INVESTIGATION OF PHYSICAL PROPERTIES OF DIFFERENT CAKE FORMULATIONS DURING BAKING WITH MICROWAVE AND INFRARED-MICROWAVE COMBINATION

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ABSTRACT

INVESTIGATION OF PHYSICAL PROPERTIES OF DIFFERENT CAKE FORMULATIONS DURING BAKING WITH MICROWAVE AND INFRARED-MICROWAVE COMBINATION

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The main objective was to determine the variation of physical properties of different cake formulations during baking in microwave and infrared-microwave combination ovens.

In the first part of the study, rheological and dielectric properties of cake batter with different formulations were determined. Different concentrations of fat and different types of emulsifier and fat replacer were used. The variation of formulation had a significant effect on the apparent viscosity of the cake batter. Cake batter was found to show shear thinning and time independent behaviour for all formulations. Dielectric properties of cake batter were dependent on formulation, frequency and temperature.

In the second part of the study, physical properties (dielectric properties, volume, texture, color and porosity) of cakes baked in microwave and infrared-microwave combination oven were determined. In addition, starch gelatinization during baking was investigated. For comparison, cakes were also baked in conventional oven.

Formulation and baking time were found to affect physical properties and gelatinization degree of cakes. Addition of fat to the formulation was found to increase the dielectric properties and gelatinization degree of microwave and infrared-microwave combination baked cakes. For both microwave and combination baking, cake samples with Simplesse™ had the highest volume but the firmest texture. Addition of maltodextrin resulted in a more uniform structure for infrared-microwave combination baking.

There was insufficient gelatinization in microwave baked cakes ranging from 70 to 78% depending on fat content. The gelatinization degree ranged from 88 to 93% in conventionally baked cakes. Combining infrared with microwaves increased gelatinization degree (80-90%).

Keywords: Microwave Baking, Infrared, Cake, Dielectric Properties, Rheology

ÖZ

MİKRODALGA VE MİKRODALGA-KIZIL ÖTESİ KOMBİNASYONU İLE PİŞİRİLEN DEĞİŞİK KEK FORMÜLASYONLARININ FİZİKSEL ÖZELLİKLERİNİN İNCELENMESİ

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Bu tezin ana amacı, farklı formülasyonlardaki keklerin mikrodalga ve mikrodalga-kızıl ötesi kombinasyonlu fırın ile pişirilmesi sırasındaki fiziksel özelliklerinin değişiminin incelenmesidir.

Çalışmanın birinci bölümünde farklı formülasyonlardaki kek hamurlarının reolojik ve dielektrik özellikleri belirlenmiştir. Farklı yağ konsantrasyonları ve emülgatör ve yağ ikamesi çeşitleri kullanılmıştır. Formülasyondaki değişimin, kek hamurunun görünür akışkanlığı üzerinde önemli derecede etkili olduğu bulunmuştur. Bütün formülasyonlar için kek hamurunun kayma ile incelen bir

yapı gösterdiği ve reolojik açıdan zamandan bağımsız olduğu bulunmuştur. Kek hamurunun dielektrik özelliklerinin formülasyona, frekansa ve sıcaklığa bağlı olduğu gösterilmiştir.

Çalışmanın ikinci kısmında, mikrodalga ve kızıl ötesi-mikrodalga fırında pişirilen kek örneklerinin fiziksel özellikleri (dielektrik özellikler, hacim, tekstür, renk ve gözeneklilik) belirlenmiştir. Ayrıca, pişirme sırasında nişasta jelatinizasyonu incelenmiştir. Karşılaştırma için kekler konvansiyonel fırında da pişirilmişlerdir.

Formülasyon ve pişirme süresinin keklerin fiziksel özelliklerini ve jelatinizasyon derecelerini etkilediği bulunmuştur. Formülasyona yağ eklenmesinin, mikrodalga ve kızıl ötesi-mikrodalga kombinasyonu ile pişirilen keklerin dielektrik özelliklerini ve jelatinizasyon derecelerini arttırdığı bulunmuştur. Hem mikrodalga hem de kombinasyonlu pişirme için Simplesse^{TM} içeren kek örnekleri en yüksek hacim değerlerine fakat en sert tekstüre sahiptir. Kızıl ötesi-mikrodalga kombinasyonu ile pişirme için maltodekstrin eklenmesi daha homojen bir yapıya neden olmuştur.

Yağ oranına bağlı olarak mikrodalga ile pişirilen keklerde %70 ile %78 aralığında değişen jelatinizasyon derecelerinde yetersiz jelatinizasyon gözlenmiştir. Bu aralık konvansiyonel olarak pişirilen kekler için %88 ile %93 olarak belirlenmiştir. Mikrodalgayi kızıl-ötesi ile birleştirmek örneklerin jelatinizasyon derecelerini arttırmıştır (80-90%).

Anahtar Kelimeler: Mikrodalga ile Pişirme, Kızıl ötesi, Kek, Dielektrik Özellikler, Reoloji

To My Family

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INTRODUCTION

1.1 Microwave Heating

Microwaves are electromagnetic waves of radiant energy having wavelength between radio and infrared waves on the electromagnetic spectrum (Giese, 1992). They have the frequency range of 300 MHz to 30 GHz. For food applications frequencies 915 MHz and 2450 MHz are approved. Microwaves are usually generated by an electromagnetic device called a “magnetron” which produces an alternating electric field.

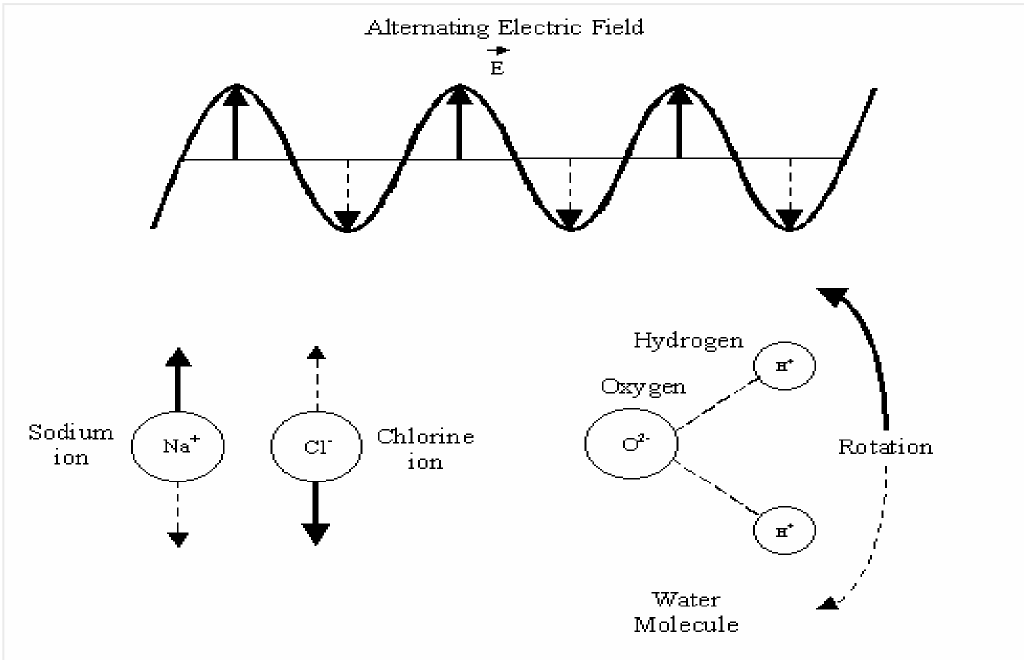
Microwaves have been used as a heat source since the 1940s (Mermelstein, 1997). This technique has been extensively employed in the food and chemical engineering industries. Application areas include polymer and ceramics industries, medicine and food processing. The food industry is the largest consumer of microwave energy, where it can be employed for cooking, thawing, tempering, drying, freeze-drying, pasteurization, sterilization, baking, heating and re-heating (Ayappa et al., 1991).

There are two microwave heating mechanisms: ionic conduction and dipolar rotation. Microwave energy penetrates into a food material and produces a volumetrically distributed heat source, due to molecular friction resulting from dipolar rotation of polar solvents and from the conductive migration of dissolved ions. These two mechanisms are caused by alternating electric field around product (Alton, 1998). Ionic conduction and dipolar rotation mechanisms of microwave heating are shown in Figure 1.1. Water, the major constituent of most food products, is the main source for microwave interactions due to its dipolar nature. Heat is generated throughout the material, leading to faster heating rates and shorter processing times compared to conventional heating, where heat is usually transferred from the surface to the interior. Besides faster heating, other advantages of microwave heating include space savings, energy efficiency, precise process control, selective heating and food with high nutritional quality (Decareau and Peterson, 1986).

For microwave heating, the energy equation includes a heat generation term, governing equation for heat transport in microwave heating is given in equation (1.1).

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

where T is temperature (K), t is time (s), α is thermal diffusivity (m^2/s), ρ is density (kg/m^3), C_p is specific heat of the material (J/kg.K) and Q is the rate of heat generated per unit volume of material ($J/s.m^3$).



(a) (b)

Figure 1.1 Microwave heating mechanisms (a) Ionic conduction (b) Dipolar rotation (Sahin and Sumnu, 2006)

The heat generated per unit volume of material per unit time (Q) represents the conversion of electromagnetic energy. Its relationship to the electric field intensity (E) at that location can be derived from Maxwell's equation of electromagnetic waves as shown by Metaxas and Meredith (1983):

$$Q = 2\pi\varepsilon_o\varepsilon'' fE^2 \quad (1.2)$$

where the magnetic loses of the food material have been ignored, ε_0 is the dielectric constant of free space, ε'' is the dielectric loss factor of the food, f is the frequency of oven and E is the electric field intensity.

If a food is heated by microwave, the driving forces for heat and mass transfer differ from conventional methods. Internal heat generation owing to the absorption of electrical energy from the microwave field and heat transfer by conduction, convection and evaporation are the main causes of time-temperature profiles within the product when heated by microwave (Mudgett, 1982). Since there is a lack of ambient heat and the cooling effects of evaporation in the microwave oven, the interior temperature of a food heated by microwave energy is hotter than the surface temperature (Decareau, 1992). Besides, Wei et al. (1985a, 1985b), found that a porous media was hotter in the inside when heated by microwaves and hotter on the outside when heated by convection. Compared to conventional heating, moisture flows, owing to concentration and pressure gradients, are uniquely and significantly altered during microwave heating. An increase in moisture vapor generation inside a solid food material was occurred due to relatively large amounts of internal heating, and this situation creates significant internal pressure and concentration gradients (Datta, 1990). This positive pressure increase causes the flow of vapour and liquid through food to the boundary. Governing equation for mass transport in microwave processing is as the following;

$$\frac{\partial M}{\partial t} = \alpha_m \nabla^2 M + \alpha_m \delta_p \nabla^2 P \qquad (1.3)$$

where M is the total moisture content (liquid and vapour phases), α_m is the moisture diffusivity, δ_p is the pressure gradient coefficient and P is pressure.

1.2 Food Properties Affecting Microwave Heating

Dielectric properties and penetration depth are the electrical properties which play an important role in understanding the interaction of microwave energy with foods. Knowledge of dielectric properties of foods is essential for proper understanding of heating behaviour of foods in microwave oven. Dielectric properties are dielectric constant (ε') and dielectric loss factor (ε'') which are the real and imaginary parts, respectively of the relative complex permittivity (ε_r) given by the following equation:

$$\varepsilon_r = \varepsilon' - j\varepsilon'' \tag{1.4}$$

Dielectric constant is an ability of a material to store microwave energy while dielectric loss factor is the ability of a material to dissipate microwave energy into heat. Dielectric properties of foods depend on frequency, composition, moisture content, bulk density and temperature of the food (Calay et al., 1995).

Penetration depth is defined as the distance from the surface of material at which the microwave power has decreased to 1/e ≈ 36.8% of its value at the surface shown in equation 1.5 (Metaxas and Meredith, 1983).

$$Z = \frac{\lambda_0}{2\pi(2\varepsilon')^{0.5}}\left\{\left[1+\left(\frac{\varepsilon''}{\varepsilon'}\right)^2\right]^{0.5}-1\right\}^{-0.5} \tag{1.5}$$

where Z is the penetration depth (cm), λ_o is the wavelength in free space (cm), ε' is the dielectric constant and ε'' is the dielectric loss factor.

The relative magnitudes of penetration depth and sample size determine the uniformity of heating. If the penetration depth is much larger than the sample size there will be little variation in the rate of heat from surface to the interior of food and the resulting heating will be uniform (Datta, 1990). When the penetration depth is much less than the sample size, heating will be restricted to near the surface and will be non-uniform. In the extreme case of a very small penetration depth, non-uniform profiles, typical of conventional heating, is expected.

As a result of an extensive and comprehensive literature review, Venkatesh and Raghavan (2004) stated that temperature, moisture content, composition, physical structure, density and frequency are the factors influencing the dielectric properties of the related food product.

The research about dielectric properties of bakery products is limited in literature. Goedeken et al. (1997) searched the change in dielectric properties of bread with and without salt. They found that as the bread was heated, the dielectric constant increased until the sample reached 60°C, once the temperature reached 60°C the dielectric constant remained constant. In the case of dielectric loss factor, for samples containing salt, it increased with temperature but for the ones without salt, dielectric loss factor decreased with increasing temperature.

Dielectric properties of baked biscuit dough samples of various moisture contents, temperatures and densities were measured at 27MHz by using a parallel plate capacitor connected to an Impedance Analyzer (Kim et al., 1998). They developed models which predicted the dielectric properties of baked dough at different moisture content, density and high temperature.

The dielectric properties of wheat flour dough were measured by using a parallel plate capacitor (Kim and Cornillon, 2001). The variation of dielectric properties with respect to temperature and mixing time were studied. They found that temperature was effective on both dielectric constant and dielectric loss factor. The dielectric constant was found to remain constant as temperature increased up to 60 °C, and then decreased. Whereas, it was observed that dielectric loss factor increased with increasing temperature.

Sumnu et al. (2007) studied the dielectric properties of breads baked with different heating modes of microwave plus infrared and microwave plus jet impingement. They found that dielectric properties during baking were affected by the decrease in moisture content and increase in porosity.

The effects of different gums on dielectric properties of doughs and breads baked in infrared-microwave combination oven were investigated by Keskin et al. (2007). They concluded that the dielectric properties and quality parameters of breads baked in infrared-microwave combination oven were dependent on gum type. It was found that the bread samples formulated with κ-carrageenan had the highest dielectric properties among the other gum types.

Nelson et al. (1991) investigated the moisture and temperature dependence of permittivities of potato starch and some other hydrocolloids. They found a positive correlation between dielectric properties and moisture and temperature. And they concluded that the degree of temperature dependence of all hydrocolloids increased as moisture content increased.

Arámbula et al. (1998) discussed the use of dielectric measurements to monitor the gelatinization of corn starch during its processing by extrusion.

Aiming for a better understanding of the changes induced by the processing temperature, the thermal and dielectric data were further supplemented by viscosity and X-ray diffraction.

When dielectric properties of starch solutions of different concentration were investigated at different temperatures (Piyasena et al., 2003), it was found that temperature, frequency, concentration and their interactions had different levels of significance on the dielectric properties of starch solutions.

Thermal conductivity, specific heat and gelatinization enthalpy are the thermal properties of food which affect microwave heating. For microwave heating, specific heat can often be considered as a negligible parameter but in case of foods that have a low dielectric constant such as fats and oils, it should have an overriding effect. Oil samples which have low dielectric constant generally believed to be heated faster than water samples of the same mass (Barringer et al., 1994). Specific heat can cause a material with a low dielectric constant to heat well in the microwave field (Schiffmann, 1986). Barringer et al. (1994) showed that for sufficiently large and thick samples oil may be heated faster in a microwave oven than water of the same mass. But for smaller samples, the trend was not the same.

1.3 Cake Batter and Cake

Cakes are defined as being aerated, chemically leavened bakery products. Essentially there are two types of cakes. Sponge cakes are very airy batters that turn into cakes with a rather open structure. Layer cakes, on the other hand, contain a solid fat which, when creamed with sugar results in an aerated batter with distinct flow properties and a cake that has a fine grain and relatively small air cells (Mc Williams, 1989). There are three steps on which the manufacture of layer and sponge cakes is based. The first step is aeration of a liquid batter to form a foam. The second step is the expansion of air bubbles within the foam during baking. The last step is the transformation of the foam to a sponge structure, caused by a large increase in viscosity as the starch granules gelatinize and swell (Guy and Sahi, 2006).

Cake batter can be considered as an oil in water emulsion. The dry ingredients, such as sugar, flour, salt and baking powder are incorporated into the liquid phase but the fat or oil phase remains dispersed in lakes or clumps throughout the continuous or liquid phase and does not become part of the liquid phase (Painter, 1981). Almost all air bubbles which finally create texture of cakes are incorporated during the preparation of the batter. The air bubbles are incorporated and stabilized in the fat phase when sugar is beaten into the shortening to give an aerated cream. In the finished batter (containing flour, eggs, sugar and shortening), most of the air bubbles are held in the fat phase at room temperature. During heating, many of the bubbles move from fat into the aqueous phase where it appears, the bubbles become partly stabilized by egg proteins. It has been interfered that the bubbles take a layer of fat with them as they move into the aqueous phase because in the baked cake, the surface of the air bubbles is coated with fat (Brooker, 1993).

The complexity of cake batters containing many ingredients, such as wheat flour, sugar, egg, fat, leavening agents, salt, nonfat dry milk solids and water has made it difficult to clarify the mechanism of the heat setting process during baking (Mizukoshi et al., 1979). Thermal setting of the cake is defined as the time at which the batter changes from an emulsion to a porous structure (Ngo and Taranto, 1986) due to starch gelatinization together with protein denaturation

(Mizukoshi et al., 1979). During baking, as temperature increases the vapor pressure of water and the rate of formation of carbon dioxide gas increases which further diffuses into air bubbles resulting in the expansion of the cake batter (Mizukoshi, 1983; Mizukoshi et al., 1980). Further increase in temperature causes starch gelatinization and protein denaturation.

1.3.1 Role of Ingredients in Cake Batter

Complex cake batters contain a large number of highly reactive components that can interact with other components. As a definition, high ratio layer cakes are formulations containing high ratio of sugar and water to fat. For cakes containing high levels of sugar and water, an increase in batter viscosity and an improvement in batter stability are important in obtaining a noncollapsing, porous cake structure (Kim and Walker, 1992a). Incorporation of specific additives has been found to be beneficial for improving the quality of baked products (Kaur et al., 2000).

1.3.1.1 Flour

Flour is the ingredient which distinguishes bakery products. It gives unique textural and appearance characteristics to cakes in which it is used. Cake flours are generally made from wheat with lower protein level. Other than protein it contains mainly starch, lipids, some minerals and vitamins, ash, etc. When wheat starch is heated in water, the granules begin to absorb water and expand to many times their original size. The crystalline structure melts, amylose leachs out of the granules and the granules become deformed. This gelatinization occurs over a wide temperature range and is influenced by the presence of other ingredients such as sucrose or emulsifiers (Bennion and Bamford, 1997).

There are some important parameters in order to specify a flour. The first one is the moisture content. The moisture content of the flour is most commonly about 14% and should not vary more than 1%. Another important specification parameter is the protein content. According to the final product, in which the flour will be used, the protein content varies. For baking, if highly elastic dough is needed, it is preferred to handle flour with high protein content. A measurement of the ash content of flour is used as one of the main quality criteria to indicate the suitability of a flour for baking. Total alpha amylase and falling number are other important parameters for flour specification. Damaged starch is another criterion which is measured in the UK by a system that measures the level of damaged starch in arbitrary Farrand Units (FU). Water absorption and rheological properties of flour are also important for specification. Finally, the knowledge of any treatment that the flour has experienced is important to achieve optimum results. Flour treatment can be one of the following; enzyme addition to flour, gluten supplementation of flour, etc. (Bennion and Bamford, 1997).

Special cake flours are milled from specially selected soft wheat to a finer particle size. The protein content of cake flour is about 8%. The general purpose cake flours have a slightly higher protein content than the high ratio types and are given heavy treatment with a chlorine bleach, producing a flour with a pH of about 5.2. This treatment affects the gelation properties of the starch which together with the finer particle size are the significant properties necessary for making very soft batters containing high percentages of sugar, as it is the case in high ratio cakes (Bennion and Bamford, 1997).

1.3.1.2 Emulsifier

The usage of emulsifier is a common practice in baking industry. An emulsifier reduces the interfacial tension between oil and water and therefore facilitates the disruption of emulsion droplets during homogenization. The emulsifier adsorbs to the surfaces of emulsion droplets to form a protective coating that prevents the droplets from aggregating with each other (McClements and Demetriades, 1998).

An emulsifier functions in two ways. It aids in the incorporation of air and disperses the shortening in smaller particles to give the main number of available air cells. Emulsifiers contain both a hydrophilic and a lipophilic portion, usually not in an evenly balanced ratio but either primarily hydrophilic, being attracted to water, or primarily lipophilic, being attracted to fat. It is thought that the hydrophilic emulsifiers promote the uniform dispersion of fat which contains the entrapped air cells, therefore giving many sites for both water vapour expansion and carbon dioxide given off by the chemical leavening agents. The hydrophilic portion of the emulsifier extends itself into the aqueous phase of the batter and creates a membrane between the oil-water boundaries. This membrane appears to coat or encapsulate the fat droplets distributed through out the batter. This prevents the fat droplets containing air cells from migrating into the liquid-aqueous phase. Therefore, emulsifiers can be said to aid in the aeration of the batter (Painter, 1981). The effect of an emulsifier on gelatinization depends on emulsifier type (Richardson et al., 2003). This might be attributed to an amylose-lipid complex formation. The amount of complex formed was also affected by the starch and lipid sources (Kim and Walker, 1992b).

The two main classes of food emulsifiers relevant to cake manufacture are proteins and lipids, both of which can be used to aerate and reduce the density of batter (Sahi and Alava, 2003). The mechanisms by which these two molecular species stabilize foams differ: proteins do so by forming mechanically strong viscoelastic films, whereas lipid films are weaker, relying on the diffusion of molecules to counteract changes in interfacial tension when the interface is perturbed (Coke et al., 1990).

Several emulsifiers, such as Atlas A (a water dispersion of 32% sorbitan monostearate and 8% polysorbate 60 with added preservative) , propylene glycol mono fatty acid esters (PGME), Atmul P 44 (a blend of mono- and diglycerides and sodium stearoyl lactylate), RV (a mixture of sodium stearoyl lactylate, sorbitan monostearate and polysorbate 60), RV-1 (a 50% water dispersion of RV) were used to test the effects on the functionality of white layer cake batters in which vegetable oil was used (Rasper and Kamel, 1989). It was concluded that the cakes with different emulsifiers had comparable quality attributes with the control.

Sanchez et al. (1995) aimed to evaluate the effects of reduced fat content in shortbread cookies using combinations of carbohydrate-based fat substitutes and emulsifiers. The emulsifiers used in the study were diacetyl tartaric esters of monoglycerides (DATEM), glycerol monostearate (GMS), and sodium stearoyl-2-lactylate (SSL). It was found that addition of SSL appeared to have less negative effect on cookie width than either addition of GMS or DATEM had.

The effects of different emulsifiers on the properties of the dough and the volume and the firmness of the microwave-baked breads were compared (Ozmutlu et al. 2001a). DATEM, Lecimulthin M-45 and Purawave™ were the three emulsifiers used. Purawave^{TM} was found to be the most effective emulsifier on bread quality. In another study of Ozmutlu et al. (2001b), the effects of different amounts of gluten, fat, emulsifier, and dextrose on the quality of breads baked in the microwave oven were studied. For breads formulated with flour containing low gluten, the increase in fat and emulsifier contents decreased the firmness and increased the specific volume of breads.

Sahi and Alava (2003) studied the effects of emulsifiers (glyceryl monostearate and polyglycerol ester) and air inclusion on the structure of sponge batters. They found that increasing the concentration of the emulsifier affected the distribution and size of the air bubbles trapped in the batter during mixing as well as the texture and the volume of the baked sponges.

Lecigran^{TM}, Purawave^{TM} and DATEM were the emulsifiers that have been added to microwave baked cakes to improve quality (Seyhun et al., 2003). Cakes formulated with Purawave^{TM} and DATEM had the highest moisture retention and were the softest.

1.3.1.3 Fat and Fat Replacer

Fat or shortening is one of the important ingredients in a cake formulation. Fat helps to entrap air during the creaming process, resulting in aeration and hence leavens the product. Fat also imparts desirable flavor and softer texture to the cakes. Most types of cakes require fairly high levels of shortening for the development of their characteristic crumb structure. In a cake system shortening serves three major functions: to entrap air during the creaming process, to physically interfere with the continuity of starch and protein particles and to emulsify the liquid in formulation. Thus, the shortening affects the tenderness and moisture of the cake (Freeland-Graves and Peckham, 1987). In addition, fats are also known to delay gelatinization by delaying the transport of water into the starch granule due to the formation of complexes between the lipid and amylose during baking (Elliasson, 1985; Ghiasi et al., 1982; Larsson, 1980). Effect of four different fat types on the rheology of the cookie dough and subsequently their effect on the quality of cookies were studied by Jacob and Leelavathi (2007). They found that the quality of these cookies was significantly affected by the fat type.

In spite of the number of functions played by fat in improving the overall quality of cake, the current consensus is to reduce the fat content or to replace the fat in bakery products to protect consumers from several health hazards such as cardiovascular disease, atherosclerosis, diabetes and obesity. As a consequence, the number of low-calorie foods has increased steadily over the last few decades (Rasper and Kamel, 1989; Sobczynska and Setser, 1991; Zoulias et al., 2000; Kim et al., 2001; Bath et al., 2001). One approach to balance calorie intake and output is to lower the calorie density of the food eaten. Since fat contributes 9 kcal/g, while carbohydrate and protein contribute 4 kcal/g, it serves as an obvious candidate for removal. Foods that contain low-calorie sugar- and fat-replacers are popular due to a desire in calorie-reduction in the diet. High-ratio cakes, rich in sugar and fat, are extensively used in baking industry (Rosenthal, 1995), thus are ideal candidates for simultaneous sugar and fat replacement. There are numbers of fat and sugar replacers in the market, however the important point is the consideration of the functionality of these fat and sugar replacers in a variety of high sugar and/or fat containing products to obtain products with similar quality parameters (Kamel and Rasper, 1988). Some common fat replacers are given in Table 1.1. One group of fat replacer is the carbohydrate based fat replacers. These replacers, in the presence of water, form a smooth gel resulting in lubricant and flow properties similar to fats (Swanson et al., 1999). They function primarily to increase viscosity and to provide a creamy, slippery mouth feel similar to that of fat.

Table 1.1 Common fat replacers used in food industry.

Carbohydrate-based	Protein-based	Fat-based
Cellulose	Microparticulated protein	Caprenin
Dextrins	Modified whey protein concentrate	Salatrim
Fiber	Simplesse	Olestra
Gums		Emulsifiers (mono and diglycerides)
Inulin		Sucrose polyesters
Maltodextrins		
Oatrim		
Polydextrose		
Polyols		
Starch/Modified food starch		
Z-Trim		

Maltodextrins are carbohydrate based fat replacers. Maltodextrin is defined as a nonsweet oligosaccharide of α-D-glucose units with dextrose equivalent (DE) less than 20 (Frye and Setser, 1993). They are partial hydrolysates of starch prepared with either acids or enzymes. The low-DE maltodextrins have binding properties of starch and can function more effectively as a fat replacer than high-DE maltodextrins (Alexander, 1992). It is widely used for partial replacements of fats in a variety of processed foods because of its ability to form a particle gel cream in food systems (Sobczynska and Setser, 1991; Alexander, 1992).

Simplesse™ is another type of fat replacer. It is a protein based fat replacer. Simplesse™ is a patented natural multi-functional dairy ingredient made from whey protein concentrate that undergoes a unique proprietary microparticulation process. It is a versatile product that provides significant functional benefits in a wide range of full-fat and low-fat food applications. Microparticulation is the key for multi-functional properties. Simplesse™ is made from protein that comes from eggs or skim milk. Through a special process called microparticulation, the protein is formed into tiny round beads. These beads are so small that 50 billion of them fit in a teaspoon. When eaten, they roll over each other on the tongue, mimicking the creamy texture of fat. Simplesse™ fools your taste buds, making you think you are eating fat when you are really eating protein. It is absorbed through the digestive system, but it only contains 1.3 kcal/g. This is substantially less than regular fat, which has 9 kcal/g. The first commercial use of Simplesse™ was in a frozen dessert. It can also be used to replace some of the fat in sour cream, butter, margarine, yogurt, salad dressings, and processed cheeses.

Sanchez et al. (1995) aimed to evaluate the effects of combinations of carbohydrate-based fat substitutes and emulsifiers on shortbread cookies. It was found that fat substitution ended up with a higher moisture content, greater toughness, and lower specific volume.

In order to develop low calorie soft dough biscuits, fat in the biscuit formulation was reduced from 20% (control) to 10%, 8%, and 6% levels by using maltodextrin, polydextrose, glycerol mono stearate, sodium steroyl lactylate and guar gum instead of fat (Sudha et al., 2007). Replacing fat with equal quantities of maltodextrin and polydextrose reduced the dough consistency and dough hardness. Addition of glycerol mono stearate and guar gum had a positive effect on dough consistency and hardness.

Olestra is the most common example of a fat-based fat replacer. Olestra has properties similar to those of naturally occurring fat, but it provides zero calories. That's because olestra is undigestible. It passes through the digestive tract but is not absorbed into the body. This is due to its unique configuration: a center unit of sucrose (sugar) with six, seven or eight fatty acids attached. Olestra's configuration also makes it possible for the substance to be exposed to high temperatures, such as frying, quality characteristic which most other fat replacers lack of. As promising as olestra sounds, it does have some drawbacks. Studies show that it may cause intestinal cramps and loose stools in some individuals. Some other fat-based replacers are being considered or developed: Salatrim (which stands for short and long-chain acid triglyceride molecules) is the generic name for a family of reduced-calorie fats that are only partially absorbed in the body. Salatrim provides 5 kcal/g. Caprenin is a 5 kcal/g fat substitute for cocoa butter in candy bars. Emulsifiers are fat-based substances that are used with water to replace all or part of the shortening content in cake mixes, cookies, icings, and vegetable dairy products. Although they give the same calories as fat, due to their lower level of usage, fat and calorie intake reductions take place (http://www.fda.gov/fdac/features/696fat.html, http://www.cfsan.fda.gov/~dms/bgolestr.html).

1.3.1.4 Sugar

Depending upon the quantity used, sugar can affect not only the taste but also the texture and appearance of the baked cake (Table 1.2). It plays a role in controlling batter viscosity, the degree of gelatinization of starch and heat setting temperature of proteins. Sugar also serves as a tenderizing agent by retarding gluten development during mixing. Sugar also elevates the coagulation temperature of proteins from eggs and milk components, causing increased expansion of cake batter (Mc Williams, 1989). Nearly all commercially available sugar contains in excess of 99.8% sucrose, with less than 0.05% moisture, about 0.05% invert sugar and other carbohydrates besides sucrose, and a trace of ash (Matz, 1972). Sugar in the high-ratio cake formulation results in a good air incorporation leading to a more viscous and stable foam (Paton et al., 1981). In addition, sugar affects the physical structure of baked products by regulating gelatinization of starch. Sucrose is known to delay the gelatinization of the granules. Delay in starch gelatinization during baking allows air bubbles to expand properly due to vapor pressure build up by carbon dioxide and water vapor before the cake sets and this allows the formation of desired cake structure (Kim and Setser, 1992; Kim and Walker, 1992b).

Table 1.2 Characteristics of bakery products affected by sugar (Bennion and Bamford, 1997)

Product	Properties
Cakes	Cake structure
	Volume
	Texture
	Aeration
	Keeping quality
	Humectancy
	Crumb color
	Crust color
	Shelf-life
	Preservative
	Crumb tenderizing
	Whipping and creaming aid
	Flavour and aroma
Biscuits	Aeration
	Texture and dough state
	Surface appearance
	Flavour
	Browning
	Spreading during manufacture
Bread	Loaf structure
	Yeast activation
	Proof time and improved toasting
	Keeping quality and shelf life
	Crumb softness and crust color

1.3.1.5 Egg

The egg is a highly functional food ingredient and it has three primary attributes; foaming, emulsification and coagulation. Foaming is the incorporation of air into a product, usually achieved by whipping. While many food ingredients form foams, egg and egg products are especially good foaming agents because they produce a large foam volume which is relatively available for cooking and coagulate on heating to maintain a stable foam structure. The second attribute is the emulsification which is the stabilization of the suspension of one liquid in another. Egg yolk contains an excellent food emulsifier, lecithin. Coagulation is the last attribute. It is the conversion of the liquid egg to a solid or semi-solid state, usually accomplished by heating. This property of egg is difficult to duplicate with any other food ingredient (Bennion and Bamford, 1997). Eggs affect the texture of cakes as a result of their emulsifying, leavening, tenderizing, and binding actions. They add colour and nutritional value, and in many cases, desirable flavor. They are essential for obtaining the characteristic organoleptic qualities (Matz, 1972).

Eggs can be examined in two parts as egg yolk and egg white. Egg yolk is a dispersion of particles in a continuous phase. This system contains egg lipids, 70% of which are triglycerides. The particles make up 25% of the dry matter of the yolk, being phosvitin and lipovitellin. The continuous phase contains 75% of the dry matter of the yolk in the form of lipovitellin and globular protein. Cholesterol and lecithin are also present in egg yolk. The color of the yolk is determined by the amount of xanthophyll, a yellow coloring pigment.

Egg white or albumen is made up of a complex structure of proteins, such as ovalbumin and conalbumin. It contains in dry matter about 85% of the total protein content of an egg. The egg white is very viscous and alkaline in a fresh egg and contain natural inhibitors, such as lysozyme, which form a chemical protection against invading microorganisms (Bennion and Bamford, 1997).

1.3.1.6 Water

Water serves as a solvent in the cake batter to dissolve dry ingredients. It is necessary for gelatinization of starch (Mc Williams, 1989). The quality of water used as an ingredient can have greater effects on bakery products than is generally recognized. The amount and types of dissolved minerals and organic substances present in the water can affect the flavor, color, and physical attributes of the finished baked goods. The hardness of water is an important characteristic for bakery products. Soft waters may result in sticky doughs which require less than the normal amount of ingredient water, but this may be overcome by using more salt in the formulation (Matz, 1972).

1.3.1.7 Baking Powder

Baking powder is the leavening agent produced by the mixing of an acid reacting material and sodium bicarbonate, with or without starch or flour. It yields not less than 12% of available carbon dioxide. The acid reacting materials in baking powders are tartaric acid or its acid salts, acid salts of phosphoric acid and compounds of aluminum (Matz, 1972). Chemical leavening involves the action of an acid on bicarbonate to release carbon dioxide gas for aeration of a dough or batter during mixing and baking. The aeration provides a light, porous cell structure, fine grain, and a texture with desirable appearance along with palatability to baked goods.

There are essentially two components in a chemical leavening system as bicarbonate and acid. Bicarbonate supplies carbon dioxide gas and acid triggers the liberation of carbon dioxide from bicarbonate upon contact with moisture. Sodium bicarbonate is the primary source of carbon dioxide gas in practically all chemical leavening systems. It is stable and obtainable as a highly purified dry powder at relatively low production costs. The prevalent baking acids in modern chemical leavening systems are sodium or calcium salts of ortho, pyro, and complex phosphoric acids (Chung, 1992).

Basically, there are two mechanisms of decomposition of sodium bicarbonate. First one is the thermal decomposition and the second one is the acid activated decomposition. Thermal decomposition of sodium bicarbonate takes place at high temperatures (90°C and above) and is not of particular benefit in cake baking. In its simplest form, it can be represented by the following chemical reaction:

$$2NaHCO_3 + heat \quad = \quad Na_2CO_3 + CO_2 + H_2O$$

Acid activated decomposition involves reactions of hydrogen ions in aqueous solution and can be represented by the following general chemical reaction:

$$NaHCO_3 + H^+ \quad = \quad Na^+ + CO_2 + H_2O$$ (Bennion and Bamford, 1997).

1.3.2 Rheology of Cake Batter

Rheology information is valuable in product development. It is important to determine the rheological properties of a cake batter since the quality attributes of final cake such as volume and texture can be correlated with rheological properties. For cakes containing high amounts of sugar and water an increase in batter viscosity and batter stability are important to obtain a noncollapsing porous cake structure. Rheological properties of fluid foods are complex and depend on many factors such as the composition, shear rate, duration of shearing and previous thermal and shear histories (Steffe, 1996).

Various rheological models have been determined for starch based foods in literature. Sopade and Kiaka (2001) studied the flow properties of starches from different localities and found that the fluid was generally shear thinning and time-independent, irrespective of the temperature. On the other hand, starch-milk sugar pastes showed a time dependent flow behaviour. The power-law model was applied for the rheological behaviour of starches (Sopade and Kiaka, 2001; Abu-Jdayil and Mohameed, 2004). Rheological properties of rice flour based batters at different temperatures were investigated by Mukprasirt et al. (2000), and Herschel-Bulkley model was found to be the best fit to their data.

Different food ingredients affect the rheology of food materials. Prakash et al. (2001) investigated the effect of salt and oil or their mixture on the rheological constants of raw and steamed wheat flour batter. Baixauli et al. (2003) evaluated the effects of dextrin or dried egg on the rheological properties of batters for fried foods and found that addition of dextrin and egg altered the flow behaviour slightly. Fat content was the most influencing parameter as compared to emulsifier and thickener on the rheology of salad dressings (Baixauli et al., 2003). The type of starch and starch concentration had a significant effect on the time-dependent flow properties of starch-milk-sugar pastes (Abu-Jdayil and Mohameed, 2004).

The rheological properties of semi-sweet biscuit doughs were investigated and related to baking (Pedersen et. al., 2004). The rheological properties of the dough were characterized by creep recovery and oscillation. Creep recovery and oscillation measurement of biscuit dough from the tested cultivars reflected differences, which are likely to be related to dough structural differences.

There is lacking information in literature on the effects of different ingredients on rheological properties of cake batter. The bulk rheology of the different formulated sponge cake batters was determined to characterize their physical properties (Sahi and Alava, 2003). Dynamic oscillatory tests were performed to determine the viscoelastic properties of the batters. It was found that addition of emulsifier resulted in an increase in elastic and viscous moduli and viscosity.

1.3.3 Pore Size Distribution of Cake

Type of the product, nature of pretreatment and processing conditions influences the pore size, geometry or shape, and pore size distribution of the food matrix. Porosity and pore size distribution within the solid food matrix affect the mechanical, texture, and sensory properties of food (Bhatnagar & Hanna, 1997, Kassama et al., 2003, Stanley, 1987).

The research on baked products as a porous media is limited (Hicsasmaz and Clayton, 1992; Sahi and Alava, 2003; Datta et al., 2007). Pore size distribution of breads baked in different ovens has recently been studied by using liquid extrusion porosimetry, image analysis, volume displacement method and scanning electron microscopy (Datta et. al., 2007).

Computer vision or machine vision, is a novel technology for acquiring and analysing an image of a real scene by computers and other devices in order to obtain information or to control machines or processes. Image processing and image analysis are recognized as being the core of computer vision (Krutz et al., 2000).

Image analysis is the process of distinguishing the objects (regions of interest) from the background and producing quantitative information, which is used in the subsequent control systems for decision making. Computer vision systems are being used increasingly in the food industry for quality assurance purposes. Computer image analysis has recently been successfully used to characterize structural properties of meat, fish, pizza, cheese and bread (Brosnan and Sun, 2004). Tan (2004) had applied the computer vision to evaluate meat quality. Results from several applications show that color image processing is a useful technique for meat quality evaluation. Kılıç et al. (2007) developed a computer vision system to classify beans according to their size and color.

The appearance of baked products is an important quality attribute, correlating with product flavor and influencing the visual perceptions of consumers and hence potential purchases of the product. Features such as the internal and external appearance contribute to the overall impression of the products quality. Consequently such characteristics have been evaluated by computer vision. Scott (1994) described a system which measures the defects in baked loaves of bread, by analysing its height and slope of the top. The internal structure (crumb grain) of bread and cake was also examined by machine vision (Sapirstein, 1995). Sahi and Alava (2003) investigated the effects of emulsifiers on bubble size in cake batter by using an optical microscope and video camera. Kocer et al. (2007) used image analysis technique to determine the effect of polydextrose-substitution on cake batter structure and found that there were differences among formulations.

Since the heating mechanisms of microwave and conventional heating are different, the porosity and pore size distribution of cakes baked in different ovens are expected to differ. The effects of formulation on pore size distribution of cakes during baking with microwave and microwave assisted ovens have not been studied yet.

1.3.4 Gelatinization

Starch granules are insoluble in water; however, their volume may increase through absorption of water amounting up to 30% of their dry weight. These changes in volume and water absorption are reversible phenomena. If starch granules are heated in an aqueous medium, due to the break of hydrogen bonds in starch granules a transition from an ordered to a disordered structure takes place. Water diffuses into the granule and causes leaching of some amylose molecules into the surrounding water. Gelatinization can be described as a sequence of changes in starch granules upon heating: starch granules first absorb large amounts of water, then swell to many times their original size and finally their starch components are leached. The gelatinization temperature can be defined as the temperature at which the gelatinization occurs (Lund, 1984; McWilliams, 1989; Zallie, 1988).

The gelatinization temperature of starch is greatly influenced by the binding forces within the granule that varies with granule size, ratio of amylose to amylopectin and starch species. Typically, the higher the percentage of amylose and the smaller the granule, the higher the gelatinization temperature (Zallie, 1988).

