DEVELOPMENT OF FUNCTIONAL CAKES TO BE BAKED IN MICROWAVE-INFRARED COMBINATION OVEN

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DEVELOPMENT OF FUNCTIONAL CAKES TO BE BAKED IN MICROWAVE-INFRARED COMBINATION OVEN

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ABSTRACT

DEVELOPMENT OF FUNCTIONAL CAKES TO BE BAKED IN MICROWAVE-INFRARED COMBINATION OVEN

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The main objective of this study was to develop functional cake formulations to be baked in the microwave-infrared (MW-IR) combination oven by using legume flours. It was also aimed to compare quality of legume cakes baked in MW-IR oven with conventional oven. For this reason, oven type (conventional and microwave-infrared combination oven), baking time (4, 4.5 and 5 minutes), legume flour type (lentil, chickpea and pea) and legume flour concentration (10%, 20%, and 30%) were selected as independent variables. As a control, wheat cakes were used. Weight loss, specific volume, porosity, texture, color, gelatinization degree, macro and micro-structure of cakes were determined.

MW-IR baked cakes had higher specific volume, porosity, weight loss and crust color change and lower hardness values than conventionally baked cakes. Cakes baked in MW-IR oven gelatinized less than those baked in conventional oven.

Pore area fractions of MW-IR baked cakes were higher than conventionally baked cakes. Larger pores of microwave-infrared baked cakes were also observed in Scanning Electron Microscope (SEM) images.

Cakes with high quality can be obtained by replacing 10% of wheat flour with legume flour. Legume flour type did not affect the weight loss, crust and color change of cakes baked in MW-IR for 4 min. Pea flour giving the hardest structure, lowest specific volume, porosity and gelatinization degree was determined to be the least acceptable legume flour. On the other hand, lentil and chickpea cakes had the softest structure, highest specific volume and porosity showing that lentil and chickpea flour can be used to produce functional cakes.

Keywords: Functional cakes, microwave-infrared combination baking, lentil flour, pea flour, chickpea flour.

ÖZ

MİKRODALGA-KIZIL ÖTESİ FIRINDA PİŞİRİLMEK ÜZERE FONKSİYONEL KEKLERİN GELİŞTİRİLMESİ

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Bu çalışmanın amacı mikrodalga-kızıl ötesi fırında pişirilmek üzere baklagil unlarını kullanarak fonksiyonel keklerin geliştirilmesidir. Mikrodalga-kızıl ötesi fırında pişirilen keklerin konvansiyonel fırında pişirilenlerle karşılaştırılması da amaçlanmıştır. Bu nedenle, fırın tipi (konvansiyonel ve mikrodalga-kızıl ötesi fırın), pişirme süresi (4, 4,5 ve 5 dakika), baklagil un tipi (mercimek, nohut ve bezelye unu) ve baklagil unu konsantrasyonu (%10, %20 ve %30) bağımsız değişken olarak seçilmiştir. Kontrol olarak buğday unuyla hazırlanan kekler kullanılmıştır. Kekler de ağırlık kaybı, özgül hacim, gözeneklilik, renk, tekstür, jelatinizasyon derecesi, makro ve mikro yapı incelenmiştir.

Mikrodalga-kızılötesi fırında pişirilen keklerde konvansiyonel keklere oranla daha yüksek hacim, gözeneklilik, ağırlık kaybı, yüzey renk değişimi, ve daha yumuşak tekstür gözlemlenmiştir. Mikrodalga-kızılötesi fırında pişirilen kekler

konvansiyonel fırında pişirilen keklere göre daha az jelatinize olmuştur. Mikrodalga-kızılötesi fırında pişirilen keklerin alan bazında gözenek fraksiyonunun daha yüksek olduğu bulunmuştur. Taramalı elektron mikroskobu (TEM) kullanılarak da mikrodalga-kızılötesi fırında pişirilen keklerin daha büyük gözeneklere sahip olduğu gözlemlenmiştir.

Buğday ununun %10'u baklagil unuyla yer değiştirildiğinde yüksek kalitede kekler elde edilmiştir. Mikrodalga-kızılötesi fırınında 4 dk. pişirilen keklerde un tipinin ağırlık kaybı ve renk değişimi üzerine etkisinin bulunmadığı gözlenmiştir. En sert tekstür, en düşük hacim, en düşük gözeneklilik, en düşük jelatinizasyon derecesi sağladığından, bezelye unu en az kabul edilebilir un çeşidi olmuştur. Mercimek veya nohut unu içeren keklerin en yumuşak tekstür, en yüksek hacim, en yüksek gözeneklilik ve en yüksek jelatinizasyon derecesine sahip olması bu unların fonksiyonel kek üretiminde kullanılabileceğini göstermektedir.

Anahtar Kelimeler: Fonksiyonel kek, Mikrodalga-kızılötesi kombinasyon pişirme, mercimek unu, bezelye unu, nohut unu.

To my family…

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INTRODUCTION

1.1 Functional Foods

The term functional food was first used in Japan in the early 1980s as a result of the long-term studies on enhancing benefits of foods (Roberfroid, 2000). There are many different definitions of the term “functional foods”. Institute of Food Technologists (IFT) defines “functional foods” as the foods which enhances health and reduces the diseases (URL1). Japanese Ministry of Health, Labor, and Welfare (FOSHU) makes the most detailed definition as follows: “Functional foods are expected to have a specific health effect due to relevant constituents or foods that allergens have been removed. They are also likely to exert a health or physiological effect when consumed as a part of ordinary diet’’ (Roberfroid, 2000).

Although there are many terms like vitafoods, nutraceuticals, pharmafoods, medifoods, functional food has broader meaning covering all of them (Roberfroid, 2000). Moreover, according to Roberfroid (2000), functional foods must be perceived as not only a single product but also a concept. The properties of functional foods are:

- being traditional food,
- being part of ordinary diet,
- having natural ingredients,

- having further positive effect other than nutritional value (Roberfroid, 2000).

The main reason of why functional foods became so popular is the consumers' awareness about what they eat and drink. Scientific development in technology and nutrition, progress in relation between diet and diseases, exchange in people's expectations and higher health care payments are the other reasons (Roberfroid, 2000).

Probiotic milk products, low-fat and skim milk, fatty fish, probiotic fruit drinks, fermented drinks, energy drinks, vitamin or mineral-enriched foods, fruits and vegetables, weight loss products, soy products, breakfast cereals and fiber-rich bread are the examples of commonly consumed functional foods (Ozen et al., 2012).

1.2 Legume Flours

Legumes, in other words pulses, are the member of plant family named Leguminosae. They are used as meal by people for decades. Most common types that are used in the meals are beans, chickpeas, soybeans, lentils, peas and lupins.

Legumes are one of the most nutritious foods in the world. They have high amount of amino acids, carbohydrates, dietary fiber, some minerals and vitamins (Iqbal et al., 2006). The most common amino acids that legumes contain are lysine, leucine, aspartic acid, glutamic acid and arginine (Minarro et al., 2012). According to Gomez et al. (2008), legume flours are valuable source of nutrition for bakery products due to their high protein content. Legumes also contain high amount of dietary fiber. Dietary fiber provides prevention of hypertension and regulates blood pressure (Lee et al., 2008). Dietary fibers are mainly classified as soluble fiber and insoluble fiber, according to solubility in water (Dodevska et al., 2013). Insoluble fibers are mainly responsible for high water binding capacity and structure softening (Triniad et al., 2010). Table 1.1 indicates the fiber content of common legumes.

Table 1.1 Dietary fiber composition of legumes adapted from Mallillin et al. (2008)

Legumes	Dietary fiber (g/100g sample)	Soluble fiber (g/100g sample)	Insoluble fiber (g/100g sample)
Mungbean	31.7	4.8	26.9
Soybean	46.9	8.0	38.9
Peanut	24.1	4.2	20.0
Pole sitao	35.0	5.5	29.5
Cowpea	34.0	4.0	29.8
Chickpea	26.2	1.3	24.9
Green pea	29.7	2.1	27.6
Lima bean	20.9	3.7	17.7
Kidney bean	29.8	0.4	29.4
Pigeon pea	21.8	2.4	19.4

Besides, World Health Organization recommends greater consumption of legumes for a balanced diet (URL2). Therefore, use of composite flours, consisting of wheat flour and legume flours, in the bakery products can be considered good alternative in terms of balanced diet. Table 1.2 indicates the mineral amounts of some legumes and Table 1.3 shows how legumes meet the required daily essential amino acid.

Table 1.2 Mineral composition of some legumes (Iqbal et al., 2006)

Minerals (mg/100 g)	Chickpea	Lentil	Green pea
Sodium	101b ± 3.51	79c ± 2.65	111a ± 2.65
Potassium	1155b ± 5.00	874d ± 6.43	1021c ± 12.49
Phosphorus	251b ± 6.11	294a ± 3.61	283a ± 3.00
Calcium	197a ± 3.61	120c ± 6.24	110c ± 3.61
Iron	3.0a ± 0.20	3.1a ± 0.26	2.3b ± 0.05
Copper	11.6a ± 0.20	9.9b ± 0.10	10.0b ± 0.40
Zinc	6.8a ± 0.26	4.4a ± 0.20	3.2a ± 0.56
Manganese	1.9a ± 0.10	1.6a ± 0.03	2.2a ± 0.02
Magnesium	4.6ab ± 0.04	4.5b ± 0.04	4.2c ± 0.04

Table 1.3 Essential amino acid scores of legumes (adapted from Iqbal et al., (2006))

Amino acids	Reference pattern	Chickpea	Lentil	Green pea
Histidine	1.9	158	116	126
Lysine	5.8	124	121	140
Leucine	6.6	132	118	112
Isoleucine	2.8	171	146	161
Methionine + cystine	2.5	68	68	116
Phenylalanine + tyrosine	6.3	132	130	141
Threonine	3.4	91	88	111
Tryptophan	1.1	82	64	55
Valine	3.5	131	143	143

Legumes are also classified as low glycemic index food (Rizkalla et al., 2002). The glycemic index of different foods is shown in Figure 1.1. Glycemic index represents how foods affect the blood glucose. Legumes also have several health benefits due to having low glycemic index (Rizkalla et al., 2002).

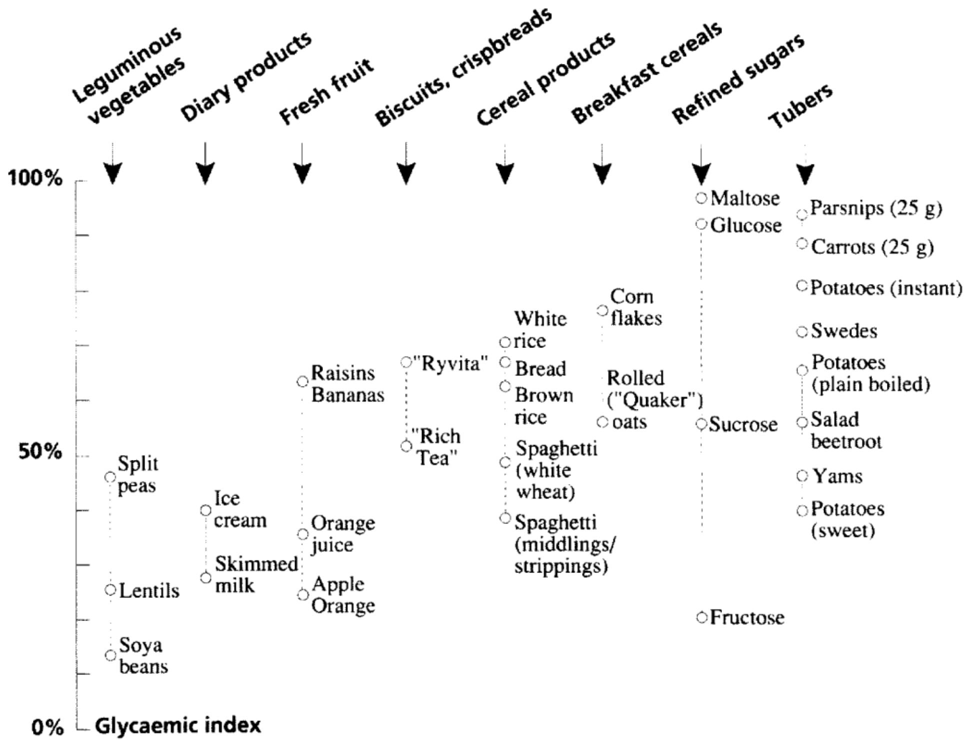


Figure 1.1 Glycemic indexes of different foods (Bornet et al., 1997)

1.3 Studies on Legume Bakery Products

There are a few studies in the literature on legume containing bakery products. Fenn et al. (2010) studied the quality of bakery products which was made by the addition of legume flours. Concentration of legume flours (soybean, yellow pea and chickpea flour) was varied between 2%-8%. It was found that addition of 2% soybean flour to bakery products provided the highest quality and increased the protein content by 28%.

Hera et al. (2012) analyzed effects of partial or total replacement of lentil flour on the quality of cakes. Two different cake types, layer and sponge cakes, were studied. It was concluded that addition of lentil flour decreased cake volume, symmetry index, cohesiveness and springiness but increased hardness.

Zucco et al. (2011) studied effects of addition of legume flours on the quality of cookies. Navy bean, pinto bean, green lentil and yellow pea flours were used in the study. The concentration of legume flours varied between 25%-100%. Although addition of the flours increased hardness, nutritional value of cakes were improved.

Another study on gluten-free legume breads was conducted by Minarro et al. (2012). It was aimed to replace soy flour with chickpea and pea flour. Breads prepared with chickpea flour were found to have better characteristics than pea flour (higher volume and softer crumb). It was concluded that chickpea flour could be alternative to soy flour in gluten-free breads.

Besides, Gomez et al. (2008) investigated the effects of addition of chickpea flour on the quality of cakes. In the study, total or partial substitution of chickpea flour was studied. Although addition of chickpea flour decreased the volume and increased the hardness as compared to wheat cake, chickpea cakes were still acceptable in terms of quality.

When the effects of addition of pea flour on quality of cakes were studied, it was found that cakes obtained by substitution of 50% pea flour were similar to wheat cakes in terms of quality (Gomez et al., 2012).

1.4 Microwave-Infrared Combination Baking

When compared with conventional baking, there are several advantages of microwave-infrared (MW-IR) combination baking. MW-IR baking combines time saving advantages of microwave and crisping advantages of IR (infrared) heating (Sumnu et al., 2005). The baking time of breads is reduced 75% by MW-IR combination oven (Keskin et al., 2004). Moreover, Demirekler et al. (2004) stated that quality of MW-IR baked breads is similar with the ones baked in conventional oven. MW-IR combination oven also provides acceptable color and crust formation with the help of halogen lamp. Besides, the color and firmness values of cakes baked in MW-IR combination oven were comparable with the conventionally baked ones (Sumnu et al., 2005).

MW-IR combination oven combines microwave and infrared technology (Figure 1.2). In order to understand the heating mechanism of MW-IR combination oven, microwave and infrared technology should be investigated separately.

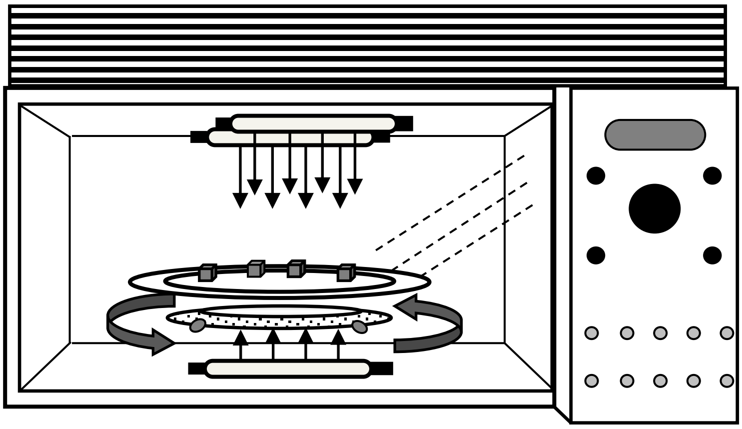


Figure 1.2 Microwave-Infrared Combination Oven (Sumnu & Sahin, 2005)

1.4.1 Microwave Heating Mechanism

Microwave heating is used more than 60 years for several purposes. It is used both in food industry and in houses. Moreover, the number of microwave oven in the kitchens is increasing day by day. Cooking, tempering, drying, pasteurization, blanching, baking and extraction are some of the microwave applications (Orsat & Raghavan, 2005).

Microwaves are electromagnetic waves in the frequency range of 300 MHz and 30 GHz (Giese, 1992) (Figure 1.2). To avoid the interferences, 2450 MHz or 915 MHz frequencies have been approved by International Telecommunications Union for industrial, scientific and medical (ISM) to be used for food processing in industry and at home, respectively (Giese, 1992).

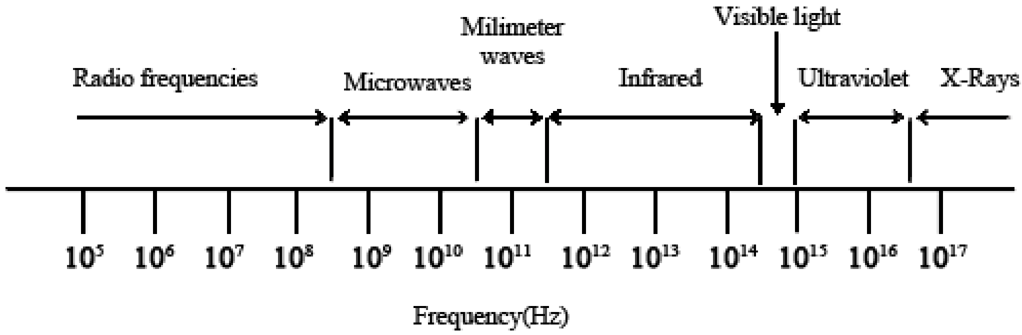


Figure 1.3 The electromagnetic spectrum (Sahin and Sumnu, 2006)

In the microwave ovens electric field is provided by magnetron. Microwaves interact with foods by two mechanisms: ionic conduction and dipolar rotation (Sahin & Sumnu, 2006) (Figure 1.3). In the ionic conduction charged particles in the food sample, such as salt particles, are accelerated and move in different directions as a result of exposure to alternating electric field (Turabi E. , 2010). Kinetic energy is generated by agitation and transferred to other molecules as a result of collision (Sahin & Sumnu, 2006). Because water is polar molecule, it is mainly responsible for dipolar rotation. Polar molecules are forced to rotate and collide when subjected to alternating electric field. The direction of rotation is reversed when the alternating electric field changed (Sahin & Sumnu, 2006). Heat is generated rapidly in the microwave ovens due to these two mechanisms.

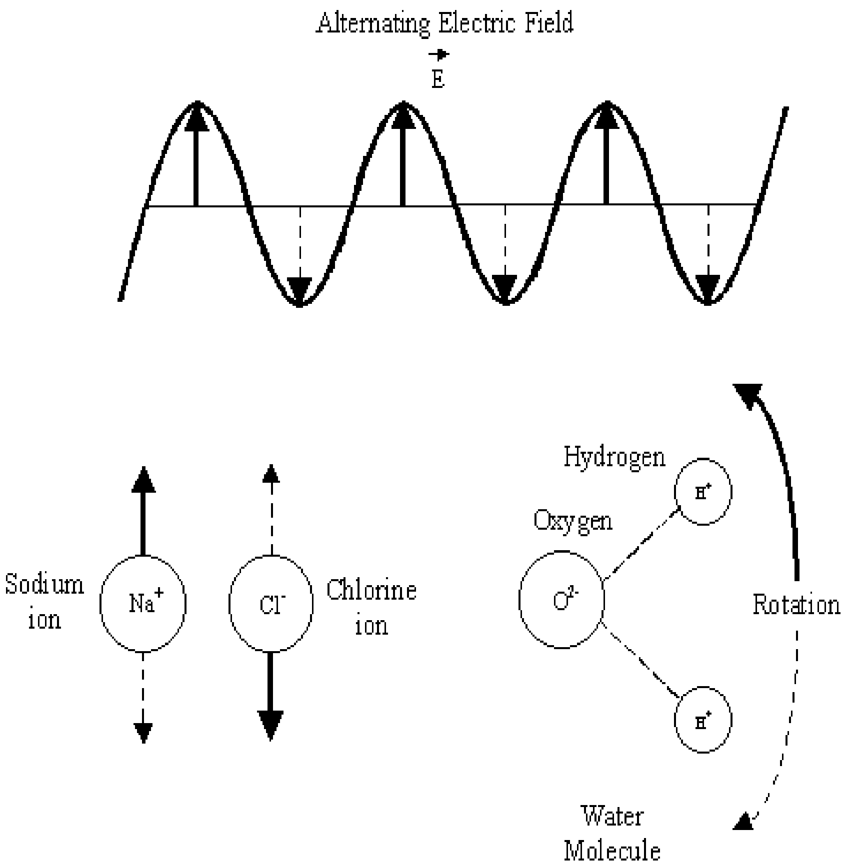


Figure 1.4 Ionic conduction and dipolar rotation (Sahin & Sumnu, 2006)

Heat transfer equation in a food material during microwave heating is expressed as;

$$\frac{\partial T}{\partial t} = \alpha \nabla^2 T + \frac{Q}{\rho C_p} \qquad (1.1)$$

where, "T" is temperature (°C), "t" is time (s), "α" is thermal diffusivity ($m^2.s^{-1}$), "ρ" is density ($kg.m^{-3}$), "Cp" is specific heat capacity of the material ($J.kg^{-1}.°C^{-1}$) and "Q" is the heat generated per unit volume of per unit time ($J.m^{-3}.s^{-1}$).

The equation of rate of heat generation;

$$Q=2\pi\varepsilon_0\varepsilon'' f E^2 \qquad (1.2)$$

where "ε_0" is the dielectric constant of free space (8.85×10^{-12} F/m), "f" is the frequency (Hz) and "E" is the electrical field (V/m) (Sahin & Sumnu, 2006).

