DESIGN OF GLUTEN FREE RICE CAKE FORMULATIONS FOR BAKING IN INFRARED-MICROWAVE COMBINATION OVEN

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY
IN
FOOD ENGINEERING

MAY 2010

Approval of the thesis:

DESIGN OF GLUTEN FREE RICE CAKE FORMULATIONS FOR BAKING IN INFRARED-MICROWAVE COMBINATION OVEN

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

DESIGN OF GLUTEN FREE RICE CAKE FORMULATIONS FOR BAKING IN INFRARED-MICROWAVE COMBINATION OVEN

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May 2010, 220 pages

The main objective of this study was to design gluten free rice cakes containing different gums and an emulsifier for baking in infrared (IR)-microwave combination oven.

In the first part of the study, the effects of different gums (xanthan, guar, xanthan-guar blend, κ-carrageenan, locust bean, hydroxypropyl methylcellulose (HPMC) and xanthan-κ-carrageenan blend) and emulsifier blend (Purawave^{TM}) on physical properties of cake batters were investigated. In the second part of the study, weight loss, specific volume and texture of the cakes baked in different ovens were determined. Macro and micro-structures of the cakes were investigated both qualitatively and quantitatively by using image analysis and Scanning Electron Microscopy (SEM). In the last part of the study, Response Surface Methodology

(RSM) was used to optimize IR-microwave baking conditions and formulation of the cakes.

Power law and Casson models were suitable to explain the rheological properties. Xanthan and xanthan-guar gum blends resulted in higher apparent viscosities as compared to other gums. Gum types affected the dielectric properties and gelatinization enthalpies of cake batter.

Emulsifier addition increased the volume and porosity but decreased the firmness of the cakes baked in IR-microwave combination oven. More porous cakes were obtained when xanthan and xanthan-guar gum blend were used. Baking method was found to be important in affecting porosity, pore size distribution and micro-structure of the cakes.

The highest quality gluten-free rice cakes were obtained when the formulation contained xanthan gum and 5.38% emulsifier and baked using 40% microwave power, 60% halogen lamp power for 7 min in IR-microwave combination oven. In addition, baking time was reduced by 76.7% as compared to conventional baking.

Keywords: Cake baking, Gluten-free, Gum, Infrared, Microwave

ÖZ

KIZIL ÖTESİ-MİKRODALGA KOMBİNASYONLU FIRIN İÇİN GLUTENSİZ PİRİNÇ KEKİ TASARIMI

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Mayıs 2010, 220 sayfa

Bu çalışmanın ana amacı, kızılötesi-mikrodalga kombinasyonlu fırında pişirmek üzere farklı gamlar ve bir emülgatör içeren glutensiz pirinç kekleri tasarlamaktır.

Çalışmanın ilk kısmında, gamların (ksantan gam, guar gam, ksantan-guar gam karışımı, κ-karragenan, keçi boynuzu gamı, hidroksipropil metilselüloz (HPMC) ve ksantan- κ-karragenan gam karışımı) ve emülgatör karışımının (Purawave^{TM}) kek hamurlarının fiziksel özelliklerine etkisi araştırılmıştır. Çalışmanın ikinci kısmında, farklı fırınlarda pişirilen keklerin ağırlık kaybı, özgül hacim ve tekstür gibi fiziksel özellikleri belirlenmiştir. Görüntü analiz yöntemi ve taramalı elektron mikroskobu (TEM) keklerin makro ve mikro yapıları niceliksel ve niteliksel olarak araştırılmıştır.

Çalışmanın son kısmında, kızılötesi-mikrodalga kombinasyonla pişirme şartları ve keklerin formülasyonlarını optimize etmek amacıyla Yanıt Yüzey Metodu (YYM) kullanılmıştır.

Reolojik özellikleri açıklamada, Power yasası ve Casson modelleri uygun bulunmuştur. Diğer gamlarla kıyaslandığında, ksantan ve ksantan-guar gam karışımı daha yüksek görünür vizkozite göstermişlerdir. Gum çeşitleri kek hamurlarının dielektrik özellikleri ve jelatinizasyon entalpilerini etkilenmektedir.

Emülgatör eklenmesi kızılötesi-mikrodalga fırında pişirilen keklerin hacmini ve gözenekliliğini arttırmış ama sertlik değerlerini düşürmüştür. Ksantan ve ksantan-guar gam karışımı kullanıldığında daha gözenekli kekler elde edilmiştir. Pişirme yöntemi, keklerin gözenekliliğini, gözenek dağılımlarını ve mikroyapılarını etkilemeleri açısından önemli bulunmuştur.

En iyi kaliteye sahip glutensiz pirinç kekleri, formülasyon ksantan gam ve %5.38 emülgatör içerdiğinde ve kızılötesi-mikrodalga fırında %40 mikrodalga gücü, %60 halojen lamba gücü kullanılarak 7 dak boyunca pişirildiğinde elde edilmiştir. Ayrıca pişirme süresi konvansiyonel fırındakine göre %76.7 kısalmıştır.

Anahtar sözcükler: Kek pişirme, Glutensiz ürün, Gam, Kızılötesi, Mikrodalga

To My Parents

ACKNOWLEDGEMENTS

I would like to thank Prof. Dr. S. Gülüm Şumnu, my advisor, for her support, guidance and encouragement. I am very grateful to my co-advisor Prof. Dr. Serpil Şahin for her valuable advices throughout this study.

Special thanks to Dr. Marc Regier and Dr. Matthias Rother for their valuable help during the dielectric properties analysis at Karlsruhe University, Karlsruhe, Germany.

I also want to express my gratitude to Prof. Dr. M. Esra Yener, and Assoc. Prof.Dr. Arzu Başman, members of my thesis committee, for their time and fruitful discussions and suggestions.

I would like to extend my thanks to all members of our research group and lab colleauges, especially Semin Özge Özkoç, Işıl Barutçu Mazı, Özge Şakıyan Demirkol for being cooperative, helpful and supportive during my study. My sincere apprecitation goes to Sibel Uzuner, Alev Emine İnce and Elife Özlem Karabacak, my close friends, for their endless support and love during my stressful days.

I also want to thank Necati Özkan from Central Laboratory METU for DSC analysis and Cengiz Tan from Department of Metallurgical and Materials Engineering for SEM analysis.

I would also like Unit of the Scientific and Technological Research Council of Turkey (TOVAG 106O702), TUBITAK-BIDEB, KIT (Karlsruhe Institute of Technology) PRO3 (Process Engineering and Technology Network of Competence)

(Karlsruhe, Germany) and The Scientific Research Funding of METU (BAP-2005-03-14-04) for the financial support during my thesis.

Special thanks to all my family members, my mother Nuray Turabi, my father Ahmet Rasim Turabi and my brother Can Turabi, who provided me everything in receiving the PhD degree. I would also like to thank to my fiancée Uğur Tansu Yolaçaner for his endless encouragement, and most important, for his patience and endless love. Words are not sufficient to express my gratitude to them. I dedicate this work to my dear parents.

