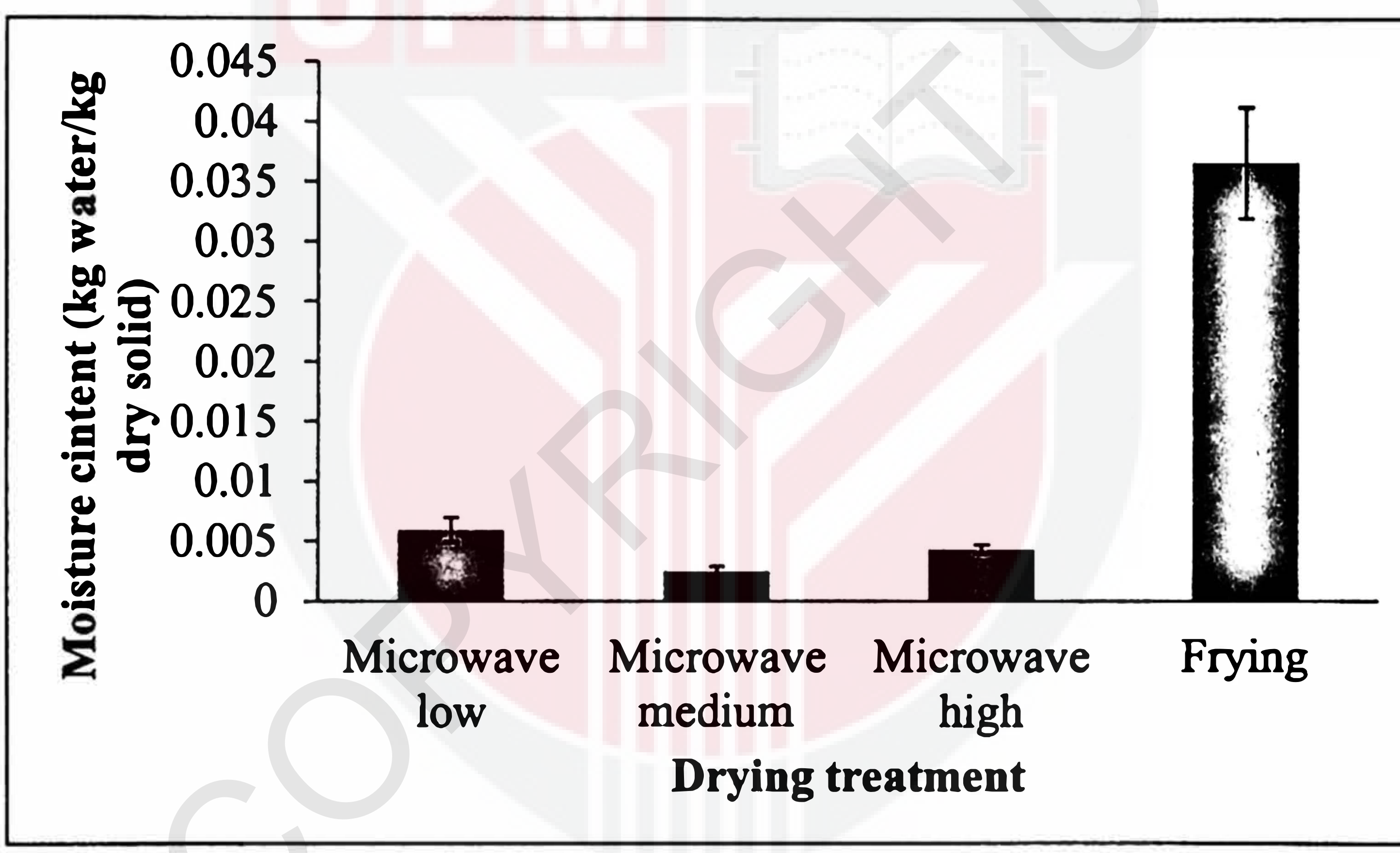

Figure 4.5: Final moisture content at different cooking method and power level.

4.3 Crispness

The force-displacement graph of microwave drying at varying power levels and frying were presented in Figure 4.6, 4.7, 4.8 and 4.9. The force-displacement curves resulted from these samples showed jaggedness pattern. Crispness were associated with jaggedness pattern in the curve (Laurindo and Peleg, 2007, 2008). The curve of frying method was more smooth by comparing to microwave drying method with many small fracture peaks. Hence, it can be concluded that banana crisp produced by microwave drying method was crisper than frying method.

Hardness was the force required to break the chips. The hardness of banana sample dried by microwave power levels at 100, 440, and 1000 W and frying method were 1005.24, 1287.26, 1282.71 and 1133.37g, respectively. Based on Figure 4.10, the banana sample dried by microwave drying at 440W showed the maximum value of hardness. It can be represented that microwave drying at 440W produced banana crisp with higher crispness because the final moisture content of banana sample had the lowest moisture content. Most of the water molecules in the banana sample had been evaporated. The area under the force-displacement graph was a measure of work done which indicated the energy required to break the strength of the internal bonds within the banana sample. The area under the curve of frying method showed the largest area. Hence, it required more energy to break the strength of internal bonds within the fried banana sample.