Dielectric constant (ε') and dielectric loss factor (ε'') are the constituents of the dielectric properties of foods. Dielectric constant (ε') refers microwave energy storage ability of food materials and the dielectric loss factor (ε'') refers ability of food material to dissipate microwave energy into heat. Temperature, frequency, protein, carbohydrate, salt, moisture and fat content mainly affect the dielectric properties of foods (Tang, 2005).

Penetration depth (Equation 1.3) (Von Hippel, 1954) shows the depth where the microwave power decreased 1/e of its initial value. It is responsible for uniform heating of foods.

$$dp=\frac{\lambda_0}{2\pi\sqrt{2\varepsilon'\sqrt{1+\left(\frac{\varepsilon''}{\varepsilon'}\right)^2}-1}} \qquad (1.3)$$

where *dp* is penetration depth (cm), ε' is the dielectric constant, ε'' is the dielectric loss factor and λ_0 is wavelength of microwave in free space (cm).

In the conventional ovens surface of food sample is heated by convection via hot air and then heat is transferred by conduction from surface to the interior parts of sample. In addition, heat is transferred from the surface of the oven to food surface by radiation. That is, convection, conduction and radiation provide heating of the sample. However, in the microwave ovens food samples are heated volumetrically. In other words, heat is generated within the sample. Then, heat is transferred from the inner side of the sample to the outer surface by conduction since the surrounding air is not heated.

Microwave ovens have a lot of advantages. These advantages are time and energy savings, high nutritional value, less start-up time, space saving, better process control and less cost (Datta, 2001; Decareau, 1992).

1.4.2 Infrared Heating Mechanism

Infrared Radiation (IR) belongs to the electromagnetic spectrum of the sun and provides heating effect (Ranjan et al., 2002). There are three different types of infrared radiation; near-infrared radiation (NIR), mid-infrared radiation (MIR) and far-infrared (FIR) radiation (Ranjan et al., 2002).

Infrared heating source provides high temperature between 500-3000°C and heat is mainly transferred by convection and radiation. Effect of infrared source is concentrated at the surface of the sample because of low penetration depth of infrared heating. Then, heat is transferred by conduction through the sample (Sepulveda & Barbosa-Canovas, 2003).

Halogen lamp used in the microwave- infrared combination oven provides the near- infrared radiation (NIR) and has the wavelength range between 0.7-5 μm (Sumnu et al., 2005). Furthermore, near- infrared radiation (NIR) provides lower penetration depth with respect to other infrared radiation types. According to Datta & Ni (2002), penetration depth of the infrared is so important that it has very significant effect on the surface temperature of food sample.

1.4.3 Problems in Microwave Baking

Although microwave processing has several advantages, there are also some disadvantages, especially in microwave baking. Quality problems can be listed as unacceptable texture, lower volume, lack of browning and crust formation, high moisture loss and rapid staling (Sumnu, 2001). The main reason is short baking time in microwave ovens. Furthermore, specific interaction of microwave with each component of food sample is another reason (Goebel et al., 1984).

One of the defects in microwave cakes is lack of browning. Color and flavor produced by Maillard reactions cannot be developed in microwave baked cakes (Yaylayan & Roberts, 2001). Low air and low surface temperature prevents Maillard and caramelization reactions, so aroma and browning formation in the microwave baked products.

Rapid staling of microwave baked products is another problem. According to Higo et al. (1983), during microwave processing higher amount of amylose is leached out starch granules. Leached amylose was observed to be more disoriented and contained less bound water. During cooling, leached amylose molecules were observed to align and resulted in firmer crumb texture. It was found that addition of emulsifiers, gums and fat to microwave baked cakes affected the retrogradation of microwave cakes (Seyhun et al., 2003).

Harder structure of samples that were baked in microwave oven could be attributed to higher moisture loss and interaction between gluten and microwave power. Adverse effect of microwave power on gluten protein was explained by high amount of amylose leaching during baking (Seyhun et al., 2003).

The other main problem is high moisture loss of microwave cakes and breads. High interior heating in MW-IR combination oven causes evaporation of water and creates high internal pressure. Pressure gradient causes greater amount of water to flow outside of the food. Thus, MW-IR combination baking results in higher moisture loss. Several studies have shown that cakes and breads baked in microwave oven have lost higher amount of moisture (Sumnu et al., 1999; Sahin et al., 2002)

Because the electric field provides heating, non-uniform baking may occur due to non-uniform electric field (Thostenson & Chou, 1999). The properties of the electric field, chemical composition of the food sample, structural changes during processing, size and shape of the food sample affect the uniformity of baking (Thostenson & Chou, 1999).

There are many studies conducted to overcome the quality problems of microwave baked products (Sumnu et al., 2000; Datta & Ni, 2002; Walker et al., 1993; Lu et al., 1998). MW-IR combination oven is one of the promising method to solve the problems of microwave baked products. Besides, combination of microwave energy and IR heating provides the advantages of both microwave oven and conventional oven together (Figure 1.4)

1.4.4 Studies on Microwave-Infrared Combination Baking

Sumnu et al. (2005) compared the quality of cakes that baked in conventional, microwave, infrared and MW-IR combination oven. It was stated that hardness and color values of MW-IR combination cakes were similar with the conventionally baked cakes.

Gelatinization degrees of cakes that baked in conventional, microwave and MW-IR combination oven was studied by Sakiyan et al. (2011). It was observed that gelatinization degrees of cakes baked in microwave oven were not sufficient while gelatinization degrees of cakes baked in MW-IR combination were comparable with conventionally baked cakes.

Physical properties of different formulations of cakes that baked in microwave and MW-IR combination oven was studied (Sakiyan et al., 2007). It was stated that formulation affected the color and firmness values of cakes. Maltodextrin, Lecigran^{TM} and Purawave^{TM} fat replacers were found to have acceptable results.

Quality results of MW-IR baked cakes were comparable with the conventional cakes.

Effect of different gums on macro and micro-structure of gluten-free rice cakes baked in MW-IR combination oven was investigated (Turabi et al., 2010). It was observed in the study that MW-IR baked cakes had higher porosity than conventionally baked cakes. According to micro-structure results, it was found that conventionally baked cakes showed more gelatinized structure than MW-IR baked cakes.

Optimization of baking conditions of rice cakes was also studied by Turabi et al. (2008). Specific volume, crust color, hardness and weight loss of rice cakes baked in MW-IR combination oven were investigated. It was concluded that rice cakes baked in 60% halogen lamp power and for 7 min had the highest quality results.

Design of gluten-free breads containing chestnut and rice flour to be baked in MW-IR combination oven was studied by Demirkesen et al. (2011). Specific volume, weight loss, firmness and color change of breads were investigated in the study. The optimum baking conditions were determined as 40% infrared power, 30% microwave power and 9 min. It was concluded that quality values of MW-IR baked breads were similar with the conventionally baked breads.

1.5 Objectives of the Study

Legumes are good sources of protein and minerals. They are widely used in Turkish culture in various ways. Legumes contain almost all essential amino acids. Therefore, addition of legume flours into the bakery products is a good way to increase their nutritional value.

Although there are some studies on legume products in the literature, there is no study on legume cakes baked in the MW-IR combination oven. Combining microwave and IR reduces processing time significantly. Therefore, in this study wheat flour was replaced with legume flours partially and cakes prepared with these legume flours were baked in MW-IR combination oven.

The main objective of the study is to develop functional cakes containing legume flours to be baked in the MW-IR combination oven. It was also aimed to compare the quality of legume cakes baked in MW-IR combination oven with those baked in conventional oven. Another objective was to determine the effects of legume flour type (lentil, chickpea and pea), legume flour concentration and baking time on quality, microstructure and gelatinization degree of legume cakes.

CHAPTER 2

MATERIALS AND METHODS

2.1 Materials

For cake batter cake flour was obtained from Başak Flour Factory Inc. (Ankara, Turkey). Egg white powder was provided from ETI Food Industry Co. Inc. (Eskisehir, Turkey). Other ingredients like sugar, non-fat dry milk (Bağdat Baharat, Ankara, Turkey), salt, fat (Becel, Unilever, İstanbul, Turkey) and baking powder (Dr. Oetker, Istanbul, Turkey) were bought from local markets in Ankara. Lentil flour with 22.2% protein, 1.7% fat, 8.9% moisture, 3% ash, chickpea flour with 20.9% protein, 2.8% fat, 7.9% moisture, 3.1% ash, and pea flour with 21.07 % protein, 1.3% fat, 10.8% moisture, 2.7% ash was bought from Smart Chemical Trading Co. Inc. via internet (URL3).

2.2 Methods

2.2.1 Procedure of Cake Batter Preparation

Basic cake batter was prepared using 100g cake flour, 100% sugar, 12% non-fat dry milk, 9% egg white powder, 25% fat, 5% baking powder, 3% salt and 90% water (in flour basis). Wheat cakes containing no legume flours were used as control. Wheat flour was partially replaced by legume flour at concentration of 10%, 20% and 30%.

While preparing cake batter first the sugar and egg white powder was mixed with mixer (Kitchen Aid, 5K45SS, USA) for 1 min at low speed (85 rpm). Then, all other dry ingredients (non-fat dry milk, salt, baking powder, flour) were added. Melted fat and water were also added. All ingredients again were mixed for 1 min at low speed (85 rpm) then 1 min at medium speed (140 rpm) and 2 min at low speed (85 rpm).

Prepared cake batter samples (100g each) were poured into glass cake cups in 8.7 cm diameter and 4.8 cm height.

2.2.2 Baking of Cakes

Two different types of oven were used which were conventional oven and MW-IR combination oven for baking.

2.2.2.1 Baking in Conventional Oven

Electric oven (Arçelik A.Ş., İstanbul, Turkey) was used for conventional baking. Oven was preheated to 175 ºC for 3 min. Four cake samples were baked at the same time. They were placed in oven and baked for 24 minutes at 175 ºC.

2.2.2.2 Baking in Microwave-Infrared Combination Oven

MW-IR combination oven (Advantium oven^{TM}, General Electric Company, Louisville, KY, USA) was used for MW-IR baking (Figure 1.2). There are two halogen lamps at the top and one at the bottom each providing 1500 W in the oven. Power level of halogen lamps was fixed (60%). Microwave power was also kept constant at 50% during baking. The microwave power of oven was found as 700W according to IMPI 2 liter test (Buffler, 1993).In order to provide required humidity in the oven two beakers having 400 ml water placed at the corners of the oven. One cake sample was placed at the center of the rotary table. Cake samples were baked for 4, 4.5 and 5 minutes.

2.2.3 Quality Analysis of Cakes

After baking, weight loss, specific volume, porosity, texture, color, gelatinization degree, macro and micro-structure of cakes were determined.

2.2.3.1 Determination of Weight Loss

Percent weight loss of cake samples were calculated by using the Equation (2.1).

$$WL(\%) = \frac{W_i - W_f}{W_f} \times 100 \tag{2.1}$$

where, W_i represents initial weight (g), W_f represents final weight after baking(g).

2.2.3.2 Determination of Specific Volume

After baked cakes were cooled to room temperature, their specific volumes were measured by rape seed displacement method (AACC, 1990). Specific volumes of cakes were determined by using Equations (2.2 - 2.5).

$$W_s = W_t - W_c - W_{cup} \tag{2.2}$$

$$V_s = W_s / \rho_s \tag{2.3}$$

$$V_c = V_{cup} - V_s \tag{2.4}$$

$$SV_c = V_c / W_c \tag{2.5}$$

Where W_s denotes weight of seeds (g), W_t is total weight (g), W_{cup} is cup weight (g), W_c is weight of cake (g), V_s is volume of seeds (cm^3), V_c is cake volume (cm^3), V_{cup} is cup volume (cm^3), ρ_s is density of seeds (g/cm^3), SV_c is specific volume of cake (cm^3/g).

2.2.3.3 Determination of Porosity

While measuring porosity of cakes, compression method was performed (Sumnu et al., 2007). Volume of samples was measured before and after compression. Compression was performed with 24 kg load for 2 minutes. Porosity of cakes was calculated according to Equation (2.6).

$$\text{Porosity} = (V_i - V_f)/V_i \tag{2.6}$$

where, V_i indicates initial volume of the sample(cm^3) and V_f is compacted volume (cm^3) determined as rape seed displacement method.

2.2.3.4 Color Measurements

Color of cake crumb and crust was measured by color reader (Minolta, CR10, Osaka, Japan). Values of L*, a* and b* were recorded (CIE coordinates). L* denotes lightness and darkness, a* denotes redness and greenness and b* denotes blueness and yellowness. ΔE* represents the color change and can be calculated as shown in the equation (2.7).

$$\Delta E^* = \left[(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2\right]^{1/2} \tag{2.7}$$

L_0^*, a_0^* and b_0^* values are the reference values obtained from barium sulphate which were 86.5,-2.3 and 7, respectively.

2.2.3.5 Texture Analysis

Cake samples were cooled to room temperature for 1 hour. Cubic cake samples were cut from center of the cake (2.5 cmx2.5 cmx2.5 cm). Texture analyzer (Lloyd Ins., England, UK) was used to measure crumb hardness value of the cakes. Samples were compressed 25% of their initial height. Speed of the probe was 55 mm/min, diameter was 10 mm and the load was 50 N (AACC, 2000).

2.2.3.6 Determination of Gelatinization Degree

The batter samples and baked cakes samples were frozen immediately at -18 ºC. The samples were freeze dried at -52 ºC for 48 hours (Christ, Alpha 1-2 LD plus, Osterode, Germany). The samples were ground and sieved via 200 μm mesh.

The gelatinization degree of both cakes and batter was measured by differential scanning calorimetry (DSC) (Perkin Elmer DSC 4000, Ohio, USA). The samples were prepared based on 1:2 ratio (dry sample: water). The pans were sealed hermetically and refrigerated for a night to equilibrate. Empty pan was used as reference and indium and zinc were used for calibration. Samples were heated from 30°C to 120°C at a heating rate of 10°C/min. Pyris software (Version 11.0.0.0449) was used to calculate onset, peak and end temperatures and gelatinization enthalpy. Gelatinization degrees of baked cake samples were calculated by the following equation (Ndife et al., 1998):

$$\text{Gelatinization degree (\%)} = \left(1-\frac{\Delta H_c}{\Delta H_b}\right) \times 100 \tag{2.8}$$

where ΔH_c denotes enthalpy of baked cake samples (J/g) and ΔH_b denotes enthalpy of cake batter (j/g).

2.2.3.7 Determination of Macro-structure

Baked cake samples were divided vertically in half. Electrical knife was used to cut samples (Arzum AR 156 Colte, Ankara, Turkey). Then the samples were scanned by scanner with 300 dpi resolution.

Image J software (URL 4) was used to calculate the total pore numbers, pore size distribution and pore area fractions. Images were converted to 8 bit scale (gray scale) and cropped into the possible largest rectangle (5.61 cm x 4.02 cm). Pixel was converted to centimeter.

To determine the pore numbers, pore area fraction and pore size distribution in cake crumbs, the method (Binarise SEM and Compute Stats) of Impoco et al. (2007) was used. Auto thresholding in Binarise SEM plug-in was used to determine pores and structure. Compute Stats plug-in was used to calculate the number and distribution of pores.

2.2.3.8 Determination of Microstructure

Freeze dried and ground cake samples were sputter coated with gold- palladium. Scanning electron microscope (JSM-6400, JEOL, Tokyo, Japan) was used to determine the microstructures of cake samples. Images obtained with 30× and 500× magnification were analysed.

2.2.4 Statistical Analysis

Analysis of variance (ANOVA) was used in order to identify significant differences between flour type, flour concentration and baking time by using 9.1 SAS software (SAS Institute Inc., NC, USA). If significant difference was found, Duncan's Multiple Comparison Test was used to compare cake samples ($p \leq 0.05$).

CHAPTER 3

RESULTS AND DISCUSSION

3.1 Effects of Legume Flour Concentration and Baking Time on Quality Parameters

The effects of legume flour concentration (10%, 20% and 30%) and the baking times (4, 4.5 and 5 minutes) on quality parameters of cakes baked in different ovens were determined. Weight loss, specific volume, porosity, texture, color change in crust and crumb of cakes were investigated.

3.1.1 Weight Loss

Weight loss was mainly due to moisture loss from cake surface during baking. The weight loss of legume cakes baked in conventional oven was shown in Figure 3.1. Variation of legume flour concentration affected weight loss significantly. It was found that as the concentration of legume flour increased, weight loss decreased for all flour types. This might be due to higher water binding capacities of legume flours as compared to wheat flour. According to study conducted by Fenn et al. (2010), composite flours (legume-wheat flour blend) had higher water holding capacity than control flour (wheat flour). The high protein and fiber contents of legume flours were responsible for high water binding capacity. That is why, weight loss decreased as the concentration of legume flours increased. It was also reported that addition of soy flour to cakes enhanced the water holding capacity and decreased the moisture loss of soy-cakes (Sakıyan, 2014).

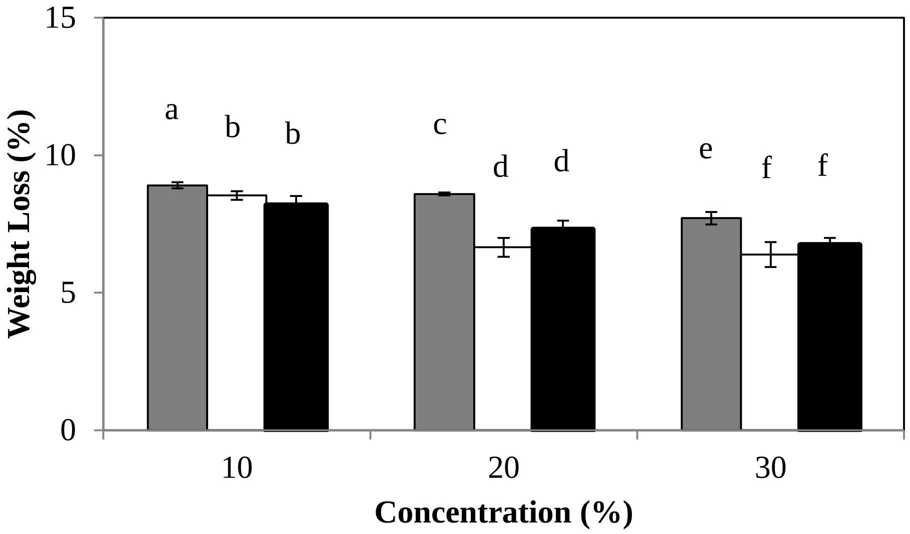


Figure 3.1 Effect of legume flour type and concentration on weight loss of cakes baked in conventional oven for 24 min; (■): lentil flour, (□): chickpea flour, (■): pea flour

Baking time was found to be effective on weight loss for all concentrations of lentil cakes baked in MW-IR combination oven (Figure 3.2). High internal pressure resulted in high moisture loss during baking in MW-IR combination oven. As exposure to microwave and IR power increased, further heating occurred and weight loss increased. Increasing weight loss with baking time was also observed in other studies (Sevimli, 2004; Sumnu et al., 1999). Similar results were found when wheat flour partially replaced by chickpea or pea flour in cakes baked in MW-IR combination oven (Figure 3.3 and Figure 3.4).