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INTRODUCTION

1.1 Celiac Disease

Celiac Disease (gluten sensitive entropathy) is a multisystemic disorder and a permanent intolerance to certain amino acid sequences found in the prolamin fraction of wheat (gliadin), rye (secalin), barley (hordein) and possibly oats (avenin). Recent in-vitro and in-vivo studies show that high molecular weight glutenin sub-units of gluten proteins have also toxic effects to celiac patients as well as the gliadin part (Molberg et al., 2003; Dewar et al., 2006; Ellis et al., 2006). Celiac disease is a lifelong disorder and epidemiological studies in Europe and the United States indicate that it is common. The prevalence is approximately 1% in the general population (Niewinski, 2008). In Table 1.1, data on the prevalence of celiac disease according to recent studies can be seen. There is not a certain percentage for Turkey due to insufficient diagnosis but it is estimated that there are 500000 celiac patients and only 1% of them have been diagnosed until now (http://www.xn--lyak-zoa4g.com/haber/45-2colyak-hastaligi-bilimsel-toplantisi-bursa.html. Last visited: May, 2010). According to recent national scientific researches, 1 in every 100 people has celiac disease in Turkey.

Table 1.1 Estimated prevalence of celiac disease (Adapted from Niewinski, 2008).

Population	Prevalence
In general population	1 in 133
In symptomatic children	1 in 322
In symptomatic adults	1 in 105
In the first-degree relatives of people with CD	1 in 22
In the second-degree relatives of people with CD	1 in 39
In chronic diseases (such as type 1 diabetes)	1 in 60
In African-, Hispanic-, and Asian-Americans	1 in 236
World-wide prevalence	1 in 266

The reaction to gluten ingestion by sufferers of celiac disease is inflammation of the small intestine leading to the maldigestion and malabsorption of several important nutrients including iron, folic acid, calcium and fat-soluble vitamins (Feighery, 1999; Kelly et al., 1999). No single test exists that can definitely diagnose celiac disease in every person. The available serological tests, which are used as an initial noninvasive screen, include antigliadin antibodies, EmA (anti-endomysium antibodies) and anti-Ttg (tissue transglutaminase) (Green et al., 2005). The serological gold standard for diagnosis is EmA with its virtual 100% specificity, though a somewhat lower sensitivity than anti-tTG (Green, 2007).

There are three main strategies to find a remedy for celiac disease recently, which are consumption of a gluten-free diet, use of peptidase supplement therapy (able to breakdown the toxic prolamins) or development of cereal varieties free from the toxic amino acid sequences in the proteins that trigger celiac disease (Abdel-Aal, 2009). Until now, the only available and scientifically proven treatment for celiac disease has been a strict adherence to gluten-free diet and avoidance of gluten containing foods such as wheat, rye, barley and possibly oats. Various novel approaches to treatment have been explored (Ciclitira and Ellis, 2009). One of the toxic gluten peptides is resistant to breakdown by human intestinal proteases; however, this 33-mer is degraded by bacterial prolyl endopepdidases (Shan et al., 2002). High concentrations of these enzymes can reduce the amount of immunotimulatory peptide reaching the mucosa when used ex-vivo in an Ussing Chamber system (Matysial-Budnik et al., 2005). No in-vivo studies have been performed to date. Foods not allowed in a gluten-free diet include: (i) any bread, cereal or other food made with wheat, rye, barley, triticale, dinkel, kamut and oat flour or ingredients, and by-products made from those grains; (ii) processed foods that contain wheat and gluten-derivatives as thickeners and fillers, such as hot dogs, salad dressings, canned soups/dried soup mixes, processed cheese and cream sauces, (iii) medications that use gluten as pill or tablet binders (Gallagher et al., 2004). On the other hand, there is an ongoing debate regarding the accepted definition for what constitutes "gluten-free" (Niewinski, 2008). In each study on gluten-free products, a different threshold for gluten-contamination was set: 100 parts per million (ppm) per day (equivalent of 30 mg gluten) (Collin et al., 2004), between 10 and 100 mg intake daily (Hischenhuber et al., 2006), and <50 mg per day in the treatment of celiac disease (Catassi et al., 2007). Researchers and experts continue to work on an agreeable safe threshold for gluten contamination in gluten-free products.

There is no federal regulation that defines the term gluten-free used in the labeling of foods in the United States at the moment. However, the US Food and Drug Administration is proposing to define the food-labeling term gluten-free to mean that a food bearing this claim does not contain any of the following (Pietzak 2005);

- An ingredient that is a "prohibited grain", which refers to any species of wheat (such as durum wheat, spelt wheat or kamut), rye, barley or their crossbred hybrids;
- An ingredient (such as wheat flour) that is derived from a "prohibited grain" and that has not been processed to remove gluten;
- An ingredient (such as wheat starch) that is derived from a "prohibited grain" that has been processed to remove gluten, if the use of that ingredient results in the presence of 20 ppm (6 mg equivalent) or more gluten in the food;

- 20 ppm or more gluten.

Most European countries have accepted the definition of gluten-free designated in the Codex Alimentarius guidelines as containing <200 ppm (60 mg equivalent) gluten for cereal derived and <20 ppm (6 mg equivalent) for non-cereal derived foods (Codex Standard 118, 1979). AOAC 991.19 method (AOAC, 1995) is the formally validated method for the determination of relatively high levels of gluten in food and its raw materials. Contamination tests can be performed by using gluten assay kits. The Gluten Assay kits are used for the detection and quantification of gluten at very low concentrations in uncooked and cooked foods. The assay utilizes antibodies to gliadin protein in a non-competitive, sandwich type ELISA. The ready to use standards provide accurate quantification in parts per million (ppm).

1.2 Gluten Proteins and Gluten-free Product Development

Gluten is an essential protein mixture to form a strong network required for the desired viscoelasticity and it helps retaining gas to obtain the desired volume and texture in bakery products. As isolated from flour, gluten contains about 80% protein (on a dry basis) and 8% lipids, with the remainder being ash and carbohydrate (Hoseney, 1994). The protein fractions of gluten are glutenin and gliadin. Glutenin is insoluble in aqueous alcohols and gliadin is soluble. The former is rough, rubbery mass and swells considerably and becomes tough and inextensible with no coherence. On the other hand, gliadin produces a soft, viscous, fluid mass like thick glue on hydration. The coiled and folded protein molecules (polypeptide chains) are responsible for the elasticity of gluten, while the plastic flow can be explained as imperfect rigidity, due to slipping in the molecular arrangement. Gliadins are mainly monomeric proteins with molecular weights of around 28,000–55,000 and can be classified according to their different primary structures into the α/β-, γ-, and ω-type. Disulphide bonds are either absent or present as intrachain crosslinks. The glutenin fraction comprises aggregated proteins linked by interchain disulphide bonds; they have a varying size ranging from about 500,000 to more than 10 million (Wieser, 2007). Gluten proteins are characterized by high glutamine and proline contents and low contents of amino acids with charged groups. Non-covalent bonds such as hydrogen bonding and ionic bonding among amide and hydroxyl groups, hydrophobic interactions and sulfhydryl-disulfide interchange reactions, all contribute to the development of the unique viscoelastic properties of gluten in wheat dough (Damodaran, 1996).