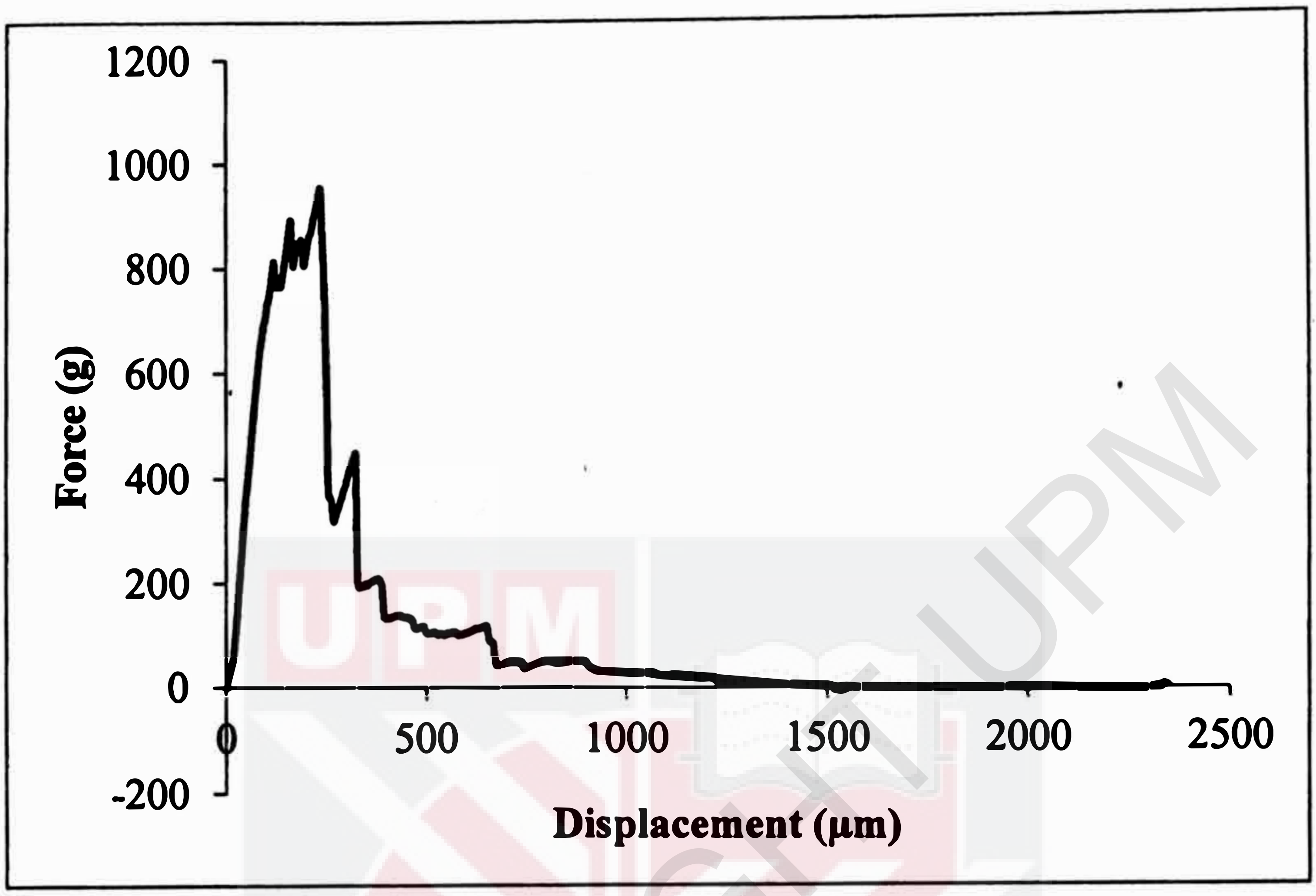

Figure 4.6: Force-displacement graph of microwave drying at 100W.

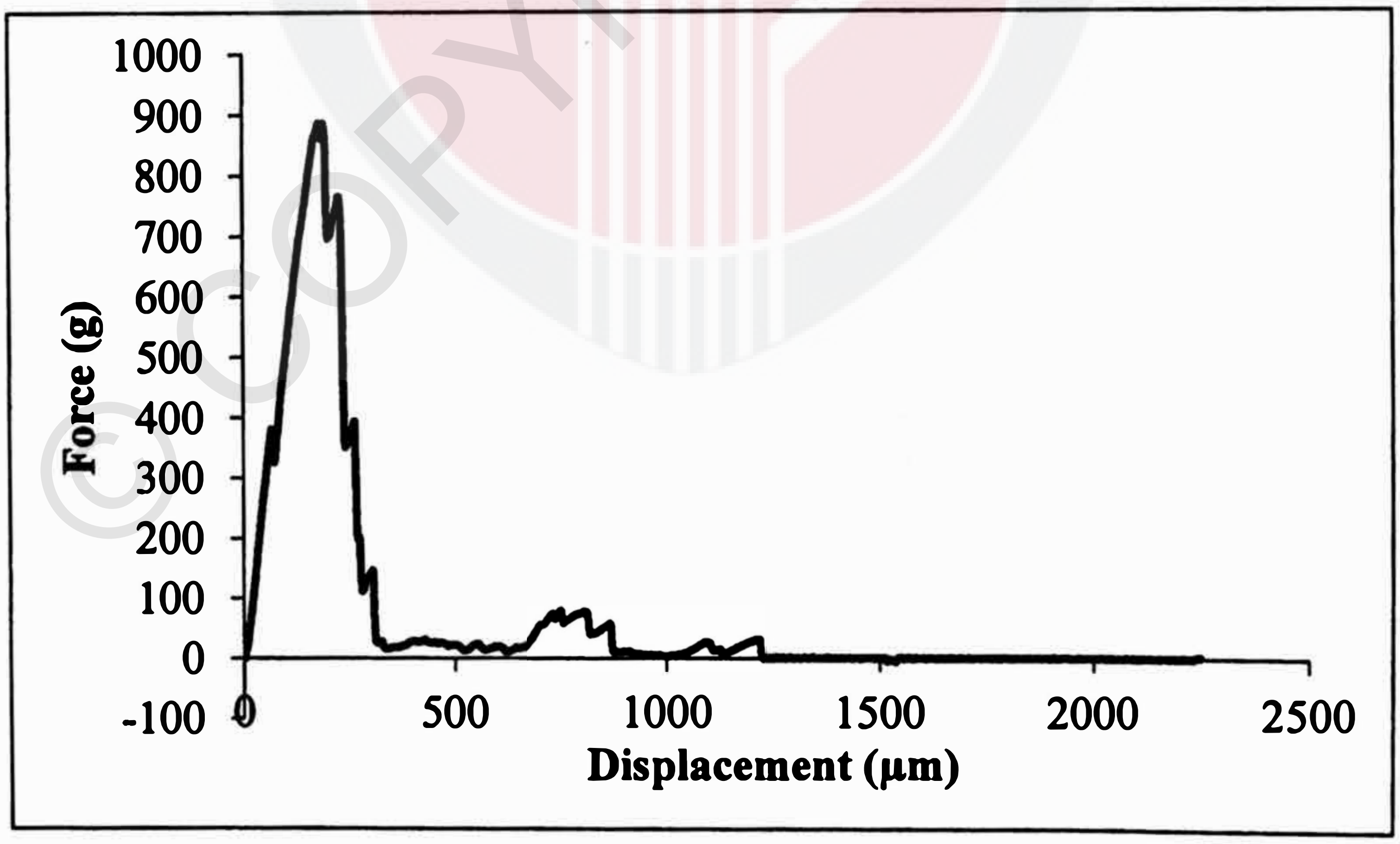

Figure 4.7: Force-displacement graph of microwave drying at 440W.