The major steps of gelatinization and gelation are summarized as hydration and swelling of granules to several times of their original size, loosing the birefringence of the granules, an increment in the clarity of the mixture, a rapid increase in consistency and reaching to a maximum, dissolving and diffusion of linear molecules from ruptured granules and finally upon cooling, formation of a gel or paste-like mass from uniformly dispersed matrix.

Various analytical methods have been used to describe starch gelatinization, e.g. light microscopy (LM), electron microscopy (EM), viscometry, enzymatic analysis (EA), nuclear magnetic resonance (NMR), X-ray crystallography, and thermal analysis (Zobel, 1984). The determination of the degree of starch gelatinization allows the assessment of starch susceptibility to hydrolysis and the relative metabolic response. It also allows understanding and the control of the correctness of the process and the assessment of the influence of the process and product variables. Standardization and optimization of some of the operational conditions of extrusion cooking, and the assessment of cooking time and gelatinization temperature also can be allowed by determination of the degree of gelatinization. Degree of gelatinization can be determined qualitatively and quantitatively by physical, chemical and biochemical methods such as loss of birefringence, increase in viscosity, increase in enzyme susceptibility, decrease in enthalpy, proton magnetic resonance, loss of X-ray diffraction pattern and differential scanning calorimetry (Marconi et al., 2004).

In this thesis, in order to determine gelatinization degree, differential scanning calorimetry and increase in viscosity methods were used. Thermal properties are important in starch and have been a primary area of starch research for many years (Roos, 1995; Whistler et al., 1984). Study of thermal properties can provide guides for processing and utilization of starch and also information for exploring and understanding the structure of starch. Differential scanning calorimetry (DSC) is a powerful tool used to investigate thermal properties and phase transition of starch (Roos, 1995). Endothermal and exothermal changes in a DSC thermograph reveal transitions or reactions occurring during DSC testing, such as glass transition, gelatinization, and melting. DSC thus can directly provide the temperature and enthalpy of transition/reaction, as well as capacities. Analysis of DSC data can provide additional information about starch, such as its structure and composition, its interaction with other components, the effects of water, and related properties.

The Rapid Visco Analyzer (RVA) is a computer-integrated instrument developed to determine the viscous properties of cooked starch, grain, batter and other foods. This instrument continuously measures apparent viscosity under variable conditions of shear and temperature.

Semolina milled from different durum wheat was analyzed for starch pasting properties as measured by the Rapid Visco Analyzer (Sharma et al., 2002). One result of the study was the highly correlation of the semolina swelling power with RVA peak viscosity.

Guler et al. (2002) investigated the effects of industrial pasta drying temperatures on various starch properties and the quality of pasta. Starch properties were examined by Rapid Visco Analyzer, differential scanning calorimeter, X-ray diffractometer and polarized light microscope. Starch from very high temperature dried pasta had greater RVA peak viscosity and breakdown viscosity than hot temperature dried pasta. Both gelatinization enthalpy and peak temperature of high temperature dried pasta were significantly lower than those of very high temperature dried pasta.

Zhong and Sun (2005) aimed to investigate the thermal behavior of corn starch systematically at various hydration levels and large temperature scan ranges, to determine the amount of nonfreezing water and water status as affected by starch gelatinization and water content, and to measure and predict glass transition temperature. They found that phase behavior and thermal properties of corn starch–water were dependent on water content, composition, and gelatinization.

Palav and Seetharaman (2006) investigated the process of gelatinization, granule swelling, and polymer leaching following microwave heating of wheat starch suspensions. The changes during gelatinization were reported as granule swelling due to absorption of moisture in the amorphous regions of the granule, leaching of small molecular weight polymers including amylose, loss of the crystalline order and the consequent loss of birefringence, leaching of larger molecular weight polymers from the granule including fragments of amylopectin and, finally, starch solubilization.These specific changes were believed to occur sequentially and synchronously. They hypothesized that these specific events of starch gelatinization during microwave heating will be different from that observed following conduction modes of heating due to the particular mechanism of heating by microwave energy. They found that the gelatinization process during microwave heating is asynchronous compared to samples heated by using conduction heating.

The gelatinization rates of different types of starches (wheat, corn and rice) were compared during microwave heating (Ndife et al., 1998). It was found that usage of rice and wheat starch in microwave-baked products was advisable where poor starch gelatinization resulting from a short baking time needs to be avoided.

The control of starch gelatinization in cake systems has been emphasized as important in obtaining a noncollapsing, porous cake structure (Kim and Walker, 1992b). One of the most important drawbacks of microwave baking is the insufficient starch gelatinization in microwave baked products. This can be because of the short baking period of microwave system.

1.4 Baking Process

Baking is a complex process that brings about a series of physical, chemical and biochemical changes in food such as gelatinization of starch, denaturation of protein, liberation of carbon dioxide from leavening agents, volume expansion, evaporation of water, crust formation and browning reactions. It can be described as a simultaneous heat and mass transfer within the product and with the environment inside the oven.

There are three main stages of cake baking; batter preparation and the early part of baking, intermediate baking stage, and finally the structure development. In batter preparation and the early part of baking, sugar is beaten into the fat to give an aerated cream. The importance of fat properties, used, is clear. Specific volume of cake is closely related to the entrapped air in the batter. The incorporation of air cells during batter preparation creates final texture of the cake. After preparing the fat sugar cream, the next step is egg addition. The sugar goes into solution and water in oil emulsion is formed, the air cells being dispersed in the fat phase only. Addition of flour results in a change to a multiphase structure. The batter is water continuous but parts of it are still water-in-oil emulsion type. The flour particles are suspended in the aqueous phase of the complete batter (Shepherd and Yoell, 1976). In the early stages of baking the batter, there is little apparent change. However at 37 to 40 °C as the fat in the batter melts, the irregular shaped fat particles roll up into spherical droplets, and any water-in-oil emulsion portions of the batter convert into oil-in-water. Finally the air bubbles are released from the fat phase to the aqueous phase (Shepherd and Yoell, 1976).

The intermediate stage has been defined as the period between the final melting of fat and the beginning of setting up the final structure. The flour particles are still suspended in the continuous aqueous phase, throughout which the fat is dispersed as liquid droplets. During this stage, cake batter can undergo a considerable amount of bulk flow. The air bubbles incorporated in the batter preparation step act as a nuclei for the expansion of total batter by the movement of water vapor and carbon dioxide into air cells (Shepherd and Yoell, 1976).

The third and final stage of cake baking mechanism is the development of cake structure. This is a result of gelatinization of starch and coagulation of proteins in the final stages of baking (Shepherd and Yoell, 1976).

1.4.1 Conventional Baking

During conventional baking heat is transferred, mainly by convection, from the heating media and by radiation from oven walls to the product surface followed by conduction to the center (Sablani et al., 1998). There is also conduction from the product container and convection in the product by the movement of water vapour as the temperature rises. Pei (1982) has classified conventional baking into four baking stages; formation of white crust, heat transmission from crust to interior, gelatinization or cooking process, and browning.

Baik et al. (2000a) characterized the baking conditions inside the baking chamber in two different multi-zone industrial ovens, in order to understand the general industrial cake baking process. They had measured the internal temperature profile, air velocity, absolute humidity and oven wall temperature and estimated heat and mass transfer parameters in each zone of two different tunnel type multi-zone industrial ovens (gas fired band oven and electric powered mold oven). In addition to characterization of baking conditions during industrial cake baking, some important quality parameters, such as texture, color, density and viscosity of the cake batter were evaluated (Baik et al., 2000b).

1.4.2 Microwave and Infrared-Microwave Combination Baking

The use of microwave energy in food industry can offer many advantages such as savings in time and space (Martin and Tsen, 1981). Megahey et al. (2005) investigated the microwave baking characteristics of Maderia cakes and microwave baking was found to allow for up to a 93% reduction in baking time, in comparison with conventional baking. But in case of microwave baking some quality problems like dense or gummy texture, crumb hardness, low volume, lack of surface color, high moisture loss has been reported in the final baked product (Sumnu, 2001). The lack of completion of some physicochemical changes and interactions of major ingredients, which would normally occur over a lengthy baking period in a conventional system, during the short baking period of a microwave system, can be suggested as reasons for these quality problems (Hegenbert, 1992). Other reasons are specific interactions of each component in the formulation with microwave energy (Goebel et al., 1984).

During microwave baking, the product can not experience the browning reactions. This is the biggest difference between convection ovens and microwave ovens. Since the ambient temperature inside the microwave oven is cool, this situation causes surface cooling of microwave-baked products. Maillard browning reactions, which are responsible for the production of many flavored and colored compounds, can not occur due to low surface temperature (Decareau, 1992; Hegenbert, 1992). Brown surfaces, produced by the Maillard reaction and caramelization of sugars, are a result of high temperatures accompanied by dehydration (Burea et al., 1987).

The other reason for the lack of flavor development can be the short microwave baking time, as the flavor compounds may not have the opportunity to develop as they would under conventional baking. It was found that microwave energy causes different flavor components to become completely lost at different rates and in different proportions than occurs during conventional heating through distillation, flavour binding by starches and proteins and chemical degradation. When compared to conventional baking, it was observed that different chemical reactions took place during microwave baking, so different flavors are produced (Hegenbert, 1992). In order to solve these problems one can substitute modified starches by low amylose starches, thus the number of potential binding sites can be eliminated (Osnabrugge, 1989). Special flavours, developed for microwave-baked products, can be used to improve the final taste of the product.

During microwave heating due to relatively larger amounts of interior heating than conventional heating, moisture vapor generation inside the food material increases and this creates significant interior pressure and concentration gradients. This causes higher rate of moisture losses during microwave heating, creating an outward flux of rapidly escaping vapor (Datta, 1990). Breads and cakes baked in microwave oven were shown to lose more moisture as compared to conventionally baked ones (Sumnu et al., 1999; Zincirkiran et al., 2002).

There have been many studies in order to solve the problems observed in microwave baked products and to improve the quality of these products such as microwave-impingement combination heating (Walker et al., 1993) and microwave-hot air combination heating (Lu et al., 1998).

It was found that gluten content was the significant factor in affecting the firmness of microwave baked breads (Ozmutlu et al., 2001a). Breads formulated with low gluten flour were softer and had higher volume as compared to the ones formulated with high gluten flour. Besides, it was found that there was a negative correlation between fat, emulsifier and dextrose contents and weight loss of microwave baked cakes. When proofing was performed in the microwave oven, the time of proofing affected the volume and firmness of microwave baked breads (Ozmutlu et al., 2001b).

Seyhun et al. (2003) investigated the effects of different types of emulsifiers and gums and fat contents on the retardation of staling of microwave baked cakes. It was found that use of emulsifiers and gums helped to retard the staling of microwave baked cakes. It was also concluded that fat content was a significant factor in affecting variation of firmness and weight loss of the cakes during storage.

In order to achieve the brown colour and crisp crust of microwave baked breads, effects of different browning treatments were examined (Sahin et al., 2002). When dough was placed on top of susceptors, desired browning and hardness were obtained at the bottom surfaces of the breads. Susceptors consist of metallized, generally aluminized, biaxially oriented polyester films laminated to paperboard on top of which, or within which, the product is placed (Zuckerman and Miltz, 1997). They have the property of absorbing the microwave energy and converting it to heat, which is transferred to the product by conduction and radiation.

Bell and Steinke (1991) investigated the effects of methylcellulose gums on texture of microwave cakes and it had been found that these gums favored the volume, texture and moisture holding capacity of microwave baked cakes.

Datta and Ni (2002) studied the temperature and moisture profiles for infrared and hot air assisted microwave heating of food using a multiphase porous media transport model. It has been concluded that for foods with small infrared penetration, the large power flux available with infrared heat could reduce moisture and increase surface temperature. Hot air could reduce surface moisture and increase surface temperature, but not as effectively as infrared heat, perhaps due to the lower surface heat flux for hot air as compared to the infrared energy.

Bilgen et al. (2002) investigated the effects of baking parameters on the white layer cake quality baked by combined conventional and microwave ovens. Conventional baking was applied for crust formation and later microwave baking was continued. The performance of combination baking was compared with the performance of conventional baking. They had concluded that using a combination of conventional and microwave baking produced products with quality equivalent to the quality of cakes baked in conventional oven.

Combination of microwaves with near infrared heating is a recent development in microwave baking. The infrared-microwave combination oven combines the browning and crisping advantages of near infrared heating with the time saving advantages of microwave heating. The infrared-microwave combination oven produced by General Electric Company (Louisville, KY, USA) is named as Advantium^{TM} (Figure 1.2). In this oven, halogen lamps are placed on the top and bottom of the oven. Halogen lamps provide near infrared radiation to achieve surface browning and to prevent soggy surface. Halogen lamp heating provides near-infrared radiation and its region in the electromagnetic spectrum is near the visible light with higher frequency and lower penetration depth than the other infrared radiation categories. Its wavelength range is 0.7 μm – 5 μm in the electromagnetic spectrum.

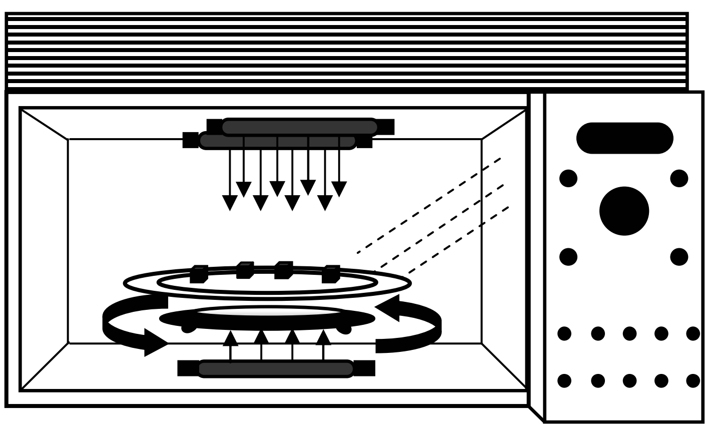


Figure 1.2 Halogen lamp-microwave combination oven

Infrared (IR) radiation is the part of the sun's electromagnetic spectrum that is predominantly responsible for the heating effect of the sun (Ranjan et al., 2002). Infrared radiation is found between the visible light and microwaves (Sepulveda and Barbosa-Canovas, 2003) and can be divided into three different categories, namely, near-infrared radiation (NIR), mid-infrared radiation (MIR) and far-infrared (FIR) radiation (Ranjan et al., 2002).

The infrared source has a high temperature (500-3000°C), and heat transfer by convection is also taking place and can not be ignored. As penetration of this kind of radiation is poor, the heating effect of infrared radiation has an impact only on the surface of the body and heat transfer through the body proceeds by conduction or convection (Sepulveda and Barbosa-Canovas, 2003). The penetration depth of infrared radiation has a strong influence on how much the surface temperature increases or the level of surface moisture that builds up over time. Infrared radiation penetration depths can vary significantly for various food materials. Datta and Ni (2002) showed that as the infrared radiation penetration depth decreases, i.e., as infrared energy is absorbed closer to the surface, the surface temperature increases.

Olsson et al. (2005) investigated the effect of air jet impingement and infrared radiation (alone or in combination) on crust formation of par-baked baguettes during post-baking. They had examined different parameters during the study such as, crust color, crust thickness, total water loss, and heating time. It was found that infrared radiation and jet impingement, as compared with heating in a conventional household oven, increased the rate of color development of the crust and shortened the heating time.

Infrared-microwave combination baking has been recently used in bread baking and it has reduced the conventional baking time of breads by about 75% (Keskin et al., 2004). Specific volume and colour values of breads baked in infrared-microwave combination oven were comparable with that of conventionally baked breads but weight loss and firmness values of those breads were higher. It was found that microwave baked breads had higher specific volume as compared to others. Microwave heating was found to be the dominant mechanism in infrared-microwave combination baking in terms of affecting weight loss and texture development. The authors recommended the infrared–microwave combination oven to solve especially the crust color problem of microwave baked breads. They emphasized that baking breads by using only halogen lamp mode of the oven was not advisable because of the formation of the very thick bread crust.

Demirekler et al. (2004) optimized the baking conditions of bread in an infrared-microwave combination oven by reducing the conventional baking time of breads by 60 %. It was found that the breads baked at optimum condition had comparable quality with the conventionally baked ones.

The processing conditions during infrared-microwave baking of cake were optimized by using Response Surface Methodology (Sevimli et al.,2005). The upper halogen lamp power, the microwave power, and the baking time were found to have significant effects on the weight loss, the specific volume, and the firmness of the cakes. Cakes baked for 5 min at 60% upper halogen lamp power, 70% lower halogen lamp power, and 30% microwave power had quality comparable with conventionally baked ones, except for color. However, in literature, the interaction of different cake formulations with microwave and infrared has not been investigated yet.

1.5 Aim of the Study

Due to the short processing times, and specific interaction of food components with microwaves, quality problems in microwave baked products can be observed. In order to overcome these problems; infrared-microwave combination oven can be used with its advantage of combining time and energy saving properties of microwave baking with browning and crisping properties of halogen lamps.

The studies on infrared-microwave combination baking are limited in literature. It is believed that there is a specific interaction between food components and the microwaves but how the cake components affect the quality of cakes in infrared-microwave combination heating is still unknown. Therefore, it is important to investigate the effects of fat content, fat replacer type and emulsifier type on quality of cakes baked in microwave and infrared-microwave combination oven.

The major objective of the study was to determine the variation of physical properties of different cake formulations during baking in microwave and infrared-microwave combination ovens.

Dielectric properties can be used to understand food materials behavior during microwave processing. These properties influence the level of interaction between food and high frequency electromagnetic energy. Dielectric properties are, therefore, important in the design of foods intended for microwave preparation. In this study, the effects of different formulations, frequency, and temperature on dielectric properties of cake batters were investigated.

Another objective of this study was to determine the effects of different formulations on the rheological properties of cake batter, to correlate them with the product quality and to develop rheological models. Another scope of the thesis was to determine the effects of different formulations on color, texture profile, volume, porosity, pore size and microstructures of cakes baked in different ovens.

It is believed that one of the most important drawbacks of microwave baking is the insufficient starch gelatinization in baked products but there is limited study in the literature about this subject. Therefore, in our study it was also aimed to determine starch gelatinization in the cakes baked in infrared-microwave combination oven and to compare this with the cakes baked in microwave and conventional ovens.

CHAPTER 2

MATERIALS AND METHODS

2.1 Materials

Commercially available cake flour containing 27% wet gluten, 0.65% ash and 13.5% moisture was obtained from Ankara Un A.Ş., (Ankara, Turkey). Sugar, non-fat dry milk, cake shortening, salt and baking powder were bought from a local market. Egg white powder was procured from Kitchen Crafts, Inc. (USA). Purawave^{TM}, which is composed of lecithin, soy protein, mono-di glycerides, and vegetable gums, was obtained from Puratos (Groot-Bijgaarden, Belgium), and Lecigran^{TM}, which is composed of oil-free soybean lecithin, wheat flour and hydrogenated vegetable oil, was provided by Cargill (Minneapolis, USA). Maltodextrin, a starch hydrolysis product of less than 20 DE, was purchased from Sigma chemical supply company (Taufkirchen, Germany). Simplesse^{TM}, which is mainly whey protein, was provided by Cp Kelco (Atlanta, USA).

2.2 Methods

2.2.1 Preparation of Cake Batter

A standard white layer cake batter recipe containing 100% cake flour, 100% sugar, 12% non-fat dry milk, 9% egg white powder, 3% salt, 5% baking powder and 90% water (all percentages were given in flour weight basis) was used in the experiments. In order to investigate the effect of fat and fat replacer, fat, maltodextrin or Simplesse^{TM} were added at a concentration of 25%. Emulsifier, Purawave^{TM} or Lecigran^{TM} was added at a concentration of 3%. Purawave^{TM} and Lecigran^{TM} are known as the emulsifiers that improve the quality of microwave baked products. Lecithin containing emulsifiers have been previously added to microwave cake and bread formulation to improve product quality (Seyhun et al., 2003; Ozmutlu et al., 2001a). Control cake formulation contained no fat, fat replacer or emulsifier.

All dry ingredients were mixed as a first step in preparation of the cake batter. Then, melted fat was added to the previously mixed sugar and egg white and mixed with a laboratory mixer/blender for 1 min at low speed (85 rpm) (Toastmaster, 1776CAN, China). All other dry ingredients and water were added and mixed for 1 min at low speed (85 rpm), 1 min at medium speed (140 rpm), and 2 additional minutes at low speed (85 rpm).

2.2.2 Determination of Power of the Microwave Oven

The power of the microwave oven was determined by IMPI (International Microwave Power Institute) 2-L test (Buffler, 1993). The oven was operated at the highest power with a load of 2000 ± 5 g water placed in two 1-L Pyrex beakers. Initial temperature of water should be 20°C ± 2°C. The beakers were placed in the center of the oven, side by side in the width dimension of the cavity, and touching each other. The oven was turned on for 2 min and 2 s. Final temperatures were measured immediately after the oven was turned off, and recorded.

The power was calculated by using Equation 2.1.

$$P(W) = \frac{70(\Delta T_1 + \Delta T_2)}{2} \tag{2.1}$$

where ΔT_1 and ΔT_2 are the temperature rises of the water in the two beakers calculated by subtracting the initial water temperature from the final temperature (Buffler, 1993).

The power measurement was done three times and the oven power was reported as the average of the three readings.

2.2.3 Baking

Both microwave baking and infrared-microwave combination baking were performed by using Advantium™ oven (General Electric Company, Louisville, KY, USA). The cavity size of Advantium™ oven was 21 cm in height, 48 cm in length and 33 cm in width. For microwave baking only microwave power was operated. The microwave power of microwave oven has been determined as 706 W by using IMPI 2-liter test (Buffler, 1993). In preliminary experiments, microwave oven powers of 50%, 80% and 100% were employed and different processing times of 120, 135, 150, 165 and 180 seconds for 50% power, 105, 120, 135 and 150 seconds for 80% power and 90, 105, 120 and 135 seconds for 100% power were used. Experiments were continued at one microwave power, 50% and the cakes were baked for 120, 135, 150, 165 and 180 seconds. For the infrared-microwave combination baking, the power levels of the upper (1500 W) and lower (1500 W) halogen lamps (IR source) were adjusted to 60%, and the microwave power of 50% were used. Cakes were baked for 210, 240, 270, 300 and 330 seconds. In order to provide the required humidity during baking in combination oven, two 600 ml beakers containing 400 ml of water were placed at the back corners of the oven. For conventional baking conventional oven (Arcelik, Istanbul, Turkey) were used. The cakes were baked for 22, 24, 26 and 28 minutes at 175 °C. One cake (100 g) was placed at a time in the oven during baking process.

2.2.4 Analysis

Rheological properties were measured for cake batter. Dielectric property measurements were done in both cake batter and baked cake samples. In addition to dielectric properties, other physical properties like specific volume, texture profile (hardness, gumminess, cohesiveness, and springiness), porosity, pore size, and color were also determined in baked cakes. Moreover, weight loss, gelatinization degree, temperature distribution and microstructure of cakes were determined.

2.2.4.1 Rheological Analysis

For rheological analysis, five different fat contents were employed as 0%, 12.5%, 25%, 37.5% and 50%. Rheological measurements were made at 25°C by using a parallel plate rotational viscometer (Haake Model CV20, Germany). For each test, the sample placed within a 1 mm gap was sheared at a programmed rate linearly increasing from 0-200 s^{-1} in 5 min. Viscosity-shear rate and shear stress-shear rate data were collected continuously throughout the test. For determination of the time dependency, the sample was sheared at a constant rate of 100 s^{-1} for 5 min. Viscosity-time data were collected continuously throughout the test. Five replications were used for all batter formulations.

2.2.4.2 Specific Volume

Cake specific volume was determined by the rape seed displacement method (AACC, 1990). Equations (2.2), (2.3), and (2.4) were used to calculate the volume of cakes.

$$W_{seeds} = W_{total} - W_{cake} - W_{container} \quad (2.2)$$

$$V_{seeds} = W_{seeds} / \rho_{seeds} \quad (2.3)$$

$$V_{cake} = V_{container} - V_{seeds} \quad (2.4)$$

Specific volume of cakes were calculated by using equation (2.5),

$$SV_{cake} = V_{cake} / W_{cake} \quad (2.5)$$

where W (kg) is weight, V (m^3) is volume, ρ (kg/m^3) is density and SV (m^3/kg) is the specific volume.

2.2.4.3 Volume Index

Volume index of the cake was determined by using AACC template method 10-91 (AACC, 1990), but this chart was modified with respect to the cake diameter used in this study (8 cm).

2.2.4.4 Texture Measurement

Texture analyzer (Lloyd Ins., UK) was used for determination of the hardness, gumminess, cohesiveness and springiness of the cake samples. The cake samples (width of 20 mm, length of 30 mm and height of 15 mm) were compressed by 25% of its initial height under the influence of a load cell of 50 N force. A cylindrical probe having a diameter of 1.27 cm was used during measurements. The data were reported as the average of six replicates.

2.2.4.5 Porosity Measurement

Compaction method was used to determine the porosity of cake samples. Sample is placed in cylindrical container of diameter 4.7 cm. Initial height of the sample was recorded and it was pressed under 24 kg load for 2 minutes. The height of sample after pressing was also recorded. Assuming that all the pores within the sample were compressed, porosity was calculated from equation 2.6.

$$Porosity(\%) = \frac{H_i - H_f}{H_i} \times 100 \qquad (2.6)$$

where H_i was initial height of the sample and H_f was final height of the sample. The data were reported as the average of two replicates (Zanoni et al., 1995).

2.2.4.6 Color Measurement

The surface color of cakes was determined by using Minolta Color Reader (CR-10 Japan). CIE L^*, a^*, b^* color values were recorded. Colour change (ΔE value) was calculated by using the formula given below:

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

Barium sulphate (white color) was used as the reference point, whose L^*, a^*, b^* values were denoted by L^*_o, a^*_o and b^*_o.

2.2.4.7 Weight Loss

Weight loss during baking was calculated by using the following equation:

$$Weightloss(\%) = \frac{W_i - W_f}{W_i} \times 100 \quad (2.8)$$

where W_i is the weight of the batter before it is placed into the oven and W_f is the weight of the baked cake immediately after it is removed from the oven.

2.2.4.8 Measurement of Dielectric Properties

Dielectric probe and a HP 8510B Network analyzer Hewlett-Packard, HP 8341B Synthesized Sweeper (10 MHz-20 GHz) and HP 8515 A Parameter test set 45 MHz-2.5 GHz (California, USA) were used to determine the dielectric properties (dielectric constant and dielectric loss factor) at a frequency range of 500MHz -5GHz. The dielectric probe was calibrated by water and air measurements. Using dielectric properties and equation (1.5) the penetration depth was calculated. The results were analyzed by using the software called 85070C software package version C1-02 Agilent technologies. For the baked cake samples, the measurements were performed at room temperature (23°C). For cake batter, the measurements were done at a temperature range of 23-90°C. The temperatures were recorded by Omega Scientific, Inc. Model 383 digital temperature tester (Connecticut, USA). The data were reported as the average of three replicates.

2.2.4.9 Determination of Cumulative Pore Area Fraction

Baked cake samples were cut vertically into two halves. The image of the cut sample was taken by using a digital camera (Sony DSC-F828 Cyber-shot, Tokyo, Japan). The images were analyzed by using the software Image J (Image Processing and Analysis in Java) that uses the contrast between the two phases (pores and solid part) in the image (Datta et al., 2007). The color image was first converted to gray scale. Using bars of known lengths, pixel values were converted into distance units. The largest possible rectangular cross section of the cake halves was cropped. After adjusting the threshold, area based pore size distribution and pore area as percent of total area were determined by using the software.

2.2.4.10 Determination of Microstructure

The baked samples were frozen immediately. The frozen samples were freeze dried at -40ºC for 48 hours by using Labconco freeze dry system/freezone 4.5 (Kansas city, Missouri, USA). The freeze dried and ground cake samples were coated with gold (Edward Sputter Coater Model S150B) and examined with the Phillips Scanning Electron Microscope (SEM 505, Phillips, Holland Electrons Optics, Eindhoven, Netherland) which was operated with 30.0 kV and the magnification was adjusted to 5.73E2 for all samples.

2.2.4.11 Determination of Gelatinization Degree

The baked samples were frozen immediately. They were freeze dried at -40ºC for 48 hours by using Labconco freeze dry system/freezone 4.5 (Kansas city, Missouri, USA). They were ground and sieved by 212 micron sieves. For gelatinization measurements DSC Refrigerated Cooling System TA instruments 2010 (Chicago, USA) and rapid visco analyzer, model RVA-4 (Newport Scientific, Australia) were used.

For DSC analysis, samples (10 mg), with 1:1 solid water proportion, were weighed in aluminum DSC pans and hermetically sealed. The samples were heated from 30 to 150°C with a heating rate of 10°C/min. For data analysis, the software called Thermal Advantage Version 1.1 A was used. Endothermic peak area and gelatinization temperature were recorded. The endothermic peak obtained by heating cake batter in DSC was considered as the enthalpy required for complete gelatinization of the starch in the sample. Gelatinization degree in the processed samples was calculated by using the following equation (Ndife et al.1998):

$$\text{Gelatinization degree } (\%) = \left(1 - \frac{\Delta H_{PS}}{\Delta H_{CB}}\right) \times 100 \qquad (2.9)$$

where ΔH_{PS} is the enthalpy of processed sample and ΔH_{CB} is the enthalpy of cake batter.

For RVA analysis, the freeze dried and ground samples were primarily defatted by soxhlet extraction method. By taking the moisture content of the sample into consideration the amount of water to be added to the sample was calculated. The total amount of the samples with water was 29 g. The heating and cooling cycles were programmed in the following manner: the sample was held at 50 °C for 1 min, heated to 95 °C within 3.5 min and then held at 95°C for 2.5 min. It was subsequently cooled to 50°C within 3.5 min and then held at 50°C for 2 min. For data analysis, the software called Termocline for Windows, version 2.0 was used.

2.2.4.12 Measurement of Temperature Distribution

The temperature near the center of the samples was determined by using fiber optic probes and FISO FTI-10 fiber-optic signal conditioner (Quebec, Canada). The temperature data were taken from the center of the cake in r direction and from approximately 5 cm below the top surface of the cake in z direction. The temperature data were recorded by using a software called FISO.

2.2.4.13 Data Analysis

The physical properties, color, texture, specific volume, volume index and porosity were compared in terms of formulation and baking time by using two-way ANOVA and Tukey Simultaneous Test ($p \leq 0.05$). Multiple regression was used to model the effects of weight loss and porosity during baking on dielectric properties. Rheological properties of batter were correlated with product quality.

CHAPTER 3

RESULTS AND DISCUSSION

3.1 Preliminary Experiments on Microwave Baking

As preliminary experiments, in order to decide which microwave power level to use during the rest of the study, three microwave power levels were tested as 50%, 80% and 100%. Non-fat and 25% fat containing cake samples were baked in microwave oven at three different powers and for different times. Weight loss, specific volume and hardness of cakes baked at different conditions were measured (Table 3.1). Microwave power of 50% was chosen for the rest of the study since lower weight loss and hardness values were obtained at this power level for both formulations.

From preliminary experiments it was found that formulation, baking time and microwave power were all effective on weight loss, specific volume and hardness of cakes. It was found that for both formulations, an increase in baking time increased the weight loss and the hardness values. For non-fat samples, the specific volume of the microwave baked cakes increased during baking at all power levels. Increasing power level increased the weight loss, hardness and specific volume of samples.

Table 3.1 Variation of weight loss (WL) (%), specific volume (SV) (ml/g) and hardness (H) (kgf) values of cakes with different formulations during microwave baking.

		Cakes containing no fat			Cakes containing 25% fat		
Time (min)	Power (%)	WL (%)	SV (ml/g)	H (kgf)	WL (%)	SV (ml/g)	H (kgf)
2.00	50	4.48	1.82	0.08	4.75	2.05	0.06
2.25		5.05	1.85	0.08	6.13	2.14	0.05
2.50		8.08	1.86	0.14	7.81	1.88	0.09
2.75		8.98	2.07	0.16	9.00	1.67	0.09
3.00		11.79	1.99	0.22	11.6	1.79	0.09
1.75	80	11.39	2.70	0.06	10.1	2.63	0.15
2.00		13.81	3.35	0.08	13.63	2.76	0.35
2.25		14.48	3.39	0.31	15.59	3.11	0.41
2.50		16.86	3.24	0.49	18.53	3.17	0.72
1.50	100	11.89	2.22	0.06	11.32	2.98	0.15
1.75		13.48	2.36	0.11	15.38	2.75	0.23
2.00		18.56	2.76	0.22	16.48	2.69	0.32
2.25		22.55	2.77	1.43	20.88	2.86	1.09

3.2 Rheology of Cake Batter

The determination of rheological properties of cake batter is essential because they give useful information related to the quality of baked cakes.Decrease in apparent viscosity with applied shear rate was observed for cake batters containing different amounts of fat (Figure 3.1). This trend was also observed for samples containing emulsifiers, Purawave^{TM} or Lecigran^{TM} (Figure 3.2 and 3.3). Fat content had a significant influence on the apparent viscosity of the cake batter. Although there is no systematic effect at low shear rates, after a certain shear rate (>50 s^{-1}) increasing fat content mostly resulted in a decrease in viscosity. The influence of fat content on viscosity became dominant after a certain shear rate. This could be explained by adaptation. For rheological measurements, the first few data can be misleading because the torque values measured for small strain rates were at the lower end capability of the torque measuring device. In a cake system fat serves to entrap air during the creaming process. As fat content increases, the amount of air entrapped in the structure of cake batter increases, which causes a decrease in viscosity. Addition of oil was shown to reduce viscosity of wheat flour batter (Prakash et al., 2001). This was explained by the lubrication effect of uniformly dispersed fat particles.

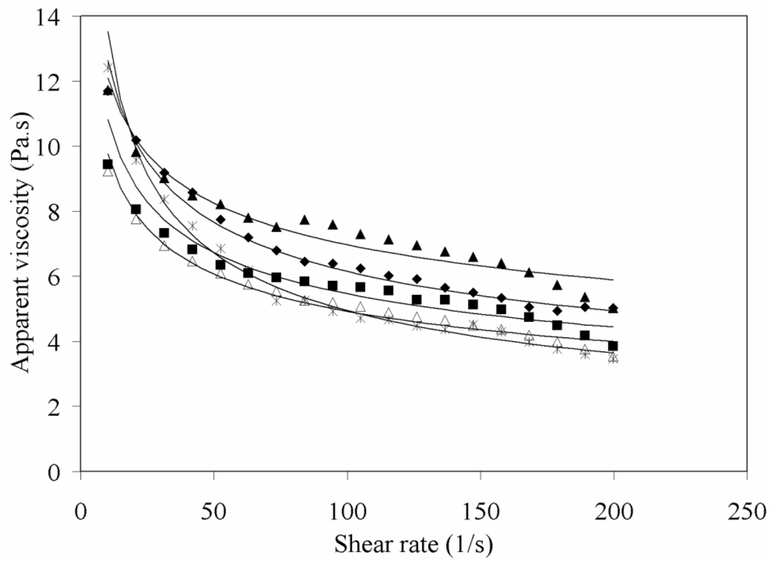


Figure 3.1 Effects of fat content on apparent viscosity of cake batter containing no emulsifier

♦ 0% fat, ■ 12.5% fat, ▲25% fat, Δ 37.5% fat, * 50% fat, ─ Power-law model

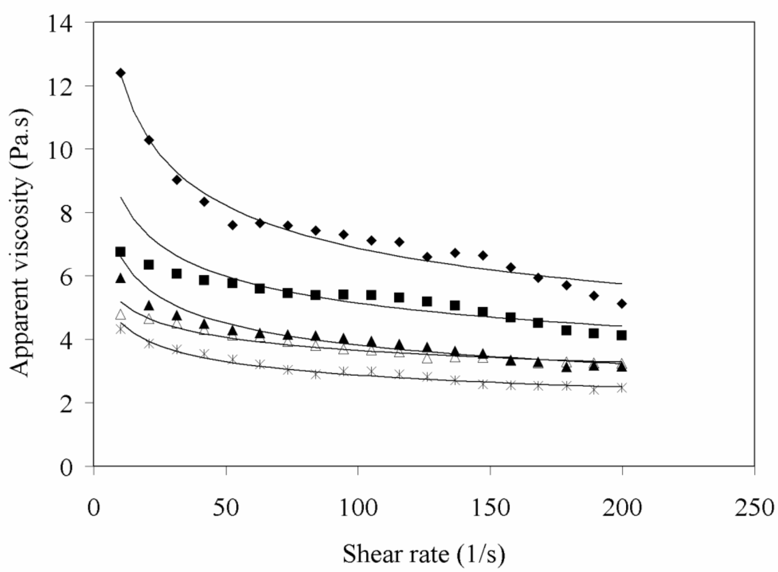


Figure 3.2 Effects of fat content on apparent viscosity of cake batter containing Purawave^{TM}

♦ 0% fat, ■ 12.5% fat, ▲25% fat, Δ 37.5% fat, * 50% fat, ─ Power-law model

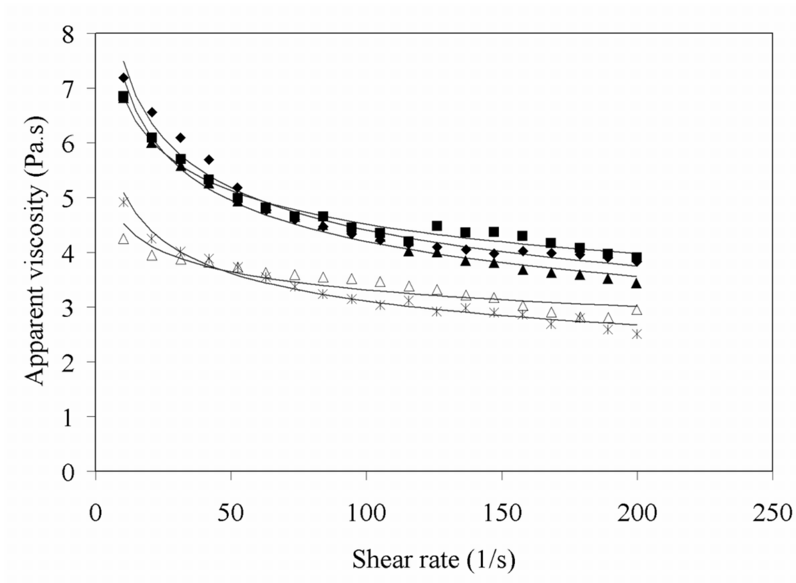


Figure 3.3 Effects of fat content on apparent viscosity of cake batter containing Lecigran™

♦ 0% fat, ■ 12.5% fat, ▲25% fat, Δ 37.5% fat, * 50% fat, ─ Power-law model

When emulsifier, Purawave™ or Lecigran™ was added to the cake formulation, a considerable decrease in apparent viscosity was observed in the case of 12.5% fat containing cake batters (Figure 3.4). The same trend can be observed in other fat contents too (Figure 3.5-3.7). Emulsifier aids in the incorporation of air and disperses the shortening into smaller particles. The decrement of viscosity caused by emulsifier addition may be due to the increase in air entrapment in cake batter. For cake formulations containing 12.5% fat, addition of Purawave™ resulted in higher apparent viscosity as compared to the Lecigran™ (Figure 3.4). Samples containing Lecigran™ might have higher air incorporation than Purawave™ containing samples, which resulted in lower viscosity. However, for higher fat concentrations no significant difference was determined between Purawave™ and Lecigran™ in affecting the viscosity

(Figure 3.5-3.7). The level of fat was important for an emulsifier to function and there was an optimum fat content for different emulsifier types.