The studies of formulation of gluten-free cereal-based products has received attention in recent years since gluten removal results in major problems of low quality, poor mouth feel and flavor. These studies involve a diverse approach which includes the use of starches, dairy products, hydrocolloids, other non-gluten proteins, prebiotics and their combinations, as alternatives to gluten, to improve the quality of gluten-free bakery products. Such additives are mainly used in combination with flours and/or starches containing no gluten such as rice flour, corn flour, corn starch, potato starch, cassava starch, soy flour, sorghum flour and buckwheat flour. Formulation of gluten-free breads is the most common research area and studies on other gluten-free bakery products such as cakes, biscuits and pasta are limited. Some studies have been conducted using wheat starch gluten-free flour. However, products containing non-wheat starches are more desirable since some celiac patients cannot tolerate wheat starch, either. In the study of Gallagher et al. (2003), crust and crumb characteristics of gluten-free breads containing commercial wheat starch gluten-free flour combining with seven types of dairy powders were investigated. In some studies, corn starch combined with cassava starch and sorghum flour was used in gluten-free bread making (Lorenzo et al., 2008; Schober, 2005). Rice flour with its properties of bland taste, white color, digestibility, hypoallergenity, low levels of sodium and lack of gluten-like proteins is one of the most suitable cereal flours used in gluten-free products. It can be used alone or in combination with other flours or starches. Rice flour containing products combined with corn flour, corn starch, potato starch and soybean flour are commonly present in the literature (Lazaridou et al., 2007; McCarthy et al., 2005; Mezaize et al., 2009; Nunes et al., 2009; Sanchez et al., 2002; Sciarini et al., 2008).

Rice flour has some drawbacks. It has low levels of protein and most of them are very hydrophobic and resist swelling in water. Moreover, rice products are known to stale rapidly and have short shelf-lives. Although there are numerous attempts to explain the mechanism of staling, several aspects still remain unclear. It is a complex process and the predominant role has been assigned to starch retrogradation since starch is the main component of the system. Retrogradation is a process in which the molecules of gelatinized starch reassociate to form crystallites upon cooling, which imply fully reversible recrystallization in the case of amylopectin and partially irreversible recrystallization in the case of amylose (Bjöck, 1996). Rice breads were shown to be more prone to retrogradation during storage and had lower specific volume and harder texture than whole wheat bread (Kadan et al. 2001). Many additives such as hydrocolloids, dairy products, non-gluten proteins or some enzymes were added to gluten-free products to improve the structure, texture and taste as well as to retard the staling of the products. Among the enzymes that were used in retarding the staling and improving the structure are different α-amylases, hemicellulases, lipases etc. (Martinez-Anaya et al., 1999; Haros et al., 2002; Leon et al., 2002). In the study of Gujral et al. (2003a), two starch hydrolyzing enzymes were used to retard the staling and improve the structure of bread. Addition of both α-amylase and cyclodextrin glycoxyl transferase (CGTase) improved bread specific volume and crumb firmness. CGTase was found as a better antistaling agent because of its starch hydrolyzing activity. Gujral et al (2004) also found that addition of fungal α-amylase combined with different hydrocolloids like guar gum, xanthan gum, locust bean gum and HPMC, improved the texture and delayed the staling of rice flour chapaties (unleavened flat bread).

Gums, which are used in food products mainly as gelling agents, thickeners or emulsifiers, have much functionality in gluten-free bakery products. These functionalities can be the improvement in the gelatinization performance and retrogradation behavior of the starches (Funami et al., 2005), high water holding capacity and formation of highly viscous solutions of pentosans in breads (Casier et al., 1977). The gas holding property is more difficult in gluten-free dough or batter as compared to gluten-containing doughs or batters. Thus, surface active substances such as gums are added into the formulations to provide gas occlusion and stabilizing mechanisms enhancing the overall quality of final products (Abdel-Aal, 2009). Hydrocolloids also enhance the elasticity and resistance to deformation of gluten-free doughs following the decreasing order of xanthan, CMC, pectin, agrose and β-glucan, which shows xanthan helps in strengthening the doughs (Lazaridou et al., 2007).

1.3 Gums

Gums are high-molecular weight (up to 1 million) hydrophilic polysaccharides used as functional ingredients in food industry. Gums can be extracted from plant, seaweed or microbial sources, as well as they can be derived from plant exudates. Modified biopolymers can be made by chemical or enzymatic treatment of starch and cellulose (Dickinson, 2003).

Gums have been widely used in baking industry as additives in order to modify the dough rheology (Mandala et al., 2007), to improve food texture (Armero and Collar, 1996), to slow down the retrogradation of starch (Davidou et al, 1996), to increase moisture retention and shelf life (Davidou et al, 1996), extend the overall quality of the product in time, and as gluten-substitutes in the formulation of gluten-free breads since gums act as polymeric substances mimicking the viscoelastic properties of gluten in bread dough (Rojas et al., 1999; Gomez et al., 2007). They can function at very low concentrations. The functionality and hydration rate of gums are affected by many factors, such as chemical nature of the gum, temperature and pH range, gum concentration, particle size, presence of other inorganic ions and chelating agents (Ward and Andon, 2002). Two or more gums can also be used together and the synergies between these gums enable to improve or create modified functional properties.

Currently, the mechanism of gums is not completely understood, although some hypotheses have been proposed (Kohajdova and Karovicova, 2009). It is generally considered that hydrocolloids have a weakening effect on the starch structure causing a better water distribution and retention, and also a decrease in the crumb resistance (Armero and Collar, 1996; Guarda et al., 2004). The effect of hydrocolloids results from two opposite phenomena: first, an increase in the rigidity as a consequence of a decrease in the swelling of starch granules and amylose lixiviation; the second effect causes weakening of the starch structure due to the inhibition of amylose chain associations, although the impact of each effect is dependent on the specific hydrocolloid applied (Guarda et al., 2004; Shalini and Laxmi, 2007).

1.3.1 Xanthan gum

Xanthan gum is a well-known anionic and extracellular microbial polysaccharide produced by the bacterium *Xanthomonas campestris.* It is a white to cream colored free flowing powder soluble in both hot and cold water, but insoluble in most organic solvents (Khan et al., 2007). Solutions exhibit highly shear-thinning behavior. Its viscosity has excellent stability over a wide pH and temperature range and the polysaccharide is resistant to enzymatic degradation (Sworn, 2000). Chemical structure of xanthan can be interpreted as a cellulose backbone (Figure 1.1), i.e. glucose units linked with β-1,4-glycoside bond, with branching at carbon-3 atoms. The branches contain D-mannopyranose-(2,1)-β-D-glucuronic acid-(4,1)-β-D-mannopyranose. Additionally, less than 40% of the terminal mannose units have a pyruvic acid group linked as a ketal to its 4 and 6 positions and the inner mannose units are 6-*O*-acetylated. The branching is not regular and some of the branches could be missing (Ptaszek et al., 2007).