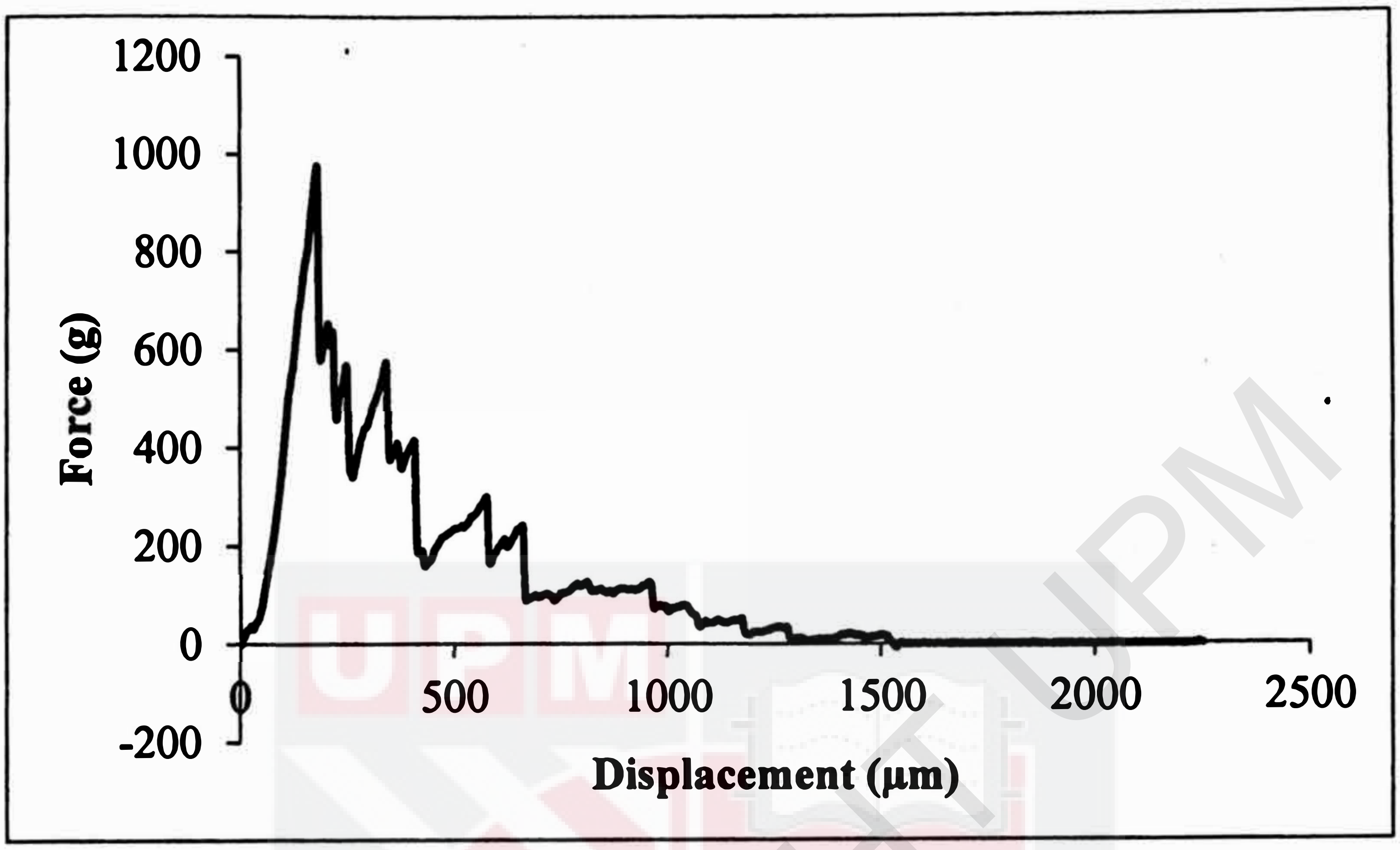

Figure 4.8: Force-displacement graph of microwave drying at 1000W.

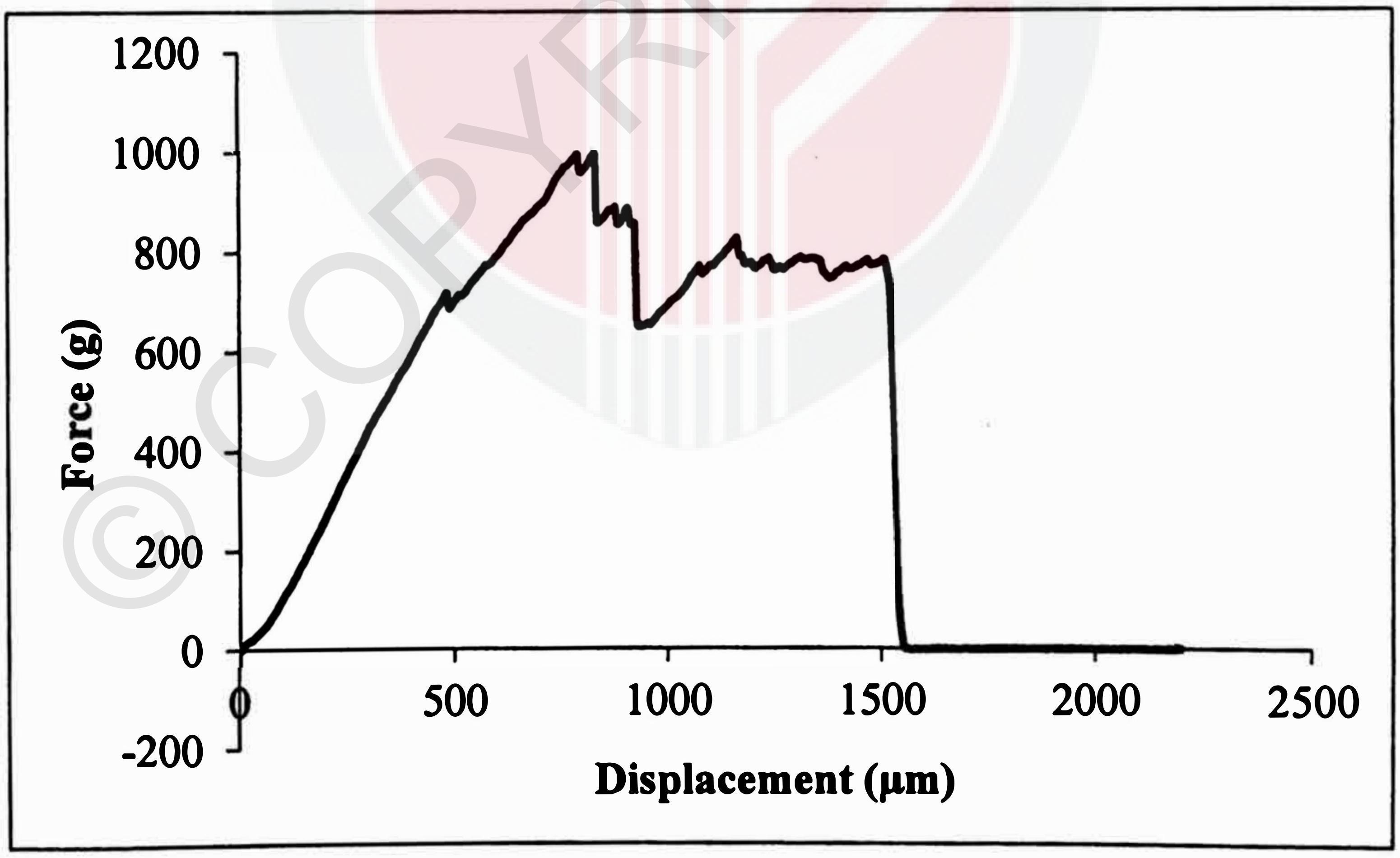

Figure 4.9: Force-displacement graph of frying.