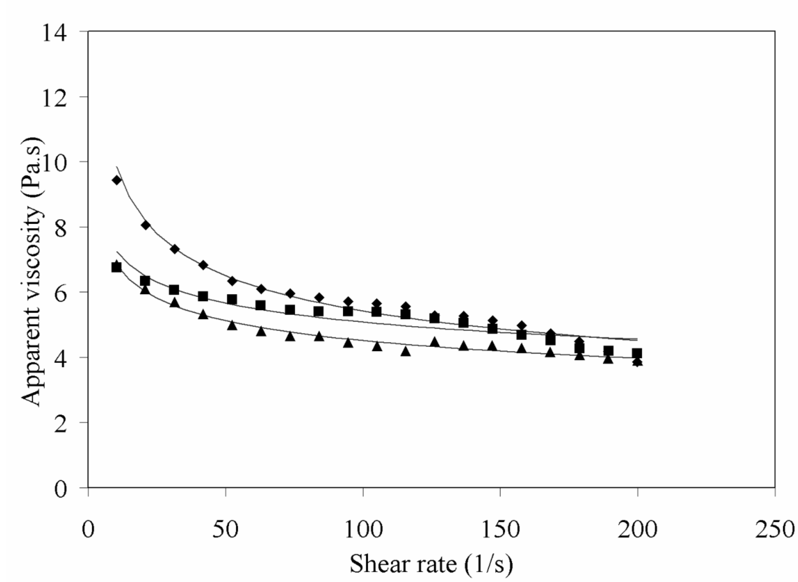


Figure 3.4 Effects of emulsifiers on apparent viscosity of cake batter containing 12.5% fat content

♦ No emulsifier, ■ Purawave™, ▲Lecigran™, ─ Power-law model

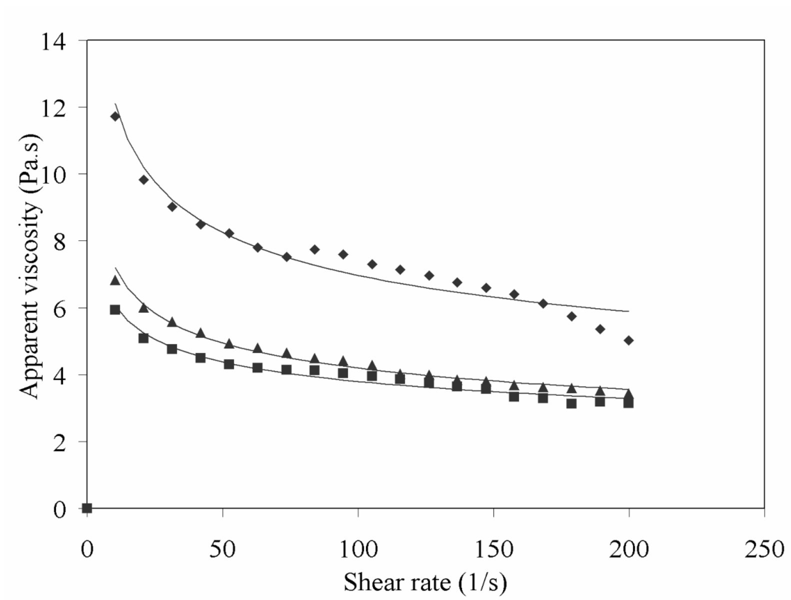


Figure 3.5 Effects of emulsifiers on apparent viscosity of cake batter containing 25% fat content

♦ No emulsifier, ■ Purawave™, ▲Lecigran™, — Power-law model

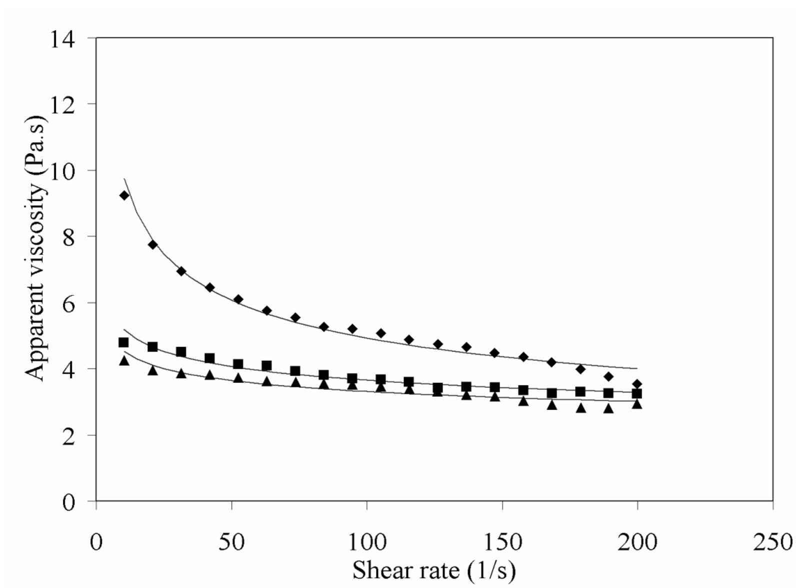


Figure 3.6 Effects of emulsifiers on apparent viscosity of cake batter containing 37.5% fat content

♦ No emulsifier, ■ Purawave™, ▲Lecigran™, — Power-law model

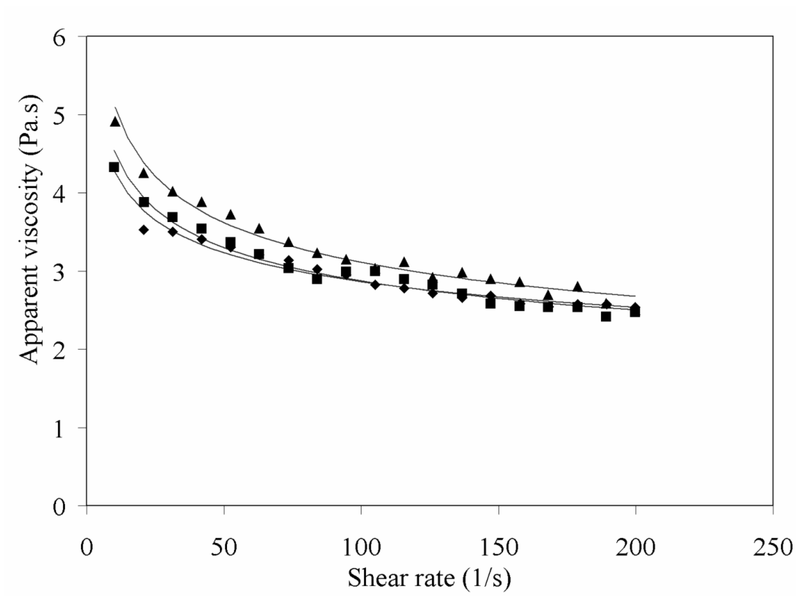


Figure 3.7 Effects of emulsifiers on apparent viscosity of cake batter containing 50% fat content

♦ No emulsifier, ■ Purawave™, ▲Lecigran™, ─ Power-law model

When the apparent viscosity of samples containing fat replacers was compared with non-fat samples it was seen that addition of fat replacer to the formulation decreased the apparent viscosity of the cake batter (Figure 3.8). This may be because of the increment of the capacity of the batter to hold air inside the structure. Due to this higher air entrapped structure of fat replacer added batter samples, highly voluminous and highly porous cake product could be baked. When viscosity of 25% fat added samples (8.4 Pa.s) was compared with viscosity of fat replacer added samples at shear rate of 50 s^{-1}, it can be concluded that Simplesse™ (6.5 Pa.s) and maltodextrin (7.6 Pa.s) added samples had lower apparent viscosity values (Figure 3.8 and 3.5).

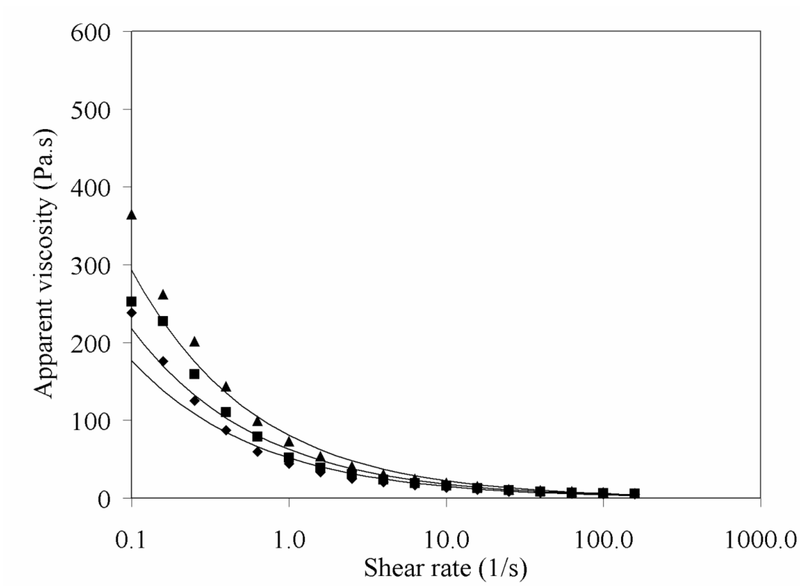


Figure 3.8 Effects of fat replacers on apparent viscosity of non-fat cake batter
♦ No fat, ■ Maltodextrin, ▲Simplesse™, — Power-law model

Experimental data provided a good fit ($r^2 \geq 0.990$) for the power law model;

$$\tau = K.\dot{\gamma}^n \tag{3.1}$$

where K and n are the consistency index and the flow behavior index, respectively. Flow behavior index provides us the information whether the flow is shear thinning or shear thickening. If n=1, the model reflects Newtonian behavior. The parameters K and n for different cake formulations are shown in Table 3.2. Since for all cake formulations n values were less than 1, it can be concluded that the cake batter was shear thinning (Table 3.2). Emulsifier addition led to a significant decrease in consistency index except for the highest fat content. This could be explained by the ability of the emulsifiers to increase level of air incorporation. Swami et al. (2004) showed that consistency index of black gram batter decreased with the increase in level of air incorporation.

Statistical analysis showed that there was no significant effect of formulation on flow behavior index (Table D.1). Similar results were also observed in literature. The flow behavior index was reported to be generally independent of the formulation (Ilicali, 1985). No significant differences were observed in flow behavior indices of different formulations of rice flour based batters (Mukprasirt et al., 2000). Dextrin addition to batters for fried foods did not produce a significant decrease or increase in flow behaviour index values (Baixauli et al., 2003).

Fig 3.9 shows the effects of fat content and emulsifier type on the consistency index of cake batter. As can be seen in the figure emulsifier type and fat content were significant factors on affecting the consistency index. In the presence of emulsifiers, consistency index decreased exponentially with fat content. However, variation of consistency index with fat content followed third order model when there is no emulsifier. For cake formulations containing 0-25% of fat, addition of Purawave^{TM} resulted in higher consistency index (Fig 3.9). Samples containing Lecigran^{TM} might have higher air incorporation than Purawave^{TM} containing samples, which resulted in lower viscosity. However, for higher fat concentrations no difference was determined between Purawave^{TM} and Lecigran^{TM} in affecting the viscosity. The level of fat was important for an emulsifier to function and there was an optimum fat content for different emulsifier types. In the absence of emulsifiers there was a steep decrease in consistency index when fat content exceeded 37.5%. This shows that at high fat contents, there is no need to use emulsifier.

Table 3.2 Rheological parameters of power law model describing flow curves of cake batter having different formulations

Fat content (%)	Emulsifier type Purawave™	Lecigran™	n	K (Pa.s^n)	r^2
0.0	0	0	0.68	26.36	0.995
0.0	3	0	0.74	22.49	0.993
0.0	0	3	0.77	12.87	0.998
12.5	0	0	0.74	18.17	0.992
12.5	3	0	0.84	10.45	0.994
12.5	0	3	0.82	10.47	0.999
25.0	0	0	0.76	21.28	0.990
25.0	3	0	0.79	9.80	0.997
25.0	0	3	0.76	12.50	0.998
37.5	0	0	0.70	19.67	0.994
37.5	3	0	0.85	7.42	0.998
37.5	0	3	0.86	6.23	0.996
50.0	0	0	0.88	5.00	0.998
50.0	3	0	0.80	7.21	0.998
50.0	0	3	0.78	8.49	0.998

The time dependency of the cake batter was examined for some selected formulations. In order to understand the effect of fat, three fat levels were selected as 0%, 25% and 50% and in order to understand the effect of emulsifier, Purawave™ and Lecigran™ was added to 25% fat containing formulation. The variation of apparent viscosity of cake batter with different formulations as a function of time was given in Figures 3.10 - 3.14.

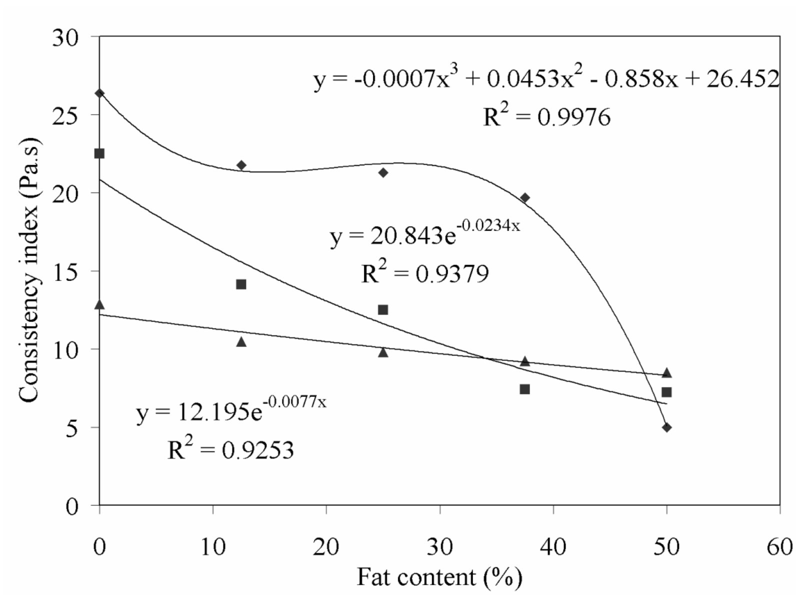


Figure 3.9 Effects of fat content and emulsifier types on consistency index

♦ No emulsifier, ■ Purawave™, ▲Lecigran™

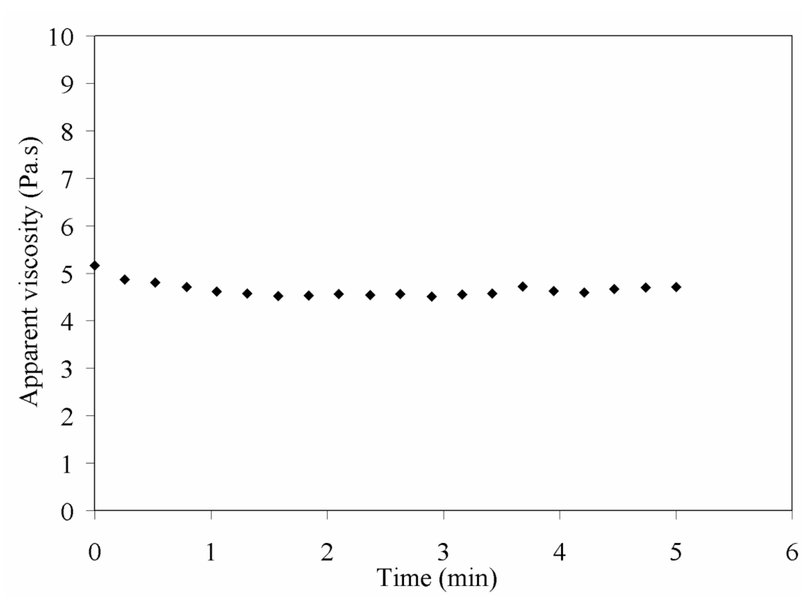


Figure 3.10 Time dependency of cake batter containing 0% fat and no emulsifier

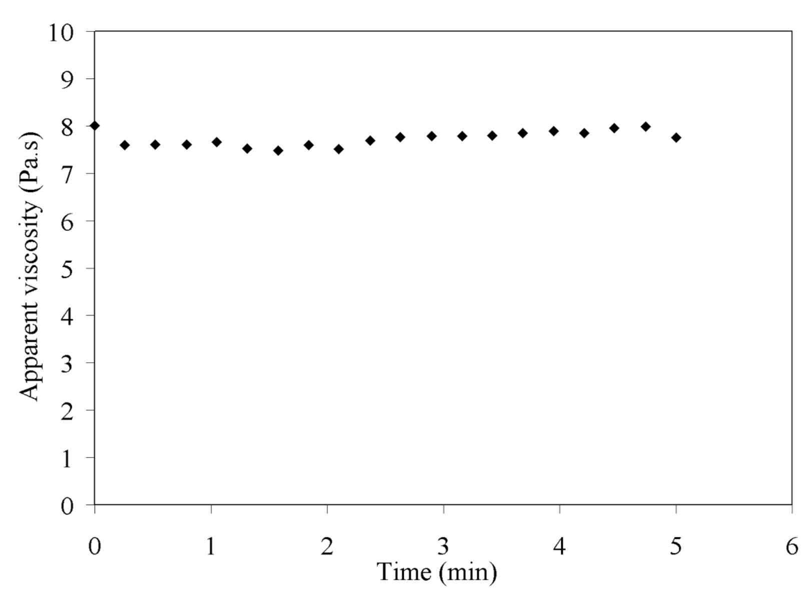


Figure 3.11 Time dependency of cake batter containing 25% fat and no emulsifier

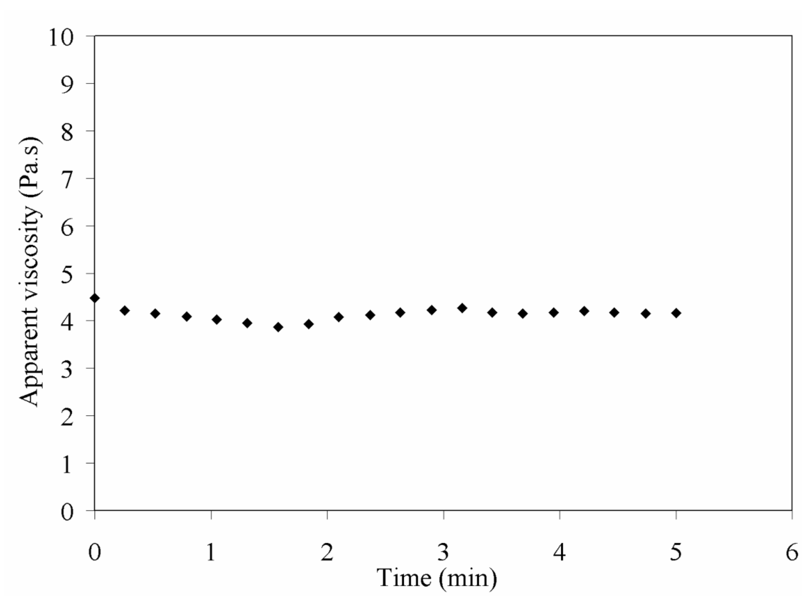


Figure 3.12 Time dependency of cake batter containing 50% fat but no emulsifier

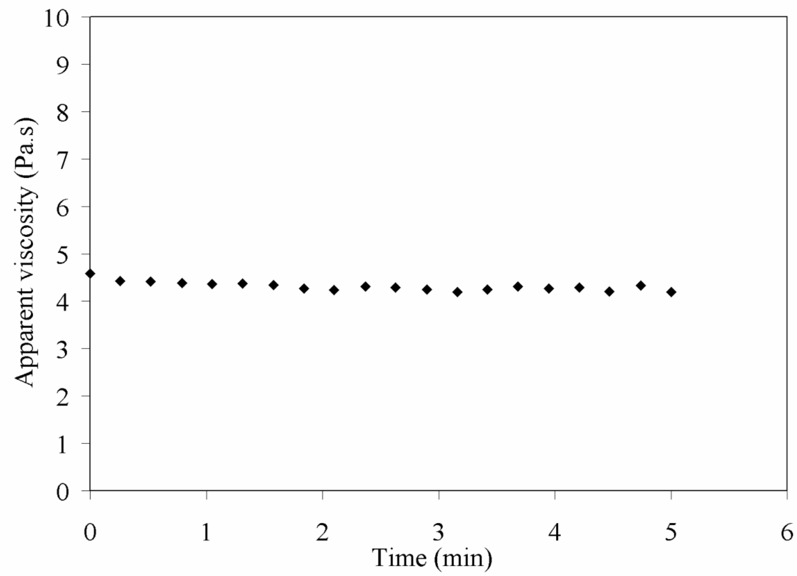


Figure 3.13 Time dependency of cake batter containing 50% fat and 3% Purawave^{TM}

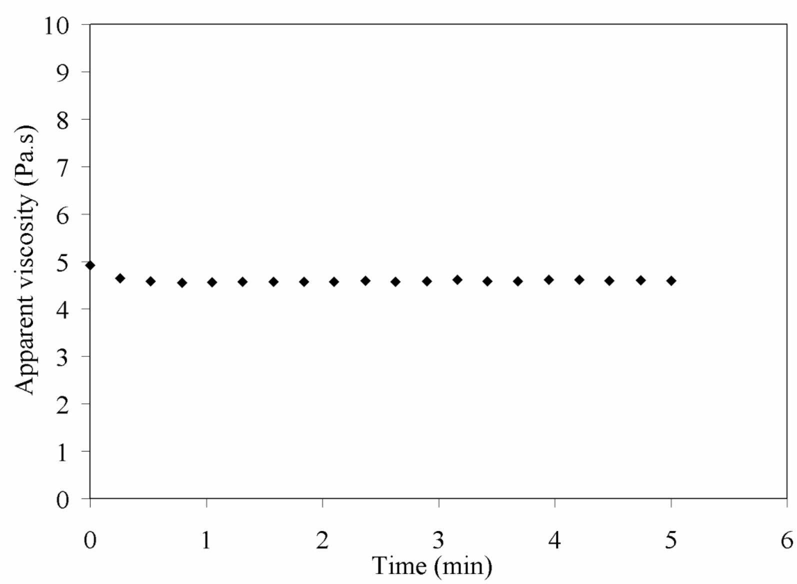


Figure 3.14 Time dependency of cake batter containing 50% fat and 3% Lecigran^{TM}

It can be seen that for all formulations apparent viscosity was almost constant for constant shear rate of 100 s^{-1} with respect to time, meaning that the flow was time-independent. As a result, it can be concluded that cake batter showed a time-independent shear thinning behaviour.

3.3 Physical Properties of Cakes

As physical properties, specific volume, volume index, texture profile, porosity, color and dielectric properties of the cakes baked in microwave and infrared-microwave combination oven were determined. In addition, the effects of fat content, emulsifier type and fat replacer type on the physical properties of cakes were studied.

3.3.1 Specific Volume of Cakes

Variation of fat content did not affect volume of cakes baked in microwave oven significantly (Figure 3.15, Table D.2). The addition of emulsifier increased the specific volume of samples. This may be explained by the positive effect of emulsifier on the incorporation of the air to the cake batter thus producing a cake that expands readily. While the addition of maltodextrin did not have an effect on specific volume of samples when compared with non-fat and 25% fat containing ones, the addition of Simplesse™ extremely increased the volume of the samples (Figure 3.15). This can be explained by the higher amount of air entrapment in cake batters when Simplesse™ was used because of its emulsion forming property due to protein structure. When the specific volume of cakes baked in infrared-microwave combination oven was examined, it was found that the cakes containing no fat had the highest specific volume values (Figure 3.16). Volume expansion of the cakes was negatively correlated with the fat content. On the other hand, volume expansion was correlated positively with emulsifier content for both types of emulsifier. This may be explained by the positive effect of emulsifier on the incorporation of the air to the cake batter thus producing a cake that expands readily. When the effects of fat replacers, maltodextrin and Simplesse^{TM}, were investigated, it was found that addition of each fat replacer resulted in samples with higher volume than the samples containing fat (Figure 3.16). For the cakes baked in conventional oven, it was observed that fat addition ended up with lower specific volume (Figure 3.17). Cakes baked in microwave oven had the lowest specific volume compared to other baking types (Figure 3.15, 3.16 and 3.17). This can be explained by failure of starch to reach its set point during the microwave baking period. Similarly, Li and Walker (1996) showed that cakes baked by microwave had lower volume than conventionally baked cakes.

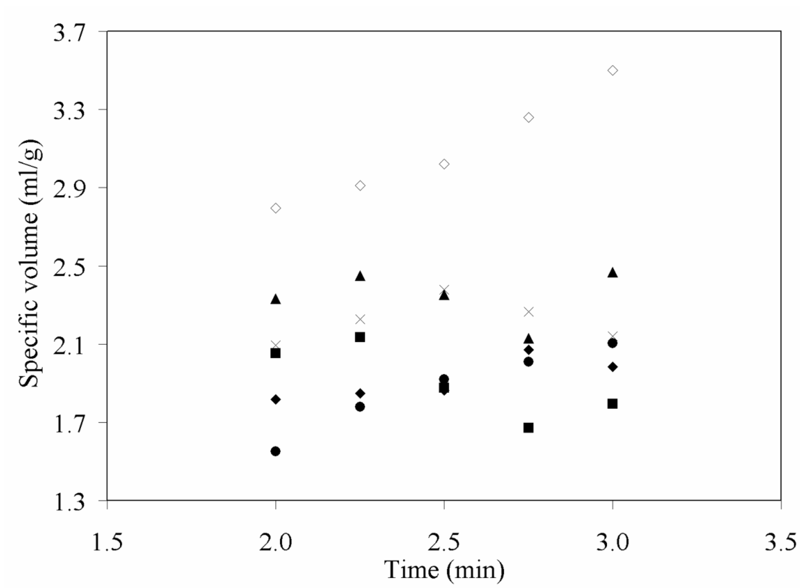


Figure 3.15 Variation of specific volume with baking time for cakes with different formulations baked in microwave oven

♦ (0% F-0% P-0% L)[c], ■ (25% F-0% P-0% L)[c], ▲(25% F-3% P-0% L)[b], x (25% F-0% P-3% L)[bc], • (25% M-0% P-0% L)[c], ◊ (25% S-0% P-0% L)[a] (F: Fat, P: Purawave™, L: Lecigran™, M: Maltodextrin, S: Simplesse™)

Formulations with different letters (a,b,i.e) are significantly different ($p \leq 0.05$).

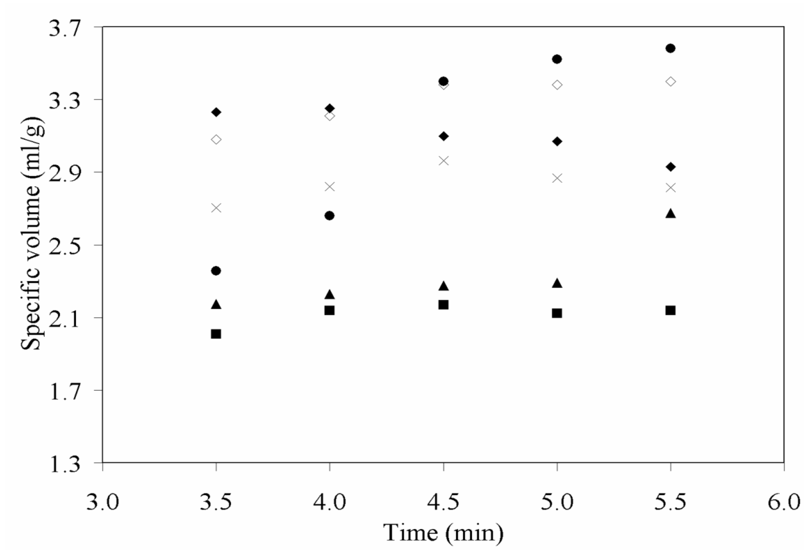


Figure 3.16 Variation of specific volume with baking time for cakes with different formulations baked in infrared-microwave combination oven

♦ (0% F-0% P-0% L)[a], ■ (25% F-0% P-0% L)[b], ▲(25% F-3% P-0% L)[b], x (25% F-0% P-3% L)[a], ● (25% M-0% P-0% L)[a], ◊ (25% S-0% P-0% L)[a]

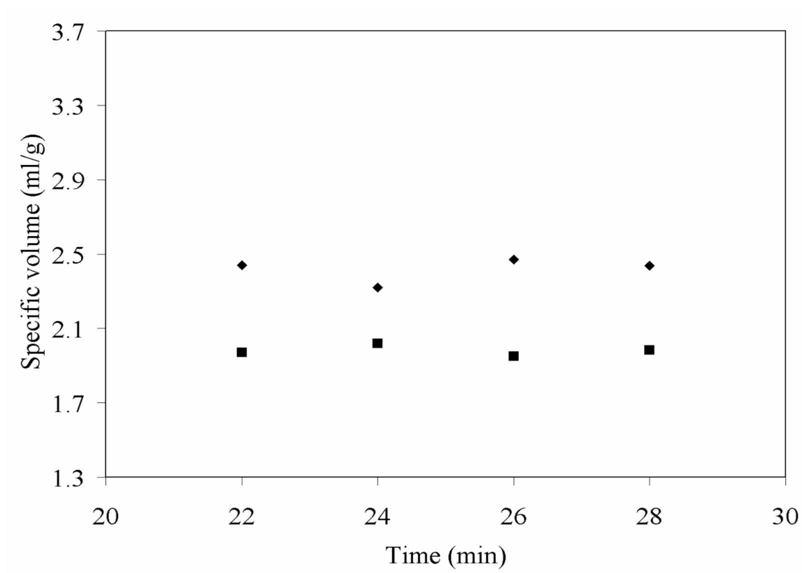


Figure 3.17 Variation of specific volume with baking time for cakes with different formulations baked in conventional oven

♦ (0% F)[a], ■ (25% F)[b]

3.3.2 Volume Index of Cakes

Volume index of cakes baked in microwave oven was significantly affected by variation of fat content (Table D.5). Emulsifier addition to the formulation caused an increase in the volume index values of the samples. This may be explained by the positive effect of emulsifier on the incorporation of the air to the cake batter thus producing a cake that expands readily (Figure 3.18). Especially Purawave^{TM} addition resulted in higher volume index values due to its higher dielectric properties with respect to Lecigran^{TM}. While the addition of both maltodextrin and Simplesse^{TM} had a significant effect on volume index of samples when compared with non-fat and 25% fat containing ones, Simplesse^{TM} added cake samples had the highest volume index values when baked in microwave oven (Figure 3.18, Table D.5). This may be because of the protein structure of Simplesse^{TM}. Since proteins increased the emulsion forming capacity of the mixture, highly porous batter had been obtained. Due to the presence of higher amount of air inside the structure of batter, the cake sample expanded more during baking. For combination baking, as in the case of microwave baking, cakes containing Simplesse^{TM} had the highest volume index values (Figure 3.19). Fat addition significantly decreased the volume index values of the samples (Table D.6). Both types of emulsifiers were found to be positively correlated with volume expansion for combination baking. It was found that addition of each fat replacer provided cakes with higher volume than the samples containing fat (Figure 3.19). For the cakes baked in conventional oven, it was observed that fat addition ended up with a volume decrease similar to other types of baking (Figure 3.20). According to the statistical analysis, it was found that rheological properties were correlated to volume index of cake samples baked in infrared-microwave combination oven (constant = -0.949, $p = 0.034$) (Table B.1 and B.2).

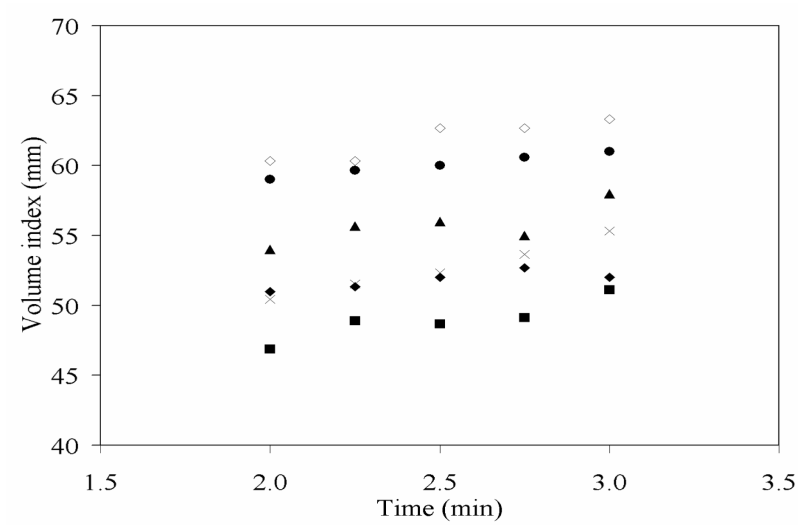


Figure 3.18 Variation of volume index with baking time for cakes with different formulations baked in microwave oven

♦ (0% F-0% P-0% L)[d], ■ (25% F-0% P-0% L)[e], ▲(25% F-3% P-0% L)[c], x (25% F-0% P-3% L)[d], • (25% M-0% P-0% L)[b], ◊ (25% S-0% P-0% L)[a]

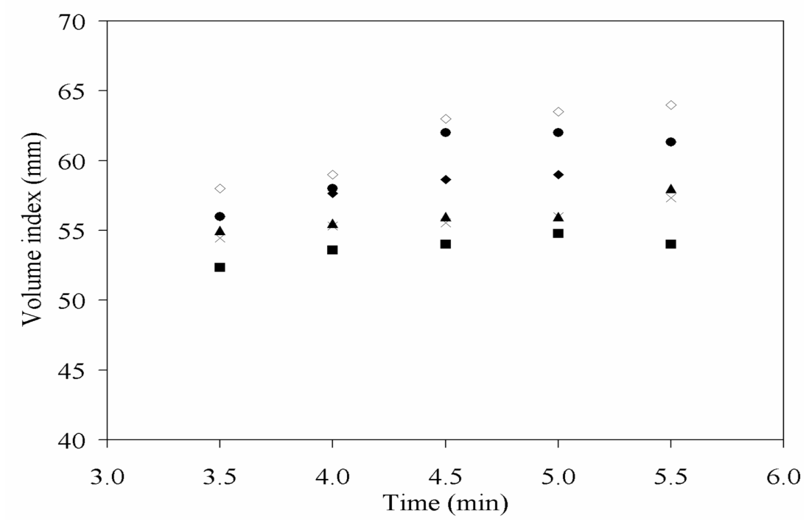


Figure 3.19 Variation of volume index with baking time for cakes with different formulations baked in infrared-microwave combination oven

♦ (0% F-0% P-0% L)[b], ■ (25% F-0% P-0% L)[d], ▲(25% F-3% P-0% L)[c], x (25% F-0% P-3% L)[cd], • (25% M-0% P-0% L)[ab], ◊ (25% S-0% P-0% L)[a]

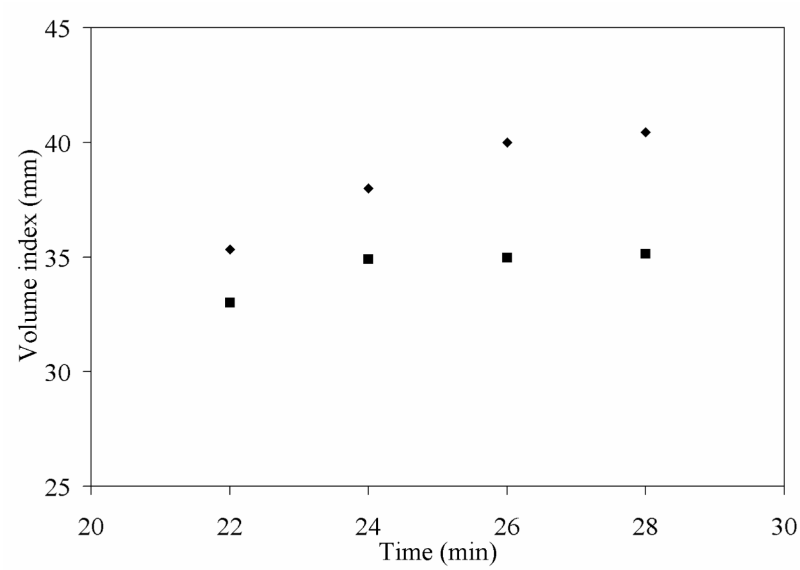


Figure 3.20 Variation of volume index with baking time for cakes with different formulations baked in conventional oven
♦ (0% F)[a], ■ (25% F)[b]

3.3.3 Texture Profile of Cakes

As texture parameters, hardness, gumminess, cohesiveness and springiness values of cake samples were recorded.

For microwave baking, addition of fat to the formulation decreased hardness of the cake samples (Figure 3.21, Table D.8). This was an expected result since tenderizing effects of fats are known (Freeland-Graves and Peckham, 1987). Addition of emulsifier did not affect the hardness of cake samples. In the case of fat replacer, the carbohydrate based maltodextrin did not affect hardness. On the other hand, usage of protein based fat replacer, Simplesse^{TM}, with microwaves gave high values of sample hardness due to the special interaction of proteins (Figure 3.21). Ozmutlu et al. (2001b) found that breads formulated with lower gluten flour were softer. Galagher et al. (2003) found that Simplesse^{TM} addition significantly increased the hardness of biscuit dough. For cake samples baked in infrared-microwave combination oven no significant effect of fat addition was observed on hardness of the samples (Figure 3.22). Similarly, addition of Purawave^{TM}, Lecigran^{TM} or maltodextrin to the formulation did not affect the hardness values of the cakes significantly (Table D.9). On the other hand, due to the unique interaction of protein with microwaves, the samples with Simplesse^{TM} had the highest hardness values. It was found that for samples baked in conventional oven, addition of fat decreased the hardness (Figure 3.23).

Two-way ANOVA results showed that hardness of the cakes baked in infrared-microwave combination oven did not change significantly during baking (Figure 3.22, Table D.9). Whereas, for microwave and conventional oven baked cakes, hardness increased significantly during baking time. This increment of hardness might be related with moisture loss (Figure 3.21 and 3.23, Table D.8 and D.10). Statistical analysis showed that hardness and volume index of cake samples were correlated for microwave, combination and conventional baking with correlation constants of 0.593 ($p = 0.001$), 0.610 ($p \leq 0.001$) and 0.85 ($p = 0.007$) respectively (Table B.3).

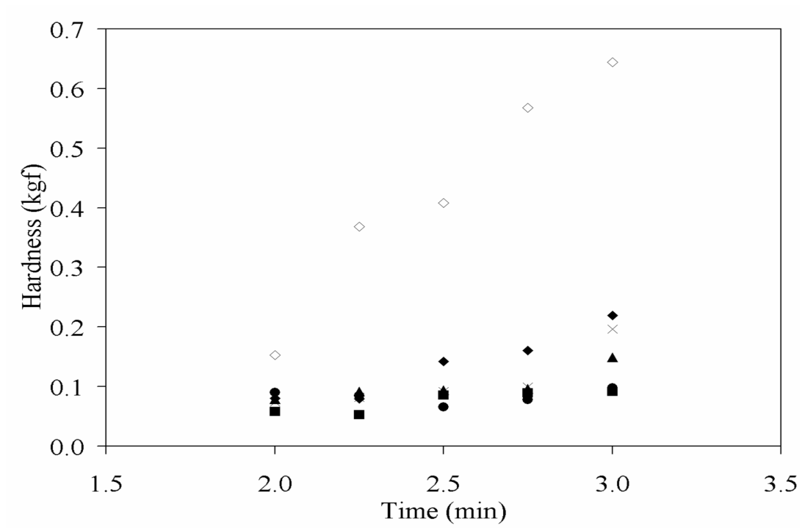


Figure 3.21 Variation of hardness with baking time for cakes with different formulations baked in microwave oven

♦ (0% F-0% P-0% L)[b], ■ (25% F-0% P-0% L)[c] ,▲(25% F-3% P-0% L)[bc], x (25% F-0% P-3% L)[bc], • (25% M-0% P-0% L)[bc], ◊ (25% S-0% P-0% L)[a]

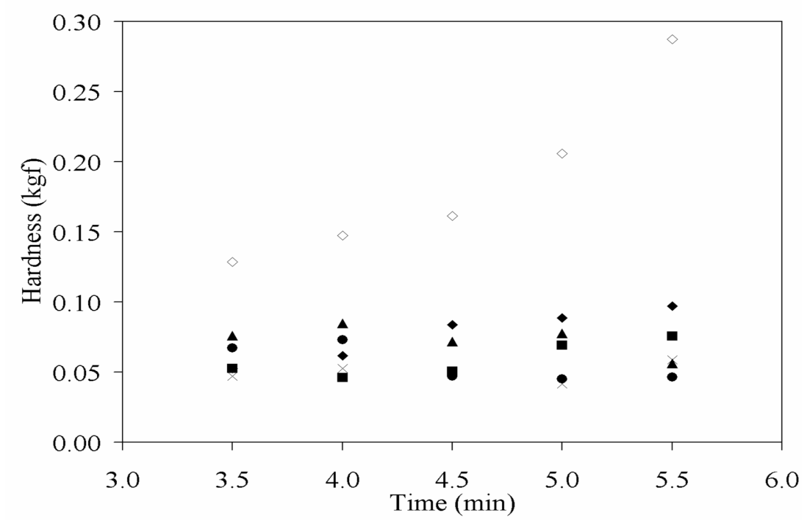


Figure 3.22 Variation of hardness with baking time for cakes with different formulations baked in infrared-microwave combination oven

♦ (0% F-0% P-0% L)[b], ■ (25% F-0% P-0% L)[b] ,▲(25% F-3% P-0% L)[b], x (25% F-0% P-3% L)[b], • (25% M-0% P-0% L)[b], ◊ (25% S-0% P-0% L)[a]

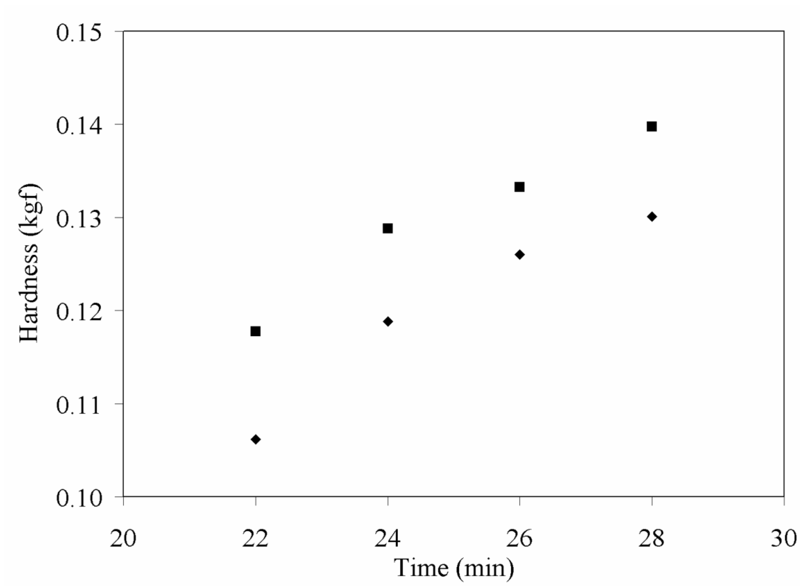


Figure 3.23 Variation of hardness with baking time for cakes with different formulations baked in conventional oven

♦ (0% F)[a], ■ (25% F)[b]

Another texture profile parameter, gumminess, which is the product of hardness and cohesiveness values, showed almost similar trends with hardness. In case of microwave baking, both formulation and baking time were found to be significantly effective on gumminess of the cake samples (Table D.11). Although the addition of fat, emulsifiers and carbohydrate based fat replacer maltodextrin did not affect the gumminess values significantly, addition of Simplesse™ tremendously increased the gumminess values (Figure 3.24). For combination baking, similar trends were observed with microwave baking (Figure 3.25), but according to the two-way ANOVA results, baking time were not effective (Table D.12). It was found that for conventional baking, increasing baking time significantly increased gumminess; moreover addition of fat to the formulation significantly decreased the gumminess values (Figure 3.26 and Table D.13).