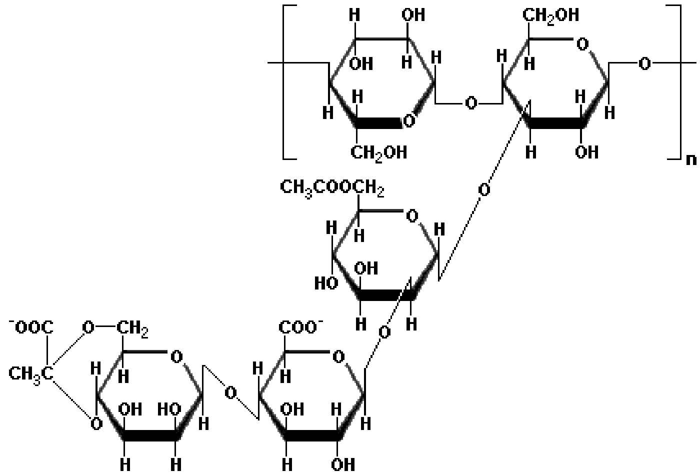


Figure 1.1 Primary structure of xanthan gum

The most important properties of xanthan are its high low-shear viscosity and strong shear thinning character (Kohajdova and Karovicova, 2009). The relatively low viscosity at high shear rates makes it easy to mix, pour, and swallow. Its high viscosity at low shear rates gives it good suspension properties and stability to colloidal suspensions (Sun et al., 2007). A particular feature of xanthan is its insensitivity to temperature which allows it to keep the batters highly viscous at elevated temperatures thus enabling their expansion before setting their structure (Gimeno et al., 2004).

Xanthan can be used in soft baked goods to replace egg white without affecting the appearance and taste (Kohajdova and Karovicova, 2009). It is also used in prepared cake mixes to control rheology and gas entrainment, and to impart high baking volume. Miller and Setser (1982) studied xanthan in a reduced-egg-white angel food cake. The role of xanthan gum in white layer cakes was studied by Miller and Hoseney (1990). Gomez et al. (2007) studied the functionality of different gums (including xanthan gum) on the quality and shelf-life of yellow layer cakes.

1.3.2 Guar gum

Guar gum is a galactomannan and derived from the seed of a leguminous plant *Cyamopsis tetragonolobus.* It is cold water soluble, nonionic and salt tolerant. Galactomannans are composed entirely of linear (1, 4)-β-D-mannan chains with varying amounts of single D-galactose substituents linked to the main backbone by (1-6)-α-glycosidic bonds. It is known that for every galactose unit there are 1.5 to 2 mannose residues (Figure 1.2). The properties of guar gum are strongly dependent on the degree of substitution of galactose. Higher mannose amounts increase the stiffness of the polymer but they also reduce the extensibility and the radius of gyration for every isolated chain (Ptaszek et al., 2007).

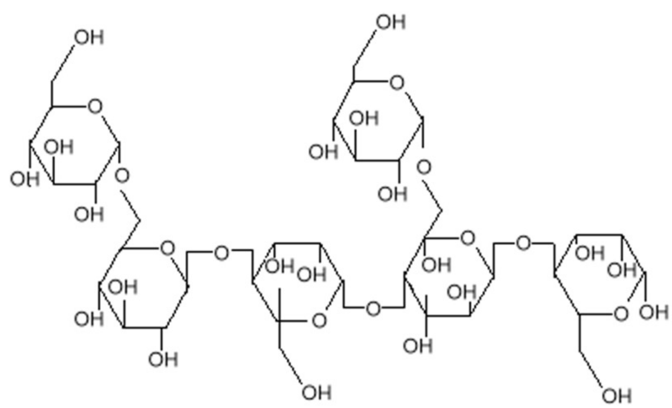


Figure 1.2 Primary structure of guar gum

In the food industry, guar gum has been widely used as a food additive due to the high viscosity of its aqueous solutions even at low concentrations (Miyazawa and Funazukuri, 2006). It is a low-cost polysaccharide, which has many uses as a food stabilizer, and as a source of dietary fiber. It is an excellent additive in salad dressings, ice cream mixes and bakery products because of its strong hydrophilic character (Berk, 1976). The incorporation of guar gum into certain types of foods (e.g. wheat bread, biscuits, and breakfast cereals) improves their palatability (Kohajdova and Karovicova, 2009). Moreover, the results of some human studies indicate that guar-containing foods are more effective in improving glycemic control than pre-meal drinks containing guar gum granules (Ellis et al., 1991; Blake et al., 1997). In baked goods, guar gum is used to improve the mouth feel, to modify rheological properties and to enhance the shelf life (Shalini and Laxmi, 2007; Selomulyo and Zhou, 2007) through moisture retention (Ribotta et al., 2004).

It was also found that through the softening effect, guar gum may delay bread staling. Since guar gum prefentially binds to the starch, it may inhibit the amylopectin retrogradation, which can be explained by the influence on the amylose network formation avoiding the creation of a spongy matrix. The hydrophilic nature of guar gum prevents water release and polymer aggregation during refrigeration. Guar gum also influences the association of inter-chain structure by hydrogen bonding of particular amylose units (Shalini and Laxmi, 2007).

1.3.3 Synergy between xanthan gum and guar gum

Synergistic interactions between hydrocolloids help improving or creating modified functional properties. Such interactions occur between galactomannans and xanthan gum, which result in enhanced viscosity or gelation. Galactomannans are hydrocolloids in which the mannose backbone is partially substituted by single-unit galactose side chains. The distribution of galactose side chains in galactomannans is uneven, and the synergistic effect is explained by different models. One of them is the association of unsubstituted regions (smooth) of galactomannan with the backbone of the xanthan helix (Dea et al., 1977; Morris et al., 1977; Sworn, 2000; Gurkin, 2002). The degree and pattern of substitution varies between the galactomannans and this strongly influences the extent of interaction with xanthan gum. Galactomannans with fewer galactose side chains and more unsubstituted regions react more strongly. The intermolecular binding between xanthan and galactomannans suggests that destabilization of the xanthan helix facilitates xanthan and galactomannan binding (Cheetham and Mashimba, 1991). It was demonstrated that galactomannan acted like a denaturant to disturb the helix-coil equilibrium of xanthan and displaced ordered conformation of xanthan to the conformation for efficient binding (Zhan et al., 1993; Morris et al., 1994). The study of Wang (2001) indicated that the intermolecular binding occurred between xanthan and guar molecules, and guar forced xanthan to change from a stiff ordered helix to a more flexible conformation. In the study of Wang et al. (2002), it was also concluded that the stability of xanthan helical structure or xanthan chain flexibility played a critical role in its interaction with guar.