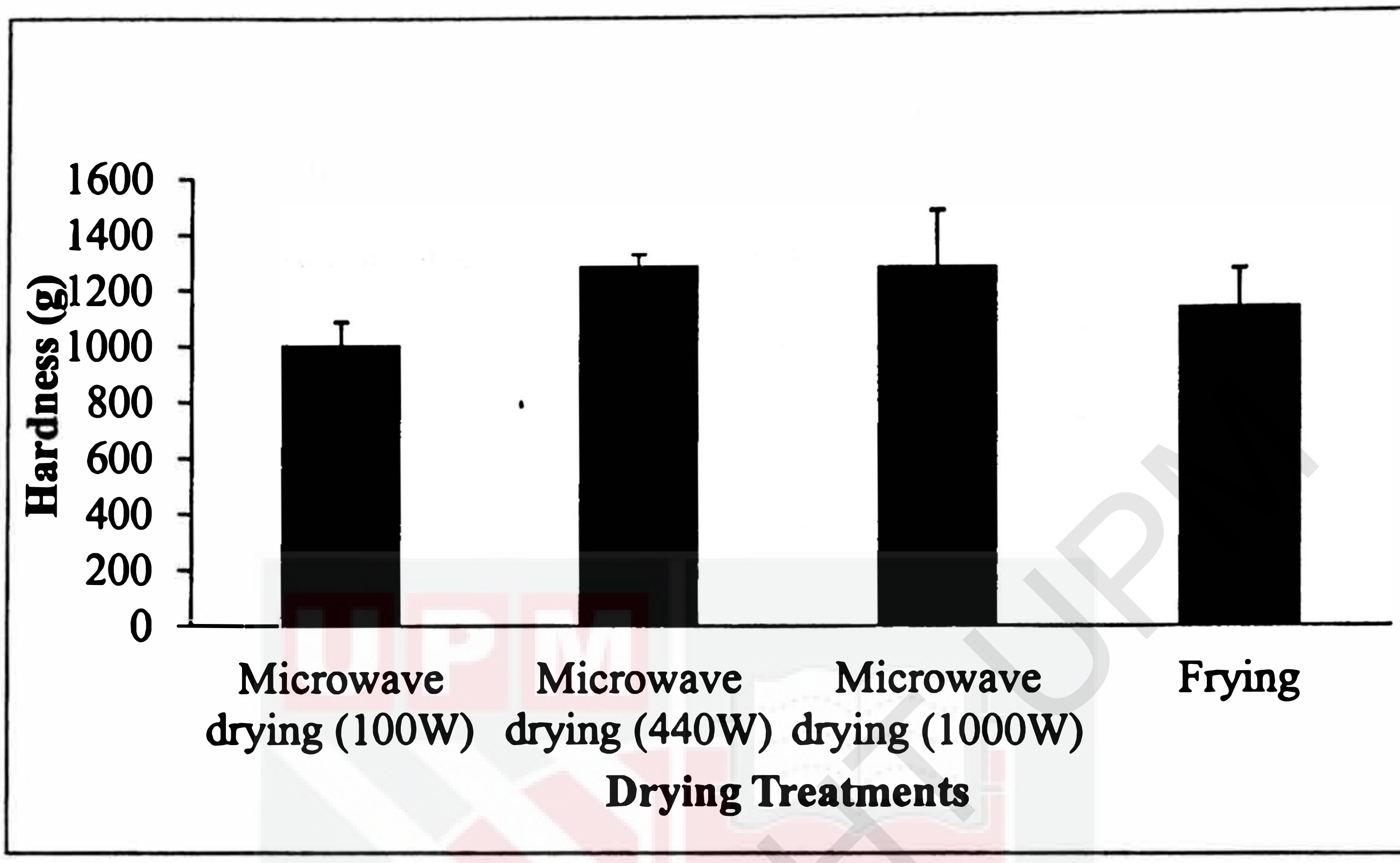

Figure 4.10: Hardness of banana slices at varying power levels and drying treatments.

4.4 Colour

Table 4.2 showed the results of colour measurement of dried banana samples with different drying treatments. The L^* colour parameter indicated whiteness of the sample; a^*colour parameter indicated the redness of the product and b^* colour parameter measured the yellowness of the product. For dried banana, preferred colours were light or golden colour. Based on the results, fried banana sample showed the lowest value of L^*, a^* and b^* which could be due to the higher temperature of frying and longer frying time causing browning of banana crisp. Fried banana was darker and had a browner, duller colour than the microwave dried banana. This was related to reducing sugar content through the formation of Malliard browning products (Krokida, Oreopoulou, Maroulis, & Marinos-Kouris, 2001). When the drying time was longer, there would be decreased in L^* and increased in a^* values, presenting darker and redder of banana (Prachayawarakorn et al., 2007). Microwave drying at 100W consumed longer time of drying, but its L^* values showed the highest because the banana was dried at low power level. Banana dried with microwave power level at 1000W showed results of highest value of a^*, presenting redder colour of banana. It can be concluded that microwave dried banana showed the highest value of L^*, a^* and b^* if compared to fried banana chip. The real picture of banana chips with different drying treatments were shown in Figure 4.11, 4.12, 4.13 and 4.14.

Table 4.2: Colour values of banana flesh at varying power and drying treatment.

Drying treatment	L^*	a^*	b^*
Microwave drying (100W)	31.04±1.57	9.48±1.09	15.74±0.60
Microwave drying (440W)	23.52±0.37	9.64±0.97	13.16±1.35
Microwave drying (1000W)	27.63±0.45	10.85±0.42	19.78±1.79
Frying	15.61±0.81	4.50±0.84	10.09±0.38

Figure 4.11: Top view of microwave dried banana at 100 W.

Figure 4.12: Top view of microwave dried banana at 440 W.

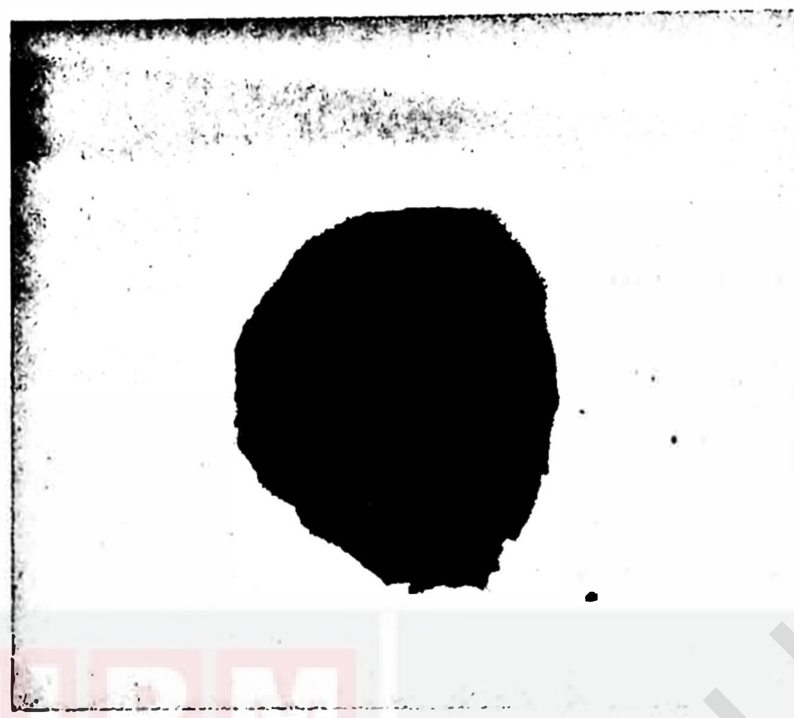

Figure 4.13: Top view of microwave dried banana at 1000 W.