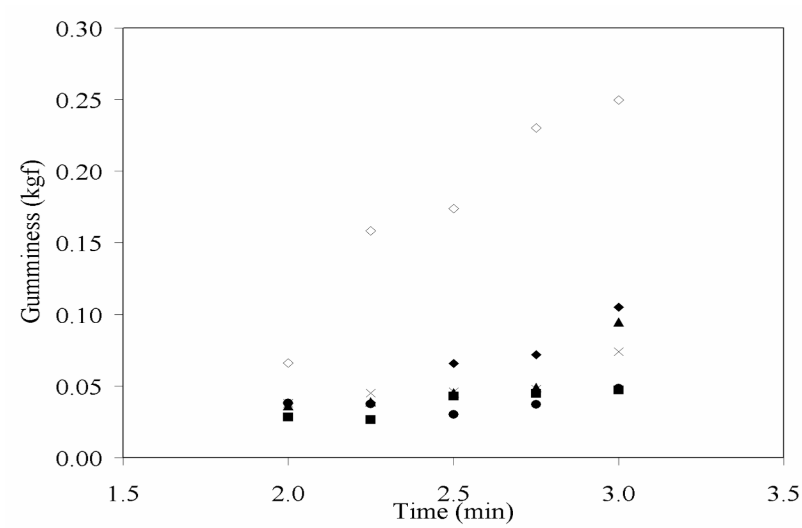


Figure 3.24 Variation of gumminess with baking time for cakes with different formulations baked in microwave oven

♦ (0% F-0% P-0% L)[b], ■ (25% F-0% P-0% L)[b] ,▲(25% F-3% P-0% L)[b], x (25% F-0% P-3% L)[b], • (25% M-0% P-0% L)[b], ◊ (25% S-0% P-0% L)[a]

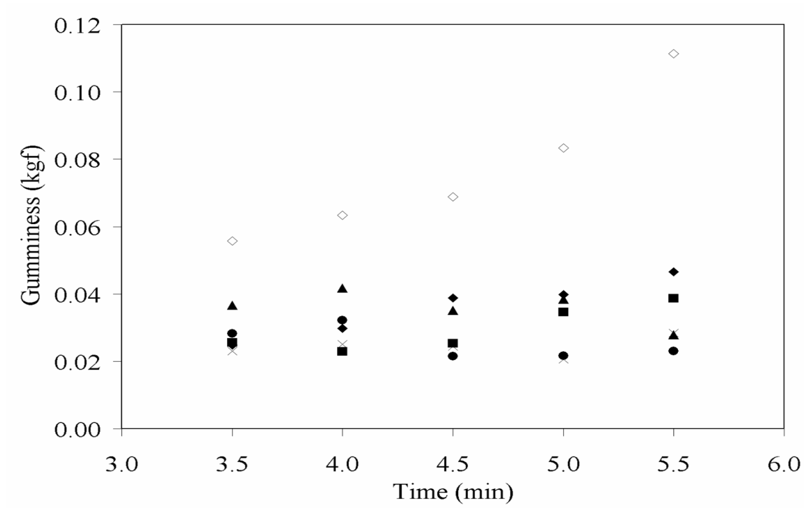


Figure 3.25 Variation of gumminess with baking time for cakes with different formulations baked in infrared-microwave combination oven

♦ (0% F-0% P-0% L)[b], ■ (25% F-0% P-0% L)[b] ,▲(25% F-3% P-0% L)[b], x (25% F-0% P-3% L)[b], • (25% M-0% P-0% L)[b], ◊ (25% S-0% P-0% L)[a]

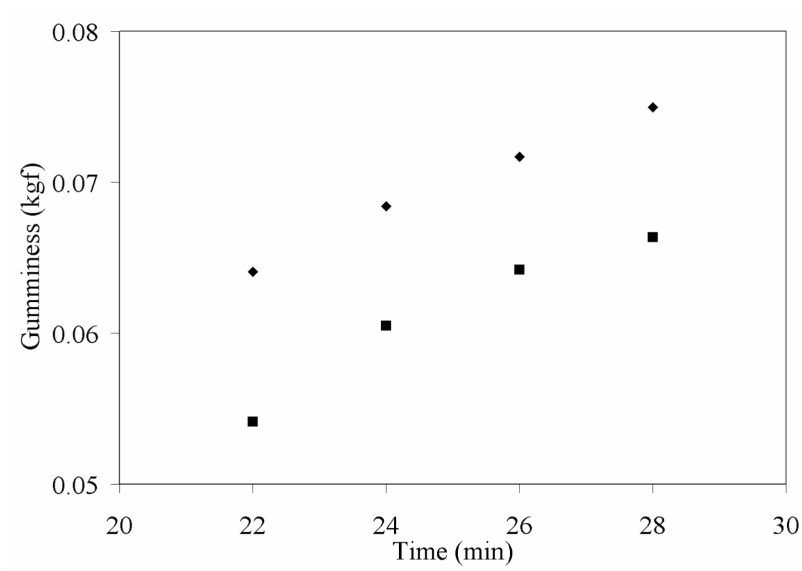


Figure 3.26 Variation of gumminess with baking time for cakes with different formulations baked in conventional oven
♦ (0% F)[a], ■ (25% F)[b]

Cohesiveness is the texture profile parameter which shows how well the product withstands a second deformation compared to its behaviour under the first deformation. As another definition, it is the integrity of the product. During this study, by performing two-way ANOVA, it was found that for all types of baking, baking time was not significantly effective, but formulation was significantly effective on cohesiveness values (Figure 3.27-3.29, Table D.14-D.16). Especially for microwave baking, a strict decrease in cohesiveness values for Simplesse™ added samples were observed after 2.5 minute baking. This trend may be due to the structure deformation of the protein based fat replacer.

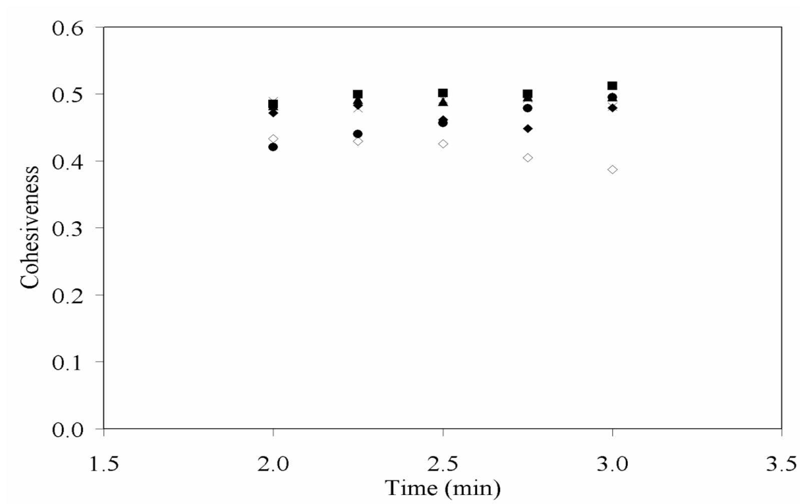


Figure 3.27 Variation of cohesiveness with baking time for cakes with different formulations baked in microwave oven

♦ (0% F-0% P-0% L)^{ab}, ■ (25% F-0% P-0% L)^{a} , ▲(25% F-3% P-0% L)^{ab}, x (25% F-0% P-3% L)^{ab}, • (25% M-0% P-0% L)^{b}, ◊ (25% S-0% P-0% L)^{c}

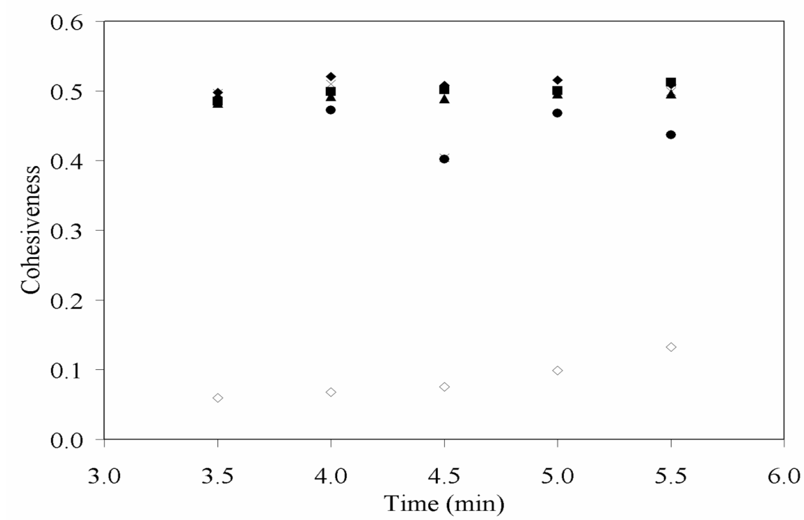


Figure 3.28 Variation of cohesiveness with baking time for cakes with different formulations baked in infrared-microwave combination oven

♦ (0% F-0% P-0% L)^{ab}, ■ (25% F-0% P-0% L)^{bc} ,▲(25% F-3% P-0% L)^{bc}, x (25% F-0% P-3% L)^{bc}, • (25% M-0% P-0% L)^{cd}, ◊ (25% S-0% P-0% L)^{e}

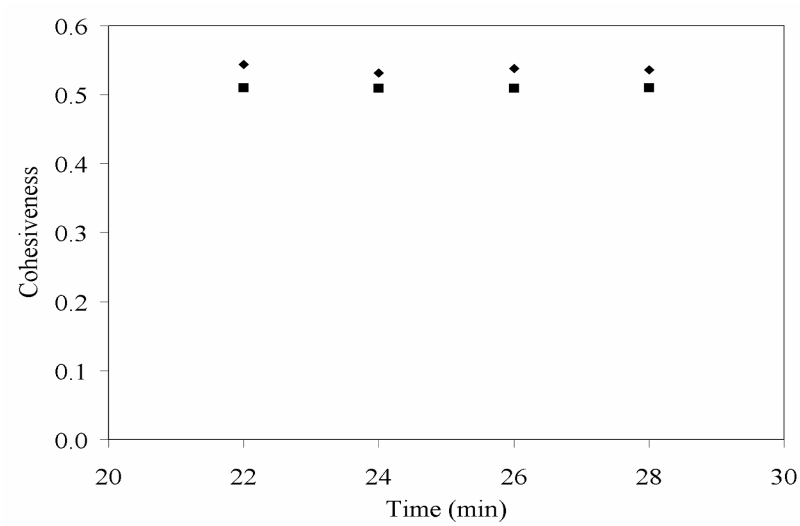


Figure 3.29 Variation of cohesiveness with baking time for cakes with different formulations baked in conventional oven

♦ (0% F)[a], ■ (25% F)[b]

The last texture profile parameter investigated in this study was springiness. Springiness shows how well the product physically springs back after it has been deformed during the first compression. In other words, it shows the elasticity of the cake sample. For all types of baking, addition of fat to the formulation was found to decrease the springiness of cake samples (Figure 3.30-3.32). Kahyaoglu et al. (2005) found that for cheese samples increasing fat content decreased the springiness values of the samples. Similarly for both microwave and combination baking, addition of emulsifier also decreased the springiness values with respect to non-fat ones (Figure 3.30 and 3.31). Frye and Setser (1991) showed that an increase in emulsifier level resulted in a decrease in springiness of yellow layer cakes. It was found that addition of both fat replacers significantly decreased springiness with respect to fat added samples (Figure 3.30 and 3.31, Table D.17 and D.18). Baking time was significantly effective on springiness value for all baking types (Table D.17-D.19).

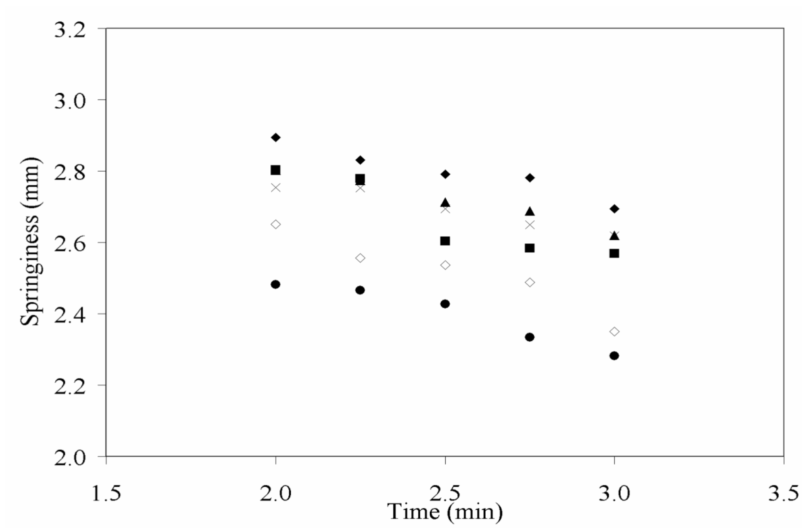


Figure 3.30 Variation of springiness with baking time for cakes with different formulations baked in microwave oven

♦ (0% F-0% P-0% L)[a], ■ (25% F-0% P-0% L)[b], ▲(25% F-3% P-0% L)[b], x (25% F-0% P-3% L)[b], • (25% M-0% P-0% L)[d], ◊ (25% S-0% P-0% L)[c]

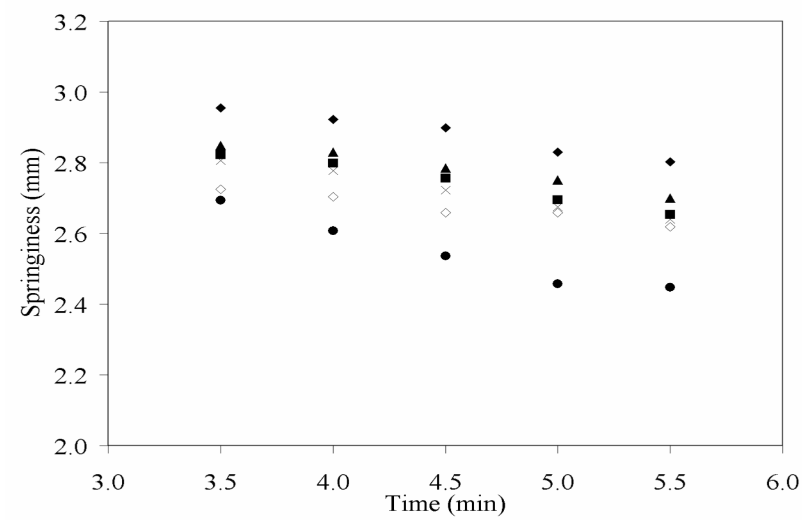


Figure 3.31 Variation of springiness with baking time for cakes with different formulations baked in infrared-microwave combination oven

♦ (0% F-0% P-0% L)[a], ■ (25% F-0% P-0% L)[bc], ▲(25% F-3% P-0% L)[b], x (25% F-0% P-3% L)[c], • (25% M-0% P-0% L)[e], ◊ (25% S-0% P-0% L)[d]

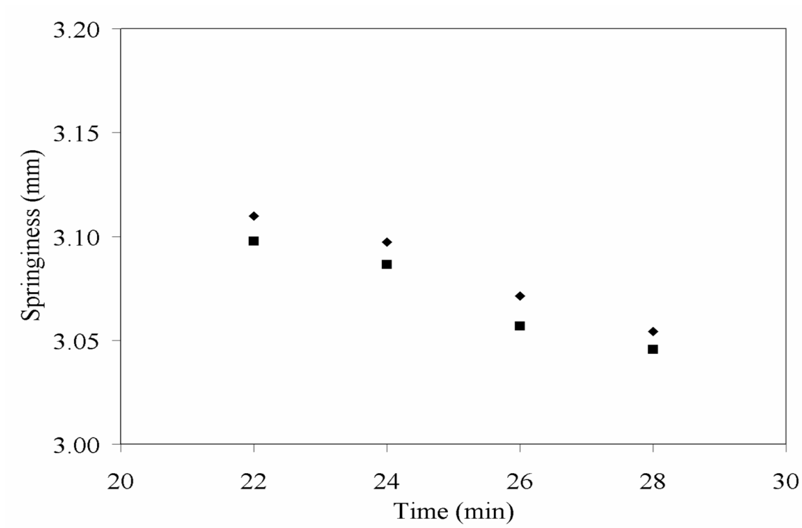


Figure 3.32 Variation of springiness with baking time for cakes with different formulations baked in conventional oven

♦ (0% F)[a], ■ (25% F)[b]

3.3.4 Porosity of Cakes

An increase in baking time resulted in an increase in porosity of cakes baked in all types of ovens (Figure 3.33, 3.34 and 3.35). Baking is a complex process that brings about liberation of carbon dioxide from leavening agents, expansion of the air entrapped in the structure and volume expansion. This fact causes the increase in porosity during baking. It was found that fat addition to the formulation caused significant decrease in porosity in microwave oven (Figure 3.33, Table D.20). Fat replacer added samples had higher porosity values than emulsifier added ones. It was also correlated with the volume index values of the cakes (Figure 3.18, Table B.4) On the other hand, for infrared-microwave combination baking, formulation was found to be not effective on porosity (Table D.21). For conventional baking, similar to microwave baking, addition of fat resulted in less porous products (Figure 3.35 and Table D.22).

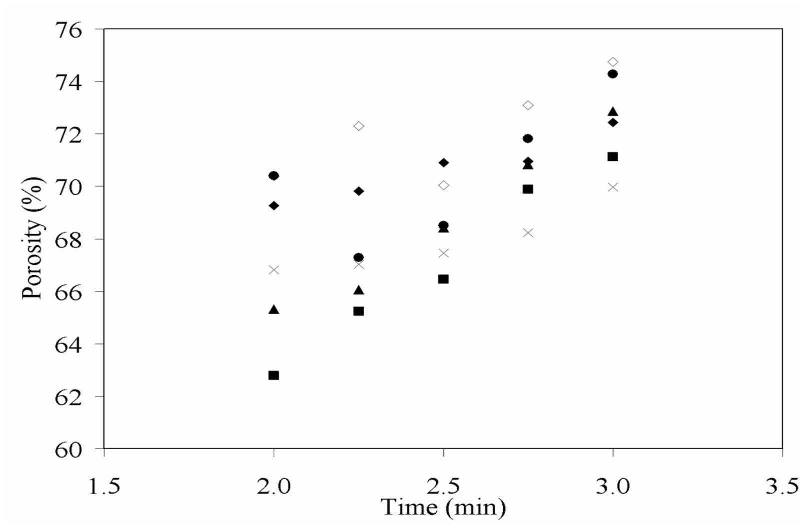


Figure 3.33 Variation of porosity with baking time for cakes with different formulation baked in microwave oven

♦ (0% F-0% P-0% L)[ab], ■ (25% F-0% P-0% L)[c], ▲(25% F-3% P-0% L)[bc], x (25% F-0% P-3% L)[c], • (25% M-0% P-0% L)[ab], ◊ (25% S-0% P-0% L)[a]

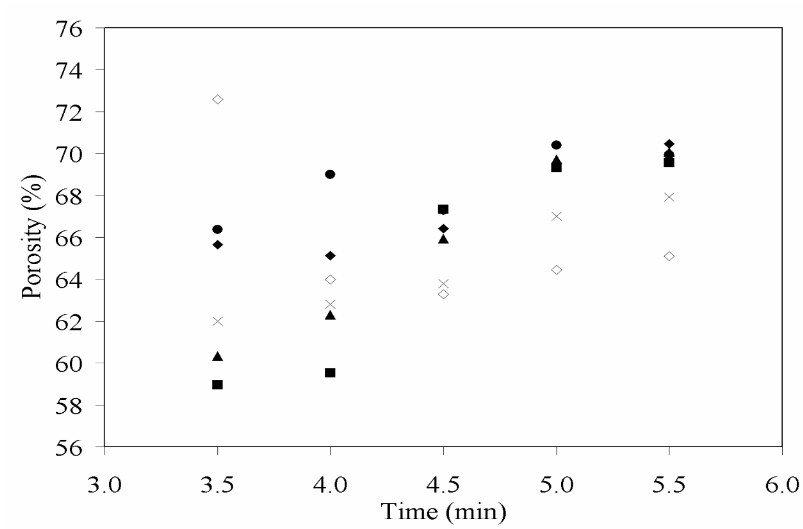


Figure 3.34 Variation of porosity with baking time for cakes with different formulation baked in infrared-microwave combination oven

♦ (0% F-0% P-0% L)[a], ■ (25% F-0% P-0% L)[a], ▲(25% F-3% P-0% L)[a], x (25% F-0% P-3% L)[a], • (25% M-0% P-0% L)[a], ◊ (25% S-0% P-0% L)[a]

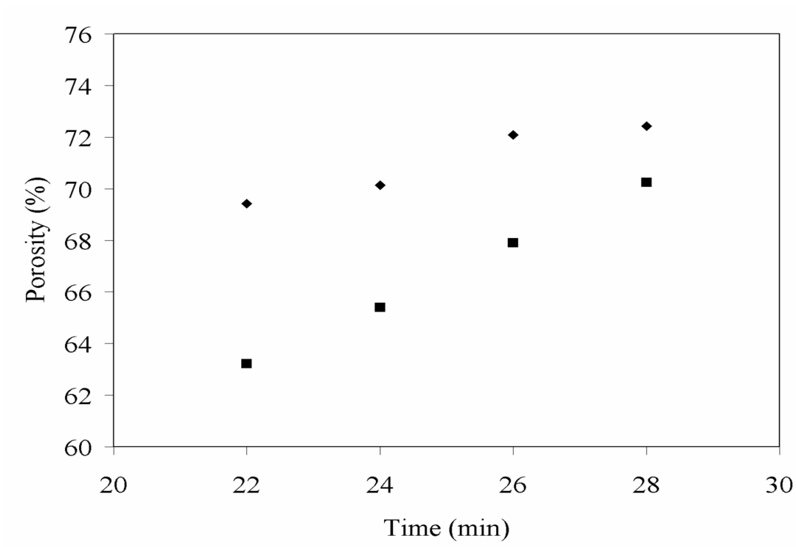


Figure 3.35 Variation of porosity with baking time for cakes with different formulations baked in conventional oven

♦ (0% F)[a], ■ (25% F)[b]

3.3.5 Color of Cakes

As expected, there was no significant difference between ΔE values of the cakes baked in microwave oven for different baking times since the surface temperature of cakes can never reach to the values required for browning reactions (Figure 3.36 and Table D.23). For higher fat content, higher ΔE values were obtained due to contribution of color of the fat itself to the final product. On the other hand addition of fat replacer (Simplesse^{TM}), yielded lower ΔE values (Figure 3.36). This was because of the lighter color of Simplesse^{TM} itself. ΔE values of cakes baked in infrared-microwave combination oven increased linearly with baking time (Figure 3.37, Table A.1). Infrared heating is known to provide low penetration depth and concentrate radiation at the surface, so the surface temperature can reach the required values for browning. Variation of fat content and addition of emulsifier and fat replacer did not have a significant effect on the color of cake samples baked in infrared-microwave combination oven. Thus, it was possible to obtain cakes having similar color with the conventionally baked ones when microwave heating was combined with infrared heating (Figure 3.37 and 3.38). Microwave baked breads had the lowest ΔE values with respect to the ones baked in other ovens which corresponded to a similar color value to that of the white standard (Figure 3.36-3.38). ΔE values of cakes baked in conventional oven also increased linearly with baking time (Figure 3.38 and Table A.2). For higher fat content, higher ΔE values were obtained due to the natural color of fat.

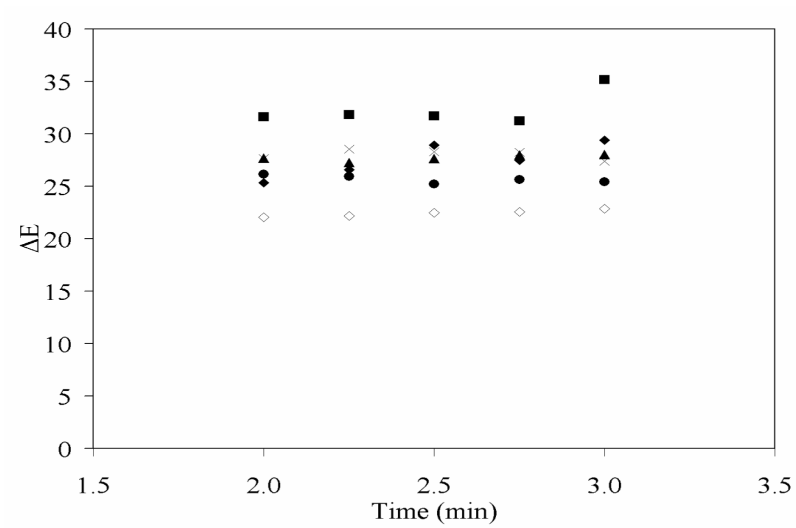


Figure 3.36 Variation of color change (ΔE value) with baking time for cakes with different formulations baked in microwave oven

♦ (0% F-0% P-0% L)^{bc}, ■ (25% F-0% P-0% L)^{a}, ▲(25% F-3% P-0% L)^{b}, x (25% F-0% P-3% L)^{b}, • (25% M-0% P-0% L)^{c}, ◊ (25% S-0% P-0% L)^{d}

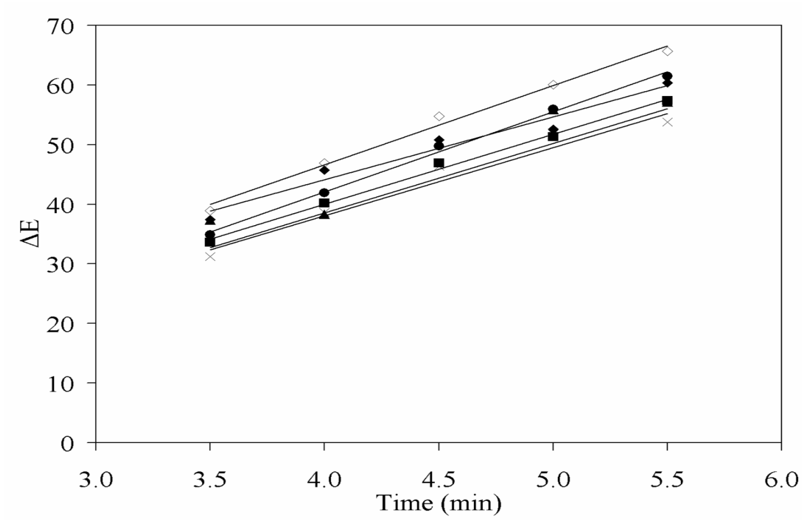


Figure 3.37 Variation of color change (ΔE value) with baking time for cakes with different formulations baked in infrared-microwave combination oven

♦ (0% F-0% P-0% L)[ab], ■ (25% F-0% P-0% L)[ab], ▲(25% F-3% P-0% L)[b], x (25% F-0% P-3% L)[b], • (25% M-0% P-0% L)[ab], ◊ (25% S-0% P-0% L)[a]

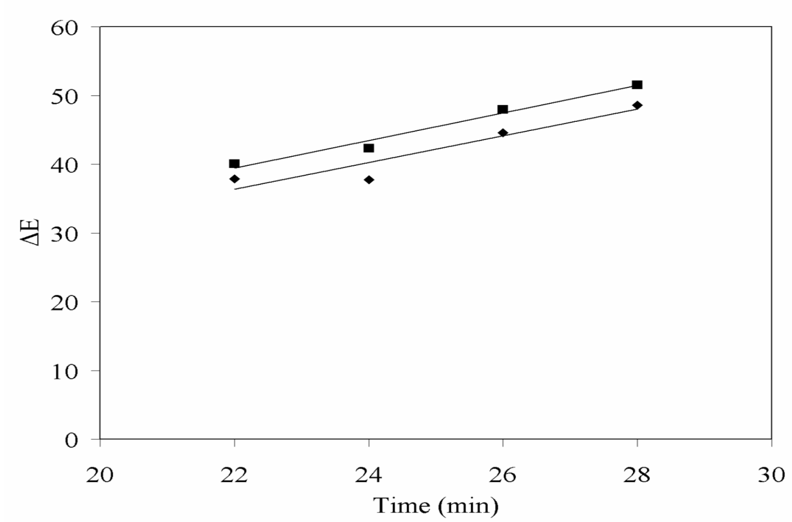


Figure 3.38 Variation of color change (ΔE value) with baking time for cakes with different formulations baked in conventional oven

♦ (0% F)[b], ■ (25% F)[a]

3.3.6 Dielectric Properties of Cake Batter and Cakes

3.3.6.1 Dielectric Properties of Cake Batter

Dielectric properties of each ingredient were measured at 2450 MHz and 25°C. Dielectric properties and bulk densities of each ingredient were given in Table 3.3.

Table 3.3 The bulk densities and dielectric properties of cake batter ingredients at 2450 MHz and 25°C

Ingredient	Bulk density(g/ml)	Dielectric constant	Dielectric loss factor	Penetration depth (cm)
Baking powder	0.930	2.848	0.285	0.116
Egg white powder	0.445	2.184	0.056	0.516
Fat	1.018	4.458	0.637	0.065
Flour	0.514	2.738	0.239	0.135
Lecigran™	0.626	1.862	0.074	0.359
Maltodextrin	0.371	1.399	0.156	0.148
Milk powder	0.425	1.442	0.071	0.328
Purawave™	1.164	3.058	0.233	0.147
Salt	1.299	2.346	0.069	0.431
Simplesse™	0.560	2.225	0.105	0.277
Sugar	0.901	1.873	0.018	1.480

When the bulk densities and dielectric properties of the ingredients for each cake formulation, fat, maltodextrin, Simplesse™, Purawave™ and

Lecigran™ were analyzed, it was found that bulk density and dielectric constant were correlated with a correlation coefficient of 0.814 (p=0.048). Calay et al. (1995) mentioned that a rise in the bulk density of pulverized materials (e.g. grains, flour and dough) served to increase the dielectric constant.

Cake formulations were found to be effective on the dielectric constant, loss factor and penetration depth of the cake batter samples (Figure 3.39, 3.40 and 3.41). Using Simplesse™ in cake formulation resulted in a significant decrease in dielectric properties as compared to formulation containing no fat and 25% fat (Table D.26, D.27 and D.28). This may be due to the lower dielectric properties of Simplesse™ with respect to fat (Table 3.3). Moreover, addition of Simplesse™ may increase the amount of air entrapped in the structure of cake batters because of its emulsion forming property due to protein structure, so they may result in highly porous products. Protein emulsifying activity is the ability of the protein to participate in emulsion formation and to stabilize the newly created emulsion. Halling (1981) had mentioned about the use of food proteins as stabilizers of emulsions and foams in his review. This fact can also be observed from the porosity data of the Simplesse™ added samples (Figure 3.33). These highly porous cake batters had lower dielectric properties due to air contribution. When the penetration depths of the samples were investigated, it was found that it had a variation due to formulation. The samples containing Simplesse™ had the highest penetration depth (Figure 3.41). As it was mentioned the penetration depths of the samples were calculated by using equation 1.5. Due to highly porous structure of Simplesse™ added samples dielectric constant and dielectric loss factor values were the lowest. These low dielectric property values caused the samples containing Simplesse™ to have the highest penetration depth (Figure 3.41).

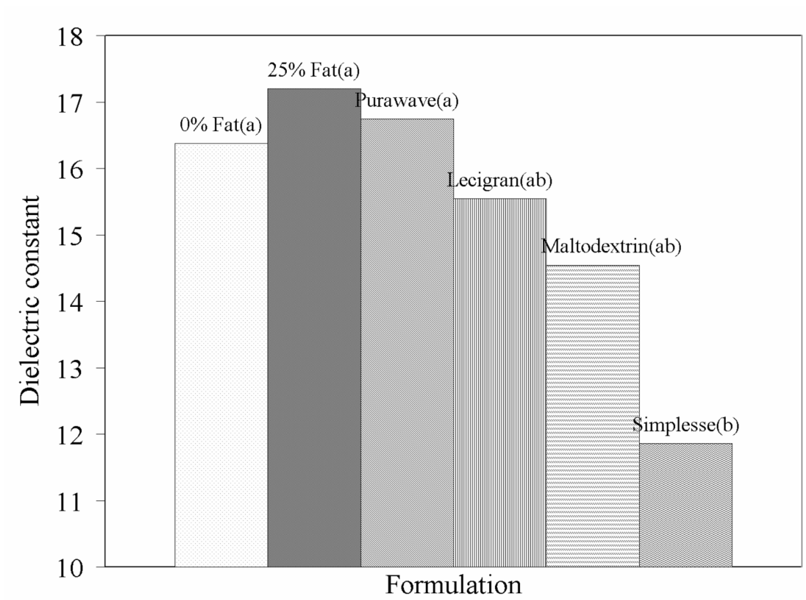


Figure 3.39 Variation of dielectric constant for different formulations of cake batters at room temperature

Columns with different letters (a,b i.e) are significantly different ($p \leq 0.05$).

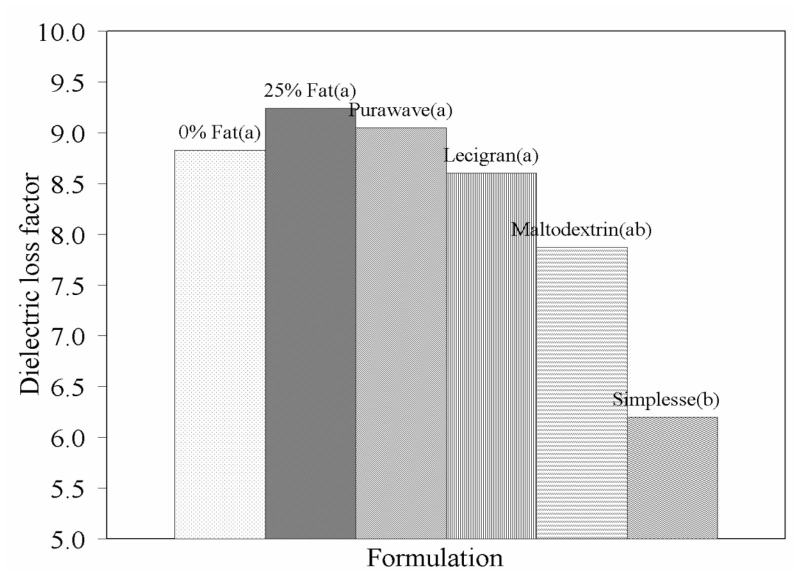


Figure 3.40 Variation of dielectric loss factor for different formulations of cake batters at room temperature

Columns with different letters (a,b i.e) are significantly different ($p \leq 0.05$).

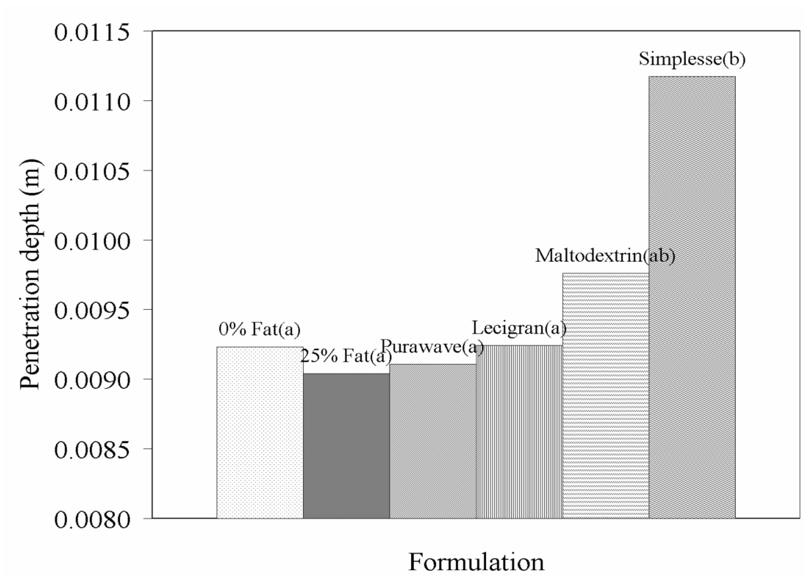


Figure 3.41 Variation of penetration depth for different formulations of cake batters at room temperature

Columns with different letters (a,b i.e) are significantly different ($p \leq 0.05$).

Another important parameter effective on the dielectric properties of cake batter was frequency. When the variation of dielectric properties of cake batter were investigated with respect to frequency, it was found that both dielectric constant and loss factor decreased for all formulations (Figure 3.42 and 3.43). The value of dielectric properties for pure water decreases with falling frequency at the microwave frequencies of interest in food processing, but for food materials they tend to increase with decreasing frequency (Calay et al., 1995). Relaxation time is the time it takes an agitated molecule to relax back to 1/e of its original condition after the field has been removed. Up to relaxation frequency the region of application is called relaxation region. After this relaxation region the dielectric properties were mostly constant. In the case of penetration depth, since there is a negative correlation between dielectric loss factor, increasing frequency caused an increase in penetration depth values of all formulations (Figure 3.44).

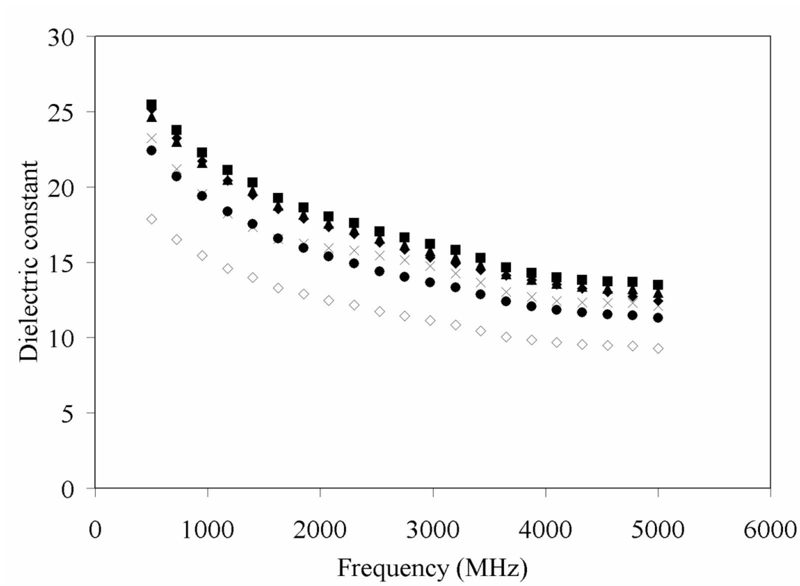


Figure 3.42 Variation of dielectric constant with frequency for cake batter
♦ 0% F-0% P-0% L, ■ 25% F-0% P-0% L, ▲25% F-3% P-0% L, x 25% F-0% P-3% L, • 25% M-0% P-0% L, ◊ 25% S-0% P-0% L

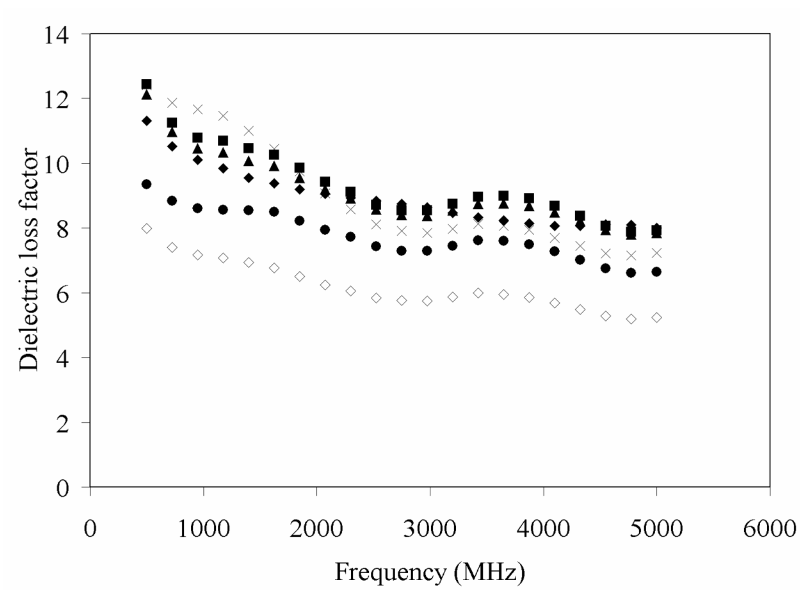


Figure 3.43 Variation of dielectric loss factor with frequency for cake batter
♦ 0% F-0% P-0% L, ■ 25% F-0% P-0% L, ▲25% F-3% P-0% L, x 25% F-0% P-3% L, • 25% M-0% P-0% L, ◊ 25% S-0% P-0% L

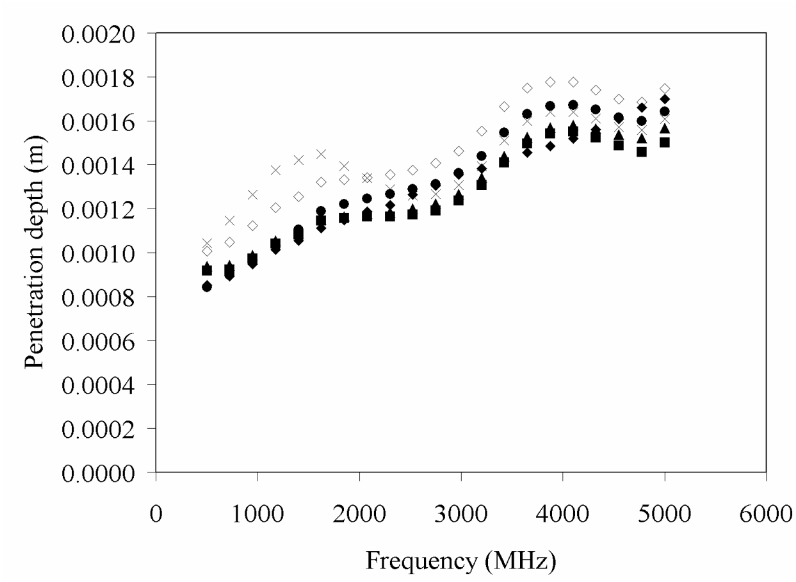


Figure 3.44 Variation of penetration depth with frequency for cake batter ♦ 0% F-0% P-0% L, ■ 25% F-0% P-0% L, ▲25% F-3% P-0% L, x 25% F-0% P-3% L, • 25% M-0% P-0% L, ◊ 25% S-0% P-0% L

It was found that each formulation was affected by temperature differently because of their interaction with the microwaves. The dielectric constant and loss factor were found to be generally decreasing by increasing temperatures. The rate of change of both dielectric constant and loss factor with respect to temperature depends on the bound and free water content and ionic conductivity of the material. The free water content has a negative temperature coefficient at the frequencies of interest in microwave food processing (Calay et al., 1995). Since during heating the free water content of the samples decreased, it caused the reduction of the dielectric constant and loss factor as shown by Figure 3.45 and 3.46, respectively. Because of its inverse relationship with dielectric loss factor, penetration depth of samples experienced an increase due to increasing temperature (Figure 3.47). For both dielectric constant and dielectric loss factor around 80°C a sharp decrease was observed due to the gelatinization of starch which entraps the air bubbles inside of the structure and caused a sudden increase in porosity. Since dielectric constant were determined by the amount of effective free dipoles that can contribute to the net capacitance, its variation can be explained in terms of water mobility. During gelatinization, more water molecules became associated with other molecules and thus less mobile. The less available effective free dipoles and the more random orientation of associated water molecules resulted in decreasing dielectric constant (Kim and Cornillon, 2001).