In the second assumed model, mannan chains that are substituted with galactose units and located on one side of the backbone are linked with the xanthan backbone. The former model (the association of unsubstituted regions of galactomannan with the backbone of the xanthan helix) is not ruled out by this second model but this provides an explanation for the interactions of xanthan with highly substituted galactomannans like guar gum (McCleary et al., 1984; Schorsh et al., 1997). On the other hand, it was reported that there were strong interactions between xanthan and totally substituted galactomannan backbone, assuming different mechanisms were involved between the two polysaccharides (Bresolin et al., 1997). In the study of Schorsh et al. (1997), the influence of the parameters, such as xanthan/galactomannan ratio, galactose content and molecular weight of galactomannan, ionic strength of the medium on viscoelastic properties of xanthan/galactomannan mixtures were examined. The results showed that xanthan gum played an important role in the rheological behavior of xanthan/galactomannan systems. According to the mannose/galactose ratio, xanthan/galactomannan ratio and the ionic strength, the differences in the mechanism may exist.

1.3.4 Locust bean gum

Locust bean gum is a natural hydrocolloid extracted from the seeds of carob tree (*Ceratonia siliqua* L.) after the removal of testa (seed coat) (Gonçalves and Romano, 2005; Bonaduce et al, 2007). The degree and quality of the separation process determine the quality of the gum. Locust bean gum is also a galactamannan having fewer branch units than does guar gum. It has a more irregular structure and it can form junction zones with its long "naked chain" sections (BeMiller and Whistler, 1996). Locust bean gum is constituted of galactomannan polysaccharides (together with GG), which are neutral polysaccharides (Gonçalves et al., 2004) with a 1,4-linked β-D-mannopyranosyl backbone partially substituted with a single 1,6-linked α-D galactopyranosyl side group (Kök et al., 1999) (Figure 1.3).

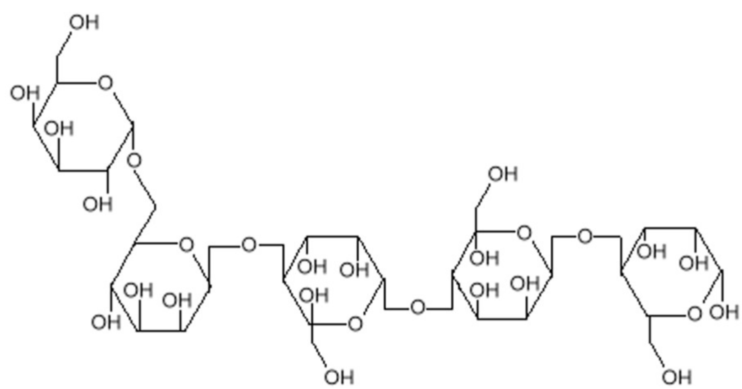


Figure 1.3 Primary structure of locust bean gum

Locust bean gum, which is generally used in combination with other gums, such as carboxymethyl cellulose (CMC), carrageenan, xanthan, guar gum, is an important additive in dairy and frozen dessert products. It is also used in bakery products. It improves the final texture of baked product and adds viscosity to the dough. Improvement in quality of frozen doughs (Sharadanant and Khan, 2003a), breads (Azizi and Rao, 2004) and cakes (Gomez et al., 2007) and extension of shelf-life of breads (Sharadanant and Khan, 2003b; Gavilighi et al., 2006) and cakes were obtained by addition of locust bean gum. In the study of Selomulyo and Zhou (2007), external appearance of bread and its internal characteristics such as texture, grain, cell wall structure, color and softness were also improved.

1.3.5 κ-carrageeenan gum

Carrageenans are water soluble galactans extracted from red seaweeds (Fernandes et al., 1993). The chemical structure of carrageenan is based on a disaccharide backbone of alternating 3-linked β-D-galactopyranose and 4-linked α-D-galactopyranose units, namely G and D units, respectively, Knutsen's nomenclature (Knutsen et al., 1994). They can be recognized according to the position of sulfation (S) (Fernandes et al., 1993), and cyclization of the D units to form an anhydro ring (A). Industrial representatives are the gelling κ-carrageenan, ι-carrageenan and non-gelling λ-carrageenan.

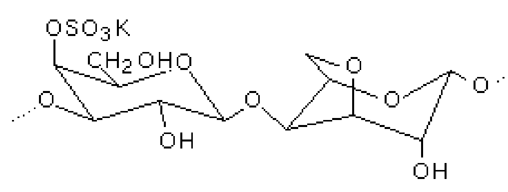


Figure 1.4 Primary structure of κ-carrageeenan

Carrageenan containing solutions are highly viscous and synergistic effect between κ-carrageeenan and locust bean gum was shown in the literature (BeMiller and Whistler, 1996). The combination of these hydrocolloids produces rigid, brittle, syneresing gels. The traditional uses of carrageenan are water gels and dairy applications, such as milk gels, frozen desserts and processed cheese (Imeson, 2000). Several works are related to the application of κ-carrageenan in the bakery industry (Leon et al. 2000, Sharadanant and Khan, 2003a, 2006). When it is used as a dough additive, κ-carrageenan has the ability to improve the specific volume of bread due to its interactions with gluten proteins (Leon et al, 2000). The presence of κ-carrageenan increased moisture content in the final bread compared to the control one although the water activity is lower. These results are in agreement with the ability of hydrocolloids to increase water absorption and maintain the moisture content of the product while reducing the water activity due to the competition for water with proteins and starch.

1.3.6 Hydroxypropyl methylcellulose (HPMC)

Cellulose belongs to the most abundant organic substances existing in nature. It is insoluble in water and it cannot be digested by the human body (Chinachoti, 1995). Its derivatives (methylcellulose, carboxy methylcellulose, and hydroxypropyl methylcellulose) are obtained by chemical modification of cellulose, which ensures their uniform properties. HPMC is obtained by reacting alkali cellulose with both propylene oxide and methyl chloride, which leads to a polymer with high surface activity and unique properties regarding its hydration-dehydration characteristics in the solution state and during temperature changes (Figure 1.5). Moreover, despite the presence of hydrophobic groups in the HPMC chain, this polymer partially maintains the hydrophilic properties of cellulose (Sarkar and Walker, 1995; Barcenas and Rosell, 2005). Methylcellulose can easily stabilize emulsions and foams because of the ether groups. They can also reduce the amount of fat in foods by providing fat-like properties or reducing absorption of fat in fried products. Due to these properties, HPMC acts as emulsifier, strengthener of the crumb grain and it increases the moisture content of the crumb (Bell, 1990; Dziezak, 1991; Barcenas and Rosell, 2005). The use of HPMC in breadmaking improves the bread quality (loaf volume, moisture content, crumb texture and sensorial properties). Additionally, it is a good anti-staling agent, retarding the crumb hardenining and amylopectin retrogradation.