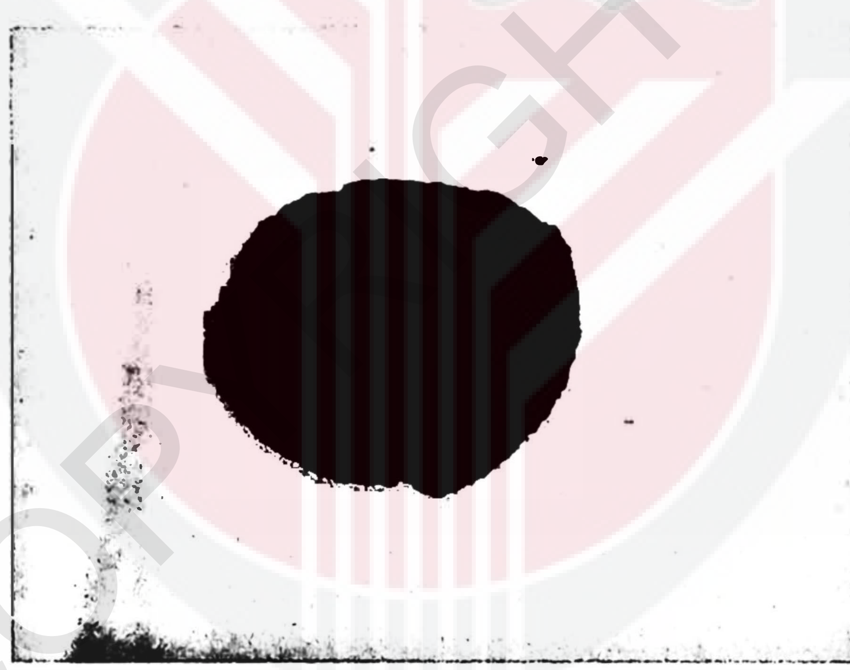

Figure 4.14: Top view of fried banana.

4.5 Sensory Evaluation

Sensory evaluation of the dried banana chips were shown in Figure 4.15. It can be seen that microwave dried banana chips had a significantly higher score in terms of crispness, appearance, aroma and overall acceptability than fried banana chips. However, dried banana crisp at power level of 440W had higher scores of overall acceptability than those from microwave drying method, but the scores of crispness were lower than another two power levels. This can be seen that the reason for overall acceptability was not due to the crispness of banana chips. Microwave dried banana crisps at 440W had the highest scores in terms of aroma and appearance. The results of the current study indicated that microwave dried banana chips would be more preferable over the fried banana chips within consumers.

There was a statistically significant difference between samples as determined by one-way ANOVA for sensory attributes of crispness, appearance and overall acceptance ($p \leq 0.05$). For sensory attributes of aroma, there was no significant difference between four samples ($p > 0.05$). A Tukey post hoc test revealed that there was a significant difference between samples A-D, B-C, B-D and C-D in terms of crispness. No significant difference was observed between samples A-B and A-C for sensory attribute of crispness was observed. For the appearance of samples, there was a significant difference can be observed between samples A-D, B-D and C-D. Meanwhile, there was no significant difference between samples A-B, A-C and B-C. In terms of overall acceptance, the results indicated that there was significant difference between samples A-D, B-D and C-D. No significant difference was observed between samples A-B, A-C and B-C.

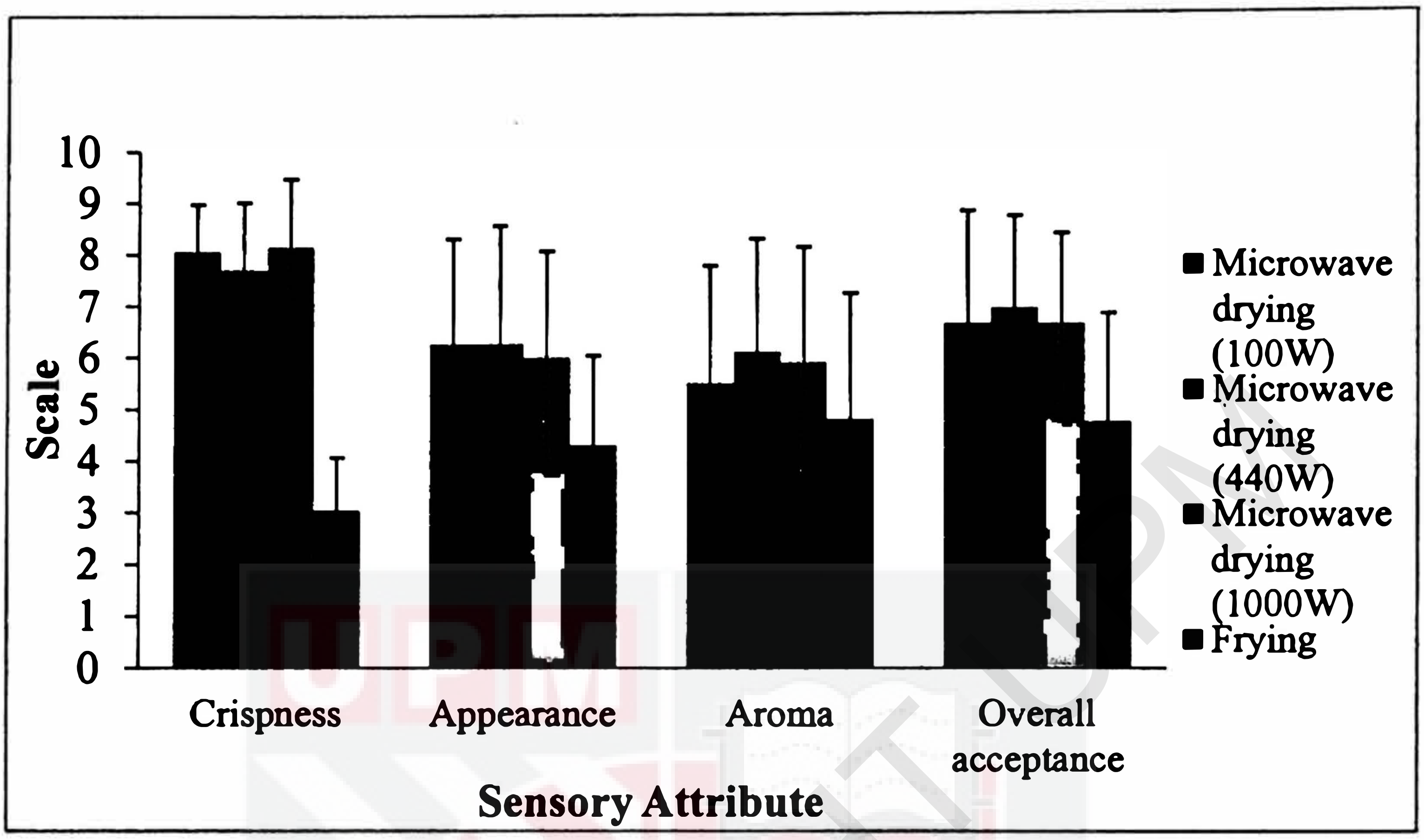

Figure 4.15: Sensory evaluation of dried banana chips.