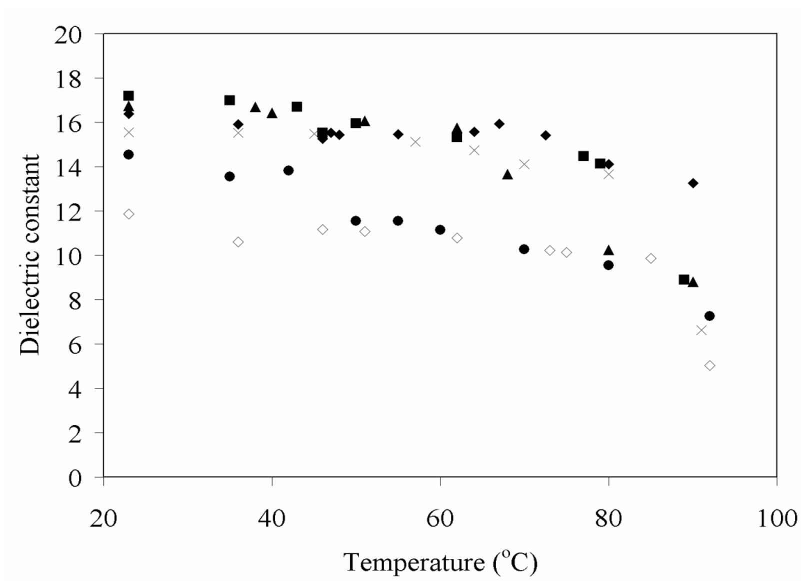


Figure 3.45 Variation of dielectric constant with temperature for different formulations of cake batters

♦ 0% F-0% P-0% L, ■ 25% F-0% P-0% L, ▲25% F-3% P-0% L, x 25% F-0% P-3% L, • 25% M-0% P-0% L, ◊ 25% S-0% P-0% L

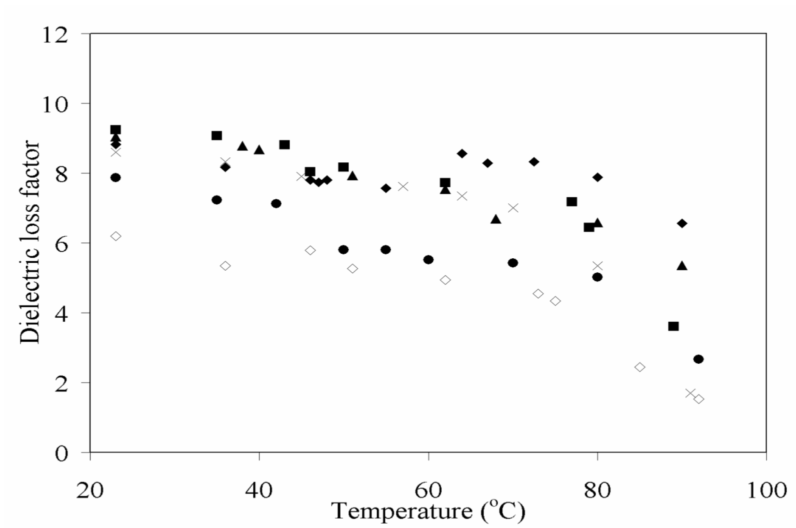


Figure 3.46 Variation of dielectric loss factor with temperature for different formulations of cake batters

♦ 0% F-0% P-0% L, ■ 25% F-0% P-0% L, ▲25% F-3% P-0% L, x 25% F-0% P-3% L, • 25% M-0% P-0% L, ◊ 25% S-0% P-0% L

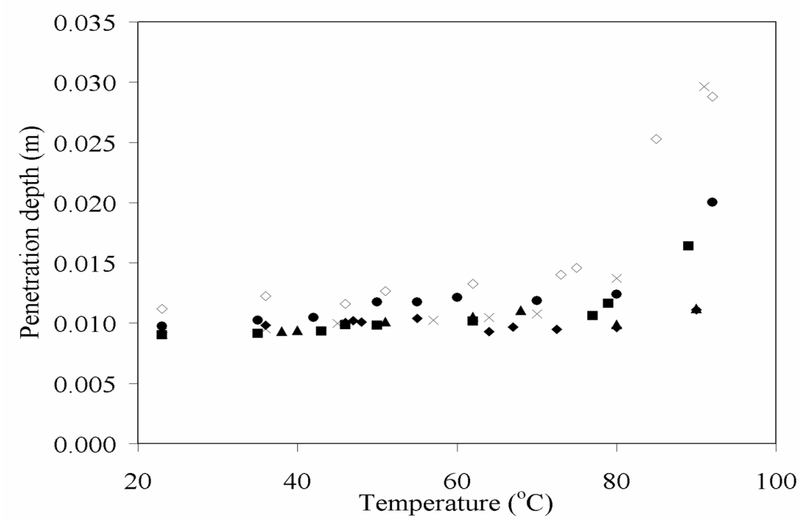


Figure 3.47 Variation of penetration depth with temperature for different formulations of cake batters

♦ 0% F-0% P-0% L, ■ 25% F-0% P-0% L, ▲25% F-3% P-0% L, x 25% F-0% P-3% L, • 25% M-0% P-0% L, ◊ 25% S-0% P-0% L

3.3.6.2 Weight Loss Values and Dielectric Properties of Cakes

Weight loss of cakes baked in all types of ovens increased with baking time (Figure 3.48-3.50, Table A.3-A.5). Weight loss data is important because it is an index of moisture loss. For cake samples baked in microwave oven, type of ingredient affected weight loss significantly (Figure 3.48, Table D.29). For combination baking, formulation was found to be not effective on weight loss values of cake samples (Figure 3.49). When the weight loss values of the samples baked in three different ovens were compared, it was found that the weight loss was quite low for the cakes baked in conventional oven (Figure 3.48-3.50). This is due to the excessive pressure gradient in case of microwave and combination baked cakes. During microwave heating of a high moisture food, pressure was found to rise much faster and reach a higher value than during conventional heating (Ni et al., 1999). Breads and cakes baked in microwave oven were shown to lose more moisture as compared to conventionally baked ones (Sumnu et al., 1999, Zincirkiran et al., 2002).

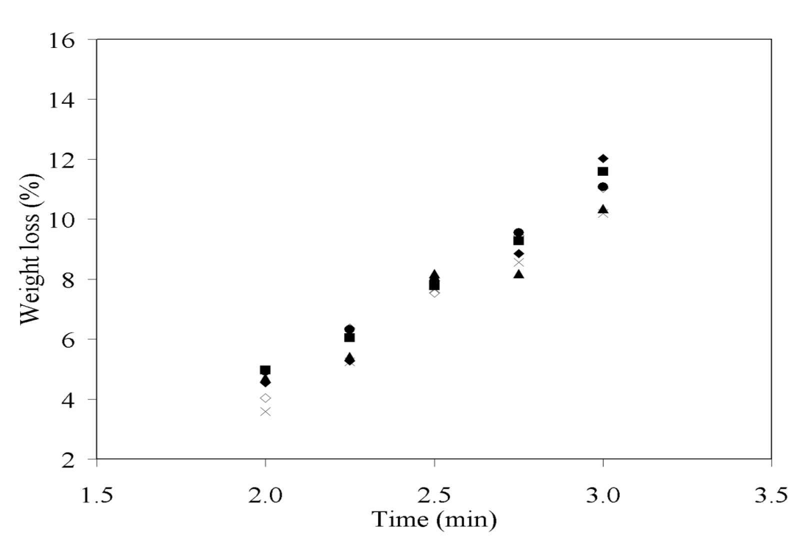


Figure 3.48 Variation of weight loss with baking time for cakes with different formulation baked in microwave oven

♦ (0% F-0% P-0% L)[ab], ■ (25% F-0% P-0% L)[ab], ▲(25% F-3% P-0% L)[ab], x (25% F-0% P-3% L)[a], • (25% M-0% P-0% L)[b], ◊ (25% S-0% P-0% L)[ab]

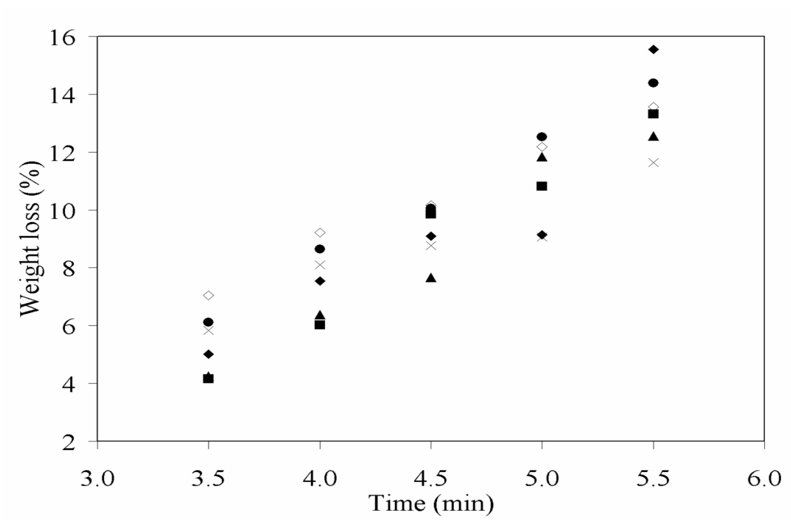


Figure 3.49 Variation of weight loss with baking time for cakes with different formulation baked in infrared-microwave combination oven

♦ (0% F-0% P-0% L)[a], ■ (25% F-0% P-0% L)[a], ▲(25% F-3% P-0% L)[a], x (25% F-0% P-3% L)[a], • (25% M-0% P-0% L)[a], ◊ (25% S-0% P-0% L)[a]

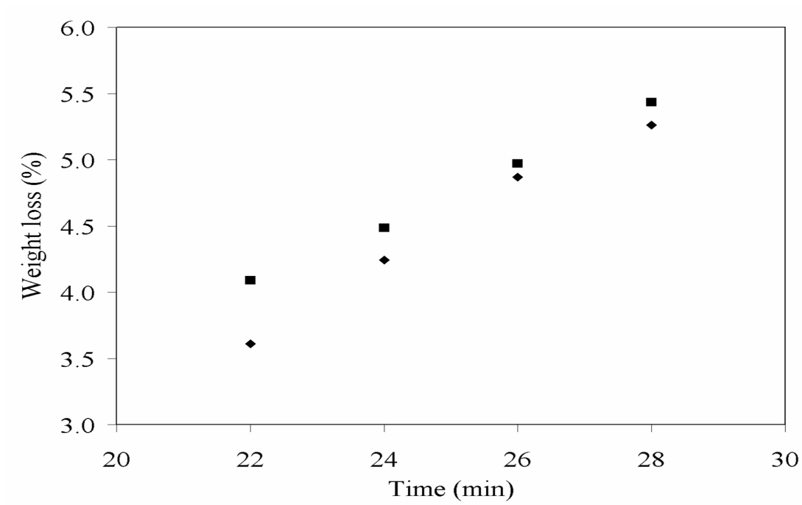


Figure 3.50 Variation of weight loss with baking time for cakes with different formulations baked in conventional oven

♦ (0% F)[a], ■ (25% F)[a]

Dielectric properties of the cake samples also changed depending on the formulation and type of the oven during baking. Addition of fat increased the dielectric constant and loss factor of the cake samples with respect to non-fat cakes (Figure 3.51 and 3.52) but decreased penetration depth (Figure 3.53). One reason for this effect is the higher dielectric properties of fat itself and another reason may be the fact that the addition of fat decreases the porosity of the sample (Figure 3.33). Sumnu et al. (2007) showed that as porosity of breads increased, the dielectric properties of breads decreased. The dependence of the dielectric properties on fat content is not yet well understood but basically it can be said that the basis for the interactions is thought to result from the rotational modes of the molecules and is related to the permanent and induced dipole moments (Mudgett, 1982). It was observed that while addition of Purawave™ did not have a significant effect on the dielectric constant of microwave baked cake samples, Lecigran™ addition caused a reduction when compared with formulation containing 25% fat (Figure 3.51, Table D.32). This may be due to the fact that Lecigran^{TM} as a raw material had lower dielectric constant than fat (Table 3.3). In case of dielectric loss factor, addition of both Purawave^{TM} and Lecigran^{TM} was not significantly effective (Figure 3.52, Table D.34). When the effect of two fat replacers on dielectric constant of microwave baked cake samples were compared, it was concluded that addition of Simplesse^{TM} to the formulation decreased the dielectric constant, whereas maltodextrin addition were not effective (Figure 3.51). This can be explained by both highly porous structure of Simplesse^{TM} added samples and low dielectric constant of Simplesse^{TM} added cake batter (Figure 3.33 and Figure 3.39). As in the case of emulsifiers, addition of each fat replacer was found to be not effective on dielectric loss factor of microwave baked samples (Figure 3.52).

Besides formulation, dielectric properties and penetration depth of microwave baked cake samples were shown to be significantly dependent on baking time (Figure 3.51-3.53, Table D.32-D.36). The increase in baking time decreased dielectric constant and loss factor and increased penetration depth of all formulations. This can be explained by the variation of the porosity of samples during baking. As baking time increases porosity of the samples increases significantly with a p value of 0.000 (Figure 3.33), and the presence of more air decreases the dielectric properties. Another reason for the decrease in dielectric constant and dielectric loss factor is the increase of weight loss or in other words the reduction of moisture content of the samples as the baking time increases (Figure 3.48). According to the results obtained from two-way ANOVA, weight loss decreased significantly with increasing baking time (Table D.29). The moisture content of the sample is quite important for microwave heating because of its dipolar mechanism. When there is much free water in the system, electric field will see more polarized dipole moments per unit volume of the sample.

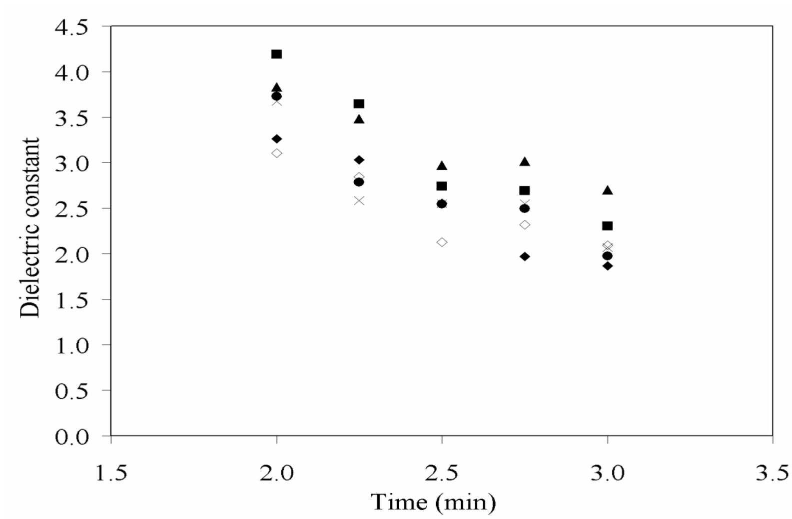


Figure 3.51 Variation of dielectric constant with baking time for cakes with different formulations baked in microwave oven

♦(0% F-0% P-0% L)[c], ■ (25% F-0% P-0% L)[ab], ▲(25% F-3% P-0% L)[a], x (25% F-0% P-3% L)[c], • (25% M-0% P-0% L)[bc], ◊ (25% S-0% P-0% L)[c]

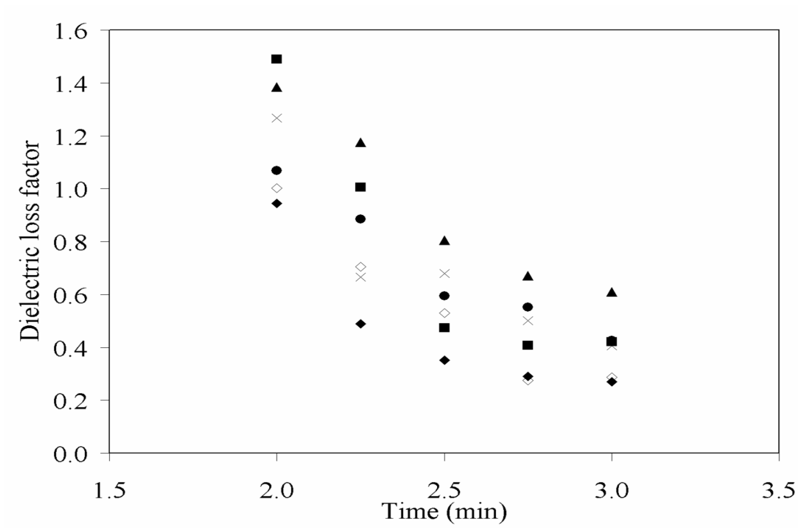


Figure 3.52 Variation of dielectric loss factor with baking time for cakes with different formulations baked in microwave oven

♦ (0% F-0% P-0% L)[c], ■ (25% F-0% P-0% L)[ab], ▲(25% F-3% P-0% L)[a], x (25% F-0% P-3% L)[b], • (25% M-0% P-0% L)[b], ◊ (25% S-0% P-0% L)[bc]

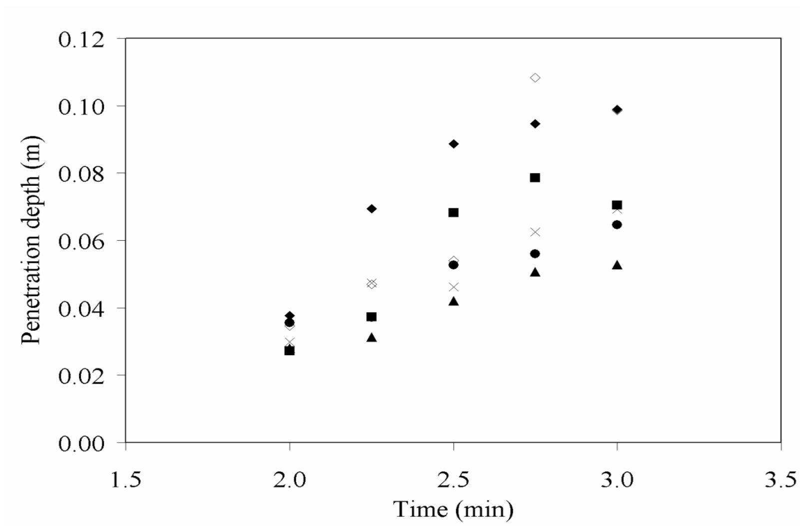


Figure 3.53 Variation of penetration depth with baking time for cakes with different formulation baked in microwave oven

♦ (0% F-0% P-0% L)[a], ■ (25% F-0% P-0% L)[bc], ▲(25% F-3% P-0% L)[c], x (25% F-0% P-3% L)[bc], • (25% M-0% P-0% L)[bc], ◊ (25% S-0% P-0% L)[ab]

Similarly, because of the same reasons discussed above dielectric properties and penetration depth of infrared-microwave combination baked cake samples were shown to be dependent on baking time too (Figure 3.54, 3.55 and 3.56). As in the case of microwave baking, dielectric constant and loss factor of all formulations decreased, penetration depth increased with an increase in baking time because their moisture content decreased and porosity increased during baking (Figure 3.34). Formulation affected the dielectric properties and penetration depth again similar to microwave baking. Addition of fat increased the dielectric properties since it caused less porous cake samples in the initial stages of baking (Figure 3.54 and 3.55). It was observed that using emulsifier Lecigran™ or Purawave™ did not significantly affect the dielectric properties of the cake samples (Table D.33 and D.35). On the other hand, addition of fat replacer, Simplesse™ resulted in a significant decrease in dielectric properties

(Figure 3.54 and 3.55, Table D.33 and D.35).

As in the case of microwave baking, baking time is significantly effective on dielectric properties of cakes baked with infrared-microwave combination oven (Figure 3.54 and 3.55). Because of the weight loss and porosity variation during baking, dielectric properties had experienced a decrease for all formulations. A significant increase in porosity ($p=0.023$) and a significant decrease in weight loss ($p=0.000$) are the main reasons. Both for weight loss and porosity, it was found statistically that heating mode was significantly effective ($p= 0.000$).

When the dielectric properties of cakes baked in different ovens were compared at the final baking time, it was found that there was no significant difference between two heating mechanisms (Figure 3.51-3.55). It was found that the dielectric properties of cake batter were much higher than those of baked cake samples due to higher moisture content.

Second order models were used to express dielectric properties in terms of porosity and weight loss. The corresponding models were given in Table C.1 and C.2. The significance of each term on affecting dielectric properties can be seen by comparing p values. Dielectric constant and dielectric loss factor of cakes baked in infrared-microwave combination were found to be affected by porosity and weight loss significantly. By looking at the negative values of constants it can be seen that the increase in weight loss and porosity decreased dielectric constant and loss factor of the cakes. In case of microwave baking, porosity was significantly effective on dielectric loss factor of the samples with different formulations. Each second order model was found to be significant with a p value of 0.000.

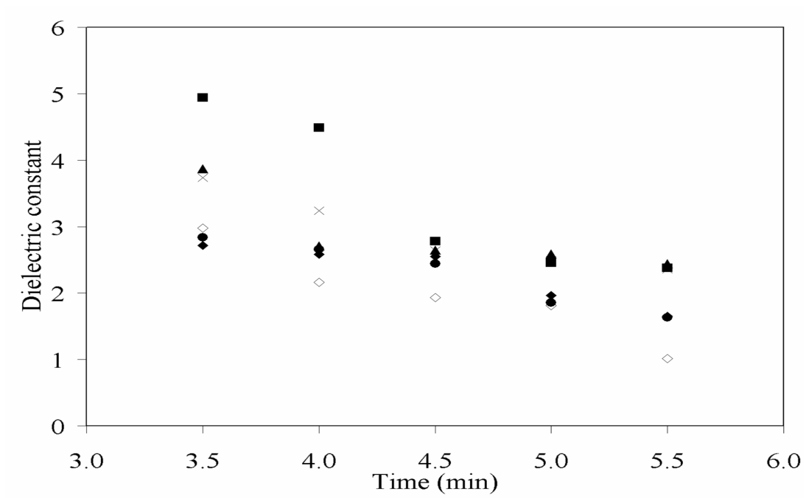


Figure 3.54 Variation of dielectric constant with baking time for cakes with different formulations baked in infrared-microwave combination oven
♦(0% F-0% P-0% L)^{bc}, ■ (25% F-0% P-0% L)^{a}, ▲(25% F-3% P-0% L)^{ab}, x (25% F-0% P-3% L)^{ab}, • (25% M-0% P-0% L)^{bc}, ◊ (25% S-0% P-0% L)^{c}

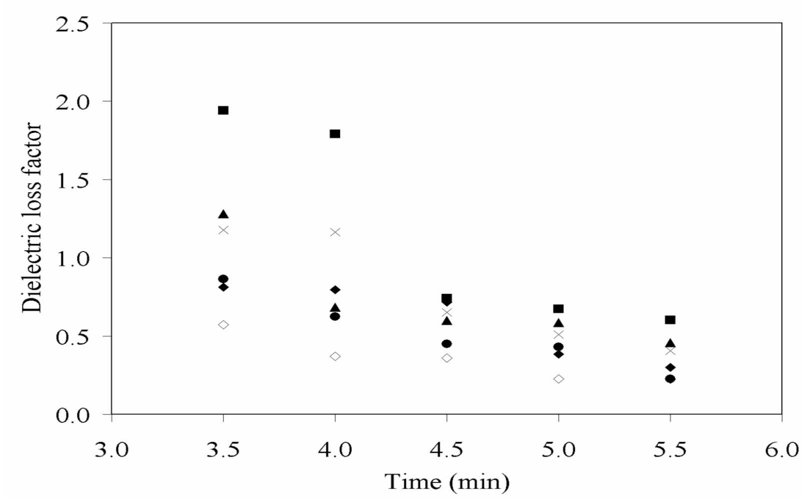


Figure 3.55 Variation of dielectric loss factor with baking time for cakes with different formulations baked in infrared-microwave combination oven
♦(0% F-0% P-0% L)^{bc}, ■ (25% F-0% P-0% L)^{a}, ▲(25% F-3% P-0% L)^{abc}, x (25% F-0% P-3% L)^{ab}, • (25% M-0% P-0% L)^{bc}, ◊ (25% S-0% P-0% L)^{c}

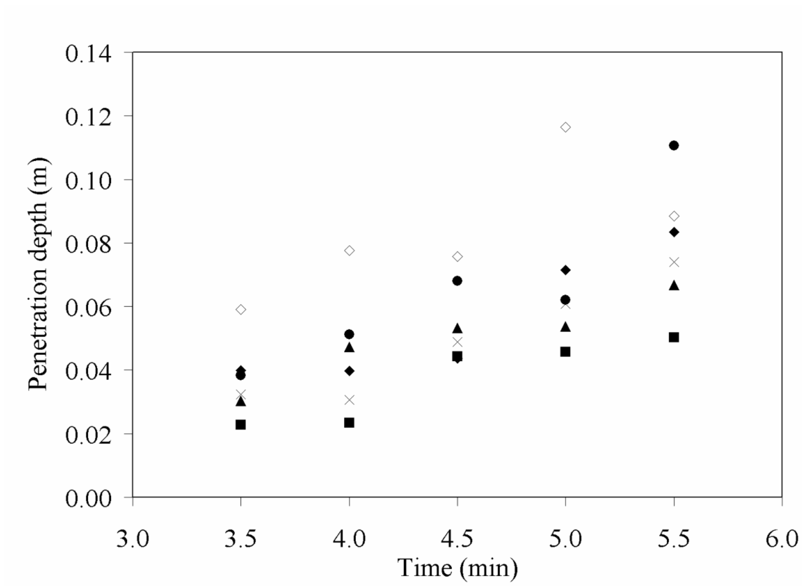


Figure 3.56 Variation of penetration depth with baking time for cakes with different formulation baked in infrared-microwave combination oven

♦ (0% F-0% P-0% L)[bc], ■ (25% F-0% P-0% L)[c], ▲(25% F-3% P-0% L)[bc], x (25% F-0% P-3% L)[bc], • (25% M-0% P-0% L)[ab], ◊ (25% S-0% P-0% L)[a]

3.4 Pore Area and Cumulative Area Fractions of Cakes

As baking time increased an increase in percent of pore area was observed for all types of baking (Figures 3.57-3.59). Upon heating, the solubility of gases reduced, and carbon dioxide was liberated with the rise in temperature. This allowed the formation of gas pool and further expansion of the heating batter. Both baking time and formulation were found to be significant on affecting the pore area of cakes baked in different ovens ($p \leq 0.05$) (Table D.38- D.40).

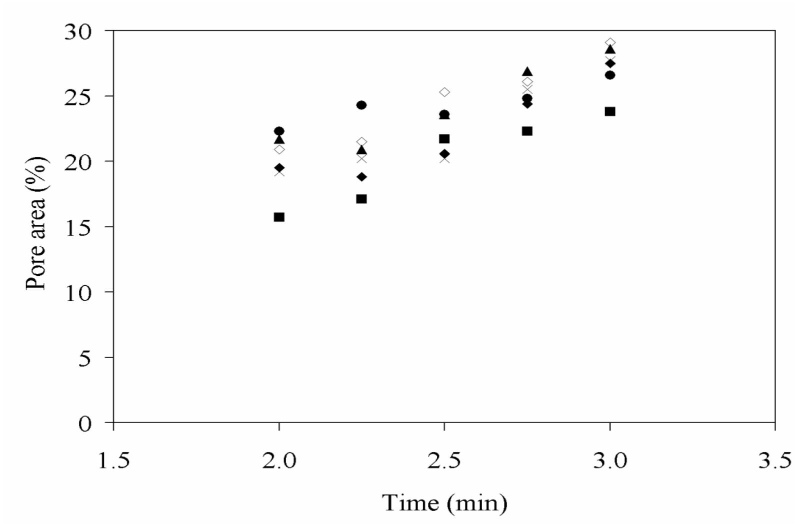


Figure 3.57 Variation of percent of pore area with baking time for cakes with different formulations baked in microwave oven

♦ (0% F-0% P-0% L)[ab], ■ (25% F-0% P-0% L)[b], ▲(25% F-3% P-0% L)[a], x (25% F-0% P-3% L)[ab], • (25% M-0% P-0% L)[a], ◊ (25% S-0% P-0% L)[a]

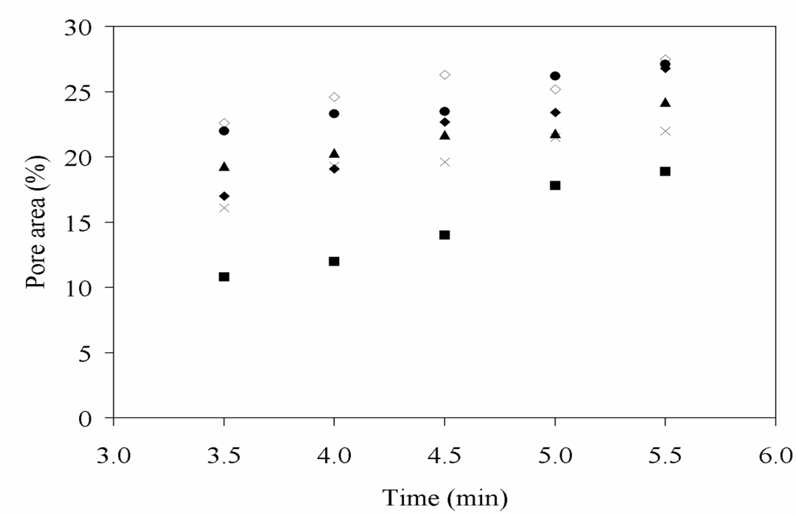


Figure 3.58 Variation of percent of pore area with baking time for cakes with different formulations baked in infrared-microwave combination oven

♦ (0% F-0% P-0% L)[b], ■ (25% F-0% P-0% L)[c], ▲(25% F-3% P-0% L)[b], x (25% F-0% P-3% L)[b], • (25% M-0% P-0% L)[a], ◊ (25% S-0% P-0% L)[a]

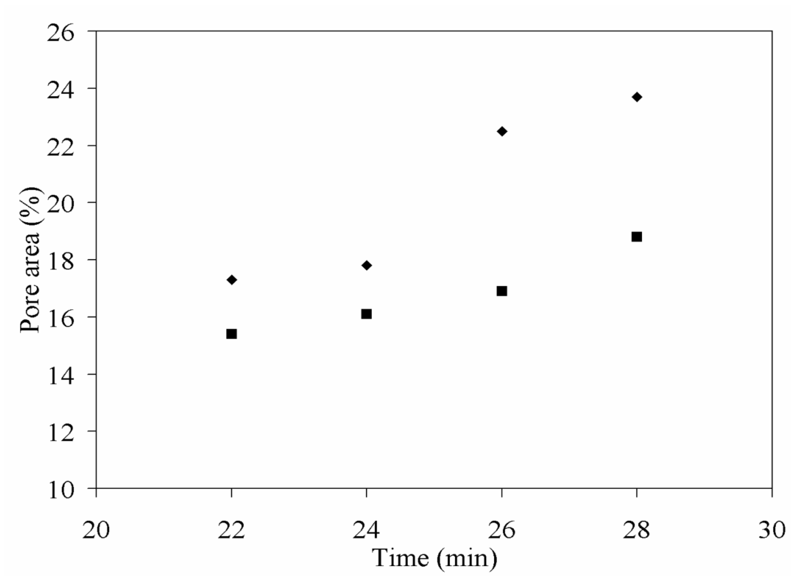


Figure 3.59 Variation of percent of pore area with baking time for cakes with different formulations baked in conventional oven
♦ (0% F)[a], ■ (25% F)[b]

When the effect of formulation on pore area was examined it can be concluded that addition of fat to the formulation ended up with a decrease in percent of pore area (Figures 3.57, 3.58 and 3.59). Similarly, addition of fat reduced the volume of cakes (Figures 3.18, 3.19 and 3.20). Increasing the amount of fat in sponge cake has been shown to decrease porosity of cakes (Roca et al., 2007). The experimental porosity data was found to be correlated with pore area results (Table B.5) which showed that image analysis was a promising method. When correlation analysis was performed, it was found that percent of pore area and volume index values of microwave, infrared-microwave combination and conventionally baked samples were significantly correlated with correlation coefficients of 0.600, 0.78 and 0.89 ($p \leq 0.001$), respectively. If it is assumed that the percent of pore area represents the porosity of the sample, it can be said that the addition of Simplesse™ resulted in a highly porous product (Figure 3.57 and

3.58). Simplesse™ might have increased the amount of gas entrapped within the structure of cake batter because of its emulsion forming property related to its protein content. Maltodextrin had similar effects on pore area as Simplesse™. It was found that the addition of each fat replacer resulted in cakes with higher volume than the samples with 25% fat baked in both microwave and infrared-microwave combination oven (Figure 3.18 and 3.19). As in the case of fat replacers, the emulsifiers added to the formulation also increased percentage of pore area as compared to 25% fat containing samples with no emulsifier (Figure 3.57 and 3.58). This result was correlated with volume index. The addition of emulsifiers increased the volume index of samples (Figure 3.18 and 3.19). Since emulsifiers increase the air retention capability of batter, a cake that expands readily could be produced and highly porous products could be obtained. Purawave™ has been previously used in microwave baked breads and it was found that addition of Purawave™ to the formulation increased the volume of microwave baked breads (Ozmutlu et al., 2001b).

When the pore formation of cakes baked at three different baking types were compared, it was observed that the cake samples baked with microwave had the highest percent of pore area values (Figure 3.57, 3.58 and 3.59). The high pressure inside the cake may have yielded a loose, void porous structure in microwave baking. The other possible reason for highly porous microwave baked cakes is the formation of unacceptable large holes in cake structure due to non-uniform heating during microwave baking. The high porosity of microwave cakes can also be seen in Figure 3.60.

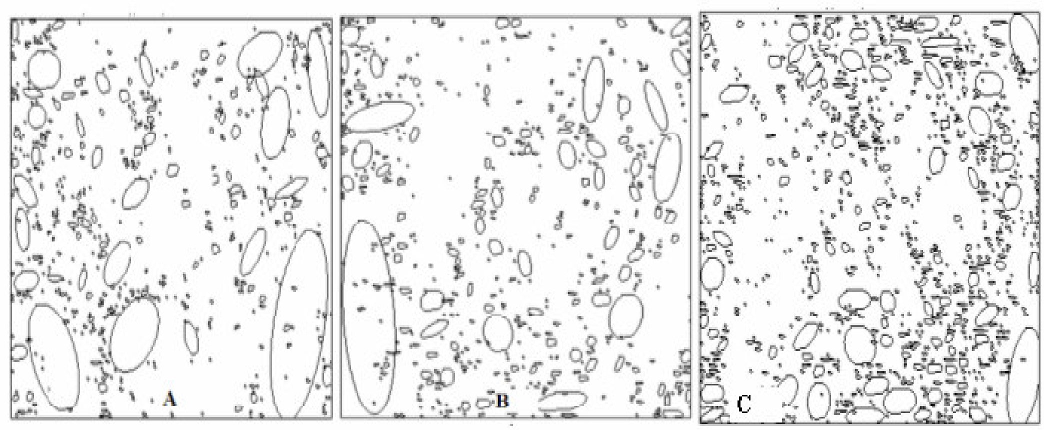


Figure 3.60 Illustration of output of software ImageJ used to determine corresponding pore area of cake samples containing 25% fat baked in different ovens (A- microwave oven, B- infrared-microwave combination oven, C- conventional oven)

In order to determine the pore size distribution of cake samples, it is more advisable in literature to use pore volume based distribution analysis (Datta et al., 2007). However, pore analysis based on area will also provide insight for pore size distribution.

Cumulative area fraction versus diameter plot of cakes baked in microwave oven is shown in Figures 3.61 at the final baking time. For microwave baking addition of fat resulted in smaller pores. For non-fat samples about 75% of the pores had diameters less than 6000 μ. Whereas, for samples containing 25% fat, this value was 5600 μ. It was found that about 70% of pores of Purawave™ containing samples had diameters less than 3000 μ, and for Lecigran™ containing samples, this value was 6400 μ (Figure 3.61). This shows that addition of Purawave™ resulted in smaller pores in microwave oven. Although Purawave™ containing samples have small pores, their porosity values were quite high (Figure

3.57 and 3.61). The type and amount of emulsifier used can affect bubble structure and distribution which affect the final structure of the product (Sahi and Alava, 2003). When maltodextrin was added to the cake recipe, 75% of the pores had diameter less than about 5900 μ. The highest pore diameter was obtained for Simplesse™ containing samples (83% of pores had diameter less than 12600 μ). Addition of fat replacers to the formulation caused very large pores in the structure. The resulted large voids may be responsible for the high percent of pore area of samples and high volume index (Figure 3.57 and 3.18). When cumulative area fraction of microwave baked cakes with different formulations were compared, it can be concluded that Purawave™ added samples had the most uniform pore size distribution. Sahi and Alava (2003) showed that addition of emulsifier at high concentration to the cake batter resulted in uniform distribution of bubbles.

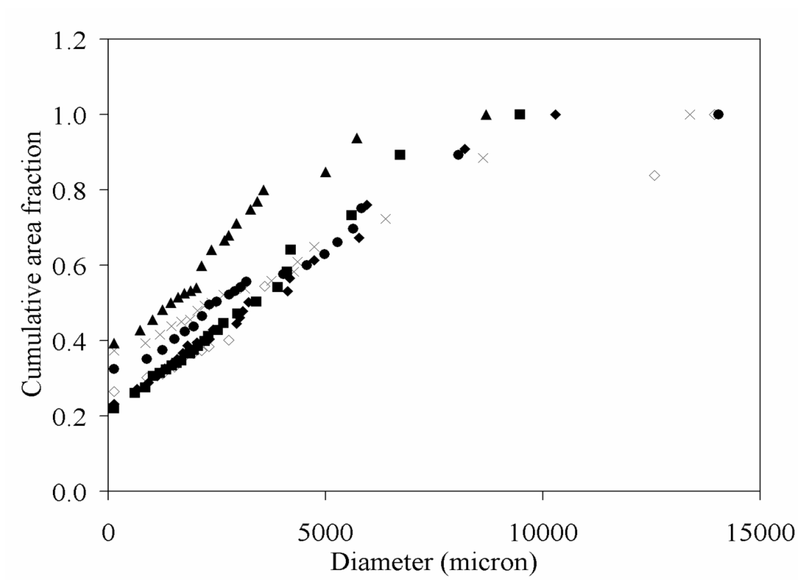


Figure 3.61 Variation of cumulative area fraction with diameter for cakes with different formulations baked in microwave oven for 3 minutes

♦ 0% F-0% P-0% L, ■ 25% F-0% P-0% L, ▲25% F-3% P-0% L, x 25% F-0% P-3% L, • 25% M-0% P-0% L, ◊ 25% S-0% P-0% L

When cumulative area fraction of the cakes baked in infrared-microwave combination oven was determined, it was seen that about 70% pores of samples containing Purawave^{TM} and Lecigran^{TM} had diameters with similar size (less than about 4800 μ) (Figure 3.62). For cakes formulated with maltodextrin, the diameters of 70% of the pores were less than 1400 μ. Since this diameter was less than that of 25% fat containing samples with no emulsifiers (less than 4000 μ), it can be concluded that addition of maltodextrin to the formulation provided smaller pores and more uniform structure. Although the pores were smaller in the case of maltodextrin added samples, percent area of pores formed in these samples were higher since the number of pores were higher (Figure 3.58). For Simplesse^{TM}, very large pores were observed in the structure causing the highest pore area values (Figure 3.58).