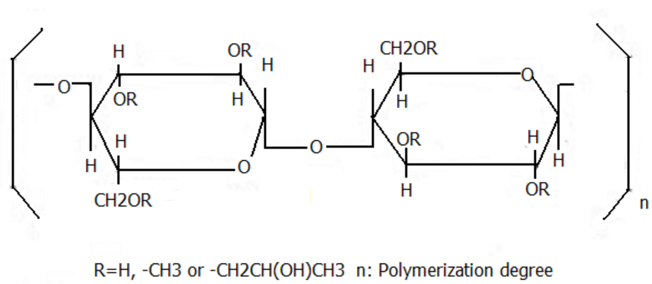


Figure 1.5 Primary structure of HPMC

1.4 Rheological Properties of Cake Batter

Rheological information is valuable in product development and the ability to control the rheological characteristics of aqueous systems makes gums important ingredients in food systems. Rheology concerns the flow and deformation of substances and, in particular to their behavior in the transient area between solids and fluids (Tabilo-Munizaga and Barbosa-Canovas, 2005). Moreover, rheology attempts to define a relationship between the stress acting on a given material and the resulting deformation and/or flow that takes place. 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).

In the literature, studies on the rheological properties of gluten-free doughs and batters are limited (Lazaridou and Biliaderis, 2009). Regarding empirical methods used for study of dough rheology, the farinograph has been used for determination of parameters such as water absorption, dough development time, consistency and elasticity of gluten-free doughs based on rice flour with or without hydrocolloid addition (Gujral and Rosell, 2004; Sivaramakrishnan et al., 2004; Lazaridou et al, 2007). Moreover, the consistency of gluten-free dough prepared cassava flour with defatted soy flour has been measured using a mixograph (Defloor et al., 1991). The RVA and Brabender viscoamylograph have been employed for determining the pasting properties of gluten-free bread doughs based on rice flour (Gujral et al., 2003b, Baxter et al., 2004; Marco and Rosell, 2008), blends of corn and cassava starches (Kobylanski et al., 2004) and cassava flour fortified with defatted soyflour (Defloor et al., 1991).

In the study performed by Chun and Yoo (2004), the rice flour dispersions showed a high shear-thinning behavior with low magnitudes of Casson yield stress. Sivaramakrishnan et al. (2004) found that the rice dough containing HPMC had similar rheological properties as that of wheat flour dough and was suitable for making rice bread. Yoo et al. (2005) found that rice starch–galactomannan mixtures such as guar gum and locust bean gum showed high shear-thinning flow behaviors with high Casson yield stress. Based on dynamic shear data, glutinous rice flour dispersions at concentrations of 4–8% exhibited rheological behavior similar to weak gels (Yoo, 2006). Rice starch–xanthan gum mixtures at 25 ^{o}C have shown shear thinning flow behavior and both consistency index and apparent viscosity of mixtures increased with the increase in gum concentration (Kim and Yoo, 2006). In the study of Yaseen et al. (2005), rheological properties of different gum solutions were investigated in different concentrations and according to modelling results, rheological properties of CMC were characterized by an exponential relationship, whereas iota-carrageenan and xanthan were described by a power-law relationship. In the study of Demirkesen et al. (2010), the rheological properties of rice bread dough containing different gums with or without emulsifier were determined and all the dough formulations had shear-thinning behavior.

Determination of the rheological properties of cake batters is important since the quality attributes of the baked cake such as volume and texture can be correlated with rheological properties. The information on cake batter rheology in the literature is not very sufficient and common. The 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. In the study of Lee et al. (2004), the increased substitution of cake shortening with flaxseed decreased measured shear viscosity, oscillatory storage and loss moduli of the cakes. However, increased substitution of cake shortening with Nutrim oat bran increased these properties. Sakiyan et al. (2004) found that cake batter with different fat concentrations and emulsifier type exhibited shear thinning and time-independent behavior. In the study of Lakshminarayan et al. (2006), it was shown that when fat was replaced by equal amount of maltodextrin the apparent viscosity of batter was reduced significantly. In the study of Celik et al. (2007), replacing egg white proteins with soapwort extract, which containing saponins, did not have any unfavorable influence on the rheological and physical properties of cakes batters. The consistency, flow behaviour indices, storage and loss moduli of low fat batter increased as the β-glucan concentrates increased in the study of Kalinga and Mishra (2009) and addition of β-glucan concentrate decreased the volume and increased hardness.

1.5 Baking of Cakes

A cake batter, which contains principally raw materials of fat, sugar, egg and flour, is a complex emulsion and foam system which is processed by heating. Baking is also a complex process in which some chemical, physical and biochemical changes occur such as gelatinization of starch, denaturation of protein, liberation of carbon dioxide from leavening agents, evaporation of water, crust formation and browning reactions. It is generally described as simultaneous heat and mass transfer within the product and with the environment inside the oven (Sumnu, 2001).

Cakes are aerated, chemically leavened bakery products and they are mainly divided into two types. Sponge cakes are very airy batters that turn into cakes with a 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). For the cake preparation, all air cells should be created during mixing in contrast to yeast leavened products such as bread. Some air cells can be lost later in the process but no new cells can be created during cake making. Depending on upon how the air is incorporated into the batter, cakes can be divided into three different types (Hoseney, 1994). These types are multi-stage mixing, single-stage mixing and a commercial type mixing, in which the air is incorporated directly into the aqueous phase by mechanical means rather than surfactants by using a high-speed mixing machine.

In a cake batter, which can be considered as a fat-in-water emulsion system, the aqueous phase contains dissolved sugar and suspended flour particles. Initially, the air bubbles are held in the fat phase in many batter systems. On the other hand, at temperatures of 37 ^{o}C to 40 ^{o}C, the air bubbles transfer from the fat to the aqueous phase, so that all the air is held in the aqueous phase foam and the batter expands as the air cells expands by the intermediate stage of baking (Shepherd and Yoell, 1976). Then, the structure of the cake is heat set as the egg protein coagulates, and the starch undergoes partial gelatinization in the final stages of baking. The final baked cake is heat-set foam and it has a light and aerated structure with regular and even cells.

The mechanism of cake making can be categorized into three main stages (Shepherd and Yoell, 1976);

Stage I: Batter preparation and the early part of baking

Stage II: Intermediate baking stage

Stage III: Structure development

Stage I involves the changes that occur after the addition of each ingredient for those batter types with a multi-stage addition and the heating of the batter to about 37 ^{o}C to 40 ^{o}C. At multi-stage addition part, sugar is beaten to into the fat to give an aerated cream and the properties of fat are very important for good aeration. Specific volume of the cake is related to the amount of air entrapped in the cake batter. All the air cells which create the final cake texture are incorporated during preparation of the batter. After preparing the fat-sugar cream, the next step is egg addition. The sugar goes into solution and a water-in-oil emulsion is formed, the air cells being dispersed in the fat-phase only. The batter changes into a multiphase structure after the addition of the flour and it 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 now complete batter (Shepherd and Yoell, 1976). In the early stages of baking, little apparent changes occur. However, at 37 ^{o}C to 40 ^{o}C, as the fat in the batter melts and three things happen. Firstly, the irregular-shaped fat particles roll up into spherical droplets. Secondly, any water-in-oil emulsion portions of the batter invert to oil-in-water and finally, the air bubbles are released from the fat phase to the aqueous phase.