CHAPTER 5

CONCLUSION

In this chapter, the results of this project is concluded in Section 5.1. Recommendation for future work is explained in Section 5.2.

5.1 Conclusion

As a conclusion, microwave characteristics of banana flesh were determined in this study. The results indicated that the drying rate of banana was affected by the varying power levels. The drying rate increased and drying time decreased as microwave power level increased. The highest drying rate was obtained with the highest microwave power level at 1000W. Among several thin layer models, the Page model was chosen as the best model to explain the drying process in banana flesh with its highest value of R^2 and lowest value of RMSE. The moisture diffusivity obtained was 1.080 x 10^{-6} to 1.572 x 10^{-6} m^2/s and the activation energy was 10.15 W/g.

The physical properties of microwave dried banana chips at varying power levels were compared with fried banana chips. In terms of final moisture content, frying method showed the highest final moisture content if compared to microwave drying method. For crispness, dried banana which dried at 440 W had the highest hardness of 1287.26g. It can be concluded that microwave dried banana chips was more crispy to fried banana chips. In terms of colour, fried banana had a browner, duller colour than microwave dried banana with lowest value of L^*, a^* and b^* values. For the sensory evaluation test, microwave dried banana crisp at 440 W was the most preferable amongst the consumers. It can be concluded that microwave dried banana chips showed better results than fried banana chips in terms of final moisture content, crispness, colour and sensory evaluation.

5.2 Recommendation

Microwave processing techniques have been widely used in the food industry due to its reduction in cooking time and energy consumption. In this study, the experiment only focuses on how the microwave power level affects the physical characteristics of dried banana chips. The study showed that microwave drying produced a more porous structure of foods and causes a serious drop in nutrients due to leaching and thermal liability (Guo et al., 2017). The power level and drying time will affect the nutritional quality of the banana chips. Thus, the effect of microwave power levels on the nutritional characteristics of dried banana chips can be determined for future work.

In addition, microwave processing techniques have been used to sterilize food due to its capacity to completely inactivate microorganisms and effectively destroy enzyme activity (Guo et al., 2017). Therefore, the shelf life of microwave dried banana chips can be determined for future work. It is recommended to investigate the effect of microwave at varying power levels on the shelf life of banana chips. Fried banana chips contain high fat content, which will shorten the shelf life of the product due to possible lipid oxidation leading to rancidity (Prachayawarakorn et al., 2008). Thus, the shelf life between microwave dried banana chips and fried banana chips can be determined.

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APPENDIX A

EXPERIMENTAL DATA

Microwave drying

Moisture content

i. Low power

Time (min)	Moisture content (kg water/ kg dry solid)		
	Batch 1	Batch 2	Batch 3
0	2.2519	2.1915	2.1890
5	0.3181	0.5753	0.5250
10	0.0820	0.1869	0.2148
15	0.0082	0.0672	0.0586
20	0.0005	0.0149	0.0266
25	0.0002	0.00676	0.0110

ii. Medium power

Time (min)	Moisture content (kg water/ kg dry solid)		
	Batch 1	Batch 2	Batch 3
0	2.0063	2.1002	2.0777
1	1.0367	0.9222	0.9662
2	0.4761	0.2820	0.2759
3	0.1815	0.0959	0.1178
4	0.0478	0.0297	0.0656
5	0.0068	0.0154	0.0192

iii. High power

Time (min)	Moisture content (kg water/ kg dry solid)		
	Batch 1	Batch 2	Batch 3
0	2.5213	2.4084	2.4670
0.33	1.3297	1.4754	1.4647
0.67	0.5848	0.8353	0.6815
1	0.2733	0.4346	0.2349
1.33	0.1508	0.1852	0.1673
1.67	0.0668	0.1209	0.0380
2	0.0298	0.0788	0.0245
2.33	0.0258	0.0588	0.0173
2.67	0.0246	0.0320	0.0107
3	0.0197	0.0202	0.0049
3.33	0.0050	0.0123	0.0009
3.67	0.0023	0.0104	0.0002

Final moisture content

Drying treatments	Moisture content (kg water/ kg dry solid)
Microwave drying (low power)	0.005942±0.001034
Microwave drying (medium power)	0.002459±0.000444
Microwave drying (high power)	0.004306±0.000362
Frying	0.036620±0.004620

Hardness

Drying treatment	Hardness (g)
Microwave drying (low power)	1005.24±83.28
Microwave drying (medium power)	1287.26±40.17
Microwave drying (high power)	1282.71±199.66
Frying	1133.37±134.18

Sensory evaluation

Drying treatment	Crispness	Appearance	Aroma	Overall acceptance
Microwave drying (low power)	8.05±0.92	6.25±2.04	5.50±2.27	6.65±2.17
Microwave drying (medium power)	7.70±1.31	6.25±2.30	6.10±2.19	6.95±1.77
Microwave drying (high power)	8.15±1.31	6.00±2.05	5.90±2.23	6.65±1.74
Frying	3.05±1.02	4.30±1.73	4.80±2.44	4.75±2.09

Scale 1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like or dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, 9 = like extremely.

Crispness

ANOVA

Source of Variation	SS	df	MS	F	p-value	F crit
Between Groups	729.675	3	243.225	177.886	3.94×10^{-50}	1.5654
Within Groups	213.3	156	1.3673			
Total	942.75	159				

Tukey-Kramer

Comparison	Absolute Difference	Critical Range	Results
A to B	0.35	0.4385	Not significantly different
A to C	0.1	0.4385	Not significantly different
A to D	5	0.4385	Significantly different
B to C	0.45	0.4385	Significantly different
B to D	4.65	0.4385	Significantly different
C to D	5.1	0.4385	Significantly different

Appearance

ANOVA

Source of Variation	SS	df	MS	F	p-value	F crit
Between Groups	106.2	3	35.4	8.2745	3.83×10^{-5}	1.5654
Within Groups	667.4	156	4.2782			
Total	773.6	159				

Tukey-Kramer

Comparison	Absolute Difference	Critical Range	Results
A to B	0	0.7757	Not significantly different
A to C	0.25	0.7757	Not significantly different
A to D	1.95	0.7757	Significantly different
B to C	0.25	0.7757	Not significantly different
B to D	1.95	0.7757	Significantly different
C to D	1.70	0.7757	Significantly different