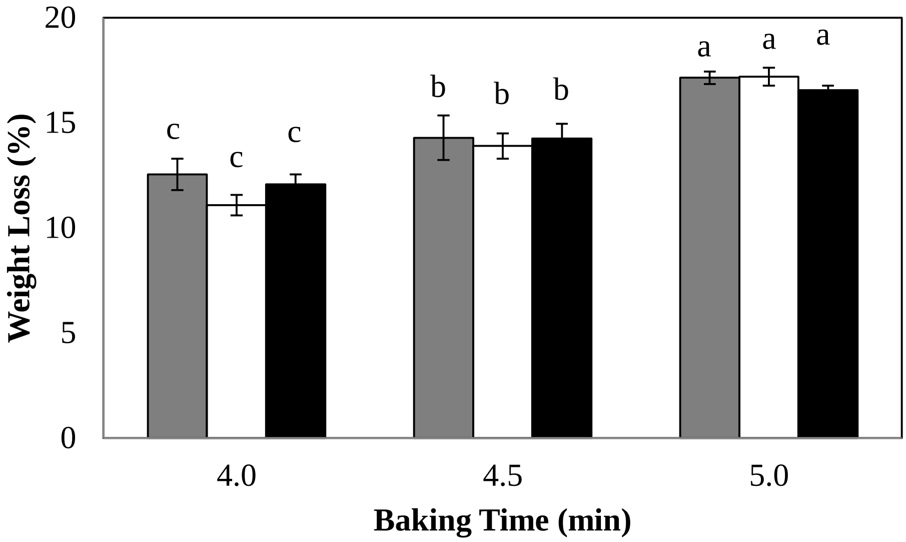


Figure 3.2 Effect of baking time and lentil flour concentration on weight loss of cakes baked in MW-IR combination oven; (■):10%, (□):20%, (■):30%

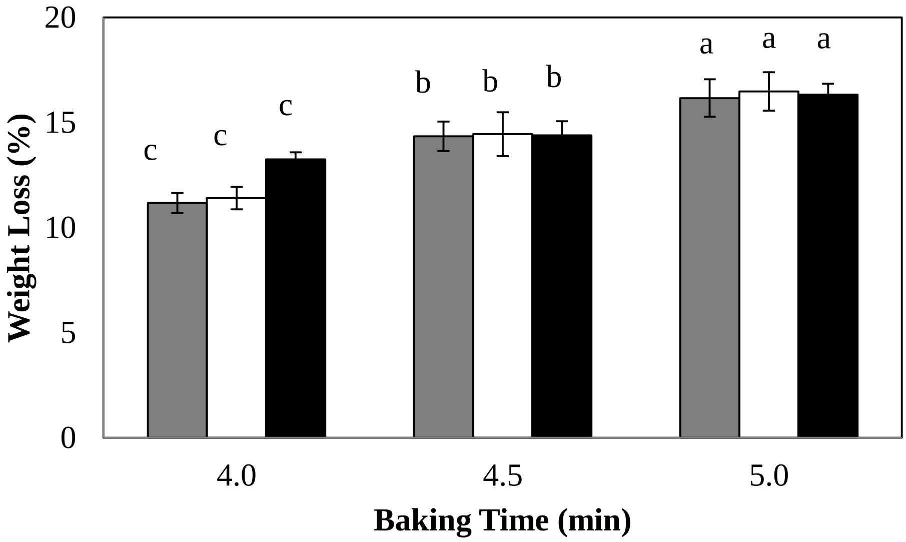


Figure 3.3 Effect of baking time and chickpea flour concentration on weight loss of cakes baked in MW-IR combination oven; (■):10%, (□):20%, (■):30%

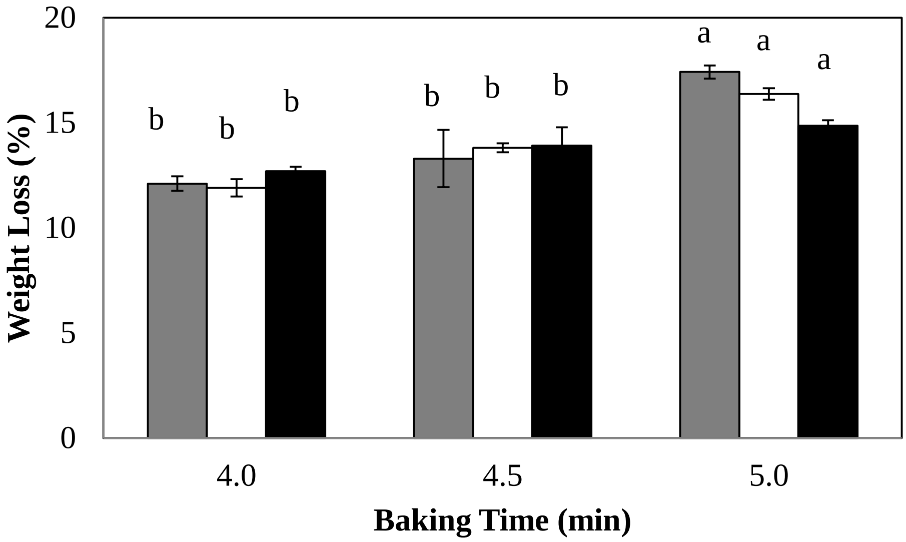


Figure 3.4 Effect of baking time and pea flour concentration on weight loss of cakes baked in MW-IR combination oven; (■):10%, (□):20%, (■):30%

3.1.2 Specific Volume

According to ANOVA results legume flour concentration did not affect specific volumes of conventionally baked cakes significantly (p>0.05) (Figure 3.5 and Table A.5). On the other hand, flour type had significant effect on specific volumes of cakes baked in conventional oven. Using lentil flour in cakes provided higher specific volume as compared to the cakes containing pea flour. Minarro et al. (2012) explained that specific volume differences of legume cakes might be due to different foaming properties of legume flours. Foaming expansion is one of the functional properties of legume flours providing high quality. Moreover, according to Boye et al. (2010), chickpea flour had higher foam expansion than pea flour. Lower density of lentil batter might be another reason for higher specific volume of cakes. Gularte et al. (2012) stated that lentil cakes had lower batter density and higher specific volume than chickpea and pea cakes. It was also indicated in the same study that low batter density means more air bubbles entrapped into the batter which resulted in higher specific volume.

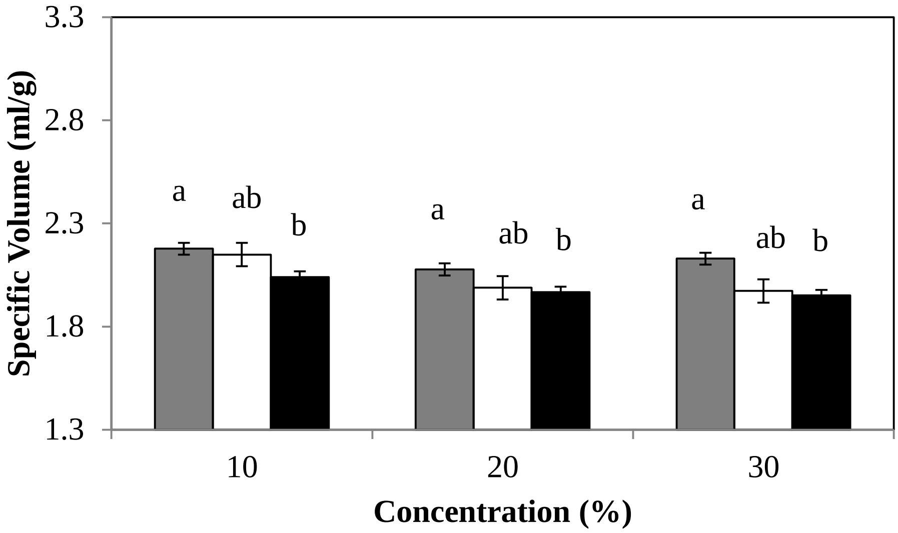


Figure 3.5 Effect of legume flour type and concentration on specific volume of cakes baked in conventional oven for 24 min; (■): lentil flour, (□): chickpea flour, (■): pea flour

As can be seen in Figure 3.6, baking time did not affect the specific volumes of lentil cakes baked in MW-IR combination oven significantly. In the experiments it was observed that crumb and crust formation was completed in cakes baked for 4 min. Therefore, there was no significant difference between the specific volumes of cakes baked at different times ($p>0.05$, Table A.6). However, variation of lentil flour concentration affected the specific volumes of cakes significantly. The lowest specific volume was observed at the 30% concentration level. There are many factors influencing the specific volume of the cakes. One of them can be that addition of protein source increases the viscosity of cake batter (Gomez et al., 2012). Minarro et al. (2012) and Gomez et al. (2012) reported that addition of legume flour increased the viscosity of batter and decreased the volume due to the fact that thicker structure allows lower amount of air to enter inside. Another reason might be dielectric properties of legume protein. Study conducted by Guo et al. (2010) indicated that dielectric properties (dielectric constant and loss factor) of legume flours increased with increasing temperature. This also accelerates heating rate. Therefore, rapid heating might have caused earlier crust formation and crust formation might have limited the expansion. Lower specific volume at higher lentil flour concentration were in accordance with many studies in the literature (Gomez et al., 2008; Moiraghi et al., 2012; Gomez et al., 2012; Minarro et al., 2012; Gularte et al., 2012). Similar results were obtained for chickpea and peas cakes baked in MW-IR combination oven (Figure 3.7 and Figure 3.8).

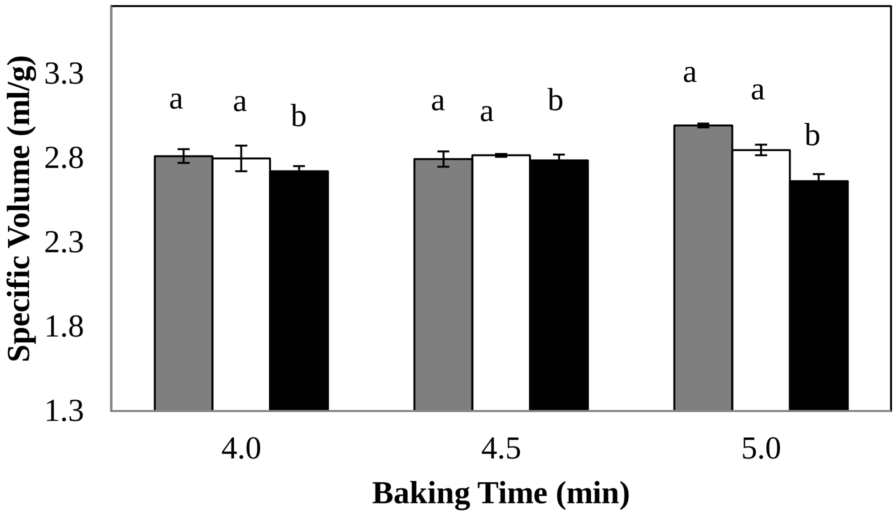


Figure 3.6 Effect of baking time and lentil flour concentration on specific volume of cakes baked in MW-IR combination oven; (■):10%, (□):20%, (■):30%

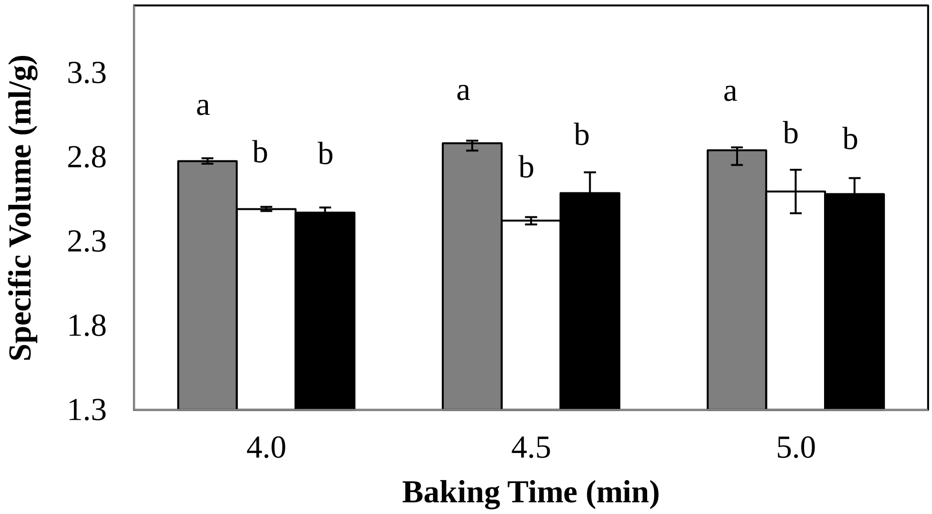


Figure 3.7 Effect of baking time and chickpea flour concentration on specific volume of cakes baked in MW-IR combination oven; (■):10%, (□):20%, (■):30%

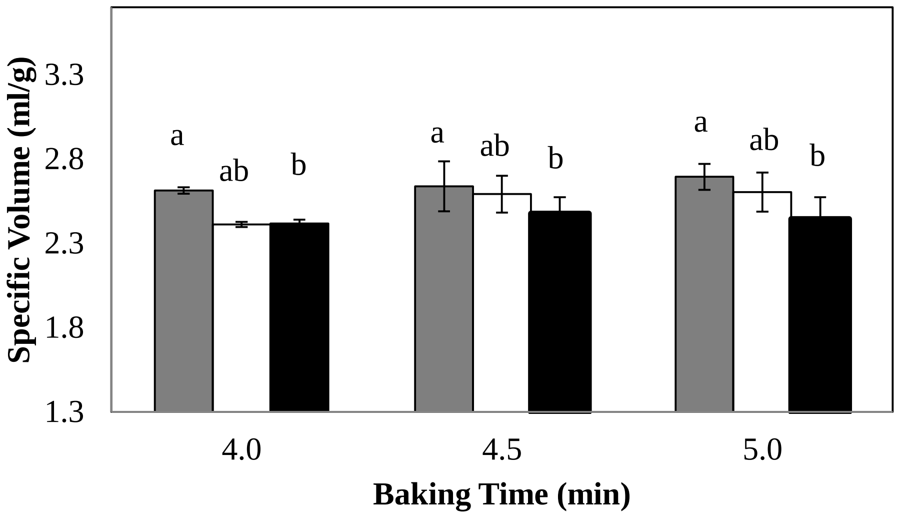


Figure 3.8 Effect of baking time and pea flour concentration on specific volume of cakes baked in MW-IR combination oven; (■):10%, (□):20%, (■):30%

3.1.3 Porosity

Pores are formed during expansion of cake batter by carbon dioxide liberation from baking powder. Therefore, number and size of pores are directly related to volume of cake. Effect of legume flours and their concentration on porosity of conventional cakes was shown in the Figure 3.9. There was significant difference between legume flours. Lentil cakes were found to be more porous than other cakes at all concentrations. As previously discussed, lentil cakes were also found to have the highest specific volume (Figure 3.5). This shows that specific volume results were supported by porosity results. In other words, the same discussion can be valid for volume and porosity results. Cakes containing lower legume concentration (10% and 20%) were less porous than cakes containing higher concentration (30%).

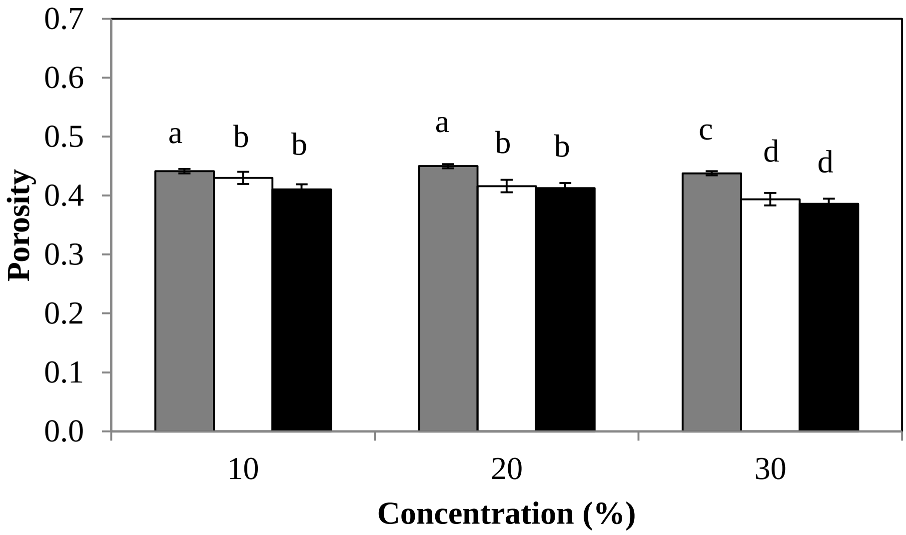


Figure 3.9 Effect of legume flour type and concentration on porosity of cakes baked in conventional oven for 24 min; (■): lentil flour, (□): chickpea flour, (■): pea flour

Legume flour concentration was found to have a significant effect on porosity. As the concentration of legume flour increased porosity of MW-IR cakes decreased (Figure 3.10). That is, cakes with 30% legume flour concentration were observed to be the least porous. The specific volumes of cakes having 30% legume flour were also found to be the lowest. Similar results were obtained for chickpea and pea cakes (Figure 3.11 and Figure 3.12).

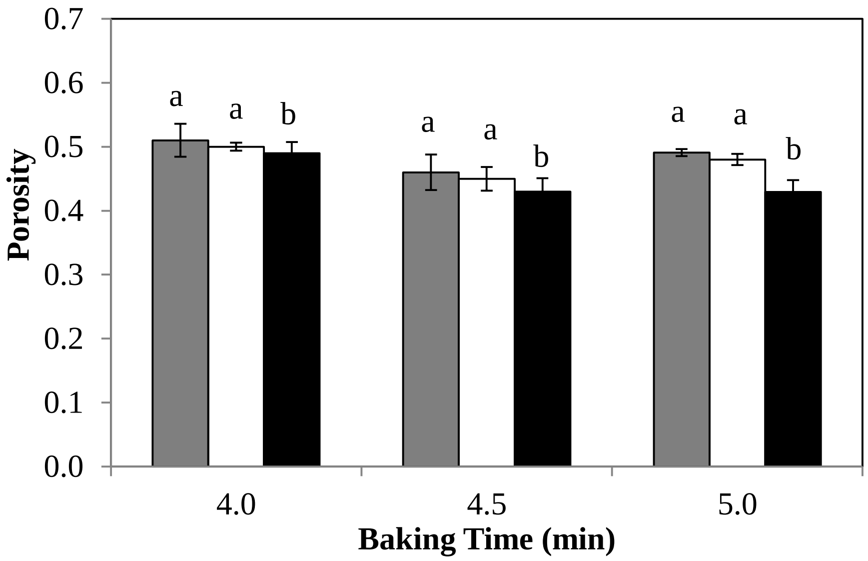


Figure 3.10 Effect of baking time and lentil flour concentration on porosity of cakes baked in MW-IR combination oven; (■):10%, (□):20%, (■):30%

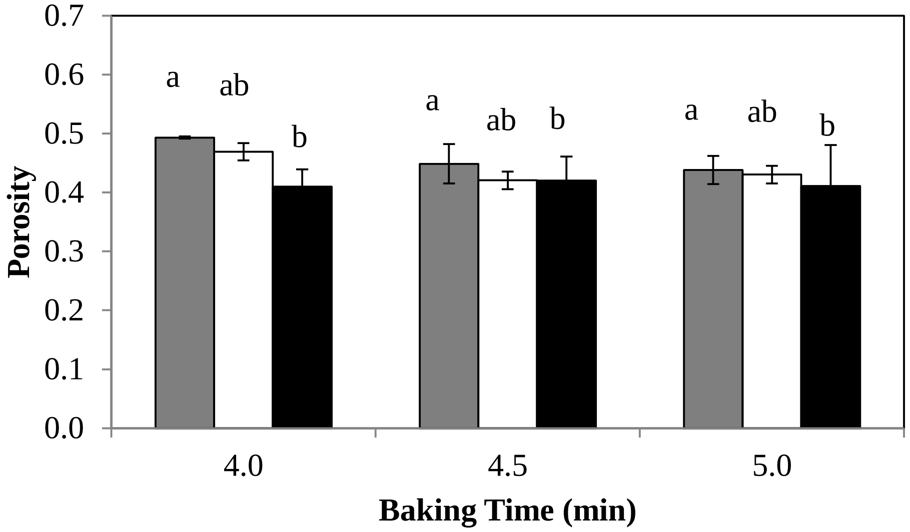


Figure 3.11 Effect of baking time and chickpea flour concentration on porosity of cakes baked in MW-IR combination oven; (■):10%, (□):20%, (■):30%

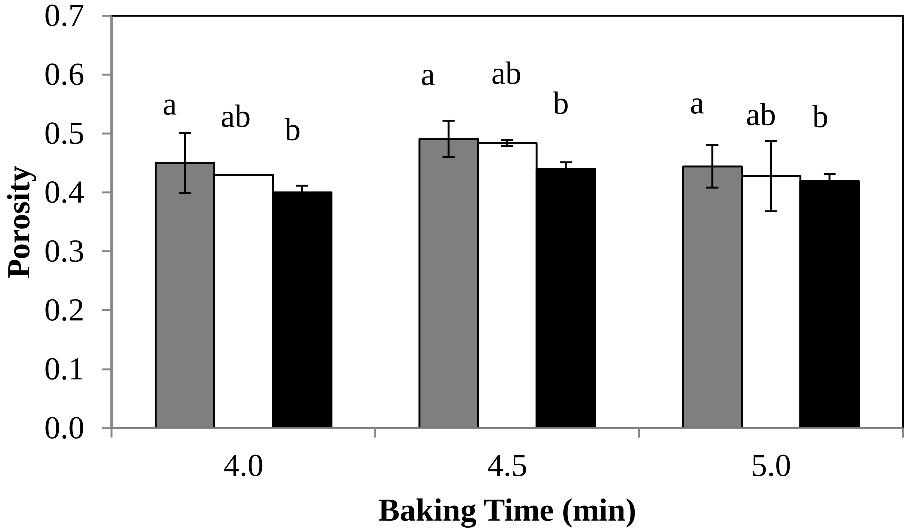


Figure 3.12 Effect of baking time and pea flour concentration on porosity of cakes baked in MW-IR combination oven; (■):10%, (□):20%, (■):30%

3.1.4 Texture Analysis

Hardness values were investigated as textural properties of cakes. Legume flour type and concentration had significant effect on the hardness of conventionally baked cakes (Figure 3.13). Addition of legume flours increased the hardness of cakes. As shown in the figure, lentil cakes were found to have the softest crumb while pea cakes had the hardest one. The hardness results were consistent with specific volume values. Generally, harder structure was observed at the lower specific volume. Hard structure and low specific volume are undesirable. Pea cakes had the lowest specific volume probably due to its lower foaming properties. The results were in agreement with those obtained by Minarro et al. (2012) and Gularte et al. (2011) who found that pea flour gave the hardest structure to breads and cakes as compared to other legume flour (chickpea, lentil and bean), respectively. On the other hand, as the concentration of legume flour increased, hardness of cakes also increased. These results were also correlated with the specific volume results. Gomez et al. (2008) also reported that the percentage of chickpea flour increased the firmness of cakes.

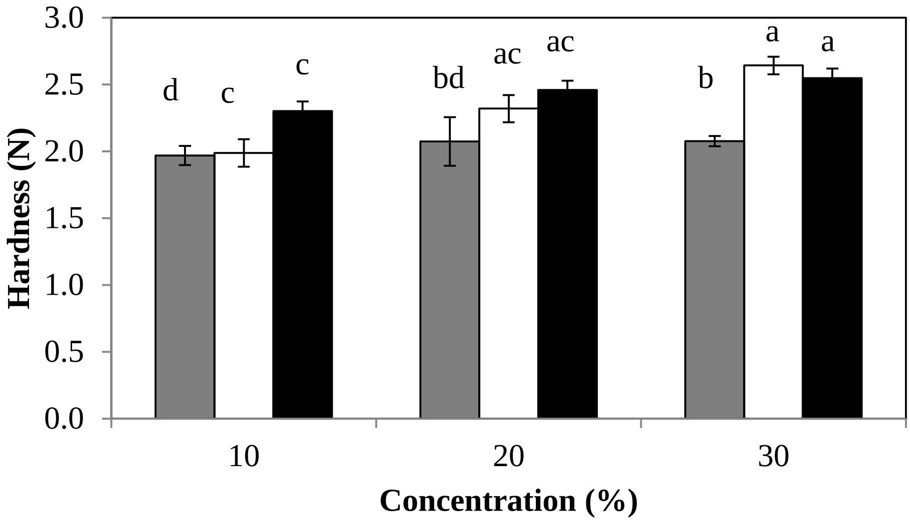


Figure 3.13 Effect of legume flour type and concentration on porosity of cakes baked in conventional oven for 24 min; (■): lentil flour, (□): chickpea flour, (■): pea flour

As shown in the Figure 3.14-3.16, harder legume cakes were obtained at the higher concentration level. Hardness results of chickpea and pea cakes were not affected by baking time. As mentioned above, as the concentration of legume flour increased, specific volumes decreased. Lower cake volume resulted in lower porosity and harder texture.