The period between the final melting of the fat, with consequent changes told above and the beginning of the setting up of final structure has been defined as stage II or intermediate baking stage (Shepherd and Yoell, 1976). The air bubbles are in the aqueous phase whichever the method of batter preparation type and the general assumption has been that the foam is stabilized by egg protein molecules at the air bubble-water interface. The flour particles are still suspended in the continuous aqueous phase, throughout which the fat is dispersed as liquid droplets. Due to convection currents, the cake batter may undergo a considerable amount of bulk flow during this stage. The air bubbles incorporated in the batter preparation step act as nuclei for the expansion of the total batter by the movement of water vapor and carbon dioxide (if leavening agent is added) into the air cells.

Development of the cake structure is the third and final stage of cake-making process. Partial gelatinization of the flour and egg protein coagulation are the main reasons for this structure development. Onset of structural formation occurs at 65 ^{o}C to 70 ^{o}C and expansion of the air bubbles become very rapid at 70 ^{o}C to 80 ^{o}C. At temperatures of 95 to 100 ^{o}C, bubbles may distort from a spherical shape and come into contact as the structure becomes fixed (Shepherd and Yoell, 1976).

1.6 Gluten-free Cakes

It is challenging to ensure the quality of gluten-free bakery products. The absence of gluten deteriorates the quality and so the use of polymeric substances that mimic the viscoelastic properties of gluten is often required.

Cakes vary among the countries as in all bakery products, containing various types of cereal flours or starches and depending on the different amounts of ingredients. Rice, which is one of the leading food crops in South East Asia, is produced in much higher amounts than wheat. Therefore, rice can be a suitable alternative for producing several types of cakes. On the other hand, scientific studies on gluten-free bakery products containing rice are mainly about gluten-free breads and the studies on cakes based on rice flour or starch are limited in the literature.

In the study of Ji et al. (2007), staling of cakes prepared from rice flour and sticky rice flour were investigated and it was found that moisture content, water activity, texture and sensory quality of cakes were significantly affected by staling. Staling of gluten-free rice cakes containing different gums and baked in different ovens investigated in the study of Köksel (2009). It was found that xanthan-guar gum blend was the most effective to improve quality and retard staling of cakes baked in IR-microwave combination oven. In another study performed by Chuang and Yeh (2006), rheological characteristics and texture attributes of glutinous rice cakes called mochi were investigated and it was found that the water content of the mochi varied depending upon the addition of sugar. Both water and sugar acted as plasticizer to soften the mochi.

Schober (2009) recommended that fine milling of the flour to damage the starch structure, addition of emulsifiers and exchange of sugars (use of glucose instead of saccharose) to lower the gelatinization temperature of the flour can be some solutions to have a desirable structure in the gluten-free cakes.

1.7 Infrared-Microwave (IR-microwave) Combination Baking of Foods

Combining microwave heating with IR heating is a new development in food industry. The browning and crisping advantages of near-IR heating and the time-saving advantage of microwave heating are combined in IR-microwave combination baking (Keskin et al., 2004). In IR-microwave combination baking, infrared heating can act at different times and at different spatial locations relative to microwave heating, which allows increasing the spatial uniformity and the overall rate of heating (Datta et al., 2005). Moisture distribution inside the food can also be improved by the selectivity of the combination heating and moisture can easily be removed keeping the food crisp.

Demirekler et al. (2004) showed that breads baked in IR-microwave combination oven had comparable quality with conventionally baked ones in terms of color, texture and volume (Demirekler et al., 2004). In the study of Keskin et al. (2004), microwave heating was found the dominant mechanism in IR-microwave combination baking in terms of weight loss and textural properties. Additionally, IR mechanism was helpful in color and crust formation in breads, which was desirable. The three baking methods (microwave, IR, IR-microwave) were compared for cakes in the study of Sumnu et al., (2005) and found that IR-microwave combination oven reduced conventional baking time by about 75%. In the study of Keskin et al., 2007, in which the effects of different gums on quality of IR-microwave baked breads were studied, κ-carrageenan resulted in undesirable final bread quality, while xanthan-guar blend addition improved bread quality (high specific volume and porosity, low hardness values). Sakiyan et al. (2007) investigated the dielectric propertis of different cake formulations during microwave and IR-microwave combination baking and found that these properties were found to be dependent on formulation, baking time and temperature. The studies on gluten-free products baked in IR-microwave combination oven are limited. Sumnu et al., 2010 studied the effects of xanthan and guar gums on staling of gluten-free rice cakes and xanthan-guar gum blend decreased hardness, weight loss, retrogradation enthalpy and the change in setback viscosity values of cakes during storage for both types of ovens as compared to control formulation.

It is important to discuss the mechanisms of both microwave and IR heating to understand the mechanism of IR-microwave combination baking.

1.7.1 Microwave heating mechanism

Microwaves are electromagnetic waves within a frequency band of 300 MHz to 30 GHz. In the electromagnetic spectrum (Figure 1.6) they are embedded between the radio frequency range at lower frequencies and infrared and visible light at higher frequencies (Regier and Schubert, 2005). Thus, microwaves belong to the non-ionizing radiations.

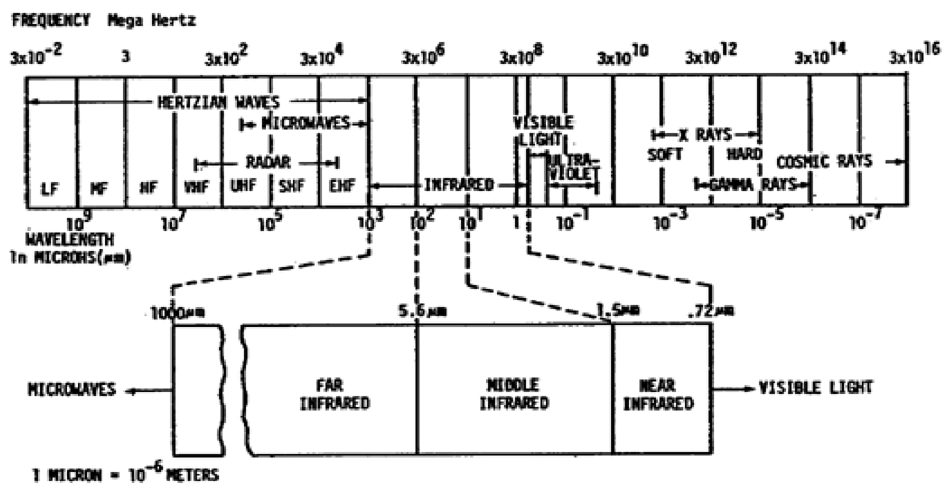


Figure 1.6 The electromagnetic spectrum

The frequency range of microwaves adjoins the range of radio frequencies used in broadcasting and it is also used for telecommunications such as mobile phones and radar transmissions. Therefore, special frequency bands are reserved for industrial, scientific and medical (so-called ISM) in order to prevent interference problems. 915 MHz and 2450 MHz are the frequencies used for industrial applications and home-type microwave ovens, respectively.

Each microwave system consists generally of three basic parts: the microwave source, the waveguide and the actual applicator. Microwave sources are called magnetrons, which are electronic vacuum tubes and produce the alternating electric field called a microwave electric field. The waveguide is a metallic conduit that guides the electromagnetic field from the magnetron into a metallic enclosure called a cavity where the food material is placed. The electric field in the enclosed cavity of a microwave oven is not in one single direction, but it extends in the three perpendicular oven directions: top to bottom, side to side and front to back (Buffler, 1993).