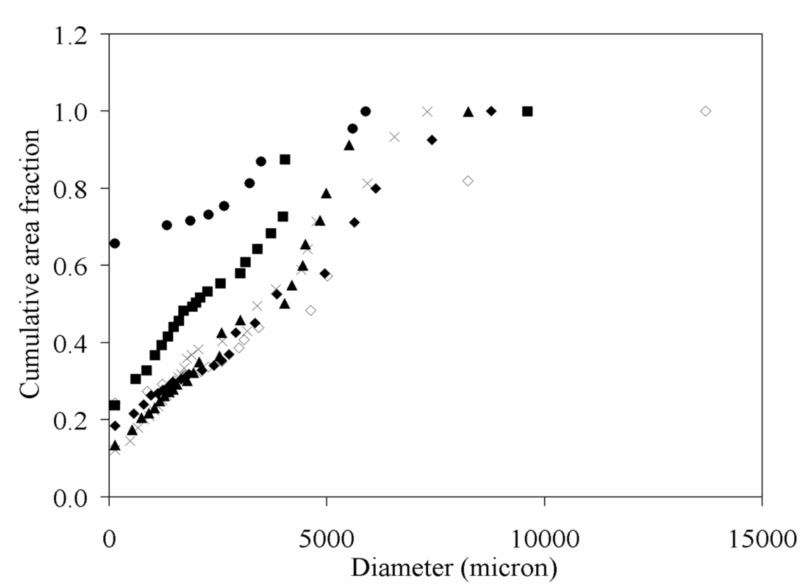


Figure 3.62 Variation of cumulative area fraction with diameter for cakes with different formulations baked in infrared-microwave combination oven for 5.5 minutes

♦ 0% F-0% P-0% L, ■ 25% F-0% P-0% L, ▲25% F-3% P-0% L, x 25% F-0% P-3% L, • 25% M-0% P-0% L, ◊ 25% S-0% P-0% L

For conventional baking the distribution of pores was more uniform than the other types of baking (Figure 3.63). Total pore count of conventional baked cakes was also relatively higher than that of cakes baked by other methods. The total pore count of microwave, infrared-microwave combination and conventionally baked cakes are 552, 540 and 2740, respectively. For nonfat samples the diameters of 70% of the pores were less than 2800 μ, whereas for 25% fat containing cakes this value was 2300 μ. When the three baking methods were compared for not fat and 25% fat containing samples, pore diameter of microwave, infrared-microwave combination and conventionally baked cakes ranged (126.8 μ - 10290.2 μ), (126.8 μ - 9611.7 μ) and (25.7 μ – 5726.9 μ), respectively. This showed that the smaller pores can be obtained by conventional baking. The results of scanning electron microscopy have shown that air cells of microwave baked cakes were coarser than those found in the conventional cake (Martin and Tsen, 1981).

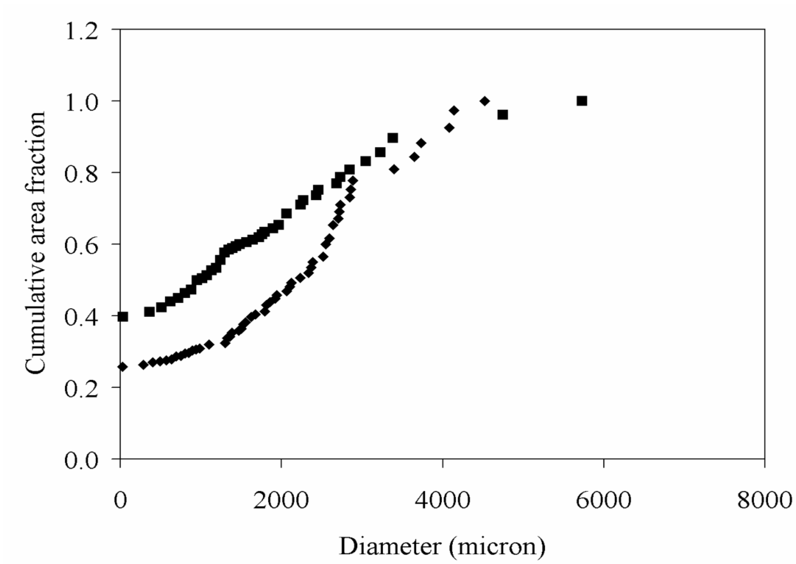


Figure 3.63 Variation of cumulative area fraction with diameter for cakes with different formulations baked in conventional oven for 28 minutes

♦ 0% F, ■ 25% F

3.5 Microstructure of Cakes

The Scanning Electron Microscopy (SEM) images of samples baked in the microwave and infrared-microwave combination oven for each formulation were shown in Figure 3.64 and 3.65, respectively. When the SEM images of cake samples (baked in microwave oven) with different formulations were compared, it was found that addition of fat to the formulation resulted in a very different structure as compared to the non-fat, fat replacer and emulsifier containing formulations (Figure 3.64). Simplesse^{TM} containing samples had smooth surfaces due to the formation of plain structure after drying of protein in both types of ovens (Figure 3.64 and 3.65). Since all the other ingredients and protein covered over the starch granules, it was hard to drive and quantify exact information about the shape and size of starch granules.

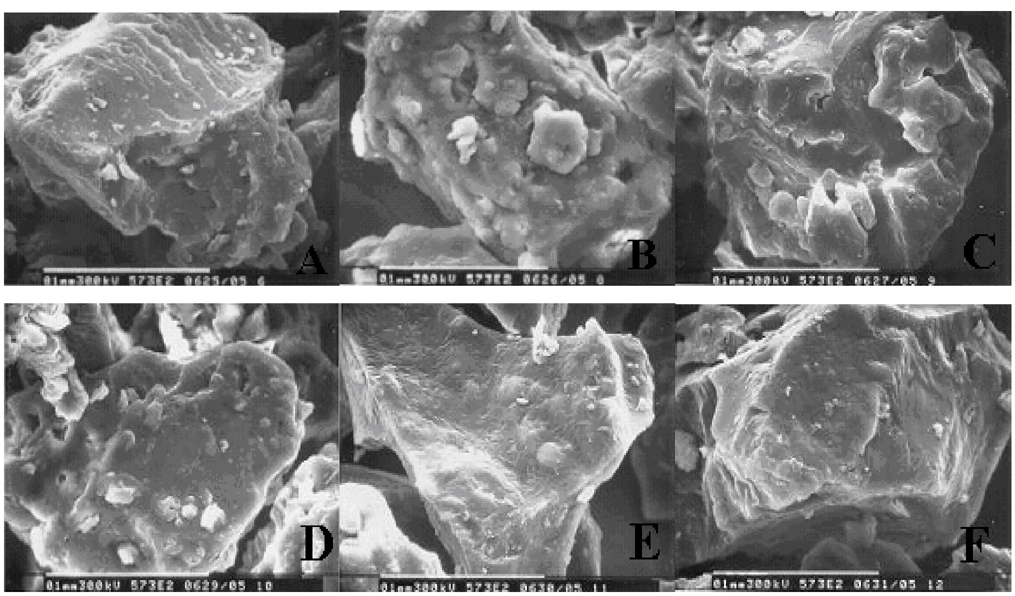


Figure 3.64 SEM images of cake samples with different formulation baked in microwave oven for 3 minutes (A: 0% Fat, B: 25% Fat, C: 3% Purawave^{TM}, D: 3% Lecigran^{TM}, E: 25% Maltodextrin, F: 25% Simplesse^{TM})

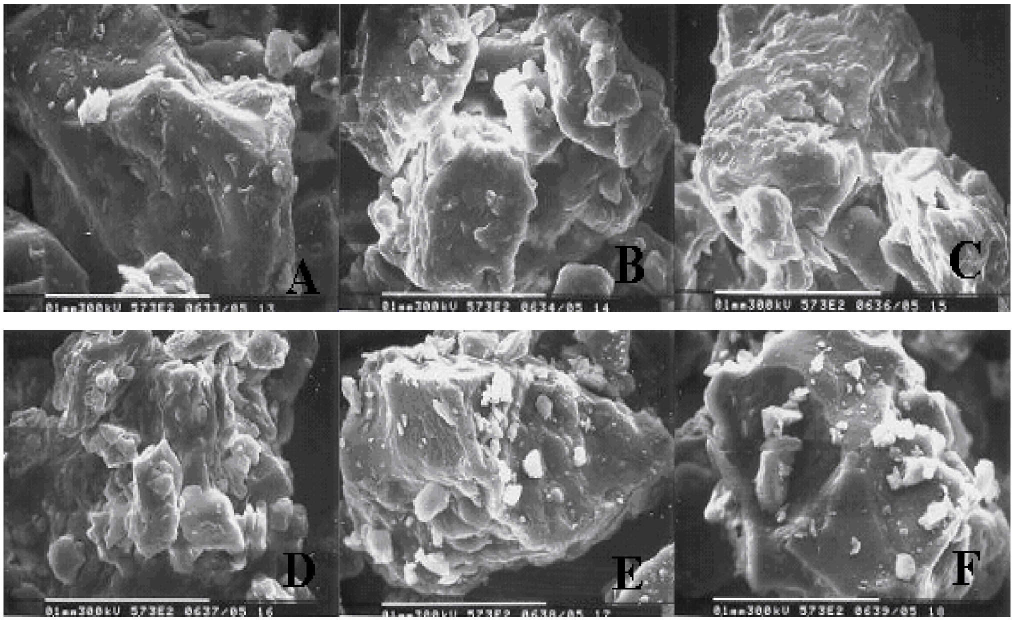


Figure 3.65 SEM images of cake samples with different formulation baked in infrared- microwave combination oven for 5.5 minutes (A: 0% Fat, B: 25% Fat, C: 3% Purawave^{TM}, D: 3% Lecigran^{TM}, E: 25% Maltodextrin, F: 25% Simplesse^{TM})

3.6 Gelatinization Degree

Gelatinization degree of cake samples were determined by differential scanning calorimeter and rapid visco analyzer. Then, the results were compared.

3.6.1 Differential Scanning Calorimeter

DSC endotherms of cakes with different formulations baked in different ovens were shown in Figure E.1-E.18. When the gelatinization degree of cake samples was investigated, it was found that an increase in baking time resulted in an increase in the gelatinization degree for all types of baking (Figure 3.66, 3.67

and 3.68). This may be due to the higher temperature and longer processing time. In the case of microwave and infrared-microwave combination baking, addition of fat to the formulation caused higher gelatinization degree (Figure 3.66 and 3.67), this was because of the higher dielectric properties of the samples with higher fat content (Figure 3.48, 3.49, 3.51 and 3.52). Due to its higher dielectric properties, the sample with higher fat content heated more within same baking time. Higher temperature ended up with higher gelatinization degree. On the other hand, for conventional baking, since the dielectric properties did not affect the heating mechanism, the non-fat samples experienced higher gelatinization degree (Figure 3.68). This may be because of the fact that fats are known to delay starch gelatinization by delaying the transport of water into the starch granule due to the formation of complexes between the lipid and amylose during baking (Elliasson, 1985; Ghiasi et al., 1982; Larsson, 1980).

This study showed that microwave baking caused insufficient gelatinization for cake baking. When three different baking types were compared in terms of gelatinization degree values, it was concluded that assisting microwaves with infrared waves seemed to solve the gelatinization problem of microwave baking by surface heating of the product (Figure 3.66, 3.67 and 3.68).

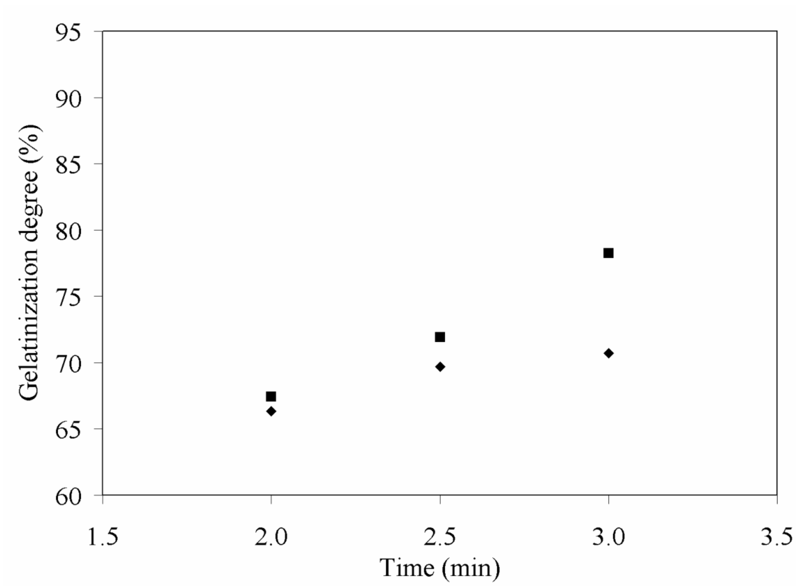


Figure 3.66 Variation of gelatinization degree with baking time for cakes with different formulations baked in microwave oven

♦ 0% F, ■ 25% F

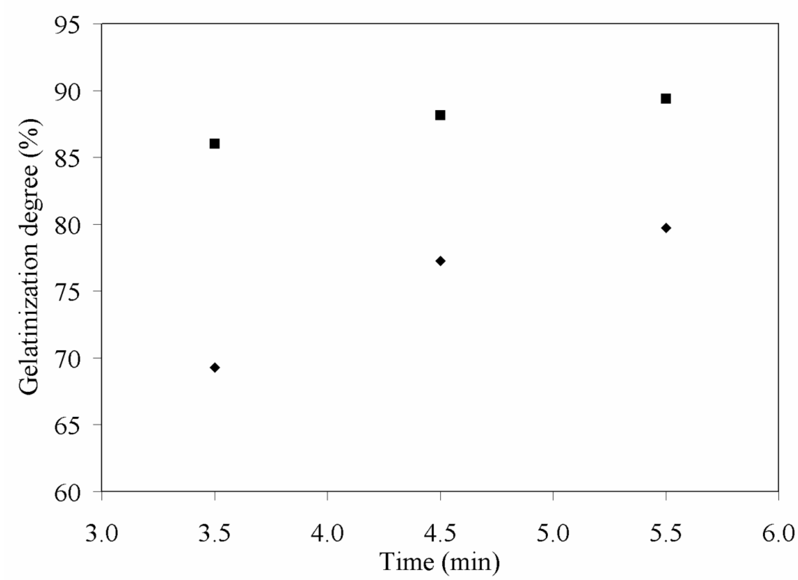


Figure 3.67 Variation of gelatinization degree with baking time for cakes with different formulations baked in infrared-microwave combination oven

♦ 0% F, ■ 25% F

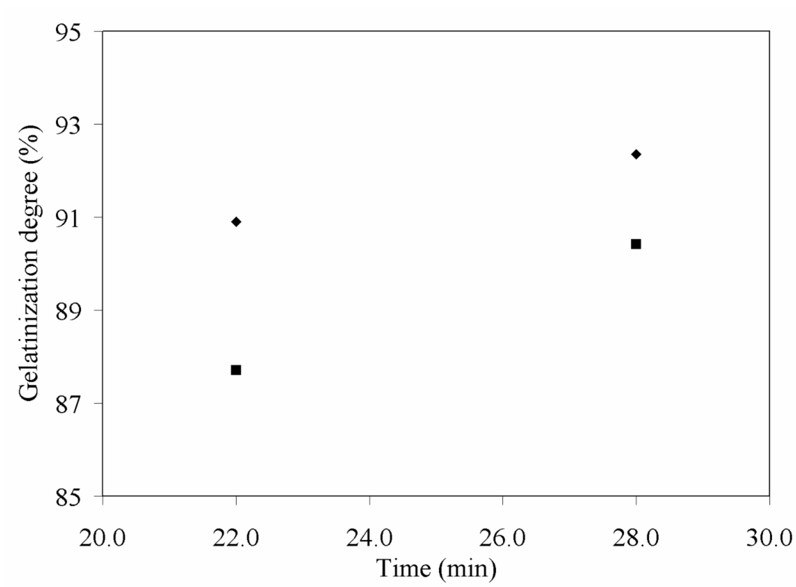


Figure 3.68 Variation of gelatinization degree with baking time for cakes with different formulations baked in conventional oven

♦ 0% F, ■ 25% F

3.6.2 Rapid Visco Analyzer

Generally, when we go through the data obtained from RVA measurements, it was seen that the same discussion with DSC data was valid for RVA data. In fact gelatinization degree was found to be correlated with peak viscosity (constant=-0.878, p=0.000). For both formulations, it was observed that an increase in baking time caused a decrease in peak viscosity, showing that more gelatinization occurred during longer baking time (Table 3.4 and Table 3.5, Figure 3.69 and 3.70).

When the profiles and peak viscosity values for two different formulations were investigated, similar with DSC, it can be concluded that mostly fat added samples had lower peak viscosities with respect to non-fat samples for microwave and combination baking (Table 3.4 and Table 3.5, Figure 3.69 and 3.70). This means, due to higher dielectric properties of fat added samples, they experienced higher gelatinization during microwave and combination baking. But, when the data for conventional baking were investigated, it was concluded that the peak viscosity of fat added samples were higher which means, lower gelatinization (Table 3.4 and Table 3.5, Figure 3.69 and 3.70).

If microwave and infrared-microwave combination baking were compared, higher RVA values were observed for microwave baked cakes than the infrared-microwave combination baked ones. This indicates that a higher level of gelatinization occurred during baking of infrared-microwave combination baked cakes. The peak viscosity values for infrared-microwave combination baking were almost equal to the ones for conventional baking which means combination baking solved the insufficient gelatinization problem of microwave baking.

Table 3.4 RVA characteristics of non-fat cake samples

Baking condition	Peak Visc (cp)	Trough1 (cp)	Break Down (cp)	Final Visc (cp)	Set back	Peak Time (s)
Batter	190.00	162.00	28.00	376.00	214.00	6.20
Conventional 22 min	92.00	71.00	21.00	135.00	64.00	6.80
Conventional 28 min	74.00	60.00	14.00	124.00	64.00	6.87
Microwave 2 min	176.00	161.00	15.00	233.50	72.50	6.17
Microwave 2.5 min	163.50	130.00	33.50	232.50	102.50	5.97
Microwave 3 min	127.50	110.50	17.00	199.00	88.50	6.43
Combination3.5 min	149.00	116.00	33.00	208.00	85.00	6.40
Combination 4.5 min	123.33	99.67	23.67	171.67	72.00	6.80
Combination 5.5 min	97.33	81.00	16.33	123.00	42.00	6.93

Table 3.5 RVA characteristics of cake samples containing 25% fat

Baking condition	Peak Visc (cp)	Trough1 (cp)	Break Down (cp)	Final Visc (cp)	Set back	Peak Time (s)
Batter	198.00	183.00	15.00	356.00	173.00	6.57
Conventional 22 min	94.00	78.00	16.00	124.00	46.00	6.93
Conventional 28 min	80.00	57.00	23.00	129.00	72.00	6.53
Microwave 2 min	175.00	158.00	17.00	264.00	106.00	6.00
Microwave 2.5 min	172.00	127.00	45.00	236.50	109.50	5.93
Microwave 3 min	147.33	117.33	30.00	212.00	94.67	6.04
Combination3.5 min	136.00	117.00	19.00	210.00	93.00	6.60
Combination 4.5 min	116.00	81.50	34.50	143.00	61.50	6.93
Combination 5.5 min	96.50	73.00	23.50	132.50	59.50	6.63

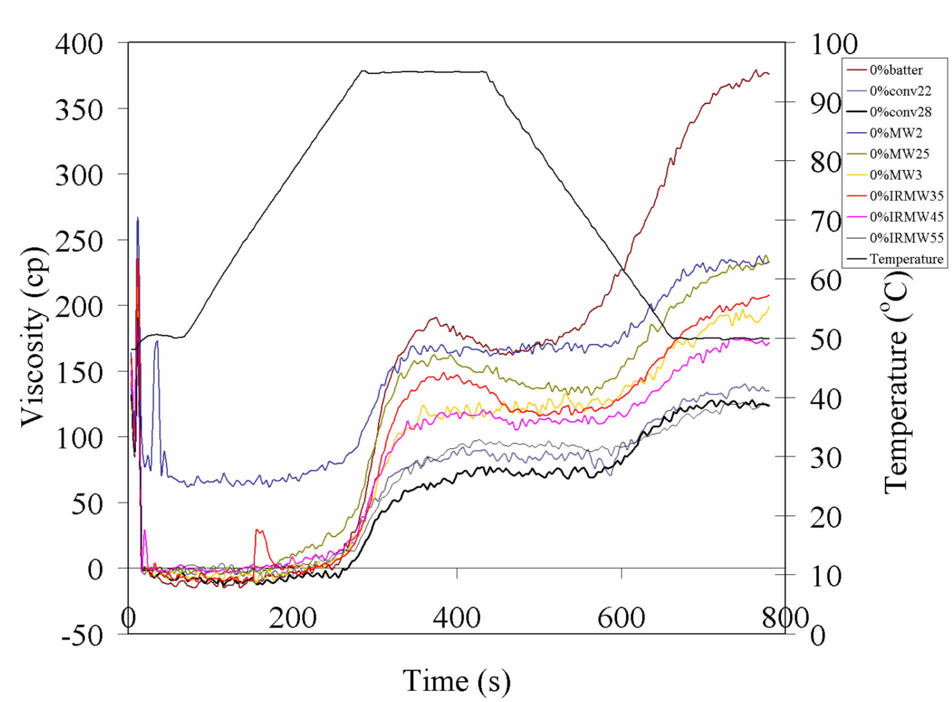


Figure 3.69 Variation of viscosity with time for non-fat cakes baked in different ovens and for different baking times (conv22: 22 min conventional baking, conv28: 28 min conventional baking, MW2: 2 min microwave baking, MW25: 2.5 min microwave baking, MW3: 3 min microwave baking, IRMW35: 3.5 infrared-microwave combination baking, IRMW45: 4.5 infrared-microwave combination baking, IRMW55: 5.5 infrared-microwave combination baking)

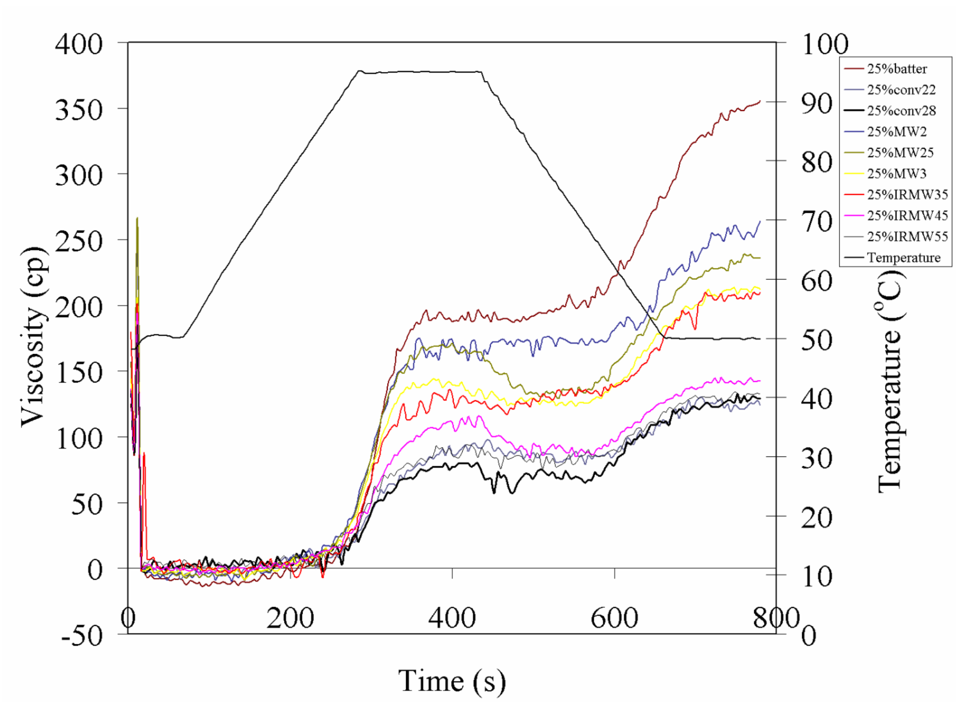


Figure 3.70 Variation of viscosity with time for cakes with 25% fat content baked in different ovens and for different baking times (conv22: 22 min conventional baking, conv28: 28 min conventional baking, MW2: 2 min microwave baking, MW25: 2.5 min microwave baking, MW3: 3 min microwave baking, IRMW35: 3.5 infrared-microwave combination baking, IRMW45: 4.5 infrared-microwave combination baking, IRMW55: 5.5 infrared-microwave combination baking)

3.7 Temperature Distribution

For microwave heating, reaching to maximum temperature took approximately 75 seconds, for infrared-microwave combination it took 175 seconds. This difference is because of the beakers containing water placed inside of the oven during combination baking to prevent excessive drying of sample. After that time it remained constant at that temperature (Figure 3.71 and 3.72).

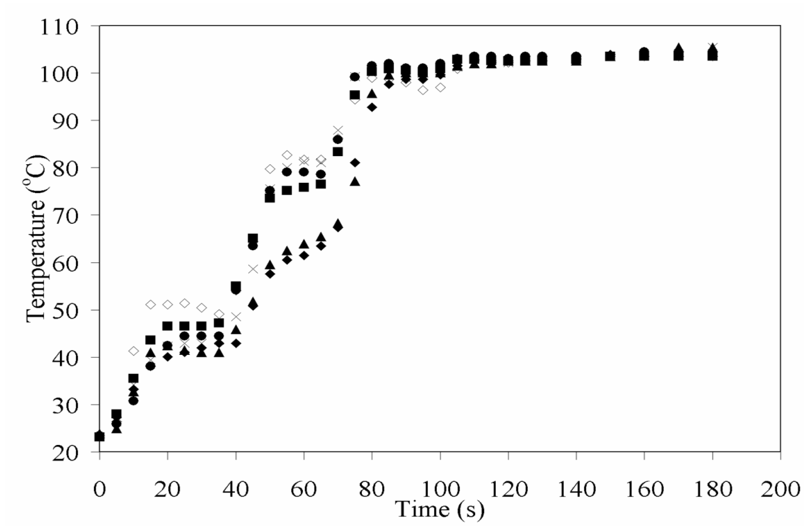


Figure 3.71 Temperature distribution of cakes with different formulations during baking in microwave oven

♦ 0% F-0% P-0% L, ■ 25% F-0% P-0% L , ▲ 25% F-3% P-0% L, x 25% F-0% P-3% L, • 25% M-0% P-0% L, ◊ 25% S-0% P-0% L

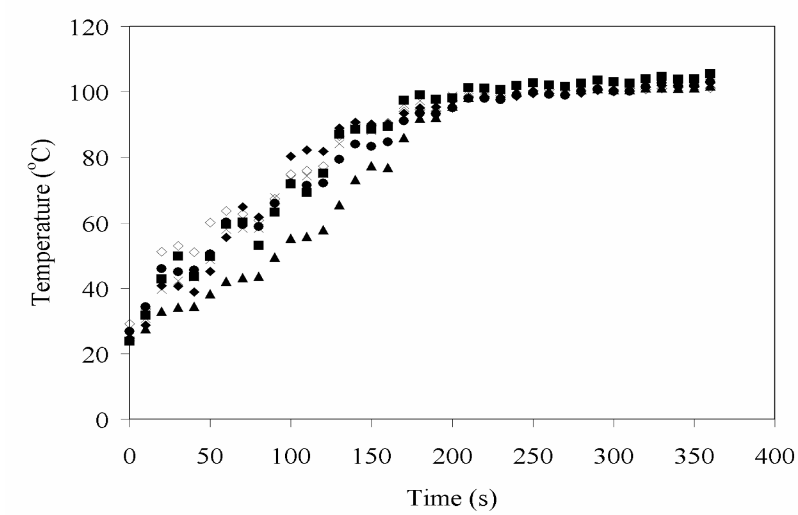


Figure 3.72 Temperature distribution of cakes with different formulations during baking in infrared-microwave combination oven

♦ 0% F-0% P-0% L, ■ 25% F-0% P-0% L , ▲ 25% F-3% P-0% L, x 25% F-0% P-3% L, • 25% M-0% P-0% L, ◊ 25% S-0% P-0% L

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

In this study, it was aimed to determine the variation of physical properties of different cake formulations during baking in microwave and infrared-microwave combination ovens.

In rheological measurements, the power law model was found to fit the experimental data very well. No significant difference was determined between the flow behaviour indices of different cake formulations, but consistency index decreased with increasing fat content and addition of emulsifier. All cake batters exhibited shear thinning and time-independent behaviour.

Formulation had a significant effect on most of the physical properties of the cakes. Addition of fat to the formulation provided softer cake samples. It also increased the gelatinization degree of the samples due to higher dielectric properties of fat. For microwave baking, emulsifier, Purawave^{TM} can be recommended to be used due to its higher dielectric properties and ability to provide more uniform pore size distribution as compared to the cakes containing Lecigran^{TM}. Adding maltodextrin to cake recipe may be a promising way to obtain low calorie foods in infrared-microwave combination oven. Maltodextrin resulted in products with high volume, soft texture, more porous structure and uniform pore diameters. Although protein based fat replacer, Simplesse^{TM}, added formulations had high specific volume, usage of Simplesse^{TM} in microwave and infrared-microwave combination oven is not recommended due to their hard texture. This conflict was believed to occur because of the interaction of microwaves with protein structure. Moreover, Simplesse^{TM} added products had very large pores in their structure.

Baking time was also found to be significantly effective on physical properties. It was shown that an increase in baking time increased hardness, gumminess, porosity, ΔE value, weight loss and starch gelatinization of cake samples. Whereas, increasing baking time provided a decrease in springiness, dielectric constant and loss factor of samples. Dielectric properties of the cakes were found to be affected by porosity of samples. Dielectric properties and penetration depth are the electrical properties which play an important role in understanding the interaction of microwave energy with foods. In this respect, the data obtained in this study can be useful in modeling and development of microwave and infrared-microwave combination baked products.

Image analysis was found to be a promising tool to determine pore area. Porous structure of cakes baked by different methods was found to be different due to the differences in heating mechanisms. The cake samples baked with microwave had the highest percentage of pore area values.

This study showed that gelatinization was not completed in microwave baked cakes. When different baking methods were compared in terms of degree of starch gelatinization, assisting microwaves with infrared seemed to solve the insufficient starch gelatinization problem observed in microwave baking.

Usage of emulsifier, Purawave^{TM} and carbohydrate based fat replacer, maltodextrin can be recommended for microwave and combination baking. The effects of some other ingredients (emulsifiers, gums, etc.) may be studied to obtain the best formulation in terms of product quality in a future work. In addition, as further research, heat transfer during microwave-infrared combination baking can be modelled. Finally, it is strongly recommended to study on the special interaction of proteins and microwaves, since there is no information about this topic in the literature yet.

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APPENDIX A

MODEL CONSTANTS

Table A.1 Model constants for ΔE values of different formulated cakes baked in infrared-microwave combination oven (F: Fat, P: Purawave^{TM}, L: Lecigran^{TM}, M: Maltodextrin, S: Simplesse^{TM})

y = ax + b			
	0% F-0% P-0% L	25% F-0% P-0% L	25% F-3% P-0% L
a	10.551	11.711	11.407
b	1.893	-6.827	-7.562
r^2	0.962	0.995	0.859
	25% F-0% P-3% L	25% M-0% P-0% L	25% S-0% P-0% L
a	11.653	13.446	13.327
b	-8.074	-11.827	-6.704
r^2	0.961	0.996	0.990

Table A.2 Model constants for ΔE values of different formulated cakes baked in conventional oven (F: Fat)

y = ax + b		
	0% F	25% F
a	1.946	2.006
b	-6.447	-4.662
r^2	0.894	0.977

Table A.3 Model constants for weight loss values of different formulated cakes baked in microwave oven (F: Fat, P: Purawave^{TM}, L: Lecigran^{TM}, M: Maltodextrin, S: Simplesse^{TM})

y = ax + b			
	0% F-0% P-0% L	25% F-0% P-0% L	25% F-3% P-0% L
a	7.425	6.596	5.621
b	-10.829	-8.558	-6.683
r^2	0.957	0.985	0.935
	25% F-0% P-3% L	25% M-0% P-0% L	25% S-0% P-0% L
a	6.608	6.224	6.830
b	-9.467	-7.596	-9.389
r^2	0.983	0.999	0.992

Table A.4 Model constants for weight loss values of different formulated cakes baked in infrared-microwave combination oven (F: Fat, P: Purawave^{TM}, L: Lecigran^{TM}, M: Maltodextrin, S: Simplesse^{TM})

y = ax + b			
	0% F-0% P-0% L	25% F-0% P-0% L	25% F-3% P-0% L
a	4.538	4.626	4.419
b	-11.154	-11.986	-11.347
r^2	0.849	0.974	0.958
	25% F-0% P-3% L	25% M-0% P-0% L	25% S-0% P-0% L
a	2.516	4.086	3.198
b	-2.646	-8.038	-3.958
r^2	0.911	0.994	0.989

Table A.5 Model constants for weight loss values of different formulated cakes baked in conventional oven (F: Fat)

y = ax + b		
	0% F	25% F
a	0.279	0.226
b	-2.488	-0.897
r^2	0.989	0.998

APPENDIX B

CORRELATION COEFFICIENTS

Table B.1 Correlation coefficients of rheology of cake batters and hardness of cake samples baked in microwave and combination ovens

	Correlation coefficient	P value
Microwave oven	0.627	0.111
Infrared-microwave combination oven	0.902	0.065

Table B.2 Correlation coefficients of rheology of cake batters and volume index of cake samples baked in microwave and combination ovens

	Correlation coefficient	P value
Microwave oven	-0.538	0.319
Infrared-microwave combination oven	-0.949	0.034

Table B.3 Correlation coefficients of volume index and hardness of different formulated cakes baked in microwave oven, infrared-microwave combination oven and conventional oven

	Correlation coefficient	P value
Microwave oven	0.593	0.001
Infrared-microwave combination oven	0.610	0.000
Conventional oven	0.850	0.007

Table B.4 Correlation coefficients of porosity and volume index of different formulated cakes baked in microwave oven, infrared-microwave combination oven and conventional oven

	Correlation coefficient	P value
Microwave oven	0.333	0.072
Infrared-microwave combination oven	0.600	0.000
Conventional oven	0.855	0.007

Table B.5 Correlation coefficients of experimental porosity data and pore area of different formulated cakes baked in microwave oven, infrared-microwave combination oven and conventional oven

	Correlation coefficient	P value
Microwave oven	0.724	0.000
Infrared-microwave combination oven	0.429	0.018
Conventional oven	0.974	0.000

APPENDIX C

MULTIPLE REGRESSION EQUATIONS

Table C.1 The constants of multiple regression equations of dielectric constant of cake samples baked in microwave and infrared-microwave combination oven.

	Dielectric Constant			
	Microwave Baking		IR-MW Combination Baking	
Term	Constant	p value	Constant	p value
A	59.200	0.074	102.000***	0.000
X_1	-0.591	0.490	-1.920**	0.002
X_2	-1.490	0.130	-2.720**	0.002
X_1^2	0.010	0.168	-0.026**	0.009
X_2^2	0.008	0.573	0.018**	0.006
X_1X_2	0.004	0.739	0.034***	0.001
r^2	0.758		0.876	

* means significant at p≤0.05, ** means significant at p≤0.01, *** means significant at p≤0.001

$Y=A+BX_1+CX_2+DX_1^2+EX_2^2+FX_1X_2$ (where A, B, C, D, E, F are constants, X_1 is weight loss, X_2 is porosity, Y is dielectric constant)

Table C.2 The constants of multiple regression equations of dielectric loss factor of cake samples baked in microwave and infrared-microwave combination oven.