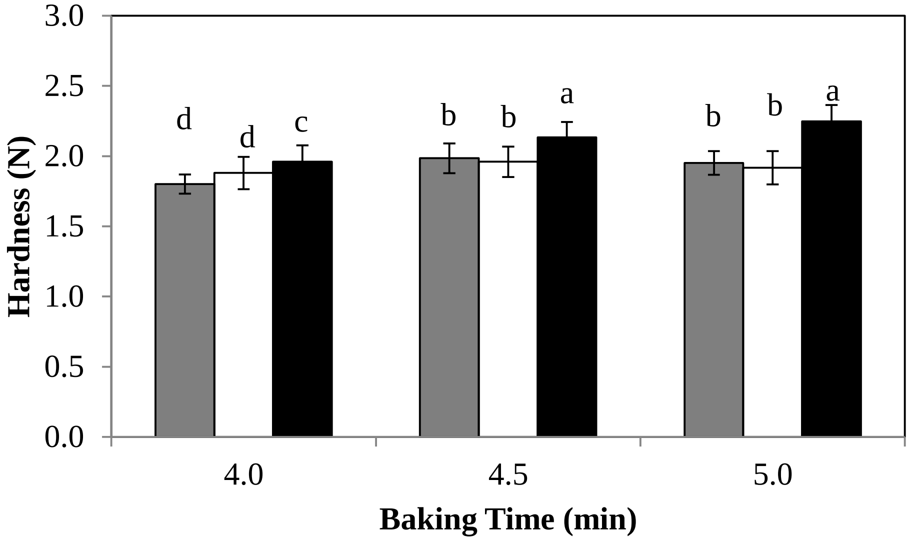


Figure 3.14 Effect of baking time and lentil flour concentration on hardness of cakes baked in MW-IR combination oven; (■):10%, (□):20%, (■):30%

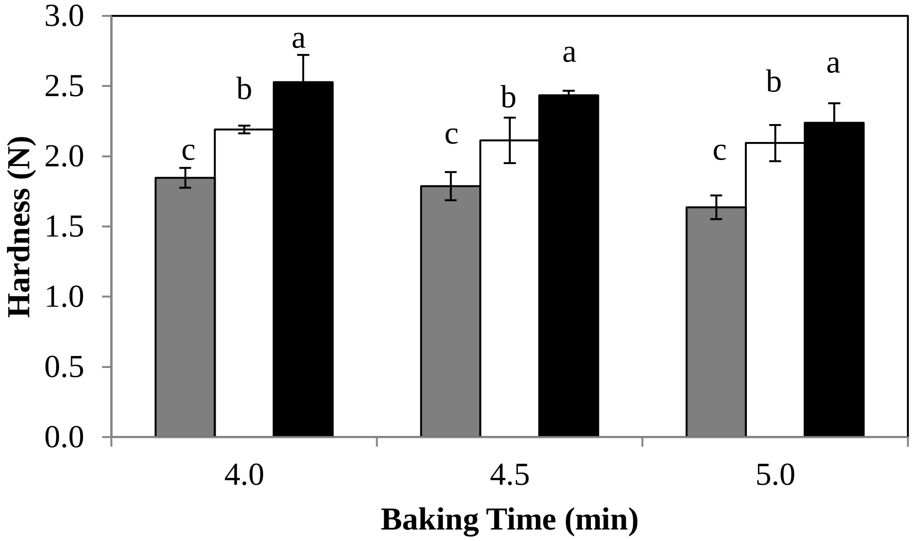


Figure 3.15 Effect of baking time and chickpea flour concentration on hardness of cakes baked in MW-IR combination oven; (■):10%, (□):20%, (■):30%

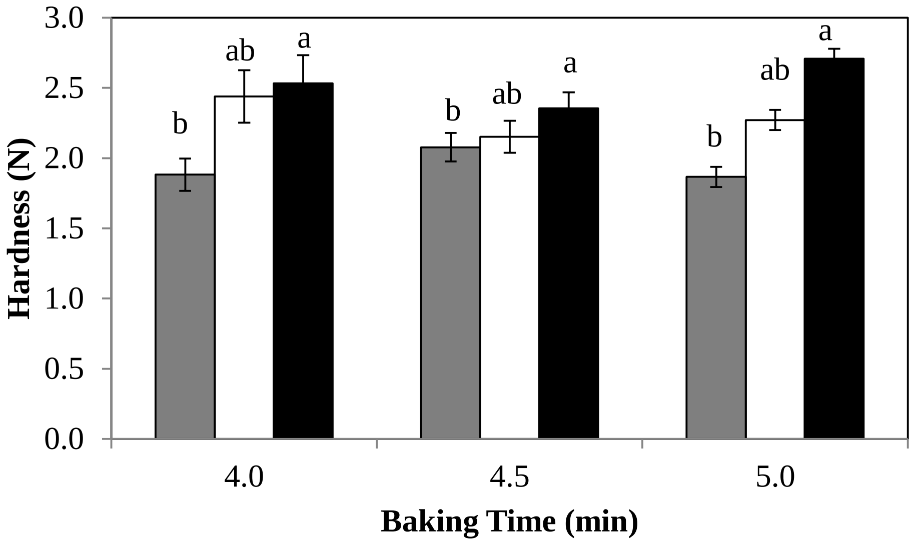


Figure 3.16 Effect of baking time and pea flour concentration on hardness of cakes baked in MW-IR combination oven; (■):10%, (□):20%, (■):30%

3.1.5 Crust Color Change

Color is one of the most important quality parameters for bakery products. Color of foods directly affects the appearance, and thus acceptability of product. Crust color formation is provided by Maillard reactions (non-enzymatic browning) between amino acids and reducing sugars and by the caramelization of sugar (Purlis, 2010).

The effects of legume flour type and concentration on cakes baked in conventional oven were represented in Figure 3.17. When the legume flour concentration increased, differences between crust colors were observed. Increasing ΔE^* value with increasing concentration can be attributed to higher protein content, and so higher browning degree. According to ANOVA results (Table A.17) there was no significant difference between flour types ($p>0.05$). Similar results were obtained from different legume flours. Increasing darkness of cakes with increasing chickpea and lentil flour concentration was previously reported by Gomez et al. (2008) and Hera et al. (2012), respectively.

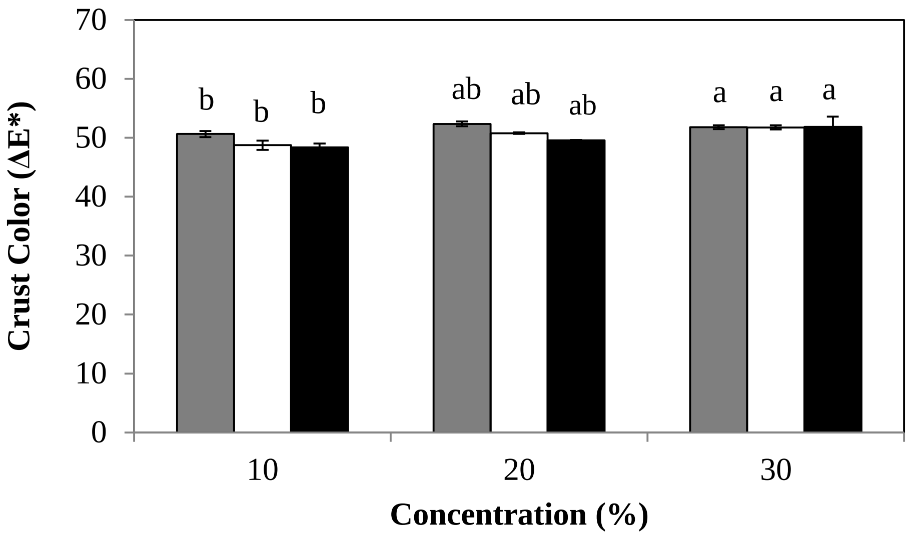


Figure 3.17 Effect of legume flour type and concentration on crust color (ΔE*) of cakes baked in conventional oven for 24 min; (■): lentil flour, (□): chickpea flour, (■): pea flour

Increase in ΔE* values of lentil, chickpea and peas cakes baked in MW-IR combination oven with increasing time can be explained by longer exposure to heat (Figure 3.18, Figure 3.19 and Figure 3.20). Higher temperature achieved in longer baking time resulted in accelerated Maillard reaction rate. Therefore, further browning at the longer baking time was observed. There are number of studies in which similar results were obtained (Sakiyan et al., 2007; Sumnu et al., 2005; Demirekler et al., 2004; Demirkesen et al., 2011). Color change also increased with the increasing concentration of legume flours.

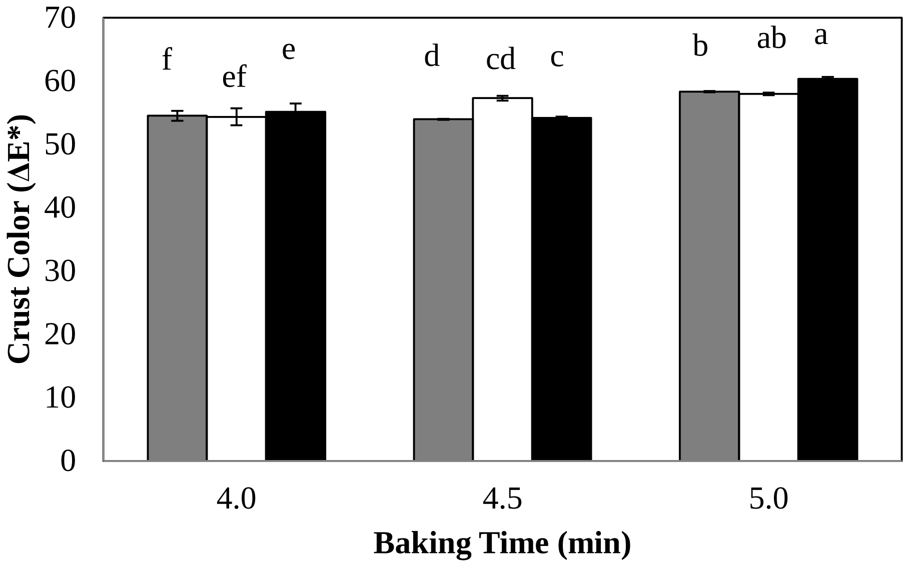


Figure 3.18 Effect of baking time and lentil flour concentration on crust color (ΔE*) of cakes baked in MW-IR combination oven; (■):10%, (□):20%, (■):30%

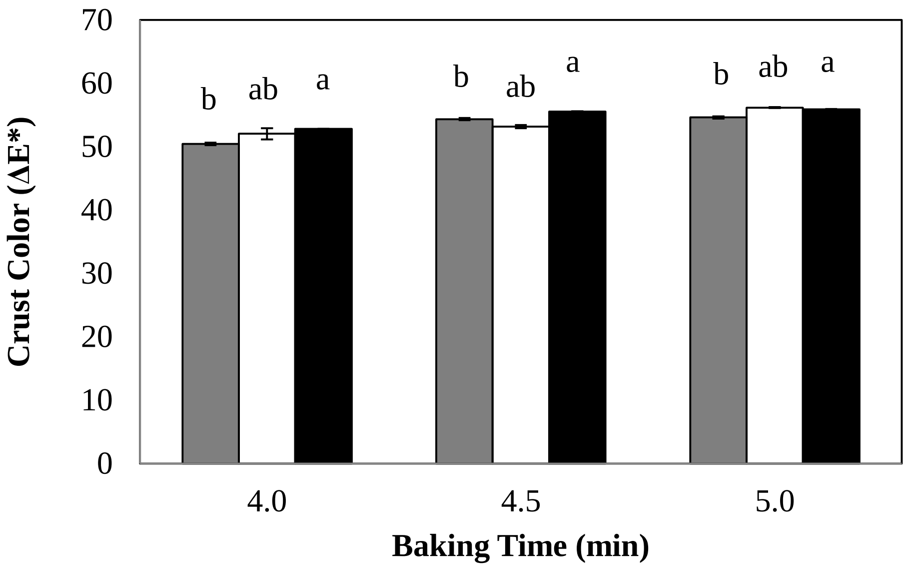


Figure 3.19 Effect of baking time and chickpea flour concentration on crust color (ΔE*) of cakes baked in MW-IR combination oven; (■):10%, (□):20%, (■):30%

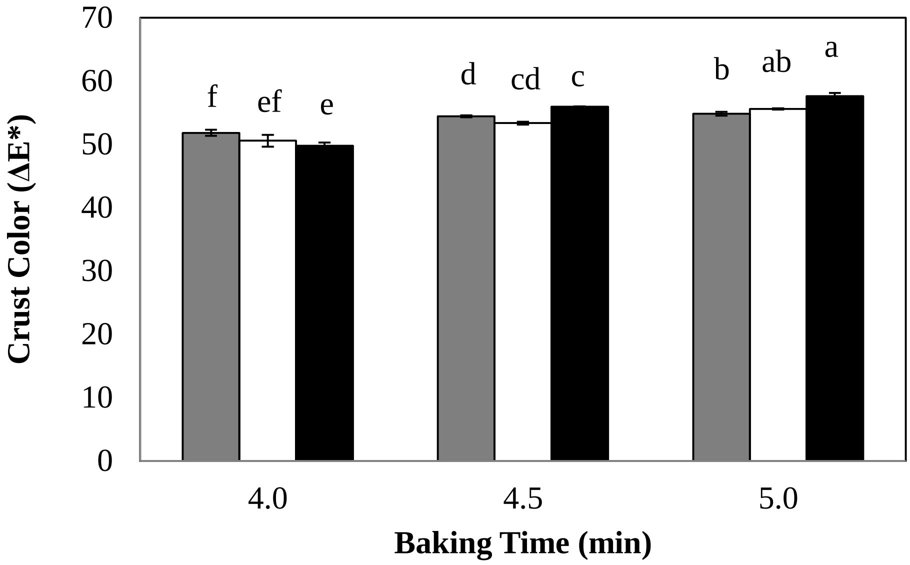


Figure 3.20 Effect of baking time and pea flour concentration on crust color (ΔE*) of cakes baked in MW-IR combination oven; (■):10%, (□):20%, (■):30%

3.1.6 Crumb Color Change

The effects of flour type and concentration on crumb color of legume cakes baked in conventional oven were shown in Figure 3.21. There were significant difference between flour types and concentrations. Since the inside of the cake did not reach high temperatures, Maillard and caramelization reactions did not take place. Thus, crumb browning did not occur. For this reason, the color differences between flour types were mainly due to original color of legume source. In this study, color results were investigated in terms of ΔE* of cakes. However, while calculating ΔE* values, CIE L*, a* and b* values were used (Table C.2). Differences between flour types and concentrations were caused by different L*, a* and b* values of legume flours. Ma et al. (2011) studied functional properties of lentil, pea and chickpea flours and reported that lentil flour had the highest a* value (due to redness) while chickpea had the highest lightness (L* value). It is not surprising to see as the concentration of legume flour increased, ΔE* value increased.

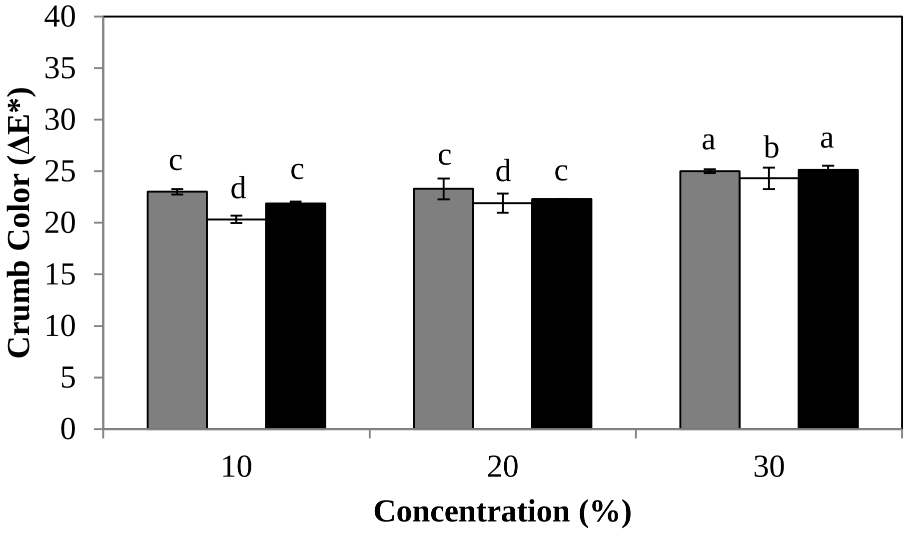


Figure 3.21 Effect of legume flour type and concentration on crumb color (ΔE*) of cakes baked in conventional oven for 24 min; (■): lentil flour, (□): chickpea flour, (■): pea flour

Concentration had a significant effect on ΔE* values of legume cakes baked in the MW-IR combination oven too (Figure3.22- 3.24). As in the conventional oven the color change was observed due to color of legume flours. In general, baking time did not affect the color change (ΔE*) significantly. As the concentration of legume flour increased L*, a* and b* values of cakes changed and their total color change (ΔE*) increased (Table C.2).

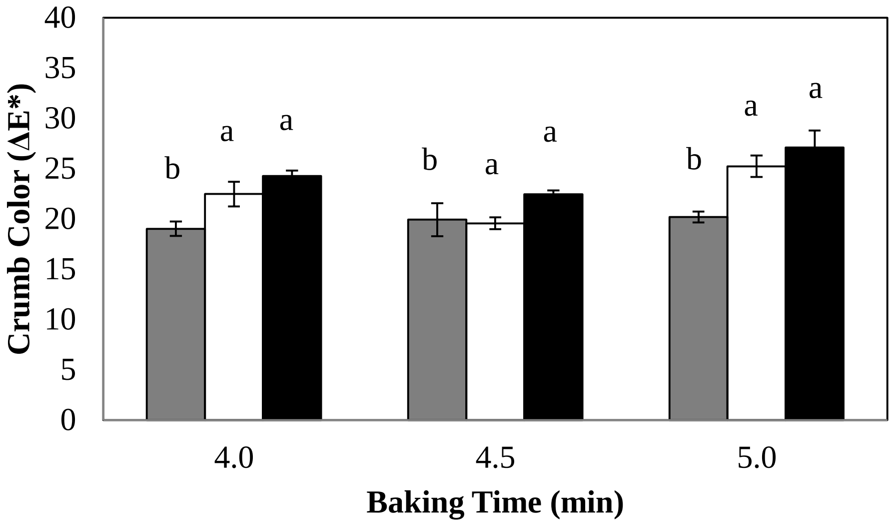


Figure 3.22 Effect of baking time and lentil flour concentration on crumb color (ΔE*) of cakes baked in MW-IR combination oven; (■):10%, (□):20%, (■):30%

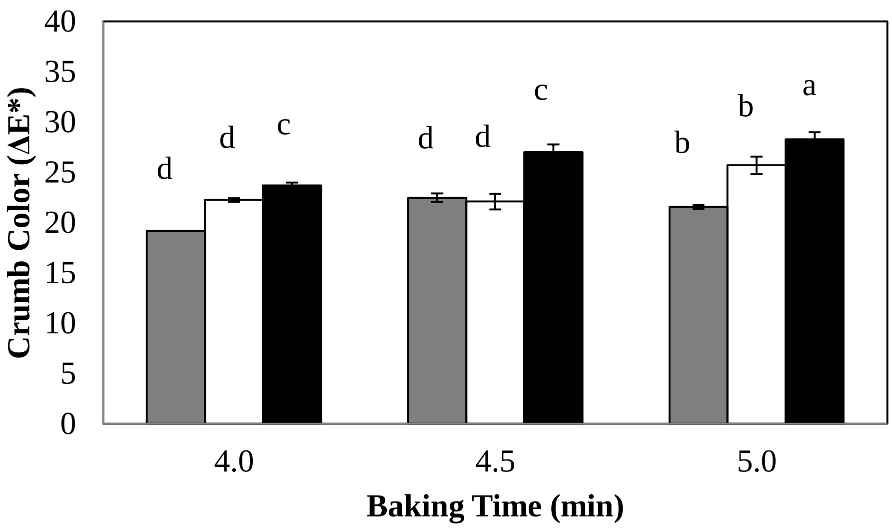


Figure 3.23 Effect of baking time and chickpea flour concentration on crumb color (ΔE*) of cakes baked in MW-IR combination oven; (■):10%, (□):20%, (■):30%

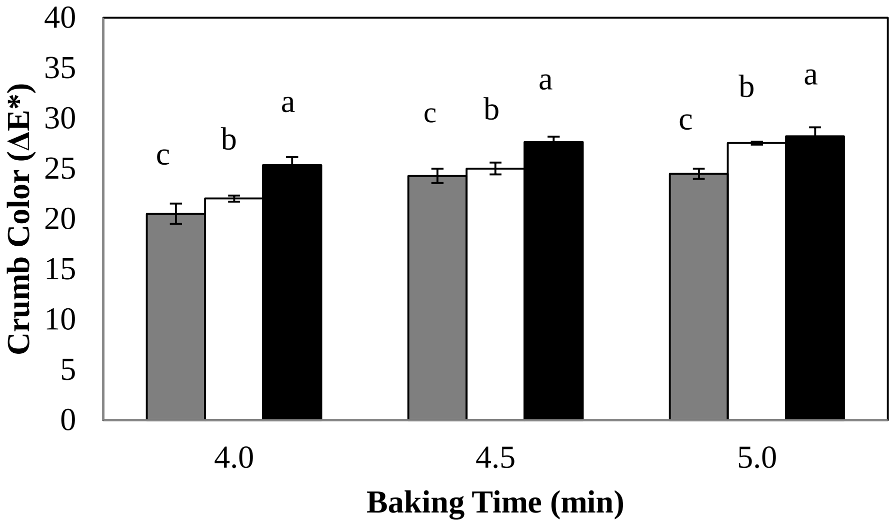


Figure 3.24 Effect of baking time and pea flour concentration on crumb color (ΔE*) of cakes baked in MW-IR combination oven; (■):10%, (□):20%, (■):30%

3.2 Comparison of Quality of Different Legume Cakes and Baking Types

Quality parameters were discussed above in order to determine the optimum concentration of legume flours and the optimum baking time for MW-IR combination oven. In general, it was observed that porosity, specific volume, hardness, crust color (ΔE*) and crumb color (ΔE*) did not change significantly with the increasing baking time. On the contrary, as the baking time increased weight loss increased for all legume flour types. Therefore, in order to save time and energy, minimum time (4 min) was determined as optimum time. On the other hand, specific volume and porosity decreased but hardness of cakes increased with increasing legume flour concentration. Best quality results were obtained when wheat flour replaced with 10% legume flour. In brief, 4 min of baking and 10% legume flour concentration were determined as the optimum conditions.