Aroma

ANOVA

Source of Variation	SS	df	MS	F	p-value	F crit
Between Groups	39.5	3	13.1667	2.4581	0.06497	1.5654
Within Groups	835.6	156	5.3564			
Total	875.1	159				

Overall Acceptance

ANOVA

Source of Variation	SS	df	MS	F	p-value	F crit
Between Groups	122.4	3	40.8	10.4068	2.79×10^{-6}	1.5654
Within Groups	611.6	156	3.9205			
Total	734	159				

Tukey-Kramer

Comparison	Absolute Difference	Critical Range	Results
A to B	0.3	0.7426	Not significantly different
A to C	0	0.7426	Not significantly different
A to D	1.90	0.7426	Significantly different
B to C	0.30	0.7426	Not significantly different
B to D	2.20	0.7426	Significantly different
C to D	1.90	0.7426	Significantly different

APPENDIX B

FIGURES

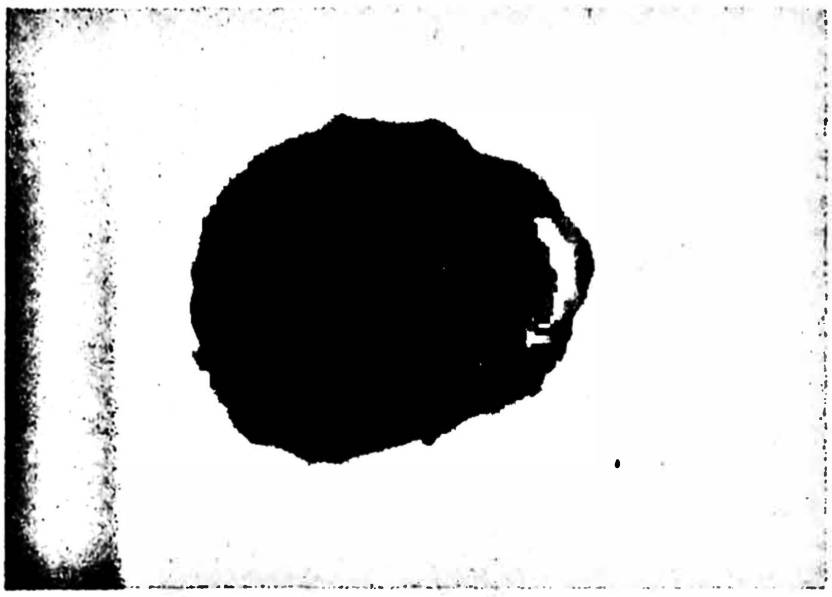

Figure B.1: Top view of microwave dried banana at 100 W.

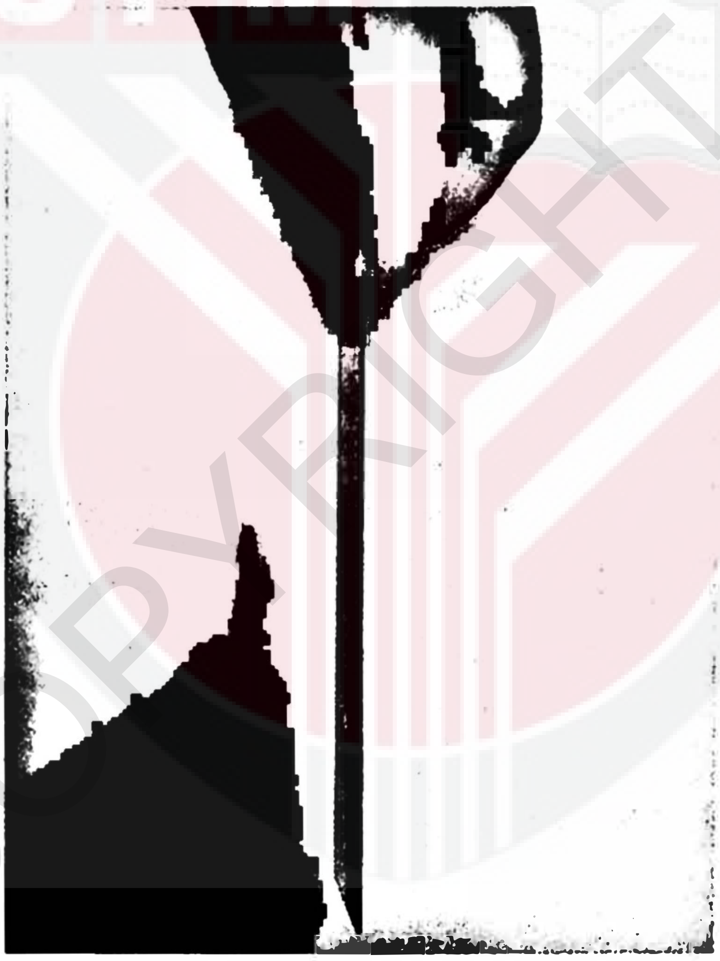

Figure B.2: Side view of microwave dried banana at 100 W.

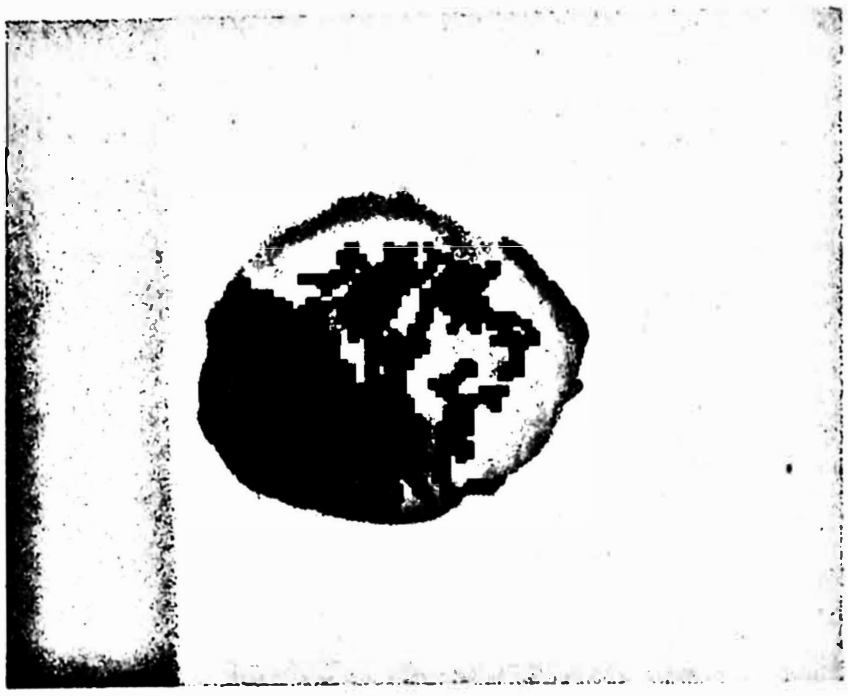

Figure B.3: Top view of microwave dried banana at 440 W.

Figure B.4: Side view of microwave dried banana at 440 W.