	Dielectric Loss Factor			
	Microwave Baking		IR-MW Combination Baking	
Term	Constant	p value	Constant	p value
A	39.900*	0.018	44.800**	0.004
X_1	-0.358	0.400	-0.987**	0.005
X_2	-1.040*	0.036	-1.170*	0.015
X_1^2	0.012	0.110	-0.008	0.134
X_2^2	0.007	0.052	0.008*	0.041
X_1X_2	0.001	0.835	0.016**	0.007
r^2	0.811		0.840	

* means significant at $p \leq 0.05$, ** means significant at $p \leq 0.01$, *** means significant at $p \leq 0.001$

$Y=A+BX_1+CX_2+DX_1^2+EX_2^2+FX_1X_2$ (where A, B, C, D, E, F are constants, X_1 is weight loss, X_2 is porosity, Y is dielectric loss factor)

APPENDIX D

ANOVA and TUKEY TEST TABLES

Table D.1 Significant effect of cake formulation on flow behavior index

Factor	Type	Levels	N	Values
Formulation	Fixed	15	2	0% Fat, 3% Purawave^{TM}, 3% Lecigran^{TM}, 12.5% Fat, 12.5% Fat and 3 % Purawave^{TM}, 12.5% Fat and 3 % Lecigran^{TM}, 25% Fat, 25%Fat and 3 % Purawave^{TM}, 25% Fat and 3 % Lecigran^{TM}, 37.5% Fat, 37.5% Fat and 3 % Purawave^{TM}, 37.5% Fat and 3 % Lecigran^{TM}, 50% Fat, 50%Fat and 3 % Purawave^{TM}, 50% Fat and 3 % Lecigran^{TM}

ANOVA Results

Source	DF	SS	MS	F	P
Formulation	14	0.002629	0.000188	0.96	0.533
Error	14	0.002750	0.000196		
Total	28	0.005379			

Table D.2 Two way ANOVA and Tukey Simultaneous Test Table for specific volume of cakes baked in microwave oven with respect to formulation and baking time (0-0-0: 0% Fat, 25-0-0: 25% Fat, 25-0-3: 25% Fat and 3 % Lecigran™, 25-3-0: 25% Fat and 3% Purawave™)

Factor	Type	Levels	Values
Time	Fixed	5	2.00, 2.25, 2.50, 2.75, 3.00
Formulation	Fixed	6	0-0-0, 25-0-0, 25-0-3, 25-3-0, maltodextrin, Simplesse™

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	4	0.15225	0.15225	0.03806	1.14	0.365
Formulation	5	5.48099	5.48099	1.09620	32.89	0.000
Error	20	0.66657	0.66657	0.03333		
Total	29	6.29981				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:			
Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	-0.0113	0.1155	1.0000
25-0-3	0.3044	0.1155	0.1341
25-3-0	0.4297	0.1155	0.0147
maltodextrin	-0.0444	0.1155	0.9987
Simplesse™	1.1810	0.1155	0.0000
Formulation = 25-0-0 subtracted from:			
25-0-3	0.3157	0.1155	0.1118
25-3-0	0.4411	0.1155	0.0118

maltodextrin	-0.0331	0.1155	0.9997
Simplesse™	1.1913	0.1155	0.0000
Formulation = 25-0-3 subtracted from:			
25-3-0	0.1254	0.1155	0.8813
maltodextrin	-0.3488	0.1155	0.0641
Simplesse™	0.8756	0.1155	0.0000
Formulation = 25-3-0 subtracted from:			
maltodextrin	-0.4742	0.1155	0.0063
Simplesse™	0.7502	0.1155	0.0000
Formulation = maltodextrin subtracted from:			
Simplesse™	1.2240	0.1155	0.0000

Table D.3 Two way ANOVA and Tukey Simultaneous Test Table for specific volume of cakes baked in infrared-microwave combination oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	5	3.50, 4.00, 4.50, 5.00, 5.50
Formulation	Fixed	6	0-0-0, 25-0-0, 25-0-3, 25-3-0, maltodextrin, Simplesse™

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	4	0.46325	0.46325	0.11581	2.04	0.128
Formulation	5	5.61782	5.61782	1.12356	19.76	0.000
Error	20	1.13741	1.13741	0.05687		
Total	29	7.21848				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	-1.0000	0.1508	0.0000
25-0-3	-0.2820	0.1508	0.4469
25-3-0	-0.7870	0.1508	0.0005
maltodextrin	-0.0130	0.1508	1.0000
Simplesse™	0.1740	0.1508	0.8520

Formulation = 25-0-0 subtracted from:

25-0-3	0.7183	0.1508	0.0015
25-3-0	0.2136	0.1508	0.7175

maltodextrin	0.9877	0.1508	0.0000
Simplesse^{TM}	1.1747	0.1508	0.0000
Formulation = 25-0-3 subtracted from:			
25-3-0	-0.5047	0.1508	0.0328
maltodextrin	0.2695	0.1508	0.4956
Simplesse^{TM}	0.4565	0.1508	0.0634
Formulation = 25-3-0 subtracted from:			
maltodextrin	0.7742	0.1508	0.0006
Simplesse^{TM}	0.9612	0.1508	0.0001
Formulation = maltodextrin subtracted from:			
Simplesse^{TM}	0.1870	0.1508	0.8125

Table D.4 Two way ANOVA and Tukey Simultaneous Test Table for specific volume of cakes baked in conventional oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	4	22, 24, 26, 28
Formulation	Fixed	2	0-0-0, 25-0-0

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	3	0.002173	0.002173	0.000724	0.16	0.914
Formulation	1	0.380090	0.380090	0.380090	85.78	0.003
Error	3	0.013294	0.013294	0.004431		
Total	7	0.395557				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	-0.4359	0.0471	0.0027

Table D.5 Two way ANOVA and Tukey Simultaneous Test Table for volume index of cakes baked in microwave oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	5	2.00, 2.25, 2.50, 2.75, 3.00
Formulation	Fixed	6	0-0-0, 25-0-0, 25-0-3, 25-3-0, maltodextrin, Simplesse^{TM}

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	4	33.895	33.895	8.474	15.90	0.000
Formulation	5	627.471	627.471	125.494	235.54	0.000
Error	20	10.656	10.656	0.533		
Total	29	672.021				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	-2.8700	0.4616	0.0001
25-0-3	0.8600	0.4616	0.4515
25-3-0	3.9310	0.4616	0.0000
maltodextrin	8.2470	0.4616	0.0000
Simplesse^{TM}	10.0630	0.4616	0.0000

Formulation = 25-0-0 subtracted from:

25-0-3	3.7300	0.4616	0.0000
25-3-0	6.8010	0.4616	0.0000
maltodextrin	11.1170	0.4616	0.0000

Simplesse™	12.9340	0.4616	0.0000
Formulation = 25-0-3 subtracted from:			
25-3-0	3.0710	0.4616	0.0000
maltodextrin	7.3870	0.4616	0.0000
Simplesse™	9.2030	0.4616	0.0000
Formulation = 25-3-0 subtracted from:			
maltodextrin	4.3160	0.4616	0.0000
Simplesse™	6.1330	0.4616	0.0000
Formulation = maltodextrin subtracted from:			
Simplesse™	1.8170	0.4616	0.0092

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Time

Time = 2.00 subtracted from:

Time	Difference of Means	SE of Difference	Adjusted P-Value
2.25	0.9647	0.4214	0.1894
2.50	1.6680	0.4214	0.0062
2.75	2.0086	0.4214	0.0010
3.00	3.1874	7.563	0.0000
Time = 2.25 subtracted from:			
2.50	0.7032	0.4214	0.4741
2.75	1.0439	0.4214	0.1360
3.00	2.2227	0.4214	0.0003
Time = 2.50 subtracted from:			
2.75	0.3407	0.4214	0.9250
3.00	1.5194	0.4214	0.0135
Time = 2.75 subtracted from:			
3.00	1.1790	0.4214	0.0740

Table D.6 Two way ANOVA and Tukey Simultaneous Test Table for volume index of cakes baked in infrared-microwave combination oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	5	3.50, 4.00, 4.50, 5.00, 5.50
Formulation	Fixed	6	0-0-0, 25-0-0, 25-0-3, 25-3-0, maltodextrin, Simplesse™

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	4	64.442	64.442	16.110	13.23	0.000
Formulation	5	209.209	209.209	41.842	34.35	0.000
Error	20	24.364	24.364	1.218		
Total	29	298.015				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	-4.7910	0.6980	0.0000
25-0-3	-2.7980	0.6980	0.0078
25-3-0	-2.4320	0.6980	0.0245
maltodextrin	1.3350	0.6980	0.4235
Simplesse™	2.9680	0.6980	0.0045

Formulation = 25-0-0 subtracted from:

25-0-3	1.9930	0.6980	0.0888
25-3-0	2.3590	0.6980	0.0306
maltodextrin	6.1260	0.6980	0.0000

Simplesse™	7.7590	0.6980	0.0000
Formulation = 25-0-3 subtracted from:			
25-3-0	0.3667	0.6980	0.9945
maltodextrin	4.1333	0.6980	0.0001
Simplesse™	5.7667	0.6980	0.0000
Formulation = 25-3-0 subtracted from:			
maltodextrin	3.7670	0.6980	0.0004
Simplesse™	5.4000	0.6980	0.0000
Formulation = maltodextrin subtracted from:			
Simplesse™	1.6330	0.6980	0.2245

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Time

Time = 3.5 subtracted from:

Time	Difference of Means	SE of Difference	Adjusted P-Value
4.0	1.2210	0.6372	0.3411
4.5	2.9070	0.6372	0.0016
5.0	3.2500	0.6372	0.0005
5.5	4.0370	0.6372	0.0000
Time = 4.0 subtracted from:			
4.5	1.6860	0.6372	0.0994
5.0	2.0290	0.6372	0.0336
5.5	2.8160	0.6372	0.0022
Time = 4.5 subtracted from:			
5.0	0.3429	0.6372	0.9822
5.5	1.1301	0.6372	0.4151
Time = 5.0 subtracted from:			
5.5	0.7873	0.6372	0.7315

Table D.7 Two way ANOVA and Tukey Simultaneous Test Table for volume index of cakes baked in conventional oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	4	22, 24, 26, 28
Formulation	Fixed	2	0-0-0, 25-0-0

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	3	16.130	16.130	5.377	5.07	0.108
Formulation	1	31.127	31.127	31.127	29.33	0.012
Error	3	3.183	3.183	1.061		
Total	7	50.440				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	-3.945	0.7284	0.0124

Table D.8 Two way ANOVA and Tukey Simultaneous Test Table for hardness of cakes baked in microwave oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	5	2.00, 2.25, 2.50, 2.75, 3.00
Formulation	Fixed	6	0-0-0, 25-0-0, 25-0-3, 25-3-0, maltodextrin, Simplesse™

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	4	0.24855	0.24855	0.06214	9.26	0.000
Formulation	5	0.97937	0.97937	0.19587	29.19	0.000
Error	20	0.13421	0.13421	0.00671		
Total	29	1.36212				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	0.2007	0.0518	0.0105
25-0-3	0.0775	0.0518	0.6703
25-3-0	0.0824	0.0518	0.6136
maltodextrin	0.1533	0.0518	0.0725
Simplesse™	-0.3517	0.0518	0.0000

Formulation = 25-0-0 subtracted from:

25-0-3	-0.1232	0.05181	0.2110
25-3-0	-0.1183	0.05181	0.2462
maltodextrin	-0.0474	0.05181	0.9380
Simplesse™	-0.5524	0.05181	0.0000

Formulation = 25-0-3 subtracted from:			
25-3-0	0.0049	0.05181	1.0000
maltodextrin	0.0758	0.05181	0.6906
Simplesse™	-0.4292	0.05181	0.0000
Formulation = 25-3-0 subtracted from:			
maltodextrin	0.0709	0.05181	0.7446
Simplesse™	-0.4341	0.05181	0.0000
Formulation = maltodextrin subtracted from:			
Simplesse™	-0.5050	0.05181	0.0000

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Time

Time = 2.00 subtracted from:			
2.25	-0.0499	0.04730	0.8269
2.50	-0.1161	0.04730	0.1417
2.75	-0.1581	0.04730	0.0239
3.00	-0.2638	0.04730	0.0002
Time = 2.25 subtracted from:			
2.50	-0.0662	0.04730	0.6348
2.75	-0.1083	0.04730	0.1894
3.00	-0.2139	0.04730	0.0017
Time = 2.50 subtracted from:			
2.75	-0.0421	0.04730	0.8975
3.00	-0.1477	0.04730	0.0382
Time = 2.75 subtracted from:			
3.00	-0.1056	0.04730	0.2082

Table D.9 Two way ANOVA and Tukey Simultaneous Test Table for hardness of cakes baked in infrared-microwave combination oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	5	3.50, 4.00, 4.50, 5.00, 5.50
Formulation	Fixed	6	0-0-0, 25-0-0, 25-0-3, 25-3-0, maltodextrin, Simplesse^{TM}

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	4	0.0039627	0.0039627	0.0009907	1.28	0.312
Formulation	5	0.0659529	0.0659529	0.0131906	17.02	0.000
Error	20	0.0155003	0.0155003	0.0007750		
Total	29	0.0854159				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	-0.01805	0.01761	0.9039
25-0-3	-0.02686	0.01761	0.6530
25-3-0	-0.00350	0.01761	0.9999
maltodextrin	-0.02095	0.01761	0.8364
Simplesse^{TM}	0.10935	0.01761	0.0001

Formulation = 25-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-3	-0.008803	0.01761	0.9956
25-3-0	0.014550	0.01761	0.9590
maltodextrin	-0.002898	0.01761	1.0000

Simplesse™	0.127409	0.01761	0.0000
Formulation = 25-0-3 subtracted from:			
25-3-0	0.023353	0.01761	0.7676
maltodextrin	0.005904	0.01761	0.9993
Simplesse™	0.136212	0.01761	0.0000
Formulation = 25-3-0 subtracted from:			
maltodextrin	-0.01745	0.01761	0.9155
Simplesse™	0.11286	0.01761	0.0001
Formulation = maltodextrin subtracted from:			
Simplesse™	0.1303	0.01761	0.0000

Table D.10 Two way ANOVA and Tukey Simultaneous Test Table for hardness of cakes baked in conventional oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	4	22, 24, 26, 28
Formulation	Fixed	2	0-0-0, 25-0-0

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	3	0.0005784	0.0005784	0.0001928	104.38	0.002
Formulation	1	0.0001676	0.0001676	0.0001676	90.71	0.002
Error	3	0.0000055	0.0000055	0.0000018		
Total	7	0.0007516				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	-0.009153	0.000961	0.0025

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Time

Time = 22 subtracted from:

Time	Difference of Means	SE of Difference	Adjusted P-Value
24	0.01275	0.001359	0.0078
26	0.01765	0.001359	0.0030
28	0.02295	0.001359	0.0014

Time = 24 subtracted from:

26	0.004898	0.001359	0.1050
28	0.010201	0.001359	0.0148
Time = 26 subtracted from:			
28	0.005302	0.001359	0.0864

Table D.11 Two way ANOVA and Tukey Simultaneous Test Table for gumminess of cakes baked in microwave oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	5	2.00, 2.25, 2.50, 2.75, 3.00
Formulation	Fixed	6	0-0-0, 25-0-0, 25-0-3, 25-3-0, maltodextrin, Simplesse^{TM}

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	4	0.0133131	0.0133131	0.0033283	4.71	0.008
Formulation	5	0.0696361	0.0696361	0.0139272	19.71	0.000
Error	20	0.0141314	0.0141314	0.0007066		
Total	29	0.0970805				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	-0.02588	0.01681	0.6444
25-0-3	-0.01095	0.01681	0.9853
25-3-0	-0.01361	0.01681	0.9624
maltodextrin	-0.02555	0.01681	0.6563
Simplesse^{TM}	0.11186	0.01681	0.0000

Formulation = 25-0-0 subtracted from:

25-0-3	0.014928	0.01681	0.9450
25-3-0	0.012275	0.01681	0.9757
maltodextrin	0.000331	0.01681	1.0000

Simplesse™	0.137747	0.01681	0.0000
Formulation = 25-0-3 subtracted from:			
25-3-0	-0.00265	0.01681	1.0000
maltodextrin	-0.01460	0.01681	0.9498
Simplesse™	0.12282	0.01681	0.0000
Formulation = 25-3-0 subtracted from:			
maltodextrin	-0.01194	0.01681	0.9784
Simplesse™	0.12547	0.01681	0.0000
Formulation = maltodextrin subtracted from:			
Simplesse™	0.1374	0.01681	0.0000

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Time

Time = 2.00 subtracted from:			
2.25	0.01664	0.01535	0.8125
2.50	0.02646	0.01535	0.4426
2.75	0.03930	0.01535	0.1166
3.00	0.06235	0.01535	0.0049
Time = 2.25 subtracted from:			
2.50	0.009821	0.01535	0.9666
2.75	0.022661	0.01535	0.5883
3.00	0.045717	0.01535	0.0514
Time = 2.50 subtracted from:			
2.75	0.01284	0.01535	0.9159
3.00	0.03590	0.01535	0.1738
Time = 2.75 subtracted from:			
3.00	0.02306	0.01535	0.5728

Table D.12 Two way ANOVA and Tukey Simultaneous Test Table for gumminess of cakes baked in infrared-microwave combination oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	5	3.50, 4.00, 4.50, 5.00, 5.50
Formulation	Fixed	6	0-0-0, 25-0-0, 25-0-3, 25-3-0, maltodextrin, Simplesse™

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	4	0.0006515	0.0006515	0.0001629	1.64	0.204
Formulation	5	0.0095781	0.0095781	0.0019156	19.28	0.000
Error	20	0.0019876	0.0019876	0.0000994		
Total	29	0.0122172				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
Formulation = 0-0-0 subtracted from:			
25-0-0	-0.01805	0.01761	0.9039
25-0-0	-0.00652	0.006305	0.9007
25-0-3	-0.01166	0.006305	0.4595
25-3-0	0.00003	0.006305	1.0000
maltodextrin	-0.01061	0.006305	0.5573
Simplesse™	0.04059	0.006305	0.0000
Formulation = 25-0-0 subtracted from:			
25-0-3	-0.005134	0.006305	0.9615
25-3-0	0.006556	0.006305	0.8987

maltodextrin	-0.004091	0.006305	0.9855
Simplesse™	0.047117	0.006305	0.0000
Formulation = 25-0-3 subtracted from:			
25-3-0	0.011690	0.006305	0.4564
maltodextrin	0.001042	0.006305	1.0000
Simplesse™	0.052251	8.2873	0.0000
Formulation = 25-3-0 subtracted from:			
maltodextrin	-0.01065	0.006305	0.5540
Simplesse™	0.04056	0.006305	0.0000
Formulation = maltodextrin subtracted from:			
Simplesse™	0.05121	0.006305	0.0000

Table D.13 Two way ANOVA and Tukey Simultaneous Test Table for gumminess of cakes baked in conventional oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	4	22, 24, 26, 28
Formulation	Fixed	2	0-0-0, 25-0-0

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	3	0.0001493	0.0001493	0.0000498	86.56	0.002
Formulation	1	0.0001436	0.0001436	0.0001436	249.87	0.001
Error	3	0.0000017	0.0000017	0.0000006		
Total	7	0.0002946				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	-0.008474	0.000536	0.0006

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Time

Time = 22 subtracted from:

Time	Difference of Means	SE of Difference	Adjusted P-Value
24	0.005453	0.000754	0.0165
26	0.008945	0.000754	0.0039
28	0.011630	0.000754	0.0018

Time = 24 subtracted from:			
26	0.003492	0.000754	0.0558
28	0.006177	0.000754	0.0115
Time = 26 subtracted from:			
28	0.002685	0.000754	0.1081

Table D.14 Two way ANOVA and Tukey Simultaneous Test Table for cohesiveness of cakes baked in microwave oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	5	2.00, 2.25, 2.50, 2.75, 3.00
Formulation	Fixed	6	0-0-0, 25-0-0, 25-0-3, 25-3-0, maltodextrin, Simplesse^{TM}

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	4	0.0004047	0.0004047	0.0001012	0.33	0.854
Formulation	5	0.0231774	0.0231774	0.0046355	15.17	0.000
Error	20	0.0061100	0.0061100	0.0003055		
Total	29	0.0296921				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	0.03083	0.01105	0.1008
25-0-3	0.01786	0.01105	0.5981
25-3-0	0.02205	0.01105	0.3790
maltodextrin	-0.01078	0.01105	0.9206
Simplesse^{TM}	-0.05265	0.01105	0.0014

Formulation = 25-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-3	-0.01297	0.01105	0.8443
25-3-0	-0.00878	0.01105	0.9653
maltodextrin	-0.04161	0.01105	0.0134

Simplesse™	-0.08348	0.01105	0.0000
Formulation = 25-0-3 subtracted from:			
25-3-0	0.00419	0.01105	0.9988
maltodextrin	-0.02864	0.01105	0.1455
Simplesse™	-0.07052	0.01105	0.0001
Formulation = 25-3-0 subtracted from:			
maltodextrin	-0.03283	0.01105	0.0709
Simplesse™	-0.07471	0.01105	0.0000
Formulation = maltodextrin subtracted from:			
Simplesse™	-0.04188	0.01105	0.0127

Table D.15 Two way ANOVA and Tukey Simultaneous Test Table for cohesiveness of cakes baked in infrared-microwave combination oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	5	3.50, 4.00, 4.50, 5.00, 5.50
Formulation	Fixed	6	0-0-0, 25-0-0, 25-0-3, 25-3-0, maltodextrin, Simplesse^{TM}

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	4	0.004782	0.004782	0.001195	2.05	0.126
Formulation	5	0.677199	0.677199	0.135440	232.36	0.000
Error	20	0.011658	0.011658	0.000583		
Total	29	0.693639				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
Formulation = 0-0-0 subtracted from:			
25-0-0	-0.0104	0.01527	0.9823
25-0-3	-0.0291	0.01527	0.4273
25-3-0	-0.0191	0.01527	0.8055
maltodextrin	-0.0568	0.01527	0.0147
Simplesse^{TM}	-0.4234	0.01527	0.0000
Formulation = 25-0-0 subtracted from:			
25-0-3	-0.0187	0.01527	0.8189
25-3-0	-0.0088	0.01527	0.9916
maltodextrin	-0.0464	0.01527	0.0615

Simplesse™	-0.4131	0.01527	0.0000
Formulation = 25-0-3 subtracted from:			
25-3-0	0.0100	0.01527	0.9852
maltodextrin	-0.0277	0.01527	0.4789
Simplesse™	-0.3943	0.01527	0.0000
Formulation = 25-3-0 subtracted from:			
maltodextrin	-0.0377	0.01527	0.1812
Simplesse™	-0.4043	0.01527	0.0000
Formulation = maltodextrin subtracted from:			
Simplesse™	-0.3666	0.01527	0.0000

Table D.16 Two way ANOVA and Tukey Simultaneous Test Table for cohesiveness of cakes baked in conventional oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	4	22, 24, 26, 28
Formulation	Fixed	2	0-0-0, 25-0-0

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	3	0.0000445	0.0000445	0.0000148	1.21	0.440
Formulation	1	0.0015326	0.0015326	0.0015326	124.78	0.002
Error	3	0.0000368	0.0000368	0.0000123		
Total	7	0.0016140				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	-0.02768	0.002478	0.0015

Table D.17 Two way ANOVA and Tukey Simultaneous Test Table for springiness of cakes baked in microwave oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	5	2.00, 2.25, 2.50, 2.75, 3.00
Formulation	Fixed	6	0-0-0, 25-0-0, 25-0-3, 25-3-0, maltodextrin, Simplesse^{TM}

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	4	0.165231	0.165231	0.041308	38.21	0.000
Formulation	5	0.542766	0.542766	0.108553	100.41	0.000
Error	20	0.021622	0.021622	0.001081		
Total	29	0.729618				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	-0.1308	0.02080	0.0001
25-0-3	-0.1043	0.02080	0.0008
25-3-0	-0.0793	0.02080	0.0119
maltodextrin	-0.4003	0.02080	0.0000
Simplesse^{TM}	-0.2823	0.02080	0.0000

Formulation = 25-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-3	- 0.0265	0.02080	0.7955
25-3-0	0.0515	0.02080	0.1784
maltodextrin	-0.2695	0.02080	0.0000

Simplesse™	-0.1515	0.02080	0.0000
Formulation = 25-0-3 subtracted from:			
25-3-0	0.0250	0.02080	0.8306
maltodextrin	-0.2960	0.02080	0.0000
Simplesse™	-0.1780	0.02080	0.0000
Formulation = 25-3-0 subtracted from:			
maltodextrin	-0.3210	0.02080	0.0000
Simplesse™	-0.2030	0.02080	0.0000
Formulation = maltodextrin subtracted from:			
Simplesse™	0.1180	0.02080	0.0002

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Time

Time = 2.00 subtracted from:			
Formulation	Difference of Means	SE of Difference	Adjusted P-Value
2.25	-0.0380	0.01898	0.3010
2.50	-0.1032	0.01898	0.0002
2.75	-0.1435	0.01898	0.0000
3.00	-0.2086	0.01898	0.0000
Time = 2.25 subtracted from:			
2.50	-0.0652	0.01898	0.0196
2.75	-0.1055	0.01898	0.0002
3.00	-0.1706	0.01898	0.0000
Time = 2.50 subtracted from:			
2.75	-0.0403	0.01898	0.2494
3.00	-0.1054	0.01898	0.0002
Time = 2.75 subtracted from:			
3.00	-0.06508	0.01898	0.0200

Table D.18 Two way ANOVA and Tukey Simultaneous Test Table for springiness of cakes baked in infrared-microwave combination oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	5	3.50, 4.00, 4.50, 5.00, 5.50
Formulation	Fixed	6	0-0-0, 25-0-0, 25-0-3, 25-3-0, maltodextrin, Simplesse™

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	4	0.108750	0.108750	0.027188	48.69	0.000
Formulation	5	0.311177	0.311177	0.062235	111.45	0.000
Error	20	0.011168	0.011168	0.000558		
Total	29	0.431096				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	-0.1368	0.01495	0.0000
25-0-3	-0.1580	0.01495	0.0000
25-3-0	-0.0992	0.01495	0.0000
maltodextrin	-0.3334	0.01495	0.0000
Simplesse™	-0.2090	0.01495	0.0000

Formulation = 25-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-3	-0.0212	0.01495	0.7158
25-3-0	0.0376	0.01495	0.1662
maltodextrin	-0.1967	0.01495	0.0000

Simplesse™	-0.0723	0.01495	0.0012
Formulation = 25-0-3 subtracted from:			
25-3-0	0.0588	0.01495	0.0092
maltodextrin	-0.1755	0.01495	0.0000
Simplesse™	-0.0511	0.01495	0.0283
Formulation = 25-3-0 subtracted from:			
maltodextrin	-0.2343	0.01495	0.0000
Simplesse™	-0.1099	0.01495	0.0000
Formulation = maltodextrin subtracted from:			
Simplesse™	0.1244	0.01495	0.0000

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Time

Time = 3.5 subtracted from:			
Time	Difference of Means	SE of Difference	Adjusted P-Value
4.0	-0.0351	0.01364	0.1144
4.5	-0.0820	0.01364	0.0001
5.0	-0.1308	0.01364	0.0000
5.5	-0.1646	0.01364	0.0000
Time = 4.0 subtracted from:			
4.5	-0.0469	0.01364	0.0196
5.0	-0.0957	0.01364	0.0000
5.5	-0.1295	0.01364	0.0000
Time = 4.5 subtracted from:			
5.0	-0.04879	0.01364	0.0144
5.5	-0.08264	0.01364	0.0001
Time = 5.0 subtracted from:			
5.5	-0.03384	0.01364	0.1351

Table D.19 Two way ANOVA and Tukey Simultaneous Test Table for springiness of cakes baked in conventional oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	4	22, 24, 26, 28
Formulation	Fixed	2	0-0-0, 25-0-0

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	3	0.0036730	0.0036730	0.0012243	409.77	0.000
Formulation	1	0.0002618	0.0002618	0.0002618	87.61	0.003
Error	3	0.0000090	0.0000090	0.0000030		
Total	7	0.0039438				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	-0.01144	0.001222	0.0026

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Time

Time = 22 subtracted from:

Time	Difference of Means	SE of Difference	Adjusted P-Value
24	-0.01188	0.001729	0.0190
26	-0.03966	0.001729	0.0006
28	-0.05384	0.001729	0.0002

Time = 24 subtracted from:			
26	-0.02778	0.001729	0.0016
28	-0.04196	0.001729	0.0005
Time = 26 subtracted from:			
28	-0.01418	0.001729	0.0115

Table D.20 Two way ANOVA and Tukey Simultaneous Test Table for porosity of cakes baked in microwave oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	5	2.00, 2.25, 2.50, 2.75, 3.00
Formulation	Fixed	6	0-0-0, 25-0-0, 25-0-3, 25-3-0, maltodextrin, Simplesse^{TM}

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	4	109.656	109.656	27.414	15.62	0.000
Formulation	5	90.383	90.383	18.077	10.30	0.000
Error	20	35.094	35.094	1.755		
Total	29	235.134				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:			
Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	-3.580	0.8378	0.0043
25-0-3	-2.774	0.8378	0.0353
25-3-0	-1.978	0.8378	0.2168
maltodextrin	-0.224	0.8378	0.9998
Simplesse^{TM}	1.434	0.8378	0.5402
Formulation = 25-0-0 subtracted from:			
25-0-3	0.8060	0.8378	0.9246
25-3-0	1.6020	0.8378	0.4237
maltodextrin	3.3560	0.8378	0.0078
Simplesse^{TM}	5.0140	0.8378	0.0001

Formulation = 25-0-3 subtracted from:			
25-3-0	0.7960	0.8378	0.9282
maltodextrin	2.5500	0.8378	0.0412
Simplesse™	4.2080	0.8378	0.0008
Formulation = 25-3-0 subtracted from:			
maltodextrin	1.754	0.8378	0.3295
Simplesse™	3.412	0.8378	0.0068
Formulation = maltodextrin subtracted from:			
Simplesse™	1.658	0.8378	0.3875

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Time

Time	Difference of Means	SE of Difference	Adjusted P-Value
Time = 2.00 subtracted from:			
2.25	0.4517	0.7648	0.9749
2.50	1.1317	0.7648	0.5865
2.75	3.3000	0.7648	0.0028
3.00	5.0717	0.7648	0.0000
Time = 2.25 subtracted from:			
2.50	0.6800	0.7648	0.8976
2.75	2.8483	0.7648	0.0104
3.00	4.6200	0.7648	0.0001
Time = 2.50 subtracted from:			
2.75	2.168	0.7648	0.0687
3.00	3.940	0.7648	0.0004
Time = 2.75 subtracted from:			
3.00	1.772	0.7648	0.1807

Table D.21 Two way ANOVA and Tukey Simultaneous Test Table for porosity of cakes baked in infrared-microwave combination oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	5	3.50, 4.00, 4.50, 5.00, 5.50
Formulation	Fixed	6	0-0-0, 25-0-0, 25-0-3, 25-3-0, maltodextrin, Simplesse^{TM}

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	4	128.926	128.926	32.231	3.61	0.023
Formulation	5	57.437	57.437	11.487	1.29	0.308
Error	20	178.397	178.397	8.920		
Total	29	364.759				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Time

Time	Difference of Means	SE of Difference	Adjusted P-Value
Time = 3.5 subtracted from:			
4.0	-0.5300	1.724	0.9979
4.5	1.3633	1.724	0.9303
5.0	4.0917	1.724	0.1638
5.5	4.5233	1.724	0.1036
Time = 4.0 subtracted from:			
4.5	1.893	1.724	0.8055
5.0	4.622	1.724	0.0930
5.5	5.053	1.724	0.0567

Time = 4.5 subtracted from:			
5.0	2.728	1.724	0.5248
5.5	3.160	1.724	0.3836
Time = 5.0 subtracted from:			
5.5	0.4317	1.724	0.9991

Table D.22 Two way ANOVA and Tukey Simultaneous Test Table for porosity of cakes baked in conventional oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	4	22, 24, 26, 28
Formulation	Fixed	2	0-0-0, 25-0-0

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	3	30.224	30.224	10.075	7.20	0.070
Formulation	1	37.411	37.411	37.411	26.75	0.014
Error	3	4.195	4.195	1.398		
Total	7	71.831				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	-4.325	0.8362	0.0140

Table D.23 Two way ANOVA and Tukey Simultaneous Test Table for color difference of cakes baked in microwave oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	5	2.00, 2.25, 2.50, 2.75, 3.00
Formulation	Fixed	6	0-0-0, 25-0-0, 25-0-3, 25-3-0, maltodextrin, Simplesse^{TM}

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	4	5.665	5.665	1.416	1.55	0.226
Formulation	5	262.155	262.155	52.431	57.40	0.000
Error	20	18.268	18.268	0.913		
Total	29	286.088				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	4.770	0.6044	0.0000
25-0-3	0.482	0.6044	0.9648
25-3-0	0.175	0.6044	0.9997
maltodextrin	-1.869	0.6044	0.0555
Simplesse^{TM}	-5.132	0.6044	0.0000

Formulation = 25-0-0 subtracted from:

25-0-3	-4.289	0.6044	0.0000
25-3-0	-4.596	0.6044	0.0000
maltodextrin	-6.639	0.6044	0.0000

Simplesse™	-9.902	0.6044	0.0000
Formulation = 25-0-3 subtracted from:			
25-3-0	-0.307	0.6044	0.9953
maltodextrin	-2.351	0.6044	0.0102
Simplesse™	-5.613	0.6044	0.0000
Formulation = 25-3-0 subtracted from:			
maltodextrin	-2.043	0.6044	0.0305
Simplesse™	-5.306	0.6044	0.0000
Formulation = maltodextrin subtracted from:			
Simplesse™	-3.263	0.6044	0.0004

Table D.24 Two way ANOVA and Tukey Simultaneous Test Table for color difference of cakes baked in infrared-microwave combination oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	5	3.50, 4.00, 4.50, 5.00, 5.50
Formulation	Fixed	6	0-0-0, 25-0-0, 25-0-3, 25-3-0, maltodextrin, Simplesse™

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	4	2182.12	2182.12	545.53	37.58	0.000
Formulation	5	324.15	324.15	64.83	4.47	0.007
Error	20	290.34	290.34	14.52		
Total	29	2796.61				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:			
Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	-3.500	2.410	0.6964
25-0-3	-5.007	2.410	0.3372
25-3-0	-5.603	2.410	0.2300
maltodextrin	-0.586	2.410	0.9999
Simplesse™	3.899	2.410	0.5968
Formulation = 25-0-0 subtracted from:			
25-0-3	-1.507	2.410	0.9877
25-3-0	-2.103	2.410	0.9487
maltodextrin	2.914	2.410	0.8274

Simplesse^{TM}	7.399	2.410	0.0580
Formulation = 25-0-3 subtracted from:			
25-3-0	-0.5963	2.410	0.9999
maltodextrin	4.4208	2.410	0.4676
Simplesse^{TM}	8.9059	2.410	0.0155
Formulation = 25-3-0 subtracted from:			
maltodextrin	5.017	2.410	0.3351
Simplesse^{TM}	9.502	2.410	0.0090
Formulation = maltodextrin subtracted from:			
Simplesse^{TM}	4.485	2.410	0.4523

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of time

Time = 3.5 subtracted from:			
Time	Difference of Means	SE of Difference	Adjusted P-Value
4.0	6.358	2.200	0.0615
4.5	10.879	2.200	0.0007
5.0	19.025	2.200	0.0000
5.5	23.715	2.200	0.0000
Time = 4.0 subtracted from:			
4.5	4.521	2.200	0.2772
5.0	12.667	2.200	0.0001
5.5	17.357	2.200	0.0000
Time = 4.5 subtracted from:			
5.0	8.146	2.200	0.0109
5.5	12.836	2.200	0.0001
Time = 5.0 subtracted from:			
5.5	4.690	2.200	0.2457

Table D.25 Two way ANOVA and Tukey Simultaneous Test Table for color difference of cakes baked in conventional oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	4	22, 24, 26, 28
Formulation	Fixed	2	0-0-0, 25-0-0

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	3	165.557	165.557	55.186	111.92	0.001
Formulation	1	21.499	21.499	21.499	43.60	0.007
Error	3	1.479	1.479	0.493		
Total	7	188.535				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	3.279	0.4965	0.0071

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Time

Time = 22 subtracted from:

Time	Difference of Means	SE of Difference	Adjusted P-Value
24	1.082	0.7022	0.5148
26	7.319	0.7022	0.0057
28	11.092	0.7022	0.0017

Time = 24 subtracted from:			
26	6.237	0.7022	0.0091
28	10.010	0.7022	0.0023
Time = 26 subtracted from:			
28	3.773	0.7022	0.0375

Table D.26 One way ANOVA and Tukey Pairwise Comparison Table for dielectric constant of cake batter with respect to formulation

ANOVA Results

Source	DF	SS	MS	F	P
Formulation	5	58.42	11.68	6.26	0.004
Error	12	22.38	1.87		
Total	17	80.81			

Tukey Pairwise Comparison

Intervals for (column level mean) - (row level mean)

	0-0-0	25-0-0	25-3-0	25-0-3	maltodextrin
25-0-0	-4.566				
	2.925				
25-3-0	-4.110	-3.289			
	3.381	4.201			
25-0-3	-2.907	-2.086	-2.542		
	4.584	5.404	4.948		
maltodextrin	-1.913	-1.093	-1.549	-2.752	
	5.577	6.398	5.942	4.738	
Simplesse^{TM}	0.802	1.622	1.166	-0.037	-1.030
	8.292	9.113	8.657	7.454	6.460

Table D.27 One way ANOVA and Tukey Pairwise Comparison Table for dielectric loss factor of cake batter with respect to formulation

ANOVA Results

Source	DF	SS	MS	F	P
Formulation	5	19.287	3.857	8.12	0.001
Error	12	5.698	0.475		
Total	17	24.985			

Tukey Pairwise Comparison

Intervals for (column level mean) - (row level mean)

	0-0-0	25-0-0	25-3-0	25-0-3	maltodextrin
25-0-0	-2.2988				
	1.4807				
25-3-0	-2.1107	-1.7017			
	1.6687	2.0778			
25-0-3	-1.6690	-1.2600	-1.4480		
	2.1105	2.5195	2.3315		
maltodextrin	-0.9333	-0.5242	-0.7123	-1.1540	
	2.8462	3.2552	3.0672	2.6255	
Simplesse^{TM}	0.7438	1.1528	0.9648	0.5230	-0.2127
	4.5233	4.9323	4.7443	4.3025	3.5668

Table D.28 One way ANOVA and Tukey Pairwise Comparison Table for penetration depth of cake batter with respect to formulation

ANOVA Results

Source	DF	SS	MS	F	P
Formulation	5	0.0000099	0.0000020	7.75	0.002
Error	12	0.0000031	0.0000003		
Total	17	0.0000129			

Tukey Pairwise Comparison

Intervals for (column level mean) - (row level mean)

	0-0-0	25-0-0	25-3-0	25-0-3	maltodextrin
25-0-0	-0.00122				
	0.00155				
25-3-0	-0.00125	-0.00141			
	0.00152	0.00136			
25-0-3	-0.00138	-0.00154	-0.00151		
	0.00139	0.00122	0.00125		
maltodextrin	-0.00195	-0.00211	-0.00208	-0.00195	
	0.00082	0.00066	0.00068	0.00081	
Simplesse^{TM}	-0.00331	-0.00347	-0.00345	-0.00332	-0.00275
	-0.00055	-0.00071	-0.00068	-0.00055	0.00002

Table D.29 Two way ANOVA and Tukey Simultaneous Test Table for weight loss of cakes baked in microwave oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	5	2.00, 2.25, 2.50, 2.75, 3.00
Formulation	Fixed	6	0-0-0, 25-0-0, 25-0-3, 25-3-0, maltodextrin, Simplesse^{TM}

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	4	162.156	162.156	40.539	204.69	0.000
Formulation	5	3.088	3.088	0.618	3.12	0.031
Error	20	3.961	3.961	0.198		
Total	29	169.205				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	0.1986	0.2815	0.9791
25-0-3	-0.6810	0.2815	0.1965
25-3-0	-0.3633	0.2815	0.7865
maltodextrin	0.2307	0.2815	0.9604
Simplesse^{TM}	-0.0467	0.2815	1.0000

Formulation = 25-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-3	-0.8796	0.2815	0.0519
25-3-0	-0.5619	0.2815	0.3784
maltodextrin	0.0321	0.2815	1.0000

Simplesse^{TM}	-0.2453	0.2815	0.9490
Formulation = 25-0-3 subtracted from:			
25-3-0	0.3177	0.2815	0.8637
maltodextrin	0.9117	0.2815	0.0410
Simplesse^{TM}	0.6343	0.2815	0.2581
Formulation = 25-3-0 subtracted from:			
maltodextrin	0.5940	0.2815	0.3215
Simplesse^{TM}	0.3166	0.2815	0.8654
Formulation = maltodextrin subtracted from:			
Simplesse^{TM}	-0.2774	0.2815	0.9172

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Time

Time = 2.00 subtracted from:

Time	Difference of Means	SE of Difference	Adjusted P-Value
2.25	1.313	0.2569	0.0005
2.50	3.383	0.2569	0.0000
2.75	4.520	0.2569	0.0000
3.00	6.585	0.2569	0.0000
Time = 2.25 subtracted from:			
2.50	2.070	0.2569	0.0000
2.75	3.207	0.2569	0.0000
3.00	5.272	0.2569	0.0000
Time = 2.50 subtracted from:			
2.75	1.137	0.2569	0.0022
3.00	3.202	0.2569	0.0000
Time = 2.75 subtracted from:			
3.00	2.065	0.2569	0.0000

Table D.30 Two way ANOVA and Tukey Simultaneous Test Table for weight loss of cakes baked in infrared-microwave combination oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	5	3.50, 4.00, 4.50, 5.00, 5.50
Formulation	Fixed	6	0-0-0, 25-0-0, 25-0-3, 25-3-0, maltodextrin, Simplesse^{TM}

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	4	229.456	229.456	57.364	51.51	0.000
Formulation	5	17.771	17.771	3.554	3.19	0.028
Error	20	22.272	22.272	1.114		
Total	29	269.499				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
Formulation = 0-0-0 subtracted from:			
25-0-0	-0.4391	0.6674	0.9846
25-0-3	-0.5909	0.6674	0.9457
25-3-0	-0.7298	0.6674	0.8783
maltodextrin	1.0787	0.6674	0.5980
Simplesse^{TM}	1.1641	0.6674	0.5207
Formulation = 25-0-0 subtracted from:			
25-0-3	-0.1518	0.6674	0.9999
25-3-0	-0.2906	0.6674	0.9977
maltodextrin	1.5178	0.6674	0.2498

Simplesse™	1.6032	0.6674	0.2024
Formulation = 25-0-3 subtracted from:			
25-3-0	-0.1388	0.6674	0.9999
maltodextrin	1.6696	0.6674	0.1706
Simplesse™	1.7550	0.6674	0.1357
Formulation = 25-3-0 subtracted from:			
maltodextrin	1.808	0.6674	0.1171
Simplesse™	1.894	0.6674	0.0918
Formulation = maltodextrin subtracted from:			
Simplesse™	0.08540	0.6674	1.0000

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of time

Time = 3.5 subtracted from:			
Time	Difference of Means	SE of Difference	Adjusted P-Value
4.0	2.250	0.6093	0.0112
4.5	3.866	0.6093	0.0000
5.0	5.530	0.6093	0.0000
5.5	8.103	0.6093	0.0000
Time = 4.0 subtracted from:			
4.5	1.616	0.6093	0.0980
5.0	3.280	0.6093	0.0003
5.5	5.853	0.6093	0.0000
Time = 4.5 subtracted from:			
5.0	1.664	0.6093	0.0843
5.5	4.237	0.6093	0.0000
Time = 5.0 subtracted from:			
5.5	2.573	0.6093	0.0034

Table D.31 Two way ANOVA and Tukey Simultaneous Test Table for weight loss of cakes baked in conventional oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	4	22, 24, 26, 28
Formulation	Fixed	2	0-0-0, 25-0-0

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	3	3.30703	3.30703	1.10234	66.06	0.003
Formulation	1	0.10366	0.10366	0.10366	6.21	0.088
Error	3	0.05006	0.05006	0.01669		
Total	7	3.46075				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Time

Time = 22 subtracted from:			
Time	Difference of Means	SE of Difference	Adjusted P-Value
24	0.5147	0.1292	0.0820
26	1.2600	0.1292	0.0070
28	1.6567	0.1292	0.0031
Time = 24 subtracted from:			
26	0.7453	0.1292	0.0309
28	1.1420	0.1292	0.0093
Time = 26 subtracted from:			
28	0.3967	0.1292	0.1525

Table D.32 Two way ANOVA and Tukey Simultaneous Test Table for dielectric constant of cakes baked in microwave oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	5	2.00, 2.25, 2.50, 2.75, 3.00
Formulation	Fixed	6	0-0-0, 25-0-0, 25-0-3, 25-3-0, maltodextrin, Simplesse^{TM}

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	4	7.7585	7.7585	1.9396	43.21	0.000
Formulation	5	2.2043	2.2043	0.4409	9.82	0.000
Error	20	0.8978	0.8978	0.0449		
Total	29	10.8607				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	0.57799	0.1340	0.0040
25-0-3	0.14890	0.1340	0.8711
25-3-0	0.66353	0.1340	0.0010
maltodextrin	0.16896	0.1340	0.8019
Simplesse^{TM}	-0.03821	0.1340	0.9997

Formulation = 25-0-0 subtracted from:

25-0-3	-0.4291	0.1340	0.0443
25-3-0	0.0855	0.1340	0.9865
maltodextrin	-0.4090	0.1340	0.0601

Simplesse™	-0.6162	0.1340	0.0021
Formulation = 25-0-3 subtracted from:			
25-3-0	0.5146	0.1340	0.0113
maltodextrin	0.0201	0.1340	1.0000
Simplesse™	-0.1871	0.1340	0.7287
Formulation = 25-3-0 subtracted from:			
maltodextrin	-0.4946	0.1340	0.0157
Simplesse™	-0.7017	0.1340	0.0005
Formulation = maltodextrin subtracted from:			
Simplesse™	-0.2072	0.1340	0.6405

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Time

Time	Difference of Means	SE of Difference	Adjusted P-Value
Time = 2.00 subtracted from:			
2.25	-0.570	0.1223	0.0013
2.50	-1.050	0.1223	0.0000
2.75	-1.125	0.1223	0.0000
3.00	-1.464	0.1223	0.0000
Time = 2.25 subtracted from:			
2.50	-0.4804	0.1223	0.0066
2.75	-0.5554	0.1223	0.0017
3.00	-0.8942	0.1223	0.0000
Time = 2.50 subtracted from:			
2.75	-0.0749	0.1223	0.9714
3.00	-0.4138	0.1223	0.0220
Time = 2.75 subtracted from:			
3.00	-0.3388	0.1223	0.0781

Table D.33 Two way ANOVA and Tukey Simultaneous Test Table for dielectric constant of cakes baked in infrared-microwave combination oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	5	3.50, 4.00, 4.50, 5.00, 5.50
Formulation	Fixed	6	0-0-0, 25-0-0, 25-0-3, 25-3-0, maltodextrin, Simplesse™