To compare the baking type and legume flour types weight loss, specific volume, porosity, hardness, crust and crumb color change of 10% legume concentration cakes that were baked for 4 min in the MW-IR combination oven were investigated.

The effects of the flour and baking type on the weight loss were shown in the Figure 3.25. Relatively higher weight loss was observed in MW-IR combination oven cakes. High interior heating in MW-IR combination oven creates high internal pressure. Pressure gradient causes greater amount of moisture to flow inside to outside of the food. This resulted in higher moisture loss in cakes baked in MW-IR combination oven. Similar results were found previously by several researchers (Sahin et al., 2002; Sumnu et al, 1999; Sumnu et al., 2005). Legume cakes lost less moisture than wheat cakes in both ovens which could be explained by higher water holding capacity of legume flours.

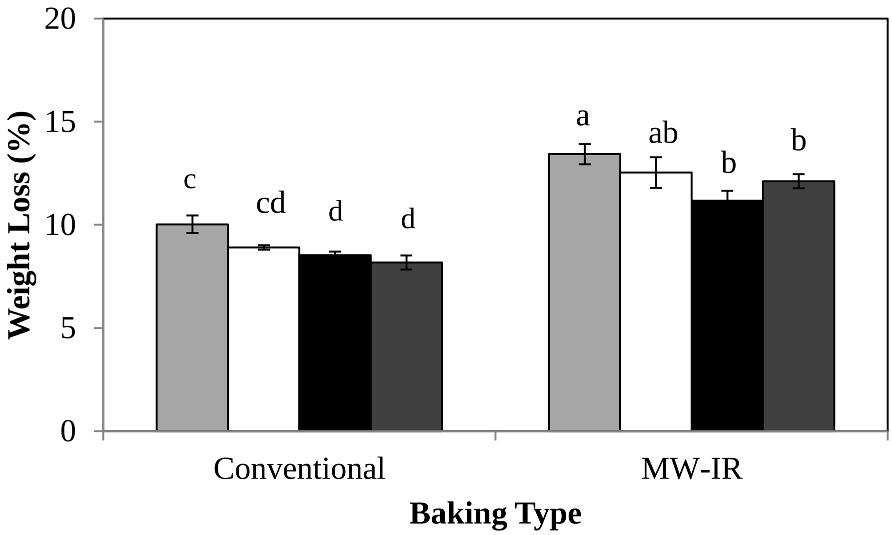


Figure 3.25 Effect of legume flour and baking type on weight loss of cakes; (■): wheat flour, (□): lentil flour, (■): chickpea flour, (■): pea flour

According to specific volume results there was significant difference between oven types (Figure 3.26). MW-IR baked cakes resulted in higher specific volume than conventionally baked ones. High internal pressure during baking might have caused higher volumes due to puffing effect. There was no significant difference between wheat, lentil and chickpea cakes (p>0.05, Table A.26). However, addition of pea flour resulted in significantly lower volumes probably due to its lower foaming properties or lower gelatinization degree. According to study conducted by Martinez et al. (2014) addition of pea fiber to gluten-free bread resulted in significant decrease in the volume of bread due to its insoluble characteristics.

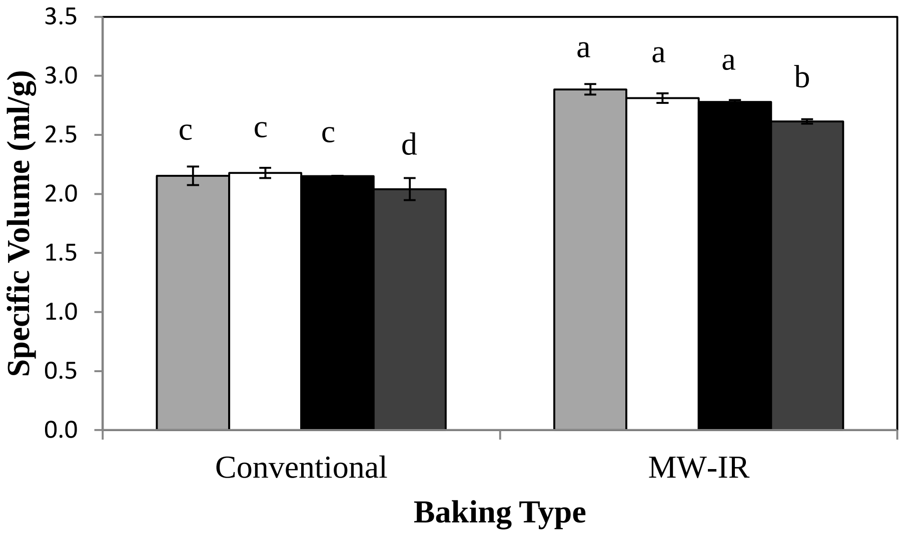


Figure 3.26 Effect of legume flour and baking type on specific volume of cakes; (■): wheat flour, (□): lentil flour, (■): chickpea flour, (■): pea flour

Porosity of cakes baked in MW-IR combination oven was significantly higher than conventional oven (Figure 3.27). MW-IR combination oven also showed larger volumes. Volumetric heating in the MW-IR combination oven causes high internal pressure. Puffing effect due to high pressure gradient resulted in high volume and porous structure. Similar results were obtained previously in studies on cake and bread (Ozkoc et al., 2009; Turabi et al., 2010; Demirkesen et al., 2012).

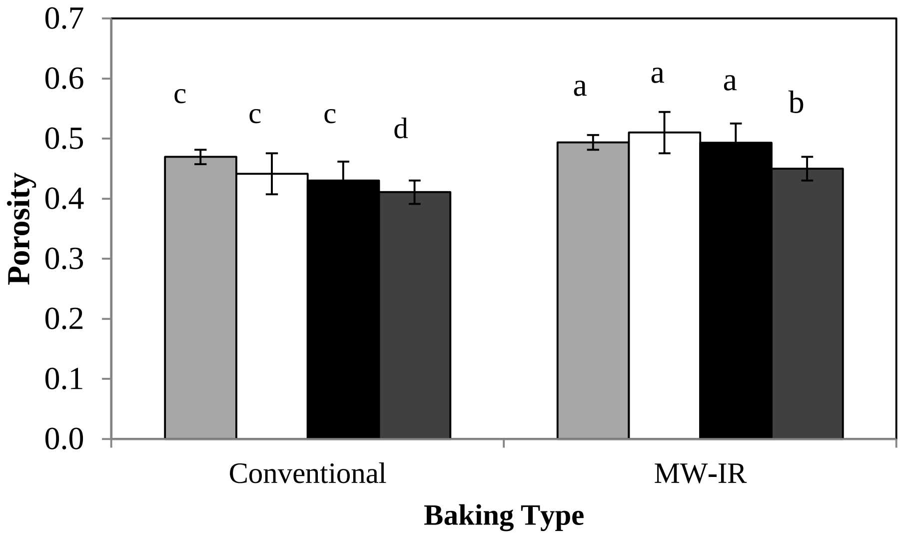


Figure 3.27 Effect of legume flour and baking type on porosity of cakes; (■): wheat flour, (□): lentil flour, (■): chickpea flour, (■): pea flour

Figure 3.28 shows the effect of baking types and legume flours on hardness of cakes. Control cakes which were baked in conventional oven were found to be harder than MW-IR baked cakes. Conventionally baked cakes had also lower volumes than MW-IR cakes. Because of pressure gradient and puffing effect, MW-IR cakes had higher volume and larger porosity. Therefore, these cakes were softer than conventionally baked ones. Inverse relation between volume and hardness of cakes was reported previously by Hera et al. (2012), Gomez et al. (2010) and Gularte et al. (2012). On the other hand, hardness values of pea cakes were higher than wheat cakes due to their lower volume (Figure 3.26).

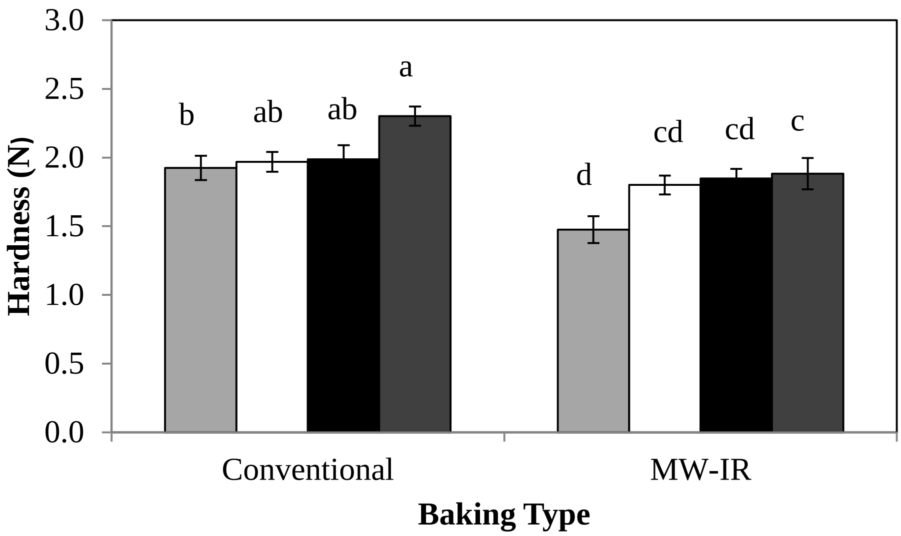


Figure 3.28 Effect of legume flour and baking type on hardness of cakes; (■): wheat flour, (□): lentil flour, (■): chickpea flour, (■): pea flour

Higher crust color change was observed in the MW-IR combination oven than conventional oven (Figure 3.29). Difference between baking type was probably due to halogen lamp which is known as generating lower penetration depth and higher surface temperature. Higher temperatures at the surface of the cakes were resulted in further browning and color change. Similar results were reported previously by Demirkesen et al. (2011) who studied baking conditions of chestnut–rice breads.

On the other hand, legume cakes where observed to have significantly higher crust color change than wheat cakes. High protein content of legume flours provided higher ΔE* values due to Maillard reaction. Fenn et al. (2010) indicated that addition of soy, yellow pea and chickpea protein to breads resulted in further browning.

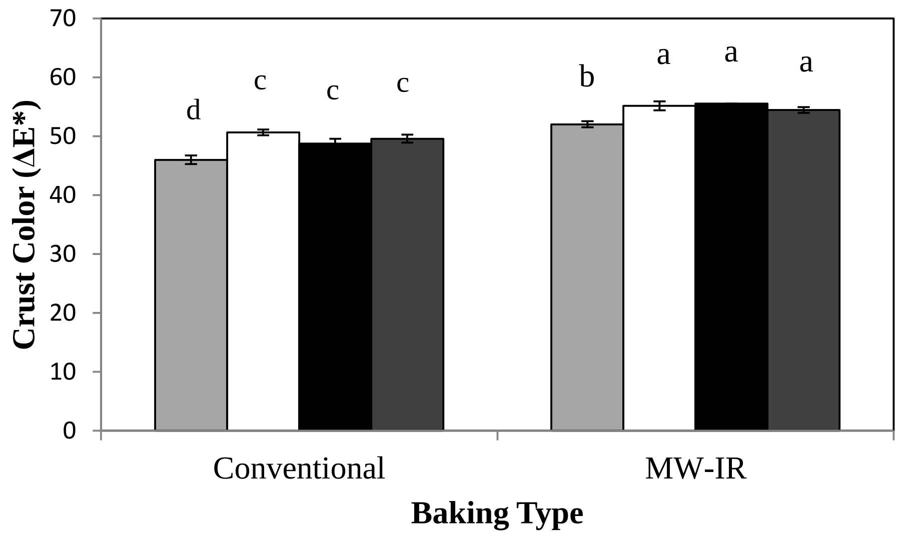


Figure 3.29 Effect of legume flour and baking type on crust color (ΔE*) of cakes; (■): wheat flour, (□): lentil flour, (■): chickpea flour, (■): pea flour

Crumb color change of cakes baked in MW-IR oven was observed to be significantly lower than conventionally baked cakes (Figure 3.30). The reason might be difference between heating mechanisms of the ovens. Halogen lamp in the MW-IR combination oven provides short penetration depth and high surface temperature. Therefore, color change might be concentrated at the surface of the cake.

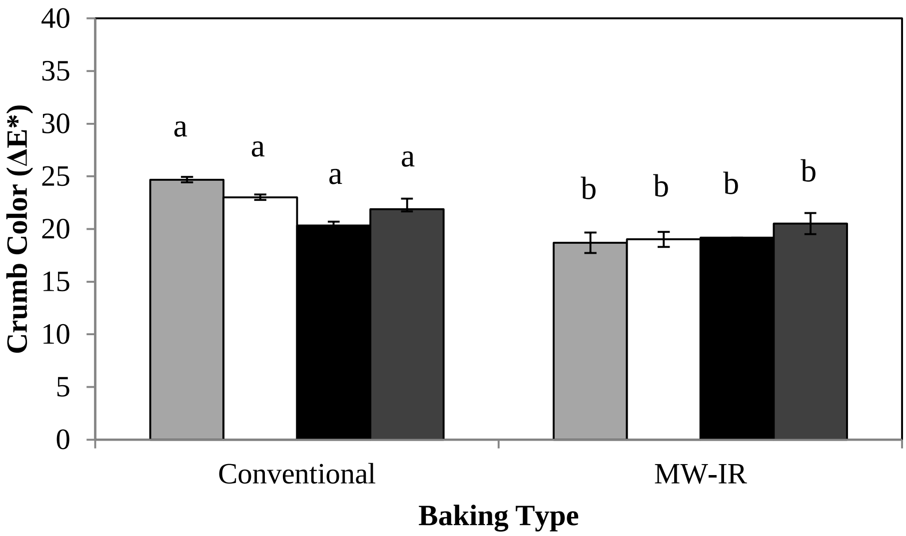


Figure 3.30 Effect of legume flour and baking type on crumb color (ΔE*) of cakes; (■): wheat flour, (□): lentil flour, (■): chickpea flour, (■): pea flour

3.3 Effects of Different Legume Flour Types on Gelatinization Degrees of Cakes Baked in Different Ovens

As shown in the Table 3.1, oven type affected the gelatinization degree of all cakes. Conventional oven had higher gelatinization degrees. The reason can be higher moisture loss which limits available water for starch gelatinization and short baking time of MW-IR combination oven. Study conducted by Sakiyan et al. (2011) showed that gelatinization degree of cakes increased with increasing baking time of microwave, MW-IR combination and conventional oven. Short baking time failed to provide enough starch gelatinization in microwave cakes.

On the other hand, addition of legume flour decreased gelatinization degrees of cakes baked in both ovens. The reason can be high water binding capacities of legume flours due to their high protein and fiber contents. In other words, protein and fiber present in the legume flours limited the available water amount, and thus starch swelling and gelatinization. Wang & Kim (1998) reported previously that the presence of protein and starch together resulted in lower gelatinization degree of corn flour. Another reason can be the increase in gelatinization temperature due to addition of protein. It was found that addition of protein to starch suspension shifted the onset gelatinization temperature to higher temperatures (Sumnu et al., 1999). Therefore, cakes with legume flours gelatinized less than wheat cakes due to the increase in gelatinization temperature. Specific volume results also supported the results of gelatinization degree of legume cakes in which pea cakes having the lowest specific volume had the highest gelatinization temperature and the lowest gelatinization degree (Table B.1). Kraus et al. (2014) studied the relation between gelatinization degree and volume expansion of extrudates and concluded that volume increased linearly with increasing gelatinization degree.

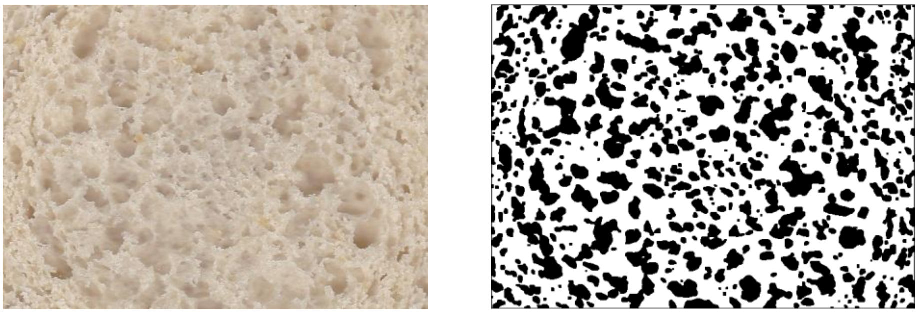
Table 3.1 Gelatinization degrees (%) of cakes baked in conventional and MW-IR oven

Flour Type	Oven Type	
	Conventional	MW-IR
Wheat	95.06	76.81
Lentil	79.12	71.22
Chickpea	64.53	61.50
Pea	59.68	51.08

3.4 Effects of Different Legume Flour Types on Macro and Micro-structures of Cakes Baked in Different Ovens

3.4.1 Macro-structure

Scanned image of lentil cake baked in MW-IR combination oven was shown in the Figure 3.31a. Binarised version of the same image was obtained by using ImageJ software (Figure 3.31b). Binarised images of legume cakes that baked in both conventional and MW-IR combination oven were used to calculate total pore numbers, pore size distribution and pore area fraction.



(a) (b)

Figure 3.31 (a) Scanned image of lentil cake baked in MW-IR combination oven (b) Binarised image of same cake

Table 3.2 shows the effect of legume flour and baking type on the total pore numbers, pore size distribution and the pore area fraction. Baking type had an effect on pore area distribution. It was observed that pore numbers of wheat and pea cakes increased in the MW-IR combination oven. Although pore numbers of lentil and chickpea cakes decreased in MW-IR oven, their pore area fractions increased since the number of larger pores increased in MW-IR oven for all flour types. The presence of larger pores could be explained by puffing effect of the MW-IR oven due to high pressure gradient inside the cakes. Because of larger pores, pore area fraction and specific volumes of cakes baked in in the MW-IR oven were also higher than conventionally baked cakes. Demirkesen et al. (2012) previously stated that pore area fractions and pore numbers of gluten-free breads increased in MW-IR combination oven. According to Table 3.2, addition of legume flour decreased the number of pores; however, increased the number of large pores. Similar results were found for lentil extrudates (Lazou & Krokida, 2010). Among all legume flours, pea cakes had the smallest pore area fraction for both baking types. The results were in agreement with specific volume and porosity results in which pea cakes had the smallest porosity and specific volume values probably due to lower gelatinization degree (Table 3.1).

Table 3.2 Pore size distribution and pore area fraction of legume cakes baked in different ovens

Range of pore area (mm^2)	Oven Type	Number of pores Flour Type W	L	C	P
0-0.5		242	238	160	162
0.5-1		92	123	90	74
1-5	Conventional	227	200	192	208
5-10		38	46	60	43
10-15		6	5	7	8
> 15		-	1	3	3
Total number of pores		**605**	**502**	**512**	**498**
Pore Area Fraction		**0.35**	**0.33**	**0.36**	**0.32**
0-0.5		245	139	148	155
0.5-1		138	52	70	118
1-5	MW-IR	193	150	155	181
5-10		35	37	41	51
10-15		4	17	9	10
> 15		1	10	12	1
Total number of pores		**616**	**405**	**435**	**516**
Pore Area Fraction		**0.36**	**0.38**	**0.38**	**0.34**

W: Wheat L: Lentil C: Chickpea P: Pea

3.4.2 Micro-structure

The Scanning Electron Microscopy (SEM) images of legume cakes baked in conventional and MW-IR combination oven at 30× magnification level were shown in the Figure 3.32. It can be easily seen that pores of cakes which were baked in MW-IR combination oven were larger than those in conventional oven. Channel like structure due to coalescence of the pores were mainly caused by puffing effect of MW-IR combination oven. Specific volumes and pore area fractions of MW-IR baked cakes were also higher than conventionally baked cakes (Figure 3.32). Similar results were obtained by Ozkoc et al. (2009) who studied microstructures of MW-IR baked cakes previously. On the other hand, images of pea cakes baked in both ovens were found to be less porous than other cakes. They were also found to have the lowest volume (Figure 3.26).

SEM images of legume cakes baked in conventional and MW-IR combination oven at 500× magnification level were shown in the Figure 3.33. It was observed that deformed starch structure was the majority in the wheat cakes that were baked in conventional oven (black arrows). However, deformed and granular starch structure can be seen together in the wheat cakes baked in MW-IR combination oven (white and black arrows). Incomplete deformation of starch granules was mainly due to lower gelatinization degrees of cakes that baked in MW-IR combination oven (Table 3.1). As can be seen in the figure, starch granules of conventional cakes were more deformed. Therefore, they lost their granular structure and created more uniform structure. These findings were in agreement with Turabi et al. (2010) who studied micro-structure of gluten-free rice cakes previously.