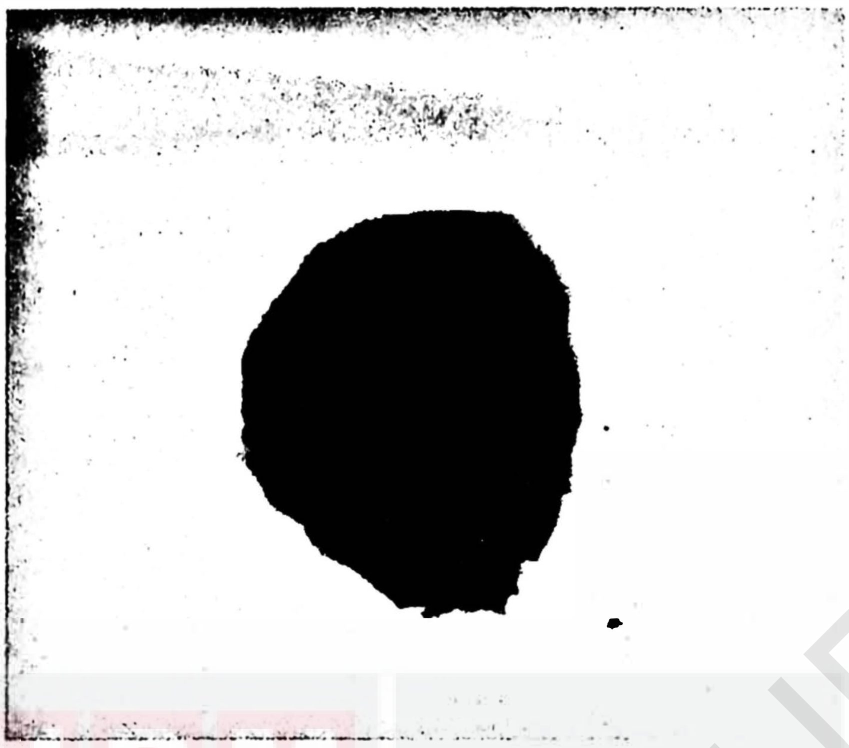

Figure B.5: Top view of microwave dried banana at 1000 W.

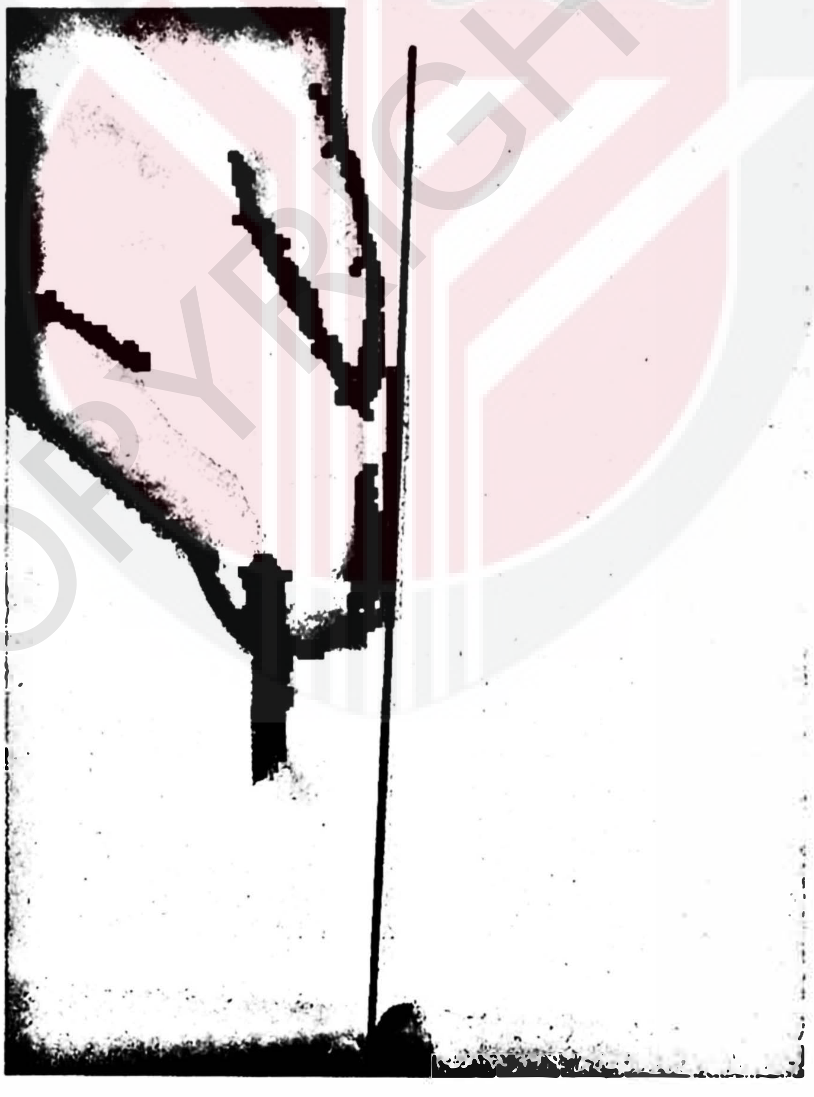

Figure B.6: Side view of microwave dried banana at 1000 W.

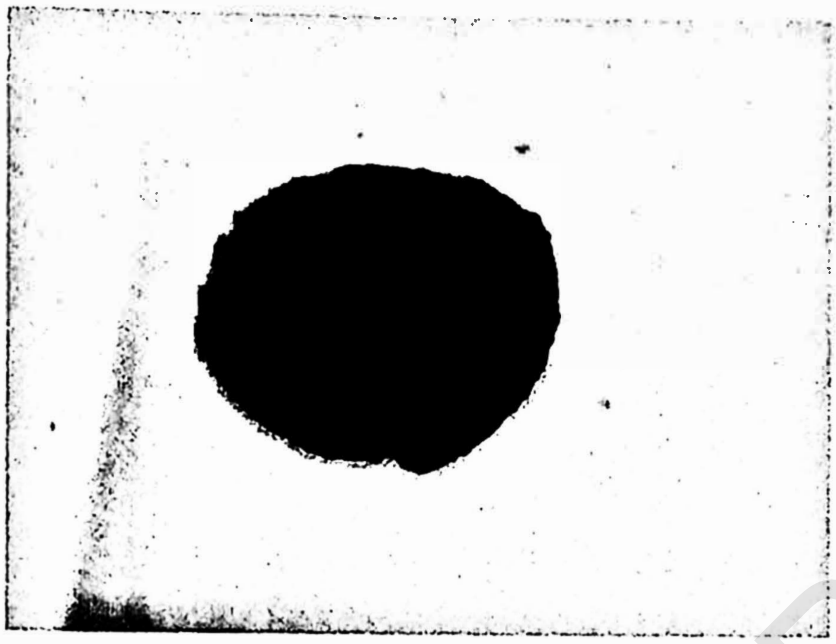

Figure B.7: Top view of fried banana.

Figure B. 8: Side view of fried banana.