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	4	9.7129	9.7129	2.4282	17.56	0.000
Formulation	5	6.9094	6.9094	1.3819	9.99	0.000
Error	20	2.7659	2.7659	0.1383		
Total	29	19.3882				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	1.1155	0.2352	0.0015
25-0-3	0.6009	0.2352	0.1552
25-3-0	0.5586	0.2352	0.2119
maltodextrin	-0.0078	0.2352	1.0000
Simplesse™	-0.3152	0.2352	0.7600

Formulation = 25-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-3	-0.515	0.2352	0.2860
25-3-0	-0.557	0.2352	0.2143
maltodextrin	-1.123	0.2352	0.0014

Simplesse™	-1.431	0.2352	0.0001
Formulation = 25-0-3 subtracted from:			
25-3-0	-0.0423	0.2352	1.0000
maltodextrin	-0.6087	0.2352	0.1463
Simplesse™	-0.9161	0.2352	0.0100
Formulation = 25-3-0 subtracted from:			
maltodextrin	-0.5664	0.2352	0.2004
Simplesse™	-0.8738	0.2352	0.0149
Formulation = maltodextrin subtracted from:			
Simplesse™	-0.3074	0.2352	0.7779

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of time

Time = 3.5 subtracted from:

Time	Difference of Means	SE of Difference	Adjusted P-Value
4.0	-0.540	0.2147	0.1264
4.5	-1.015	0.2147	0.0011
5.0	-1.318	0.2147	0.0001
5.5	-1.601	0.2147	0.0000
Time = 4.0 subtracted from:			
4.5	-0.475	0.2147	0.2159
5.0	-0.778	0.2147	0.0131
5.5	-1.061	0.2147	0.0007
Time = 4.5 subtracted from:			
5.0	-0.3028	0.2147	0.6285
5.5	-0.5860	-2.729	0.0846
Time = 5.0 subtracted from:			
5.5	-0.2832	0.2147	0.6830

Table D.34 Two way ANOVA and Tukey Simultaneous Test Table for dielectric loss factor of cakes baked in microwave oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	5	2.00, 2.25, 2.50, 2.75, 3.00
Formulation	Fixed	6	0-0-0, 25-0-0, 25-0-3, 25-3-0, maltodextrin, Simplesse^{TM}

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	4	2.54113	2.54113	0.63528	54.04	0.000
Formulation	5	0.64137	0.64137	0.12827	10.91	0.000
Error	20	0.23513	0.23513	0.01176		
Total	29	3.41763				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	0.29052	0.06858	0.0047
25-0-3	0.23490	0.06858	0.0278
25-3-0	0.46025	0.06858	0.0000
maltodextrin	0.23627	0.06858	0.0266
Simplesse^{TM}	0.09075	0.06858	0.7691

Formulation = 25-0-0 subtracted from:

25-0-3	-0.0556	0.06858	0.9621
25-3-0	0.1697	0.06858	0.1786
maltodextrin	-0.0542	0.06858	0.9659

Simplesse™	-0.1998	0.06858	0.0793
Formulation = 25-0-3 subtracted from:			
25-3-0	0.2253	0.06858	0.0372
maltodextrin	0.0014	0.06858	1.0000
Simplesse™	-0.1442	0.06858	0.3254
Formulation = 25-3-0 subtracted from:			
maltodextrin	-0.2240	0.06858	0.0388
Simplesse™	-0.3695	0.06858	0.0004
Formulation = malto dextrin subtracted from:			
Simplesse™	-0.1455	0.06858	0.3160

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Time

Time = 2.00 subtracted from:

Time	Difference of Means	SE of Difference	Adjusted P-Value
2.25	-0.3712	0.06260	0.0001
2.50	-0.6198	0.06260	0.0000
2.75	-0.7432	0.06260	0.0000
3.00	-0.7890	0.06260	0.0000
Time = 2.25 subtracted from:			
2.50	-0.2486	0.06260	0.0060
2.75	-0.3720	0.06260	0.0001
3.00	-0.4179	0.06260	0.0000
Time = 2.50 subtracted from:			
2.75	-0.1234	0.06260	0.3150
3.00	-0.1693	0.06260	0.0888
Time = 2.75 subtracted from:			
3.00	-0.04588	0.06260	0.9462

Table D.35 Two way ANOVA and Tukey Simultaneous Test Table for dielectric loss factor of cakes baked in infrared-microwave combination oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	5	3.50, 4.00, 4.50, 5.00, 5.50
Formulation	Fixed	6	0-0-0, 25-0-0, 25-0-3, 25-3-0, maltodextrin, Simplesse^{TM}

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	4	2.30305	2.30305	0.57576	12.43	0.000
Formulation	5	1.86609	1.86609	0.37322	8.05	0.000
Error	20	0.92676	0.92676	0.04634		
Total	29	5.09590				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	0.5471	0.1361	0.0076
25-0-3	0.1791	0.1361	0.7732
25-3-0	0.1193	0.1361	0.9479
maltodextrin	-0.0836	0.1361	0.9887
Simplesse^{TM}	-0.2527	0.1361	0.4554

Formulation = 25-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-3	-0.3679	0.1361	0.1186
25-3-0	-0.4278	0.1361	0.0501
maltodextrin	-0.6307	0.1361	0.0019

Simplesse™	-0.7997	0.1361	0.0001
Formulation = 25-0-3 subtracted from:			
25-3-0	-0.0599	0.1361	0.9976
maltodextrin	-0.2627	0.1361	0.4139
Simplesse™	-0.4318	0.1361	0.0472
Formulation = 25-3-0 subtracted from:			
maltodextrin	-0.2029	0.1361	0.6739
Simplesse™	-0.3720	0.1361	0.1122
Formulation = maltodextrin subtracted from:			
Simplesse™	-0.1691	0.1361	0.8115

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of time

Time = 3.5 subtracted from:

Time	Difference of Means	SE of Difference	Adjusted P-Value
4.0	-0.2031	0.1243	0.4939
4.5	-0.5217	0.1243	0.0036
5.0	-0.6398	0.1243	0.0004
5.5	-0.7390	0.1243	0.0001
Time = 4.0 subtracted from:			
4.5	-0.3185	0.1243	0.1161
5.0	-0.4366	0.1243	0.0166
5.5	-0.5359	0.1243	0.0028
Time = 4.5 subtracted from:			
5.0	-0.1181	0.1243	0.8735
5.5	-0.2174	0.1243	0.4286
Time = 5.0 subtracted from:			
5.5	-0.09924	0.1243	0.9280

Table D.36 Two way ANOVA and Tukey Simultaneous Test Table for penetration depth of cakes baked in microwave oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	5	2.00, 2.25, 2.50, 2.75, 3.00
Formulation	Fixed	6	0-0-0, 25-0-0, 25-0-3, 25-3-0, maltodextrin, Simplesse^{TM}

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	4	0.0086793	0.0086793	0.0021698	19.01	0.000
Formulation	5	0.0046023	0.0046023	0.0009205	8.06	0.000
Error	20	0.0022827	0.0022827	0.0001141		
Total	29	0.0155644				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	-0.02149	0.006757	0.0463
25-0-3	-0.02683	0.006757	0.0085
25-3-0	-0.03689	0.006757	0.0003
maltodextrin	-0.02867	0.006757	0.0046
Simplesse^{TM}	-0.00937	0.006757	0.7345

Formulation = 25-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-3	-0.00534	0.006757	0.9661
25-3-0	-0.01540	0.006757	0.2479
maltodextrin	-0.00718	0.006757	0.8905

Simplesse™	0.01212	0.006757	0.4910
Formulation = 25-0-3 subtracted from:			
25-3-0	-0.01006	0.006757	0.6747
maltodextrin	-0.00184	0.006757	0.9998
Simplesse™	0.01746	0.006757	0.1473
Formulation = 25-3-0 subtracted from:			
maltodextrin	0.008222	0.006757	0.8237
Simplesse™	0.027522	0.006757	0.0068
Formulation = maltodextrin subtracted from:			
Simplesse™	0.01930	0.006757	0.0886

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Time

Time = 2.00 subtracted from:

Time	Difference of Means	SE of Difference	Adjusted P-Value
2.25	0.01279	0.006168	0.2696
2.50	0.02648	0.006168	0.0029
2.75	0.04298	0.006168	0.0000
3.00	0.04363	0.006168	0.0000
Time = 2.25 subtracted from:			
2.50	0.01369	0.006168	0.2131
2.75	0.03019	0.006168	0.0008
3.00	0.03084	0.006168	0.0006
Time = 2.50 subtracted from:			
2.75	0.01650	0.006168	0.0939
3.00	0.01716	0.006168	0.0764
Time = 2.75 subtracted from:			
3.00	0.000654	0.006168	1.0000

Table D.37 Two way ANOVA and Tukey Simultaneous Test Table for penetration depth of cakes baked in infrared-microwave combination oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	5	3.50, 4.00, 4.50, 5.00, 5.50
Formulation	Fixed	6	0-0-0, 25-0-0, 25-0-3, 25-3-0, maltodextrin, Simplesse^{TM}

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	4	0.0069056	0.0069056	0.0017264	14.89	0.000
Formulation	5	0.0063750	0.0063750	0.0012750	11.00	0.000
Error	20	0.0023183	0.0023183	0.0001159		
Total	29	0.0155989				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	-0.01837	0.006809	0.1195
25-0-3	-0.00637	0.006809	0.9323
25-3-0	-0.00539	0.006809	0.9657
maltodextrin	0.01037	0.006809	0.6544
Simplesse^{TM}	0.02776	0.006809	0.0067

Formulation = 25-0-0 subtracted from:

25-0-3	0.01200	0.006809	0.5097
25-3-0	0.01298	0.006809	0.4267
maltodextrin	0.02875	0.006809	0.0049

Simplesse™	0.04614	0.006809	0.0000
Formulation = 25-0-3 subtracted from:			
25-3-0	0.000981	0.006809	1.0000
maltodextrin	0.016743	0.006809	0.1837
Simplesse™	0.034135	0.006809	0.0008
Formulation = 25-3-0 subtracted from:			
maltodextrin	0.01576	0.006809	0.2340
Simplesse™	0.03315	0.006809	0.0011
Formulation = maltodextrin subtracted from:			
Simplesse™	0.01739	0.006809	0.1554

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of time

Time	Difference of Means	SE of Difference	Adjusted P-Value
Time = 3.5 subtracted from:			
4.0	0.007853	0.006216	0.7155
4.5	0.018509	0.006216	0.0515
5.0	0.031214	0.006216	0.0006
5.5	0.041806	0.006216	0.0000
Time = 4.0 subtracted from:			
4.5	0.01066	0.006216	0.4481
5.0	0.02336	0.006216	0.0097
5.5	0.03395	0.006216	0.0002
Time = 4.5 subtracted from:			
5.0	0.01271	0.006216	0.2821
5.5	0.02330	0.006216	0.0099
Time = 5.0 subtracted from:			
5.5	0.01059	0.006216	0.4539

Table D.38 Two way ANOVA and Tukey Simultaneous Test Table for pore area of cakes baked in microwave oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	5	2.00, 2.25, 2.50, 2.75, 3.00
Formulation	Fixed	6	0-0-0, 25-0-0, 25-0-3, 25-3-0, maltodextrin, Simplesse^{TM}

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	4	228.965	228.965	57.241	35.04	0.000
Formulation	5	76.135	76.135	15.227	9.32	0.000
Error	20	32.675	32.675	1.634		
Total	29	337.775				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	-2.040	0.8084	0.1641
25-0-3	0.400	0.8084	0.9958
25-3-0	2.180	0.8084	0.1199
maltodextrin	2.160	0.8084	0.1255
Simplesse^{TM}	2.420	0.8084	0.0676

Formulation = 25-0-0 subtracted from:

25-0-3	2.440	0.8084	0.0644
25-3-0	4.220	0.8084	0.0005
maltodextrin	4.200	0.8084	0.0006
Simplesse^{TM}	4.460	0.8084	0.0003

Formulation = 25-0-3 subtracted from:			
25-3-0	1.780	0.8084	0.2799
maltodextrin	1.760	0.8084	0.2908
Simplesse^{TM}	2.020	0.8084	0.1714
Formulation = 25-3-0 subtracted from:			
maltodextrin	-0.02000	0.8084	1.0000
Simplesse^{TM}	0.24000	0.8084	0.9996
Formulation = malto dextrin subtracted from:			
Simplesse^{TM}	0.2600	0.8084	0.9995

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Time	Difference of Means	SE of Difference	Adjusted P-Value
Time = 2.00 subtracted from:			
2.25	0.5833	0.7380	0.9304
2.50	2.6167	0.7380	0.0154
2.75	5.1167	0.7380	0.0000
3.00	7.3333	0.7380	0.0000
Time = 2.25 subtracted from:			
2.50	2.033	0.7380	0.0804
2.75	4.533	0.7380	0.0001
3.00	6.750	0.7380	0.0000
Time = 2.50 subtracted from:			
2.75	2.500	0.7380	0.0218
3.00	4.717	0.7380	0.0000
Time = 2.75 subtracted from:			
3.00	2.217	0.7380	0.0489

Table D.39 Two way ANOVA and Tukey Simultaneous Test Table for pore area of cakes baked in infrared-microwave combination oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	5	3.50, 4.00, 4.50, 5.00, 5.50
Formulation	Fixed	6	0-0-0, 25-0-0, 25-0-3, 25-3-0, maltodextrin, Simplesse™

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	4	124.404	123.426	30.857	27.22	0.000
Formulation	5	356.138	356.138	71.228	62.84	0.000
Error	19	21.536	21.536	1.133		
Total	28	502.078				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	-6.559	0.7221	0.0000
25-0-3	-1.559	0.7221	0.3009
25-3-0	0.201	0.7221	0.9997
maltodextrin	3.161	0.7221	0.0038
Simplesse™	3.981	0.7221	0.0003

Formulation = 25-0-0 subtracted from:

25-0-3	5.000	0.6733	0.0000
25-3-0	6.760	0.6733	0.0000
maltodextrin	9.720	0.6733	0.0000

Simplesse™	10.540	0.6733	0.0000
Formulation = 25-0-3 subtracted from:			
25-3-0	1.760	0.6733	0.1419
maltodextrin	4.720	0.6733	0.0000
Simplesse™	5.540	0.6733	0.0000
Formulation = 25-3-0 subtracted from:			
maltodextrin	2.960	0.6733	0.0036
Simplesse™	3.780	0.6733	0.0003
Formulation = maltodextrin subtracted from:			
Simplesse™	0.8200	0.6733	0.8230

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of time

Time = 3.5 subtracted from:

Time	Difference of Means	SE of Difference	Adjusted P-Value
4.0	1.800	0.6147	0.0586
4.5	3.333	0.6147	0.0003
5.0	4.683	0.6147	0.0000
5.5	5.999	0.6520	0.0000
Time = 4.0 subtracted from:			
4.5	1.533	0.6147	0.1337
5.0	2.883	0.6147	0.0013
5.5	4.199	0.6520	0.0000
Time = 4.5 subtracted from:			
5.0	1.350	0.6147	0.2233
5.5	2.666	0.6520	0.0050
Time = 5.0 subtracted from:			
5.5	1.316	0.6520	0.2952

Table D.40 Two way ANOVA and Tukey Simultaneous Test Table for pore area of cakes baked in conventional oven with respect to formulation and baking time

Factor	Type	Levels	Values
Time	Fixed	4	22, 24, 26, 28
Formulation	Fixed	2	0-0-0, 25-0-0

ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time	3	36.794	36.794	12.265	11.41	0.038
Formulation	1	77.501	77.501	77.501	72.12	0.003
Error	3	3.224	3.224	1.075		
Total	7	117.519				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Formulation

Formulation = 0-0-0 subtracted from:

Formulation	Difference of Means	SE of Difference	Adjusted P-Value
25-0-0	-6.225	0.7330	0.0034

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Time

Time = 22 subtracted from:

Time	Difference of Means	SE of Difference	Adjusted P-Value
24	1.600	1.037	0.5136
26	3.650	1.037	0.1110
28	5.700	1.037	0.0352

Time = 24 subtracted from:			
26	2.050	1.037	0.3603
28	4.100	1.037	0.0835
Time = 26 subtracted from:			
28	2.050	1.037	0.3603

APPENDIX E

DSC THERMOGRAMS

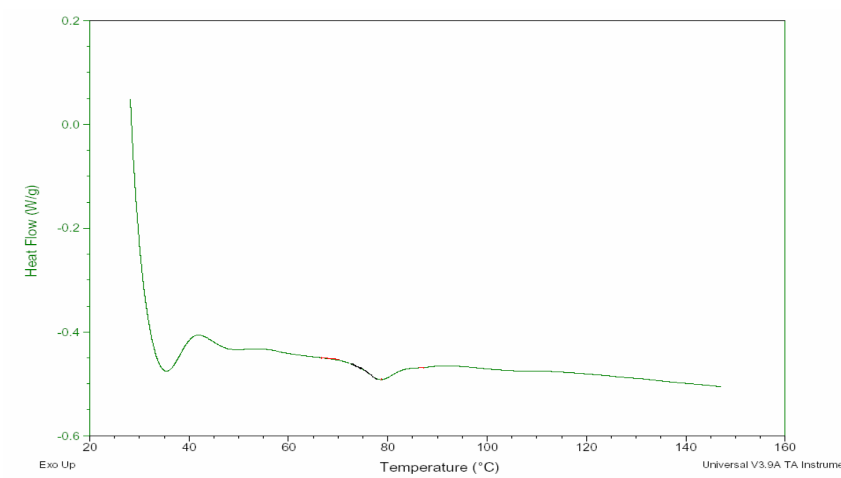

Figure E.1 DSC thermogram of non-fat cake batter

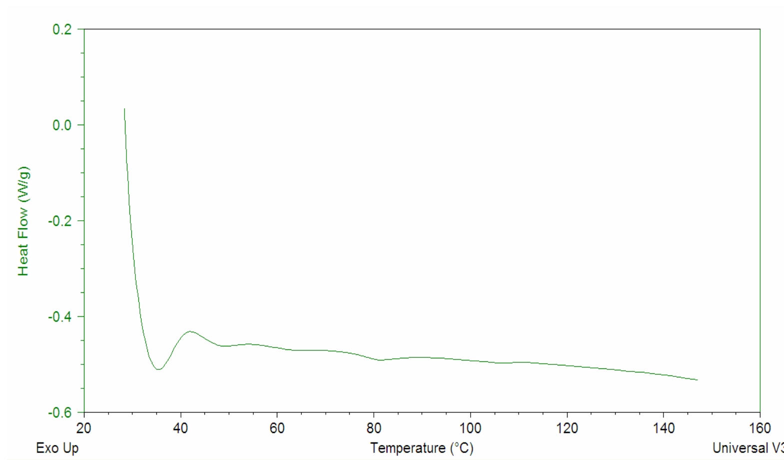

Figure E.2 DSC thermogram of non-fat cake baked in microwave oven for 2 minutes

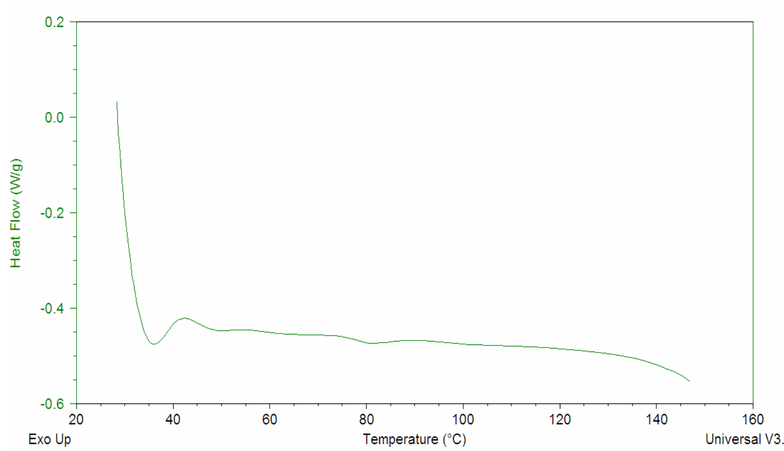

Figure E.3 DSC thermogram of non-fat cake baked in microwave oven for 2.5 minutes

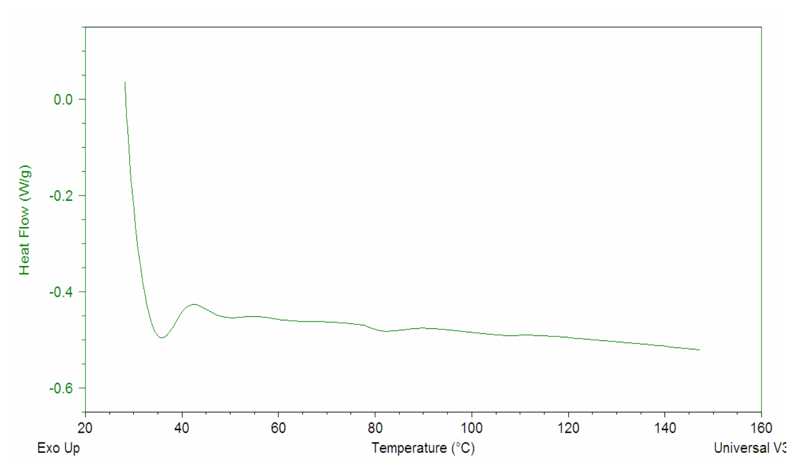

Figure E.4 DSC thermogram of non-fat cake baked in microwave oven for 3 minutes

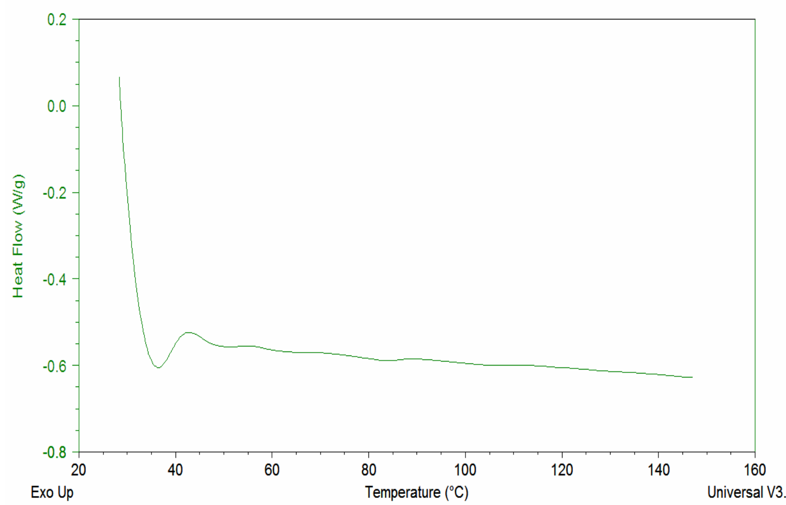

Figure E.5 DSC thermogram of non-fat cake baked in infrared-microwave combination oven for 3.5 minutes

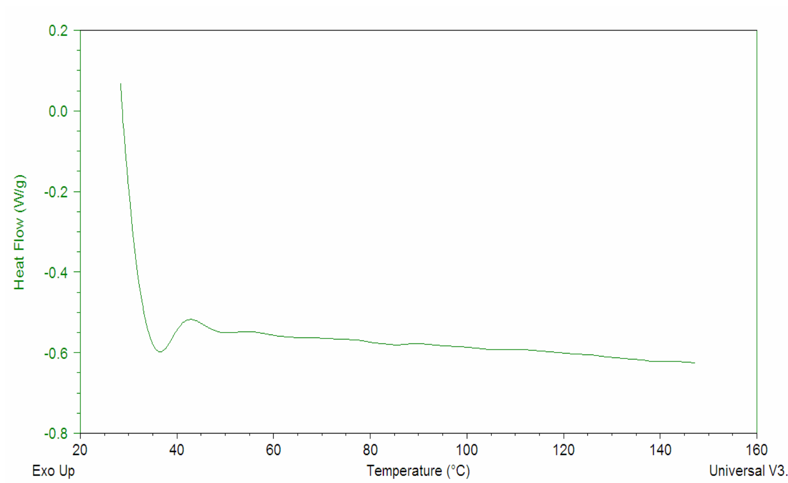

Figure E.6 DSC thermogram of non-fat cake baked in infrared-microwave combination oven for 4.5 minutes

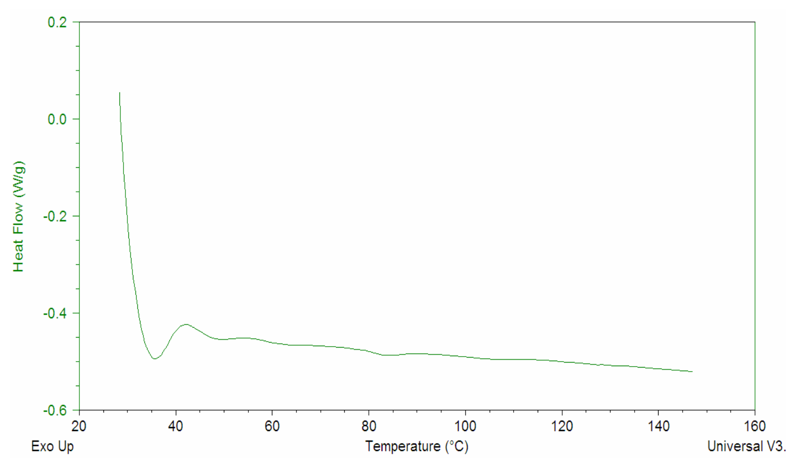

Figure E.7 DSC thermogram of non-fat cake baked in infrared-microwave combination oven for 5.5 minutes

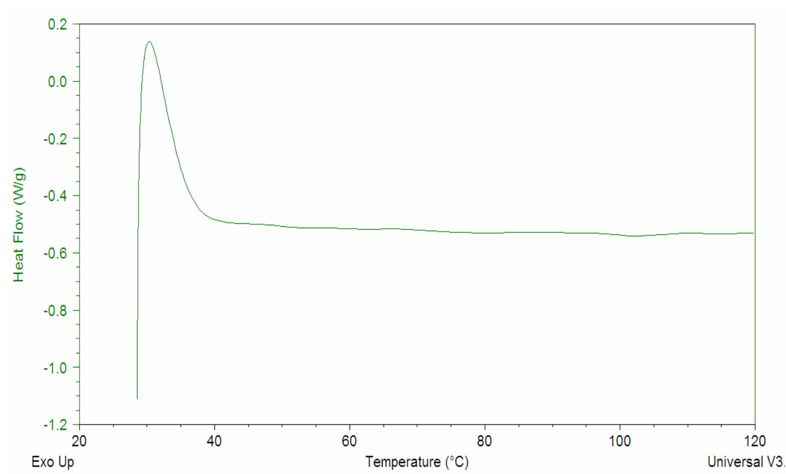

Figure E.8 DSC thermogram of non-fat cake baked in conventional oven for 22 minutes

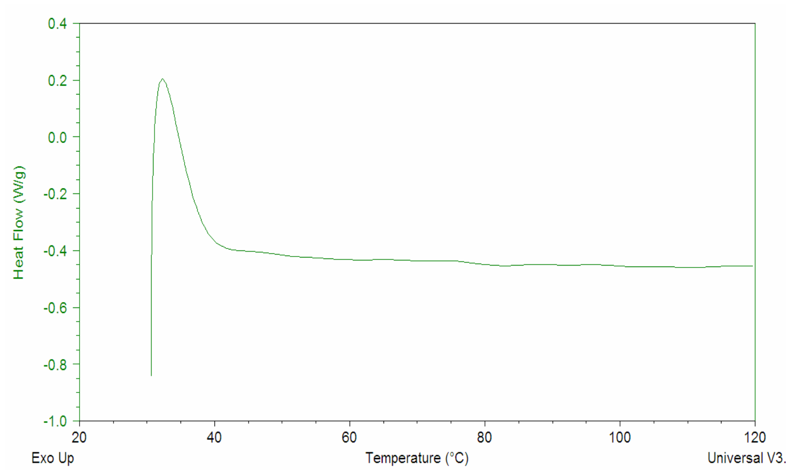

Figure E.9 DSC thermogram of non-fat cake baked in conventional oven for 28 minutes

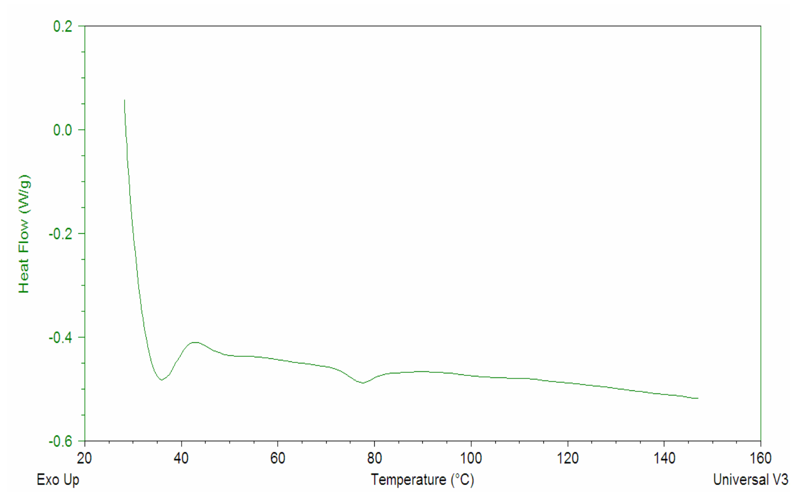

Figure E.10 DSC thermogram of cake batter containing 25% fat

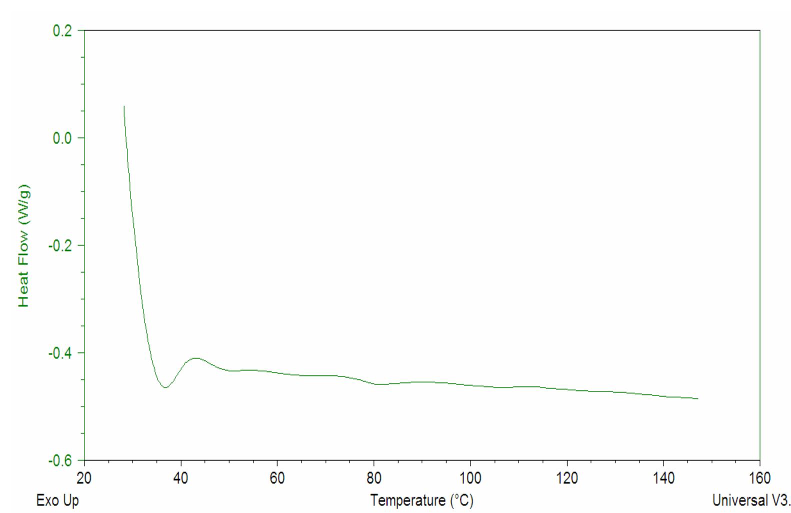

Figure E.11 DSC thermogram of cake containing 25% fat baked in microwave oven for 2 minutes

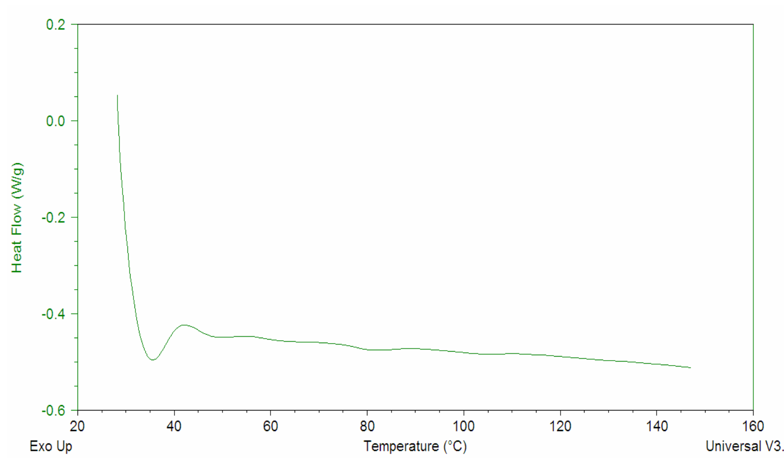

Figure E.12 DSC thermogram of cake containing 25% fat baked in microwave oven for 2.5 minutes

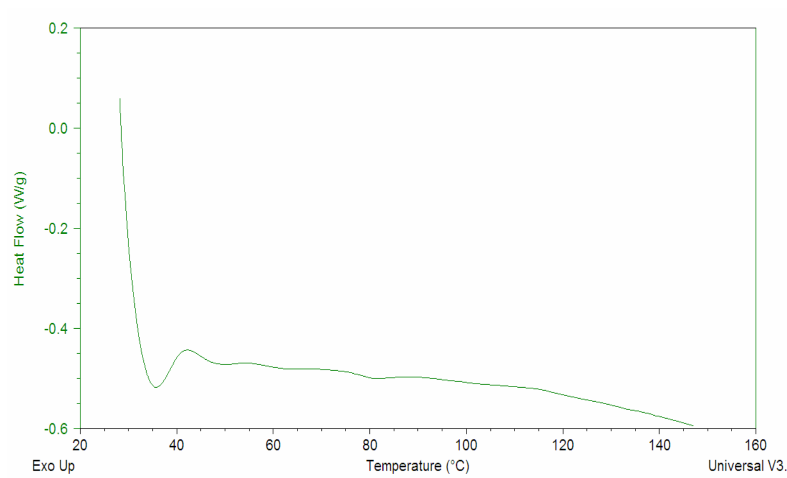

Figure E.13 DSC thermogram of cake containing 25% fat baked in microwave oven for 3 minutes

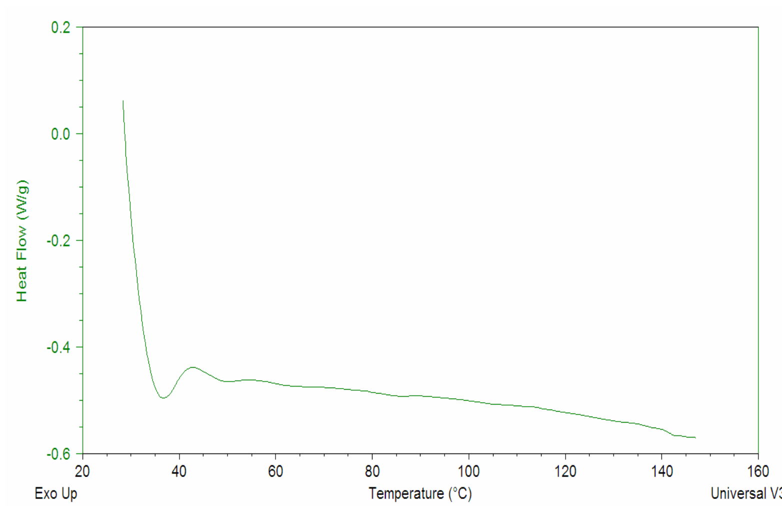

Figure E.14 DSC thermogram of cake containing 25% fat baked in infrared-microwave combination oven for 3.5 minutes

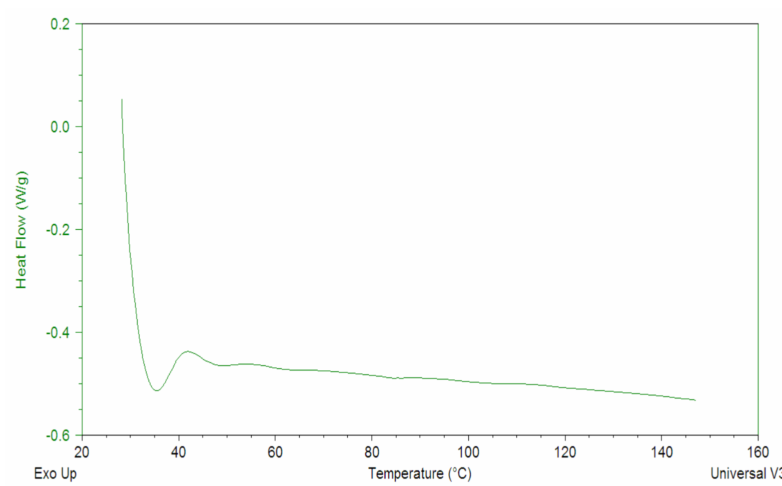

Figure E.15 DSC thermogram of cake containing 25% fat baked in infrared-microwave combination oven for 4.5 minutes

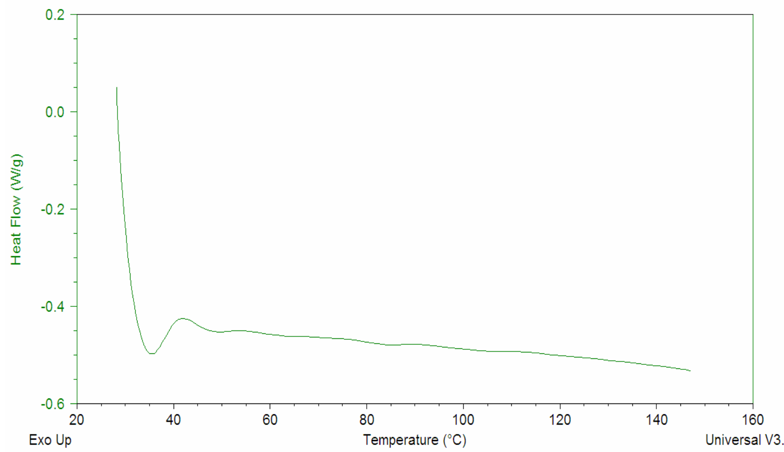

Figure E.16 DSC thermogram of cake containing 25% fat baked in infrared-microwave combination oven for 5.5 minutes

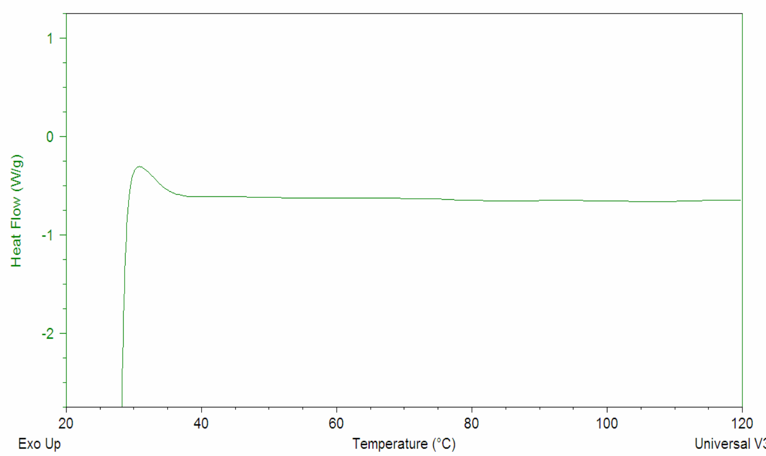

Figure E.17 DSC thermogram of cake containing 25% fat baked in conventional oven for 22 minutes

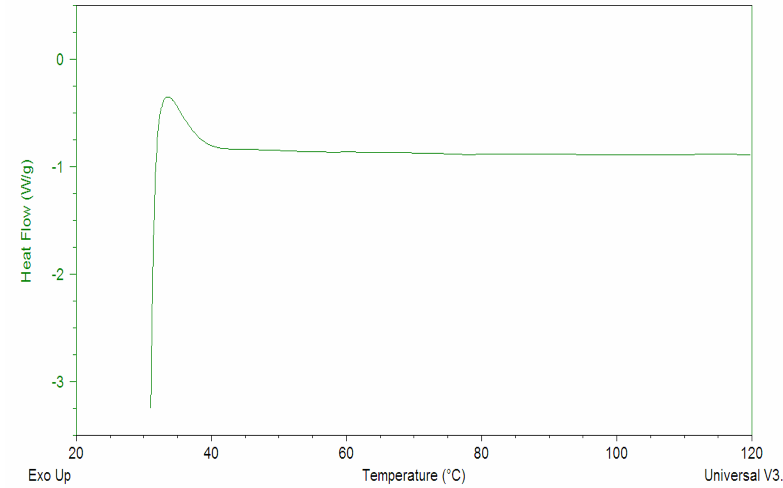

Figure E.18 DSC thermogram of cake containing 25% fat baked in conventional oven for 28 minutes

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Correlation of mixograph of different flours with cake quality, METU and Hacettepe Univeristy, Researcher, 2006-2007

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2.) **Sakiyan, O.**, Sumnu, G., Sahin, S., and Meda, V. Investigation of dielectric properties of different cake formulations during microwave and infrared-microwave combination baking (Journal of Food Science, accepted for publication).

3.) **Sakiyan, O.**, Sumnu, G., Sahin, S., and Meda, V. The effect of different formulations on physical properties of cake baked with microwave and infrared-microwave combination (Submitted to Journal of Microwave Power and Electromagnetic Energy).

4.) Sakiyan, O., Sumnu, G., and Sahin, S., 2005. Investigation of physical properties of different cake formulations during baking with halogen lamp-microwave combination and microwave. AACC Annual Meeting, Florida, USA.

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6.) Sakiyan, O., Sumnu, G., Sahin, S., and Meda, V., 2006 Effects of formulation, frequency, baking time and temperature on dielectric properties of cake during baking with microwave and infrared-microwave combination. CIGR 2006 Future of Food Engineering, Warsaw, Poland.

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8.) Sakiyan, O., Sumnu, G., Sahin, S., and Meda, V., 2006. The investigation of gelatinization degree of cakes baked with microwave and infrared-microwave combination. IMPI Annual Meeting, Boston, USA.

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10.) Sakiyan, O., Sumnu, G., Sahin, S., and Meda, V., 2006. Mikrodalga ve kızılötesi-mikrodalga kombinasyonu ile pişirilen kekin dielektrik özelliklerinin incelenmesi. 9. Gıda Kongresi, Bolu, Turkey.

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