On the other hand, although gelatinization degrees of legume cakes were lower than the wheat cakes, more uniform sheet of deformed starch was observed in the images of legume cakes (Figure 3.33c, Figure 3.33e, Figure 3.33g). The reason might be that protein in the legume flours covered the surface of starch structure and formed veil-like structure on the starch granules. When legume cakes were compared, it was observed that lentil cakes had more uniform starch structure and it was in a good agreement with gelatinization degrees of legume cakes (Table 3.1). Veil like structure was also reported by other researches (Ozkoc et al., 2009; Barcenas & Rosell, 2005).

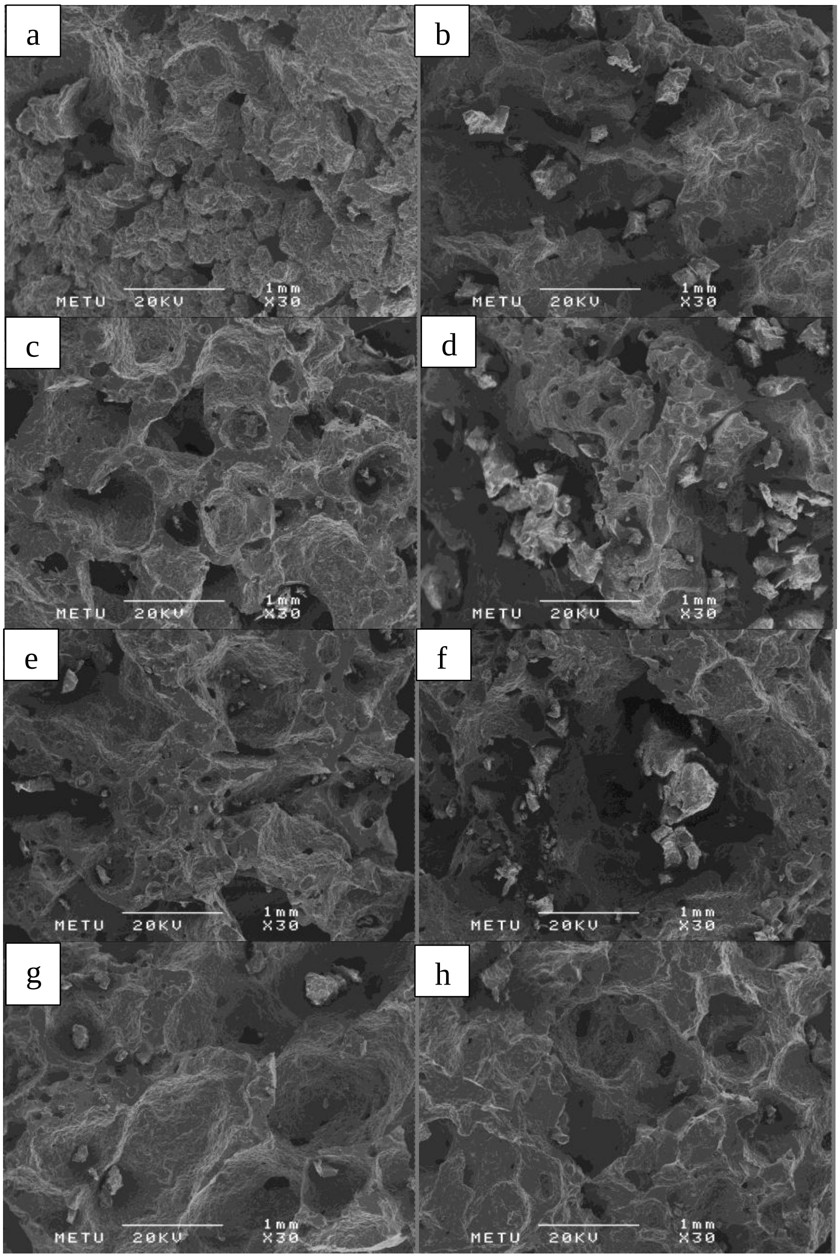


Figure 3.32 SEM micrographs (30×) of cake samples baked in different ovens. a-control cake baked in conventional oven, b-control cake baked in MW-IR oven, c-lentil cake baked in conventional oven, d- lentil cake baked in MW-IR oven, e-chickpea cake baked in conventional oven, f- chickpea cake baked in MW-IR oven, g- pea cake baked in conventional oven, h-pea cake baked in MW-IR oven

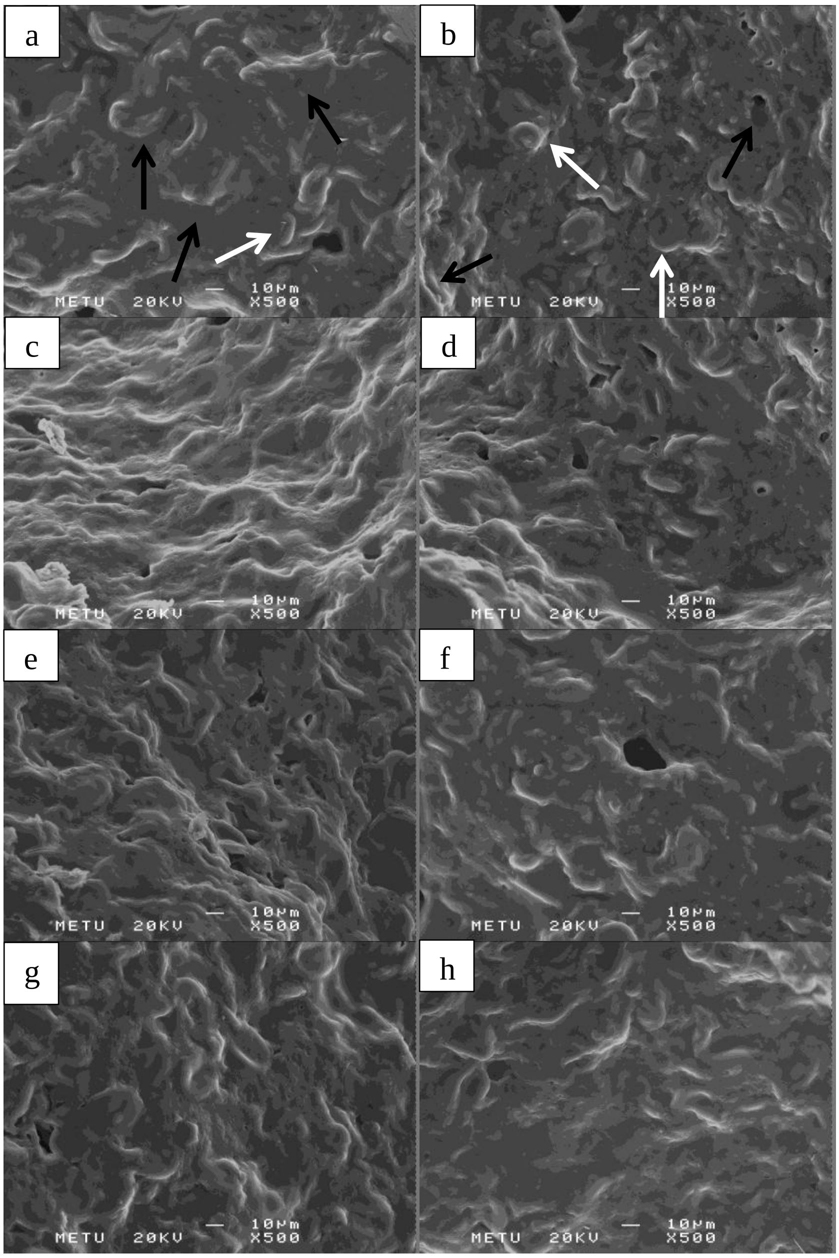


Figure 3.33 SEM micrographs (500×) of cake samples baked in different ovens. a-wheat cake baked in conventional oven, b- wheat cake baked in MW-IR oven, c- lentil cake baked in conventional oven, d- lentil cake baked in MW-IR oven, e- chickpea cake baked in conventional oven, f- chickpea cake baked in MW-IR oven, g- pea cake baked in conventional oven, h- pea cake baked in MW-IR oven (Black arrows represent deformed starches, white arrows represent granular starches)

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS

In this study, it was aimed to determine the effects of concentration and types of legume flour and oven types on quality parameters of cakes.

For all legume flour types, weight loss and crust ΔE^* values of cakes that were baked in MW-IR combination oven increased with increasing baking time. Baking time had no significant effect on specific volume, hardness and crumb color of MW-IR baked cakes. For all legume fours, the increase in legume flour concentration increased hardness, ΔE^* values of crust and crumb but decreased specific volume and porosity of cakes baked in both conventional and MW-IR combination oven. The optimum baking time of MW-IR combination oven and legume flour concentration were determined as 4 min and 10%, respectively.

Weight loss of MW-IR baked cakes was found to be higher than conventionally baked cakes. Specific volumes and porosity of MW-IR baked cakes were significantly higher but their hardness values were lower than conventionally baked cakes. The gelatinization degree of MW-IR baked cakes was less than conventionally baked cakes. Moreover, pore area fractions of MW-IR baked cakes were higher than conventionally baked cakes. Although total number of pores decreased in the MW-IR combination oven, number of large pores increased. Channel like pores were observed in the MW-IR cakes and MW-IR cakes were found to be more porous according to SEM images. On the other hand, both deformed and granular starch were observed in the MW-IR cakes while deformed starch was the majority of conventionally baked cakes.

Wheat cakes had the highest weight loss in both ovens while chickpea and pea had the lowest. Pea cakes were observed to have the lowest specific volume and porosity among other flour types. There was no significant difference between wheat, lentil and chickpea cakes in terms of specific volume, porosity and hardness. On the other hand, crust of wheat cakes had lower ΔE^* values than legume cakes in both ovens. Usage of legume flour retarded starch gelatinization in cakes.

As a result, it can be concluded that functional cakes can be developed by replacing wheat flour by lentil or chickpea flour at concentration of 10%. MW-IR combination can be recommended to be used in production of legume cakes.

For future studies, cakes containing other legume flours like lupin, bean, green lentil and soybean can be studied. In order to enhance quality properties of cakes, addition of emulsifier to legume cakes can also be studied. In addition, staling characteristics of legume cakes that are baked in MW-IR oven can be investigated.

REFERENCES

URL1: *Smart Chemical Trading and Co. Inc*. (2012, February 15). Retrieved from http:// magaza.hammaddeler.com/

URL2: *World Health Organization*. (2014, October 10). Retrieved from: http:// www.who.int/dietphysicalactivity/diet/en/

URL3: *Institute of Food Technologists* . (2014, September 14). Retrieved from http://www.ift.org/knowledge-center/focus-areas/food-health-and-nutrition/ functional-foods.aspx

URL4: *RSB Home Page*. (2014, Semtember 15). Retrieved from http://rsb.info.nih.gov/ij/

AACC, 1990. Approved Methods of the AACC. American Association of Cereal Chemists, St Paul, MN.

AACC, 2000. Approved Methods of the AACC. American Association of Cereal Chemists, St Paul, MN.

Barcenas, M. E., & Rosell, C. M. (2005). Effect of HPMC addition on the microstructure, quality and aging of wheat bread. *Food Hydrocolloids*, 19: 1037-1043.

Bornet, F. R., Billaux, M. S., & Messing, B. (1997). Glycaemic index concept and metabolic diseases. *International Journal of Biological Macromolecules*, 21: 207-219.

Boye, J. I., Aksay, S., Roufik, S., Ribereau, S., Mondor, M., Farnwoth, E., & Rajamohamed, S. H. (2010). Comparison of the functional properties of pea, chickpea and lentil protein concentrates processed using ultrafiltration and isoelectric precipitation techniques. *Food Research International* , 43: 537–546.

Buffler, C. (1993). *Microwave cooking and processing: Engineering fundamentals for the scientist.* New York: Avi Book.

Datta, A. K. (2001). Fundamentals of heat and moisture transport for microwaveable food product and process development. In A. Datta, & R. Anantheswaran, *Handbook of Microwave Technology for Food Applications* (pp. 115-172). New York: Marcel Dekker Inc.

Datta, A. K., & Ni, H. (2002). Infrared and hot air-assisted microwave heating of foods for control of surface moisture. *Journal of Food Engineering*, 51: 355-364.

Decareau, R. V. (1992). *Microwave Foods: New Product Development.*(pp. 117) Trummbull, Connecticut: Food & Nutrition Press Inc.

Demirekler, P., Sumnu, G., & Sahin, S. (2004). Optimization of bread baking in halogenlamp-microwave combination oven by response surface methodology. *European Food Research and Technology* , 219: 341-347.

Demirkesen, I., Sumnu, G., & Sahin, S. (2012). Image Analysis of Gluten-free Breads Prepared with Chestnut and Rice Flour and Baked in Different Ovens. *Food Bioprocess Technology*, DOI 10.1007/s11947-012-0850-5.

Demirkesen, I., Sumnu, G., Sahin, S., & Uysal, N. (2011). Optimisation of formulations and infrared–microwave combination baking conditions of chestnut–rice breads. *International Journal of Food Science and Technology*, 46:1809-1815.

Dodevska, M. S., Djordjevic, B. I., Sobajic, S. S., Miletic, I. D., Djordjevic, P. B., & Dimitrijevic-Sreckovic, V. S. (2013). Characterisation of dietary fibre components in cereals and legumes used in Serbian diet. *Food Chemistry*, 141: 1624-1629.

Fenn, D., Lukow, O. M., Humphreys, G., Fields, P. G., & Boye, J. I. (2010). Wheat- legume composite flour quality. *International Journal of Food Properties*, 13: 381–393.

Giese, J. (1992). Advances in microwave food processing. *Food Technology*, 46: 118-123.

Goebel, N. K., Grider, J., & Davis, E. A. (1984). The effects of microwave energy and conventional heating on wheat starch granule transformations. *Food Microstructure*, 3: 73-82.

Gomez, M., Doyague, J. M., & Hera, E. (2012). Addition of pin-milled pea flour and air-classified fractions in layer and sponge. *Food Science and Technology* , 46: 142-147.

Gomez, M., Moraleja, A., Oliete, B., Ruiz-Paris, E., & Caballero, P. A. (2010). Effect of fibre size on the quality of fibre-enriched layer cakes. *Food Science and Technology*, 43: 33-38.

Gomez, M., Oliete, B., Rosell, C. M., Pando, V., & Fernandez, E. (2008). Studies on cake quality made of wheat-chickpea flour blends. *Food Science and Technology* , 41:1701-1709.

Gularte, M. A., Gomez, M., & Rosell, C. M. (2012). Impact of Legume Flours on Quality and In Vitro Digestibility of Starch and Protein from Gluten-Free Cakes. *Food Bioprocess Technology*, 5: 3142-3150.

Guo, W., Wang, S., Tiwari, G., Johnson, J. A., & Tang, J. (2010). Temperature and moisture dependent dielectric properties of legume flour associated with dielectric heating. *Food Science and Technology* , 43:193-201.

Hera, E., Ruiz-Paris, E., Oliete, B., & Gomez, M. (2012). Studies of the quality of cakes made with wheat-lentil composite flours. *Food Science and Technology* , 49: 48-54.

Higo, A., Shimzaki, M., Noguchi, S., & Nazakawa, F. (1983). Hardening of food texture induced by microwave radiation: Changes in bound water content of breads accompanied by hardening. *Japanese Journal of Home Economics*, 34: 474-479.

Impoco, G., Carrato, S., Caccamo, M., Tuminello, L., & Licitra, G. (2007).. Quantitative Analysis of Cheese Microstructure using SEM Imagery, *Communications to SIMAI Congress*, 2:1827-9015.

Iqbal, A., Khalil, I. A., Ateeq, N., & Khan, M. S. (2006). Nutritional quality of important food legumes. *Food Chemistry* , 97: 331-335.

Keskin, S. O., Sumnu, G., & Sahin , S. (2004). Bread Baking In Halogen Lamp-Microwave Combination Oven. *Food Research International* , 37:489–495.

Kraus, S., Enke, N., Gaukel, V., & Schuchmann, H. P. (2014). Influence of degree of gelatinization on expansion of extruded, starch-based pellets during microwave vacuum processing. *Journal of Food Process Engineering*, DOI:10.1111/jfpe.12077.

Lazou, A., & Krokida, M. (2010). Structural and textural characterization of corn–lentil extruded snacks. *Journal of Food Engineering*, 100: 392-408.

Lee, Y. P., Puddey, I. B., & Hodgson, J. M. (2008). Protein, fibre and blood pressure: potantial benefit of legumes. *Clinical and Experimental Pharmacology and Physiology*, 35: 473-476.

Lu, L., Tang, J., & Liang , L. (1998). Moisture distribution in spherical foods in microwave drying. *Drying Technology*, 16: 503-524.

Ma, Z., Boye, J. I., Simpson, B. K., Prasher, S. O., Monpetit, D., & Malcolmson, L. (2011). Thermal processing effects on the functional properties and microstructure of lentil, chickpea and pea flours. *Food Research International*, 44: 2534-2544.

Mallillin, A. C., Triniad, T. P., Raterta, R., Dagbay, K., & Loyola, A. (2008). Dietary fibre and fermentability characteristics of root crops and legumes. *British Journal of Nutrition*, 100: 485-488.

Martinez, M. M., Diaz, A., & Gomez, M. (2014). Effect of different microstructural features of soluble and insoluble fibres on gluten-free dough rheology and bread-making. *Journal of Food Engineering*, 142: 49-56.

Minarro, B., Albanell, E., Aguilar, N., Guamis, B., & Capellas, M. (2012). Effect of legume flours on baking characteristics of gluten-free bread. *Journal of Cereal Science* , 56: 476-481.

Moiraghi, M., Hera, E., Perez, G. T., & Gomez, M. (2012). Effect of wheat flour characteristics on sponge cake quality. *Journal of the Science of Food and Agriculture*, 93: 542-549.

Ndife, M., Sumnu, G., & Bayındırlı, L. (1998). Differential scanning calorimetry determination of gelatinization rates in different starches due to microwave heating. *Food Science and Technology,* 31: 484-488.

Orsat, V., & Raghavan, V. (2005). Microwave technology for food processing: an overview. In H. Schubert, & M. Reiger, *The microwave processing of foods* (pp. 105-119). Cambridge: Woodhead Publishing Limited.

Ozen, A., Pons, A., & Tur, J. (2012). Worldwide consumption of functional foods: a systematic review. *Nutrition Reviews*, 70: 472-481.

Ozkoc, S. E., Sumnu, G., & Sahin, S. (2009). The effects of gums on macro and micro-structure of breads baked in different ovens. *Food Hydrocolloids*, 23: 2182–2189.

Purlis, E. (2010). Browning development in bakery products – A review. *Journal of Food Engineering*, 99: 239–249.

Ranjan, R., Irudayaraj, J., & Jun, S. (2002). Simulation of infrared drying process. *Drying Technology*, 20: 363-379.

Rizkalla, S. W., Bellisle, F., & Slama, G. (2002). Health benefits of low glycaemic index foods, such as pulses, in diabetic patients and healthy individuals. *British Journal of Nutrition*, 3: 255-262.

Roberfroid, M. B. (2000). Defining functional foods. In G. R. Gibson, & C. M. William, *Functional foods* (pp. 9-29). Cambridge: Woodhead Publishing Limited.

Sahin, S., & Sumnu, G. (2006). *Physical Properties of Foods.* New York: Springer.

Sahin, S., Sumnu, G., & Zincirkıran, D. (2002). Effects of susceptor, coating and conventional browning applications on color and crust formation during microwave baking. *International Microwave Power Institute*, 37: 223-236.

Sakıyan, O. (2014). Optimization of formulation of soy-cakes baked in infrared-microwave combination oven by response surface methodology. *Journal of Food Science and Technology*, DOI 10.1007/s13197-014-1342-6.

Sakiyan, O., Sumnu, G., & Sahin, S. (2007). The effect of different formulations on physical properties of cakes baked with microwave and near infrared-microwave combinations. *Journal of Microwave Power & Electromagnetic Energy*, 41: 20-26.

Sakiyan, O., Sumnu, G., Sahin, S., & Meda, V. (2007). The effect of different formulations on physical properties of cakes baked with microwave and near infrared-microwave combinations. *Journal of Microwave Power & Electromagnetic Energy*, 41: 20-26.

Sakiyan, O., Sumnu, G., Sahin, S., Meda, V., Koksel, H., & Chang, P. (2011). A Study on Degree of Starch Gelatinization in Cakes Baked in Three Different Ovens. *Food Bioprocess Technology*, 4: 1237-1244.

Sepulveda, D. R., & Barbosa-Canovas, G. V. (2003). Heat transfer in food products. In J. W. Chanes, J. F. Velez-Ruizg, & G. V. Babosa-Canovas, *Transport phenomena in food processing* (pp. 25-43). Florida: CRC Press LLC.

Sevimli, K. M. (2004). *Optimization of processing conditions during halogen lamp microwave combination baking of cakes.* MS Thesis, METU, Ankara.

Seyhun, N., Sumnu, G., & Sahin , S. (2003). Effects of different emulsifier types, fat contents, and gum types on retardation of staling of microwave-baked cakes. *Nahrung-Food,* 47: 248-251.

Sumnu, G. (2001). A review on microwave baking of foods. *International Journal of Food Science and Technology, 36:117-127.*

Sumnu, G., & Sahin, S. (2005). Baking using microwave processing. In H. S. Regier, *The microwave processing of foods* (pp. 119-136). Washington DC, USA: CRC Press.

Sumnu, G., Datta, A. K., Sahin, S., Keskin, O., & Rakech, V. (2007). Transport and related properties of breads baked using various heating modes. *Journal of Food Engineering*, 78: 1382-1387.

Sumnu, G., Ndife, M. K., & Bayındırlı, L. (1999). Effects of sugar, protein and water content on wheat starch gelatinization due to microwave heating. *European Food Research and Technology*, 209: 68-71.

Sumnu, G., Ndife, M. K., & Bayındırlı, L. (1999). Temperature and weight loss profiles of model cakes baked in the microwave oven. *Journal of Microwave Power and Electromagnetic Energy, 34: 221-226.*

Sumnu, G., Ndife, M. K., & Bayındırlı, L. (2000). Optimization of microwave baking of model layer cakes. *European Food Research and Technology,*, 211: 169-174.

Sumnu, G., Sahin, S., & Sevimli, M. (2005). Microwave, infrared and infrared-microwave combination baking of cakes. *Journal of Food Engineering*, 71:150–155.

Tang, J. (2005). Dielectric properties of foods. In H. Schubert, & M. Regier, *The microwave processing of foods* (pp. 22-38). Cambridge: Woodhead Publishing Limited.

Thostenson, E. T., & Chou, T. W. (1999). Microwave processing: fundamentals and applications. *Composites: Part A*, 30: 1055–1071.

Triniad, T. P., Mallillin, A. C., Loyola, A. S., Sagum, R. S., & Encabo, R. R. (2010). The potential health benefits of legumes as a good source of dietary fibre. *British Journal of Nutrition*, 103: 569-574.

Turabi, E. (2010). *Design of Gluten Free Rice Cake Formulations for Baking in Infrared-Microwave Combination Oven.* PhD Thesis, METU, Ankara.

Turabi, E., Sumnnu, G., & Sahin, S. (2008). Optimization of Baking of Rice Cakes in Infrared–Microwave Combination Oven by Response Surface Methodology. *Food Bioprocess Technology*, 1: 64-73.

Turabi, E., Sumnu, G., & Sahin, S. (2010). Quantitative analysis of macro and micro-structure of gluten-free rice cakes containing different types of gums baked in different ovens. *Food Hydrocolloids*, 24: 755-762.

Von Hippel, A. (1954). *Dielectrics and Waves.* New York: Wiley.

Walker, C. E., & Li, A. (1993). Impingement oven technology. Part III: Combining impingement with microwave. *American Institute of Baking Technology Bulletin*, 15: 1-6.

Wang, S. S., & Kim, Y. (1998). The Effect of Protein and Fiber on the Kinetics of Starch Gelatinization and Melting in Waxy Corn Flour. *Food Science and Technology,* 50: 419-423.

Yaylayan, V. A., & Roberts, D. D. (2001). Generation and Release of Food Aromas Under Microwave Heating. In A. K. Datta, & R. C. Anantheswaran, *Microwave Technology For Food Applications* (pp. 173-191). New York: Marcel Dekker, Inc.

Zucco, F., Borsuk, Y., & Arntfield, S. D. (2011). Physical and nutritional evaluation of wheat cookies supplemented with pulse flours of different particle sizes. *Food Science and Technology* , 44: 2070-2076.

APPENDIX A

STATISTICAL ANALYSES

Table A.1 Two way ANOVA and Duncan's Multiple Range Test for weight loss of cakes baked in conventional oven

X1 Concentration (10%, 20% and 30%)

X2 Flour Type (lentil, chickpea and pea)

Class Level Information

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read 32

Number of Observations Used 32

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	33.70979877	8.42744969	13.03	<.0001
Error	27	17.46602811	0.64688993		
Corrected Total	31	51.17582688			

R-Square	Coeff Var	Root MSE	Y Mean
0.658706	10.59633	0.804295	7.590313

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	18.95649538	9.47824769	14.65	<.0001
X2	2	14.75330338	7.37665169	11.40	0.0003

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	19.21865699	9.60932850	14.85	<.0001
X2	2	14.75330338	7.37665169	11.40	0.0003

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	27
Error Mean Square	0.64689
Harmonic Mean of Cell Sizes	10.21622

Number of Means	2	3
Critical Range	.7302	.7671

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	8.6986	9	1
B	7.4729	14	2
C	6.6648	9	3

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha 0.05

Error Degrees of Freedom 27

Error Mean Square 0.64689

Harmonic Mean of Cell Sizes 10.51327

Number of Means	2	3
Critical Range	.7198	.7562

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	8.4485	12	1
B	7.2218	9	2
B	6.9556	11	3

Table A.2 Two way ANOVA and Duncan's Multiple Range Test for weight loss of lentil cakes baked in MW-IR combination oven

X1 Time (4, 4.5 and 5 minutes)

X2 Concentration (10%, 20% and 30%)

Class Level Information

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read 33

Number of Observations Used 33

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	131.8369411	32.9592353	8.53	0.0001
Error	28	108.2084079	3.8645860		
Corrected Total	32	240.0453490			

R-Square	Coeff Var	Root MSE	Y Mean
0.549217	14.55575	1.965855	13.50570

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	130.1398794	65.0699397	16.84	<.0001
X2	2	1.6970617	0.8485309	0.22	0.8042

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	130.4802729	65.2401365	16.88	<.0001
X2	2	1.6970617	0.8485309	0.22	0.8042

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	28
Error Mean Square	3.864586
Harmonic Mean of Cell Sizes	10.8

Number of Means	2	3
Critical Range	1.733	1.821

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	15.9623	12	3
B	13.1203	9	2
C	11.3381	12	1

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha 0.05

Error Degrees of Freedom 28

Error Mean Square 3.864586

Harmonic Mean of Cell Sizes 10.93923

NOTE: Cell sizes are not equal.

Number of Means	2	3
Critical Range	1.722	1.809

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	13.6885	11	1
A	13.5890	12	3
A	13.2047	10	2

Table A.3 Two way ANOVA and Duncan's Multiple Range Test for weight loss of chickpea cakes baked in MW-IR combination oven.

X1 Time (4, 4.5 and 5 minutes)

X2 Concentration (10%, 20% and 30%)

Class Level Information

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read 35

Number of Observations Used 35

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	98.6775956	24.6693989	9.14	<.0001
Error	30	80.9924566	2.6997486		
Corrected Total	34	179.6700522			

R-Square	Coeff Var	Root MSE	Y Mean
0.549216	12.37768	1.643091	13.27463

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	95.03442604	47.51721302	17.60	<.0001
X2	2	3.64316953	1.82158476	0.67	0.5169

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	95.21308163	47.60654082	17.63	<.0001
X2	2	3.64316953	1.82158476	0.67	0.5169

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	30
Error Mean Square	2.699749
Harmonic Mean of Cell Sizes	11.64706

Number of Means	2	3
Critical Range	1.391	1.461

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	15.1748	12	3
B	13.4582	11	2
C	11.2063	12	1

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05

Error Degrees of Freedom 30

Error Mean Square 2.699749

Harmonic Mean of Cell Sizes 11.64706

Number of Means	2	3
Critical Range	1.391	1.461

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	13.7331	11	3
A	13.1267	12	2
A	13.0023	12	1

Table A.4 Two way ANOVA and Duncan's Multiple Range Test weight loss of pea cakes baked in MW-IR combination oven.

X1 Time (4, 4.5 and 5 minutes)

X2 Concentration (10%, 20% and 30%)

Class Level Information

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read 35

Number of Observations Used 35

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	81.7238373	20.4309593	6.76	0.0005
Error	30	90.6666411	3.0222214		
Corrected Total	34	172.3904784			

R-Square	Coeff Var	Root MSE	Y Mean
0.474062	13.20753	1.738454	13.16260

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	81.20590591	40.60295295	13.43	<.0001
X2	2	0.51793138	0.25896569	0.09	0.9181

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	80.25149490	40.12574745	13.28	<.0001
X2	2	0.51793138	0.25896569	0.09	0.9181

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	30
Error Mean Square	3.022221
Harmonic Mean of Cell Sizes	11.64706

Number of Means	2	3
Critical Range	1.471	1.546

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	15.2991	11	3
B	12.7601	12	2
B	11.6067	12	1

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05

Error Degrees of Freedom 30

Error Mean Square 3.022221
,
Harmonic Mean of Cell Sizes 11.64706

Number of Means 2 3

Critical Range 1.471 1.546

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	13.3546	12	1
A	13.2409	12	2
A	12.8677	11	3

Table A.5 Two way ANOVA and Duncan's Multiple Range Test specific volume of cakes baked in conventional oven.

X1 Concentration (10%, 20% and 30%)

X2 Flour Type (lentil, chickpea and pea)

Class Level Information

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read	27
Number of Observations Used	27

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	0.12407815	0.03101954	2.77	0.0528
Error	22	0.24642793	0.01120127		
Corrected Total	26	0.37050607			

R-Square	Coeff Var	Root MSE	Y Mean
0.334888	5.169833	0.105836	2.047185

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	0.04667252	0.02333626	2.08	0.1484
X2	2	0.07740563	0.03870281	3.46	0.0496

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	0.04667252	0.02333626	2.08	0.1484
X2	2	0.07740563	0.03870281	3.46	0.0496

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error
rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	0.011201

Number of Means	2	3
Critical Range	.1035	.1086

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	2.10522	9	1
A	2.02633	9	3
A	2.01000	9	2

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22

Error Mean Square	0.011201	
Number of Means	2	3
Critical Range	.1035	.1086

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	2.11578	9	1
B A	2.04067	9	2
B	1.98511	9	3

Table A.6 Two way ANOVA and Duncan's Multiple Range Test for specific volume of lentil cakes baked in MW-IR combination oven.

X1 Time (4, 4.5 and 5 minutes)

X2 Concentration (10%, 20% and 30%)

Class Level Information

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read 21

Number of Observations Used 21

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	0.12969616	0.03242404	5.46	0.0057
Error	16	0.09494679	0.00593417		
Corrected Total	20	0.22464295			

R-Square	Coeff Var	Root MSE	Y Mean
0.577344	2.740805	0.077034	2.810619

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	0.01208006	0.00604003	1.02	0.3836
X2	2	0.11761610	0.05880805	9.91	0.0016

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	0.01208006	0.00604003	1.02	0.3836
X2	2	0.11761610	0.05880805	9.91	0.0016

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	16
Error Mean Square	0.005934
Harmonic Mean of Cell Sizes	6.75

Number of Means	2	3
Critical Range	.08889	.09321

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	2.83322	9	3
A	2.81200	6	2
A	2.77533	6	1

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha 0.05

Error Degrees of Freedom 16

Error Mean Square 0.005934

Number of Means	2	3
Critical Range	.08729	.09153

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	2.89571	7	1
A	2.82257	7	2
B	2.71357	7	3

Table A.7 Two way ANOVA and Duncan's Multiple Range Test specific volume of chickpea cakes baked in MW-IR combination oven.

X1 Time (4, 4.5 and 5 minutes)

X2 Concentration (10%, 20% and 30%)

Class Level Information

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read 27

Number of Observations Used 27

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	0.48404067	0.12101017	5.84	0.0023
Error	22	0.45621600	0.02073709		
Corrected Total	26	0.94025667			

R-Square	Coeff Var	Root MSE	Y Mean
0.514796	5.445521	0.144004	2.644444

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	0.01041867	0.00520933	0.25	0.7801
X2	2	0.47362200	0.23681100	11.42	0.0004

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	0.01041867	0.00520933	0.25	0.7801
X2	2	0.47362200	0.23681100	11.42	0.0004

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error
rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	0.020737

Number of Means	2	3
Critical Range	.1408	.1478

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	2.67222	9	3
A	2.63089	9	1
A	2.63022	9	2

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22

Error Mean Square 0.020737

Number of Means	2	3
Critical Range	.1408	.1478

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	2.83078	9	1
B	2.56778	9	3
B	2.53478	9	2

Table A.8 Two way ANOVA and Duncan's Multiple Range Test for specific volume of pea cakes baked in MW-IR combination oven.

X1 Time (4, 4.5 and 5 minutes)

X2 Concentration (10%, 20% and 30%)

Class Level Information

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read 27

Number of Observations Used 27

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	0.19637259	0.04909315	1.71	0.1842
Error	22	0.63243015	0.02874682		
Corrected Total	26	0.82880274			

R-Square	Coeff Var	Root MSE	Y Mean
0.236935	6.606277	0.169549	2.566481

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	0.00344363	0.00172181	0.06	0.9420
X2	2	0.19292896	0.09646448	3.36	0.0535

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	0.00344363	0.00172181	0.06	0.9420
X2	2	0.19292896	0.09646448	3.36	0.0535

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	0.028747

Number of Means	2	3
Critical Range	.1658	.1740

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	2.57956	9	3
A	2.56789	9	2
A	2.55200	9	1

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	0.028747

Number of Means	2	3
Critical Range	.1658	.1740

Means with the same letter are not significantly different.

Duncan Grouping		Mean	N	X2
A		2.67756	9	1
B	A	2.54922	9	2
B		2.47267	9	3

Table A.9 Two way ANOVA and Duncan's Multiple Range Test for porosity of cakes baked in conventional oven

X1 Concentration (10%, 20% and 30%)

X2 Flour Type (lentil, chickpea and pea)

Class Level Information

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read 18

Number of Observations Used 18

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	0.00833556	0.00208389	3.94	0.0262
Error	13	0.04928822	0.00379140		
Corrected Total	17	0.05762378			

R-Square	Coeff Var	Root MSE	Y Mean
0.144655	15.31277	0.061574	0.402111

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	0.00627211	0.00313606	7.07	0.0084
X2	2	0.00206344	0.00103172	0.27	0.7660

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	0.00627211	0.00313606	0.83	0.4590
X2	2	0.00206344	0.00103172	0.27	0.7660

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	13
Error Mean Square	0.003791

Number of Means	2	3
Critical Range	.07680	.08044

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	0.42617	6	2
A	0.39950	6	1
B	0.38067	6	3

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	13

Error Mean Square 0.003791

Number of Means	2	3
Critical Range	.07680	.08044

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	0.41050	6	1
B	0.40883	6	2
B	0.38700	6	3

Table A.10 Two way ANOVA and Duncan's Multiple Range Test for porosity of lentil cakes baked in MW-IR combination oven.

X1 Concentration (10%, 20% and 30%)

X2 Time (4, 4.5 and 5 minutes)

Class Level Information

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read	18
Number of Observations Used	18

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	0.01583233	0.00395808	3.94	0.0262
Error	13	0.01307217	0.00100555		
Corrected Total	17	0.02890450			

R-Square	Coeff Var	Root MSE	Y Mean
0.547746	6.627049	0.031710	0.478500

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	0.01422033	0.00711017	7.07	0.0084
X2	2	0.00161200	0.00080600	0.80	0.4696

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	0.01422033	0.00711017	7.07	0.0084
X2	2	0.00161200	0.00080600	0.80	0.4696

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	13
Error Mean Square	0.001006

Number of Means	2	3
Critical Range	.03955	.04142

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	0.51600	6	1
B	0.47117	6	3
B	0.44833	6	2

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	13
Error Mean Square	0.001006

Number of Means	2	3
Critical Range	.03955	.04142

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	0.49183	6	2
A	0.47283	6	1
A	0.47083	6	3

Table A.11 Two way ANOVA and Duncan's Multiple Range Test for porosity of chickpea cakes baked in MW-IR combination oven.

X1 Time (4, 4.5 and 5 minutes)

X2 Concentration (10%, 20% and 30%)

Class Level Information

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read 18

Number of Observations Used 18

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	0.01534322	0.00383581	2.55	0.0896
Error	13	0.01957172	0.00150552		
Corrected Total	17	0.03491494			

R-Square	Coeff Var	Root MSE	Y Mean
0.439446	9.193338	0.038801	0.422056

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	0.00089911	0.00044956	0.30	0.7468
X2	2	0.01444411	0.00722206	4.80	0.0275

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	0.00089911	0.00044956	0.30	0.7468
X2	2	0.01444411	0.00722206	4.80	0.0275

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	13
Error Mean Square	0.001506

Number of Means	2	3
Critical Range	.04840	.05069

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	0.43150	6	1
A	0.42017	6	2
A	0.41450	6	3

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	13
Error Mean Square	0.001506

Number of Means	2	3
Critical Range	.04840	.05069

Means with the same letter are not significantly different.

Duncan Grouping		Mean	N	X2
A		0.45950	6	1
B	A	0.41567	6	2
B		0.39100	6	3

Table A.12 Two way ANOVA and Duncan's Multiple Range Test for porosity of pea cakes baked in MW-IR combination oven.

X1 Time (4, 4.5 and 5 minutes)

X2 Concentration (10%, 20% and 30%)

The GLM Procedure

Class Level Information

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read 18

Number of Observations Used 18

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	0.01028222	0.00257056	1.00	0.4439
Error	13	0.03352672	0.00257898		
Corrected Total	17	0.04380894			

R-Square	Coeff Var	Root MSE	Y Mean
0.234706	11.41348	0.050784	0.444944

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	0.00614678	0.00307339	1.19	0.3348
X2	2	0.00413544	0.00206772	0.80	0.4695

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	0.00614678	0.00307339	1.19	0.3348
X2	2	0.00413544	0.00206772	0.80	0.4695

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	13
Error Mean Square	0.002579

Number of Means	2	3
Critical Range	.06334	.06634

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	0.47100	6	2
A	0.43367	6	1
A	0.43017	6	3

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha 0.05

Error Degrees of Freedom 13

Error Mean Square 0.002579

Number of Means	2	3
Critical Range	.06334	.06634

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	0.45783	6	1
B A	0.45333	6	2
B	0.42367	6	3

Table A.13 Two way ANOVA and Duncan's Multiple Range Test for hardness of cakes baked in conventional oven.

X1 Concentration (10%, 20% and 30%)

X2 Flour Type (lentil, chickpea and pea)

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read 54

Number of Observations Used 54

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	2.19126541	0.54781635	3.87	0.0082
Error	49	6.93372980	0.14150469		
Corrected Total	53	9.12499520			

R-Square	Coeff Var	Root MSE	Y Mean
0.240139	16.31572	0.376171	2.305574

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	0.77871026	0.38935513	2.75	0.0737
X2	2	1.41255515	0.70627757	4.99	0.0106

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	0.77871026	0.38935513	2.75	0.0737
X2	2	1.41255515	0.70627757	4.99	0.0106

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	49
Error Mean Square	0.141505

Number of Means	2	3
Critical Range	.2520	.2650

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	2.4307	18	3
B A	2.3425	18	2
B	2.1436	18	1

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha 0.05

Error Degrees of Freedom 49

Error Mean Square 0.141505

Number of Means	2	3
Critical Range	.2520	.2650

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	2.4554	18	3
A	2.3803	18	2
B	2.0810	18	1

Table A.14 Two way ANOVA and Duncan's Multiple Range Test for hardness of lentil cakes baked in MW-IR combination oven.

X1 Time (4, 4.5 and 5 minutes)

X2 Concentration (10%, 20% and 30%)

Class Level Information

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read	65
Number of Observations Used	65

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	12.38949064	3.09737266	11.35	<.0001
Error	60	16.37811530	0.27296859		
Corrected Total	64	28.76760594			

R-Square	Coeff Var	Root MSE	Y Mean
0.430675	28.51207	0.522464	1.832431

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	5.85502600	2.92751300	10.72	0.0001
X2	2	6.53446464	3.26723232	11.97	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	6.21525092	3.10762546	11.38	<.0001
X2	2	6.53446464	3.26723232	11.97	<.0001

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	60
Error Mean Square	0.272969
Harmonic Mean of Cell Sizes	21.27507

Number of Means	2	3
Critical Range	.3204	.3371

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	2.0227	25	3
A	2.0130	22	2
B	1.3475	18	1

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha 0.05

Error Degrees of Freedom 60

Error Mean Square 0.272969

Harmonic Mean of Cell Sizes 21.62687

Number of Means	2	3
Critical Range	.3178	.3343

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	2.1975	21	3
A	1.8835	21	2
B	1.4525	23	1

Table A.15 Two way ANOVA and Duncan's Multiple Range Test for hardness of chickpea cakes baked in MW-IR combination oven.

X1 Time (4, 4.5 and 5 minutes)

X2 Concentration (10%, 20% and 30%)

Class Level Information

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read 54

Number of Observations Used 54

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	4.45340719	1.11335180	13.40	<.0001
Error	49	4.07112565	0.08308420		
Corrected Total	53	8.52453283			

R-Square	Coeff Var	Root MSE	Y Mean
0.522422	13.93864	0.288243	2.067944

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	0.00807650	0.00403825	0.05	0.9526
X2	2	4.44533069	2.22266534	26.75	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	0.06764988	0.03382494	0.41	0.6678
X2	2	4.44533069	2.22266534	26.75	<.0001

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	49
Error Mean Square	0.083084
Harmonic Mean of Cell Sizes	17.54953

Number of Means	2	3
Critical Range	.1955	.2057

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	2.07823	22	3
A	2.07300	15	2
A	2.05018	17	1

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05

Error Degrees of Freedom 49

Error Mean Square 0.083084

Harmonic Mean of Cell Sizes 17.85124

Number of Means	2	3
Critical Range	.1939	.2039

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	2.38450	16	3
B	2.18289	18	2
C	1.71125	20	1

Table A.16 Two way ANOVA and Duncan's Multiple Range Test for hardness of pea cakes baked in MW-IR combination oven.

X1 Time (4, 4.5 and 5 minutes)

X2 Concentration (10%, 20% and 30%)

Class Level Information

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read 61

Number of Observations Used 61

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	1.64400957	0.41100239	1.86	0.1307
Error	56	12.38860968	0.22122517		
Corrected Total	60	14.03261925			

R-Square	Coeff Var	Root MSE	Y Mean
0.117156	21.43302	0.470346	2.194492

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	0.32985458	0.16492729	0.75	0.4791
X2	2	1.31415499	0.65707749	2.97	0.0594

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	0.38633431	0.19316715	0.87	0.4232
X2	2	1.31415499	0.65707749	2.97	0.0594

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	56
Error Mean Square	0.221225
Harmonic Mean of Cell Sizes	20.18447

Number of Means	2	3
Critical Range	.2966	.3120

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	2.2846	18	1
A	2.2089	22	3
A	2.1021	21	2

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha 0.05

Error Degrees of Freedom 56

Error Mean Square 0.221225

Harmonic Mean of Cell Sizes 20.32258

Number of Means	2	3
Critical Range	.2956	.3109

Means with the same letter are not significantly different.

Duncan Grouping		Mean	N	X2
A		2.3423	20	3
B	A	2.2412	21	2
B		1.9977	20	1

Table A.17 Two way ANOVA and Duncan's Multiple Range Test crust color (ΔE^*) of cakes baked in conventional oven.

X1 Concentration (10%, 20% and 30%)

X2 Flour Type (lentil, chickpea and pea)

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read 30

Number of Observations Used 30

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	42.3211681	10.5802920	1.79	0.1617
Error	25	147.4708611	5.8988344		
Corrected Total	29	189.7920292			

R-Square	Coeff Var	Root MSE	Y Mean
0.222987	6.425167	2.428752	37.80060

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	35.55972539	17.77986270	3.01	0.0672
X2	2	6.76144270	3.38072135	0.57	0.5710

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	35.11337067	17.55668534	2.98	0.0693
X2	2	6.76144270	3.38072135	0.57	0.5710

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	25
Error Mean Square	5.898834
Harmonic Mean of Cell Sizes	9.818182

Number of Means	2	3
Critical Range	2.258	2.371

Means with the same letter are not significantly different.

Duncan Grouping		Mean	N	X1
A		38.707	12	3
B	A	38.228	9	2
B		36.165	9	1

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	25
Error Mean Square	5.898834
Harmonic Mean of Cell Sizes	9.818182

Number of Means	2	3
Critical Range	2.258	2.371

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	38.314	9	2
A	37.950	12	1
A	37.088	9	3

Table A.18 Two way ANOVA and Duncan's Multiple Range Test crust color (ΔE^*) of lentil cakes baked in MW-IR combination oven

X1 Time (4, 4.5 and 5 minutes)

X2 Concentration (10%, 20% and 30%)

Class Level Information

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read 27

Number of Observations Used 27

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	352.4869768	88.1217442	8.65	0.0002
Error	22	224.2015641	10.1909802		
Corrected Total	26	576.6885410			

R-Square	Coeff Var	Root MSE	Y Mean
0.611226	5.922799	3.192331	53.89904

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	302.4360343	151.2180171	14.84	<.0001
X2	2	50.0509425	25.0254713	2.46	0.1090

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	302.4360343	151.2180171	14.84	<.0001
X2	2	50.0509425	25.0254713	2.46	0.1090

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	10.19098

Number of Means	2	3
Critical Range	3.121	3.277

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	57.931	9	3
B	54.030	9	2
C	49.736	9	1

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	10.19098

Number of Means	2	3
Critical Range	3.121	3.277

Means with the same letter are not significantly different.

Duncan Grouping		Mean	N	X2
A		55.452	9	3
B	A	54.108	9	2
B		52.137	9	1

Table A.19 Two way ANOVA and Duncan's Multiple Range Test for crust color (ΔE*) of chickpea cakes baked in MW-IR combination oven

X1 Time (4, 4.5 and 5 minutes)

X2 Concentration (10%, 20% and 30%)

Class Level Information

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read 27

Number of Observations Used 27

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	32.8138782	8.2034696	2.34	0.0872
Error	22	77.2637104	3.5119868		
Corrected Total	26	110.0775887			

R-Square	Coeff Var	Root MSE	Y Mean
0.298098	3.589675	1.874030	52.20611

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	2.60196356	1.30098178	0.37	0.6947
X2	2	30.21191467	15.10595733	4.30	0.0265

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	2.60196356	1.30098178	0.37	0.6947
X2	2	30.21191467	15.10595733	4.30	0.0265

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error
rate.

Alpha 0.05

Error Degrees of Freedom 22

Error Mean Square 3.511987

Number of Means	2	3
Critical Range	1.832	1.924

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	52.5090	9	1
A	52.3299	9	3
A	51.7794	9	2

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha 0.05

Error Degrees of Freedom 22

Error Mean Square 3.511987

Number of Means	2	3
Critical Range	1.832	1.924

Means with the same letter are not significantly different.

Duncan Grouping		Mean	N	X2
A		53.6372	9	3
B	A	51.8679	9	2
B		51.1132	9	1

Table A.20 Two way ANOVA and Duncan's Multiple Range Test for crust color (ΔE^*) of pea cakes baked in MW-IR combination oven

X1 Time (4, 4.5 and 5 minutes)

X2 Concentration (10%, 20% and 30%)

Class Level Information

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read 27

Number of Observations Used 27

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	185.8059119	46.4514780	3.21	0.0323
Error	22	318.6853973	14.4856999		
Corrected Total	26	504.4913092			

R-Square	Coeff Var	Root MSE	Y Mean
0.368303	7.363533	3.806008	51.68726

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	95.96389030	47.98194515	3.31	0.0553
X2	2	89.84202163	44.92101081	3.10	0.0651

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	95.96389030	47.98194515	3.31	0.0553
X2	2	89.84202163	44.92101081	3.10	0.0651

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	14.4857

Number of Means	2	3
Critical Range	3.721	3.907

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	54.192	9	2
B	51.226	9	3
C	49.644	9	1

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	14.4857

Number of Means	2	3
Critical Range	3.721	3.907

Means with the same letter are not significantly different.

Duncan Grouping		Mean	N	X2
A		53.631	9	3
B	A	52.184	9	1
B		49.247	9	2

Table A.21 Two way ANOVA and Duncan's Multiple Range Test for crumb color (ΔE^*) of cakes baked in conventional oven

X1 Concentration (10%, 20% and 30%)

X2 Flour Type (lentil, chickpea and pea)

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read 26

Number of Observations Used 26

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	43.52907943	10.88226986	7.92	0.0005
Error	21	28.86876257	1.37470298		
Corrected Total	25	72.39784200			

R-Square	Coeff Var	Root MSE	Y Mean
0.601248	7.337614	1.172477	15.97900

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	15.25694612	7.62847306	5.55	0.0116
X2	2	28.27213331	14.13606665	10.28	0.0008

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	14.35072642	7.17536321	5.22	0.0144
X2	2	28.27213331	14.13606665	10.28	0.0008

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	21
Error Mean Square	1.374703
Harmonic Mean of Cell Sizes	8.64

Number of Means	2	3
Critical Range	1.173	1.232

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	17.0233	9	3
B	15.5534	8	2
B	15.3130	9	1

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05

Error Degrees of Freedom 21

Error Mean Square 1.374703

Harmonic Mean of Cell Sizes 8.64

Number of Means	2	3
Critical Range	1.173	1.232

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	17.2536	8	1
A	16.1728	9	3
B	14.6522	9	2

Table A.22 Two way ANOVA and Duncan's Multiple Range Test for crumb color (ΔE*) of lentil cakes baked in MW-IR combination oven

X1 Time (4, 4.5 and 5 minutes)

X2 Concentration (10%, 20% and 30%)

Class Level Information

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read	27
Number of Observations Used	27

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	74.4132046	18.6033011	3.83	0.0165
Error	22	106.9390246	4.8608648		
Corrected Total	26	181.3522292			

R-Square	Coeff Var	Root MSE	Y Mean
0.410324	15.48895	2.204737	14.23426

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	13.29413207	6.64706604	1.37	0.2756
X2	2	61.11907252	30.55953626	6.29	0.0069

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	13.29413207	6.64706604	1.37	0.2756
X2	2	61.11907252	30.55953626	6.29	0.0069

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	4.860865

Number of Means	2	3
Critical Range	2.155	2.263

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	15.079	9	3
A	14.262	9	1
A	13.361	9	2

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	4.860865

Number of Means	2	3
Critical Range	2.155	2.263

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	15.641	9	3
A	14.913	9	2
B	12.148	9	1

Table A.23 Two way ANOVA and Duncan's Multiple Range Test for crumb color (ΔE*) of chickpea cakes baked in MW-IR combination oven

X1 Time (4, 4.5 and 5 minutes)

X2 Concentration (10%, 20% and 30%)

Class Level Information

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read 27

Number of Observations Used 27

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	191.6117537	47.9029384	8.11	0.0004
Error	22	129.8811413	5.9036882		
Corrected Total	26	321.4928950			

R-Square	Coeff Var	Root MSE	Y Mean
0.596006	15.55037	2.429751	15.62504

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	104.9527692	52.4763846	8.89	0.0015
X2	2	86.6589845	43.3294923	7.34	0.0036

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	104.9527692	52.4763846	8.89	0.0015
X2	2	86.6589845	43.3294923	7.34	0.0036

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	5.903688

Number of Means	2	3
Critical Range	2.375	2.494

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	18.193	9	3
B	15.281	9	2
B	13.401	9	1

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22

Error Mean Square 5.903688

Number of Means	2	3
Critical Range	2.375	2.494

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	18.055	9	3
B	15.031	9	2
B	13.789	9	1

Table A.24 Two way ANOVA and Duncan's Multiple Range Test for crumb color (ΔE*) of pea cakes baked in MW-IR combination oven

X1 Time (4, 4.5 and 5 minutes)

X2 Concentration (10%, 20% and 30%)

Class Level Information

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read 26

Number of Observations Used 26

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	143.8385293	35.9596323	24.17	<.0001
Error	21	31.2453041	1.4878716		
Corrected Total	25	175.0838334			

R-Square	Coeff Var	Root MSE	Y Mean
0.821541	4.855603	1.219783	25.12115

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	72.83938077	36.41969039	24.48	<.0001
X2	2	70.99914855	35.49957427	23.86	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	72.90147536	36.45073768	24.50	<.0001
X2	2	70.99914855	35.49957427	23.86	<.0001

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	21
Error Mean Square	1.487872
Harmonic Mean of Cell Sizes	8.64

Number of Means	2	3
Critical Range	1.220	1.281

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	26.7459	9	3
A	25.6426	9	2
B	22.7068	8	1

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha 0.05

Error Degrees of Freedom 21

Error Mean Square 1.487872

Harmonic Mean of Cell Sizes 8.64

Number of Means	2	3
Critical Range	1.220	1.281

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	27.0662	9	3
B	25.2086	8	2
C	23.0983	9	1

Table A.25 Two way ANOVA and Duncan's Multiple Range Test for comparison of weight loss of cakes baked in conventional and MW-IR oven

X1 Oven Type (conventional and MW-IR)

X2 Flour Type (wheat, lentil, chickpea and pea)

Class Level Information

Class	Levels	Values
X1	2	1 2
X2	4	1 2 3 4

Number of Observations Read 27

Number of Observations Used 27

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	87.6712183	21.9178046	27.06	<.0001
Error	22	17.8187780	0.8099445		
Corrected Total	26	105.4899963			

R-Square	Coeff Var	Root MSE	Y Mean
0.831086	8.263702	0.899969	10.89063

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	1	70.22847982	70.22847982	86.71	<.0001
X2	3	17.44273852	5.81424617	7.18	0.0016

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	1	73.83601574	73.83601574	91.16	<.0001
X2	3	17.44273852	5.81424617	7.18	0.0016

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha 0.05

Error Degrees of Freedom 22

Error Mean Square 0.809944

Harmonic Mean of Cell Sizes 13.03704

NOTE: Cell sizes are not equal.

Number of Means 2

Critical Range .7310

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	12.2279	16	2
B	8.9455	11	1

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha 0.05

Error Degrees of Freedom 22

Error Mean Square 0.809944

Harmonic Mean of Cell Sizes 6.72

NOTE: Cell sizes are not equal.

Number of Means	2	3	4
Critical Range	1.018	1.069	1.102

Means with the same letter are not significantly different.

Duncan Grouping		Mean	N	X2
A		11.9709	7	1
B	A	10.9840	7	2
B		10.4240	7	4
B		10.0658	6	3

Table A.26 Two way ANOVA and Duncan's Multiple Range Test for comparison of specific volume of cakes baked in conventional and MW-IR oven

X1 Oven Type (conventional and MW-IR)

X2 Flour Type (wheat, lentil, chickpea and pea)

Class Level Information

Class	Levels	Values
X1	2	1 2
X2	4	1 2 3 4

Number of Observations Read 15

Number of Observations Used 15

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	1.65208468	0.41302117	45.20	<.0001
Error	10	0.09138626	0.00913863		
Corrected Total	14	1.74347093			

R-Square	Coeff Var	Root MSE	Y Mean
0.947584	3.959635	0.095596	2.414267

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	1	1.56625950	1.56625950	171.39	<.0001
X2	3	0.08582517	0.02860839	3.13	0.0744

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	1	1.48673004	1.48673004	162.69	<.0001
X2	3	0.08582517	0.02860839	3.13	0.0744

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error
rate.

Alpha	0.05
Error Degrees of Freedom	10
Error Mean Square	0.009139
Harmonic Mean of Cell Sizes	7.466667

NOTE: Cell sizes are not equal.

Number of Means	2
Critical Range	.1102

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	2.75971	7	2
B	2.11200	8	1

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha 0.05

Error Degrees of Freedom 10

Error Mean Square 0.009139

Harmonic Mean of Cell Sizes 3.333333

NOTE: Cell sizes are not equal.

Number of Means	2	3	4
Critical Range	.1650	.1724	.1768

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	2.51825	4	1
A	2.47300	2	2
A	2.46275	4	3
B	2.26880	5	4

Table A.27 Two way ANOVA and Duncan's Multiple Range Test for comparison of porosity of cakes baked in conventional and MW-IR oven

X1 Oven Type (conventional and MW-IR)

X2 Flour Type (wheat, lentil, chickpea and pea)

Class Level Information

Class	Levels	Values
X1	2	1 2
X2	4	1 2 3 4

Number of Observations Read 15

Number of Observations Used 15

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	0.02161545	0.00540386	1.04	0.4327
Error	10	0.05184655	0.00518465		
Corrected Total	14	0.07346200			

R-Square	Coeff Var	Root MSE	Y Mean
0.294240	16.18080	0.072005	0.445000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	1	0.01039527	0.01039527	2.01	0.1872
X2	3	0.01122019	0.00374006	0.72	0.5618

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	1	0.00833637	0.00833637	1.61	0.2335
X2	3	0.01122019	0.00374006	0.72	0.5618

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha 0.05

Error Degrees of Freedom 10

Error Mean Square 0.005185

Harmonic Mean of Cell Sizes 7.466667

NOTE: Cell sizes are not equal.

Number of Means 2

Critical Range .08303

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	0.47314	7	2
B	0.42038	8	1

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha 0.05

Error Degrees of Freedom 10

Error Mean Square 0.005185

Harmonic Mean of Cell Sizes 3.692308

NOTE: Cell sizes are not equal.

Number of Means	2	3	4
Critical Range	.1181	.1234	.1265

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	0.47325	4	2
A	0.47025	4	1
A	0.42475	4	3
B	0.40067	3	4

Table A.28 Two way ANOVA and Duncan's Multiple Range Test for comparison of hardness of cakes baked in conventional and MW-IR oven

X1 Oven Type (conventional and MW-IR)

X2 Flour Type (wheat, lentil, chickpea and pea)

Class Level Information

Class	Levels	Values
X1	2	1 2
X2	4	1 2 3 4

Number of Observations Read 49

Number of Observations Used 49

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	3.97903785	0.99475946	15.02	<.0001
Error	44	2.91426754	0.06623335		
Corrected Total	48	6.89330539			

R-Square	Coeff Var	Root MSE	Y Mean
0.577232	13.77993	0.257358	1.867633

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	1	2.03504501	2.03504501	30.73	<.0001
X2	3	1.94399284	0.64799761	9.78	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	1	2.24570383	2.24570383	33.91	<.0001
X2	3	1.94399284	0.64799761	9.78	<.0001

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	44
Error Mean Square	0.066233
Harmonic Mean of Cell Sizes	24

NOTE: Cell sizes are not equal.

Number of Means	2
Critical Range	.1497

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	2.10295	21	1
B	1.69114	28	2

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha 0.05

Error Degrees of Freedom 44

Error Mean Square 0.066233

Harmonic Mean of Cell Sizes 12.15789

NOTE: Cell sizes are not equal.

Number of Means	2	3	4
Critical Range	.2104	.2212	.2283

Means with the same letter are not significantly different.

Duncan Grouping		Mean	N	X2
A		2.1212	12	4
B	A	1.9317	14	2
B	A	1.8007	11	3
B		1.6007	12	1

Table A.29 Two way ANOVA and Duncan's Multiple Range Test for comparison of crust color (ΔE*) of cakes baked in conventional and MW-IR oven

X1 Oven Type (conventional and MW-IR)

X2 Flour Type (wheat, lentil, chickpea and pea)

Class Level Information

Class	Levels	Values
X1	2	1 2
X2	4	1 2 3 4

Number of Observations Read 24

Number of Observations Used 24

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	1379.681747	344.920437	6.78	0.0014
Error	19	967.205238	50.905539		
Corrected Total	23	2346.886985			

R-Square	Coeff Var	Root MSE	Y Mean
0.587877	17.14575	7.134812	41.61271

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	1	1229.959155	1229.959155	24.16	<.0001
X2	3	149.722592	49.907531	0.98	0.4228

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	1	1229.959155	1229.959155	24.16	<.0001
X2	3	149.722592	49.907531	0.98	0.4228

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha 0.05

Error Degrees of Freedom 19

Error Mean Square 50.90554

Number of Means 2

Critical Range 6.097

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	48.772	12	2
B	34.454	12	1

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha 0.05

Error Degrees of Freedom 19

Error Mean Square 50.90554

Number of Means	2	3	4
Critical Range	8.622	9.048	9.318

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	44.180	6	4
A	43.849	6	3
A	40.167	6	2
B	38.255	6	1

Table A.30 Two way ANOVA and Duncan's Multiple Range Test for comparison of crumb color (ΔE*) of cakes baked in conventional and MW-IR oven

X1 Oven Type (conventional and MW-IR)

X2 Flour Type (wheat, lentil, chickpea and pea)

Class Level Information

Class	Levels	Values
X1	2	1 2
X2	4	1 2 3 4

Number of Observations Read 24

Number of Observations Used 24

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	118.5746562	29.6436640	8.83	0.0003
Error	19	63.7638577	3.3559925		
Corrected Total	23	182.3385138			

R-Square	Coeff Var	Root MSE	Y Mean
0.650300	12.99054	1.831937	14.10208

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	1	100.1070107	100.1070107	29.83	<.0001
X2	3	18.4676455	6.1558818	1.83	0.1752

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	1	100.1070107	100.1070107	29.83	<.0001
X2	3	18.4676455	6.1558818	1.83	0.1752

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	19
Error Mean Square	3.355993

Number of Means	2
Critical Range	1.565

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	16.1444	12	1
B	12.0598	12	2

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	19
Error Mean Square	3.355993

Number of Means	2	3	4
Critical Range	2.214	2.323	2.393

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	15.312	6	1
A	14.203	6	2
A	14.056	6	4
B	12.837	6	3

APPENDIX B

GELATINIZATION TEMPERATURES

Table B.1 Gelatinization temperatures and enthalpies of legume cakes baked in different ovens

	Conventional				MW-IR			
Flour Type	T_{onset} (°C)	T_{peak} (°C)	T_{end} (°C)	ΔH_c (J/g)	T_{onset} (°C)	T_{peak} (°C)	T_{end} (°C)	ΔH_c (J/g)
Wheat	71.3c	73.6b	78.1b	0.49c	69.0c	71.9b	76.2b	2.30c
Lentil	73.6bc	77.3ab	83.3ab	2.46ab	75.4bc	79.0ab	82.7ab	3.39ab
Chickpea	77.3ab	78.6ab	81.2ab	3.87a	83.4ab	86.3ab	90.1ab	4.20a
Pea	81.8b	84.0a	89.0a	2.25bc	83.3a	93.0a	96.8a	2.73bc

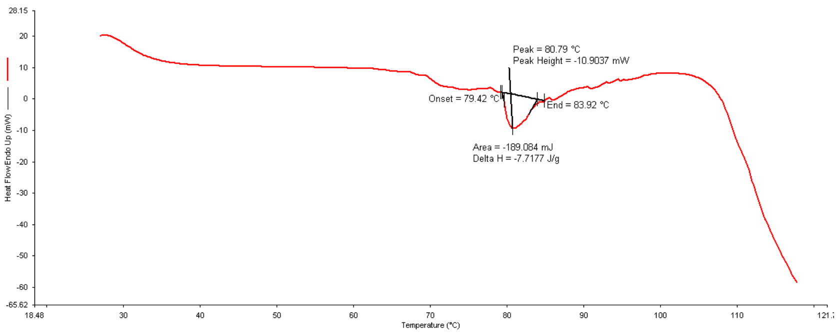


Figure B.1 DSC thermogram for cake batter containing chickpea flour

APPENDIX C

COLOR VALUES

Table C.1 Crust color (L*, a* and b* values) of legume cakes baked in different ovens

	Conventional			MW-IR		
Flour Type	L*	a*	b*	L*	a*	b*
Wheat	60.2	11.9	41.9	43.7	18.1	35.9
Lentil	54.7	17.8	41.7	44.4	20.6	31.3
Chickpea	55.5	13.9	40.9	41.1	20.5	26.8
Pea	52.2	12.1	39.6	38.9	17.7	24.1

Table C.2 Crumb color (L*, a* and b* values) of legume cakes baked in different ovens

	Conventional			MW-IR		
Flour Type	L*	a*	b*	L*	a*	b*
Wheat	74.2	3.9	27.4	74.1	-0.3	20.6
Lentil	69.6	1.5	22.2	74.8	1.3	21.5
Chickpea	72.0	-0.2	21.1	74.6	0.4	21.8
Pea	71.0	-0.9	22.3	72.8	-1.4	22.3