The major mechanisms of microwave heating of foods involve ionic conduction and dipolar rotation (Sahin and Sumnu, 2006). In the first mechanism, the charged particles in food material such as sodium (Na^+) or chlorine ions (Cl^-) are subjected to alternating microwave electric field and forced to move in three orthogonal directions at 2.45 billion times per second (i.e. in case of 2450 MHz frequency). Energy from oscillating microwave electric field in the microwave oven cavity is imparted to charged particles in terms of physical agitation. The acceleration among the charged particles in food material increases the energy of agitation or heat. Therefore, the energy transfer to the ions and then to the neighboring atoms or molecules in food material is one mechanism of microwave heating.

Microwave interaction with polar molecules such as water is the second microwave heating mechanism. The water molecules are common in most foods. The structure of this molecule is in the form of V, with the two hydrogen atoms each consist of a positive charge attached to the oxygen atom that consists of negative charge making an angle of approximately 105^o. These charges are physically separated and in this form are called a dipole, which behaves like a magnetic needle. This magnetic needle acts in an electric field in the same way that a magnetic compass needle acts in a magnetic field (Buffler, 1993). They will experience a torque or rotational force attempting to orient them in the direction of field when they are placed in a region of an oscillating electric field such as microwave electric field. Thus, energy is extracted from the oscillating electric field by the dipoles and is transferred to other molecules by the collisions. This second microwave heating mechanism is the predominant microwave interaction for most of the foods except the highly salted foods.

Dielectric properties are the physical properties of food that affect microwave heating. These properties of foods depend on food composition, temperature and frequency and studies on dielectric properties of baking ingredients and baked products are helpful in understanding the heating patterns during microwave baking (Sumnu and Sahin, 2005).

The distribution of electromagnetic energy in microwave heating systems is governed by Maxwell's equations with appropriate boundary conditions defined by the configuration of the systems and the interfaces between treated materials and remaining space. The dielectric properties of materials are the main property parameters of the Maxwell equations (Tang, 2005).

The complex relative permittivity (relative to that of free space) shown in the following equation is used to describe the dielectric properties of a material;

$$\varepsilon^* = \varepsilon' - j\varepsilon'' \quad (1.1)$$

where $j = \sqrt{-1}$. The real part ε' is the dielectric constant that reflects the ability of a material to store electrical energy when in an electromagnetic field; the imaginary part ε'' is the dielectric loss factor that influences the conversion of electromagnetic energy into thermal energy (Tang, 2005).

The energy equation for microwave heating includes a heat generation term;

$$\frac{\partial T}{\partial t} = \alpha \nabla^2 T + \frac{Q}{\rho C_p} \quad (1.2)$$

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

The relationship between Q and electric field intensity (E) at that location can be derived from Maxwell's equations of electromagnetic waves as shown by Metaxas and Meredith (1983);

$$Q = 2\pi\varepsilon_o\varepsilon'' fE^2 \tag{1.3}$$

where ε_o is dielectric constant of free space (8.854×10^{-12}), ε'' is the dielectric loss factor of the food, f (Hz) is the frequency of the oven, and E (V/m) is the electric field intensity. The electric field intensity decreases with distance (z) from the entry surface of a dielectric material as a result of electromagnetic energy dispersion. The degree of this decay can be represented as the following;

$$E = E_0 e^{-\alpha z} \tag{1.4}$$

Attenuation factor (α) in this equation (1.4) determines the degree of the decay, which is a function of the dielectric properties of the material;

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

where λ_0 is the free space wavelength

According to the eqn 1.3, thermal energy converted from electromagnetic energy in a material is proportional to the square of electric field strength. Substituting E in Eqn 1.4 by power, P, the following equation is obtained;

$$P = P_0 e^{-2\alpha z} \tag{1.6}$$

The penetration depth of microwaves is defined as the depth where the dissipated power is reduced to 1/e of the power entering the surface. The penetration depth in IR and microwave energy in a food can be calculated by (von Hippel, 1954);

$$d_p = \frac{c}{2\pi f \sqrt{2\varepsilon' \left[1+\sqrt{\left(\frac{\varepsilon''}{\varepsilon'}\right)^2}-1\right]}} \qquad (1.7)$$

The penetration depth of microwaves into a material is a function of both dielectric properties of the material, which are ε' and ε''. Knowledge about penetration depth serves as a guideline to the heating efficiency of a food and is therefore an important parameter that must be known by food product developers (Buffler, 1993).

1.7.2 Dielectric properties of baked products

Determination of dielectric properties of bakery products is necessary for proper understanding of the heating pattern during baking. The dielectric properties of bread dough and yeast were studied under different conditions in the study of Zuercher et al. (1990). Both the dielectric constant and loss factor decreased with increasing flour content in the dough sample and also during baking. The effects of temperature and mixing time on dielectric properties of wheat dough were studied by Kim and Cornillon (2001). The increased mobility of water molecules with temperature resulted in an increase in the amount of dissolved ions and thus an increase in the dielectric loss factor. It was shown that the increase in dielectric loss factor with temperature was less pronounced above gelatinization temperature.

Investigating dielectric properties of starch and gluten solutions is essential for the proper understanding of the heating pattern during microwave baking since the major components in baked products are starch and gluten (Sumnu and Sahin, 2005). The dielectric properties of food polymers depend on their interactions with water and charged food constituents such as salt ions, leavening agents and free amino acids (Shukla and Anantheswaran, 2001). Nelson et al. (1991) showed that dielectric properties of potato starch changed with moisture content and temperature. The loss factor of gelatinized potato starch was higher than that of its granular form (Roebuck and Goldblith, 1972). Gelatinized or swollen starch binds less water to its structure; therefore more water is free to respond to the alternating microwave field, resulting in heat build-up. Ryynanen et al. (1996) observed that both dielectric constant and loss factor decreased with increase in temperature for potato, wheat, corn and waxy corn starch suspensions. The higher dielectric constant values were obtained with more dilute solutions while the loss factor did not change with concentration. Ndife et al. (1998) studied the effects of temperature on dielectric properties of tapioca, corn, wheat, rice, waxy maize and amylo-maize starches in granular and suspension forms at different starch/water ratios. The dielectric content and loss factor of granular starches increased while those of starch solutions decreased with temperature.

Variation of dielectric properties of hydrocolloids with moisture content, temperature and stoichiometric charge were investigated in the study of Prakash et al. (1992). It was found that both dielectric constant and loss factor were positively correlated to moisture and temperature. However, moisture was the most important determinant. In the study of Ahmed et al. (2007), a sharp change in the dielectric properties of Indian Basmati rice flour slurry were noted above 70 ^{0}C which was related to rice starch gelatinization. The effects of different gums on dielectric properties of breads baked in IR-microwave combination oven were studied by Keskin et al. (2007). The dielectric properties of breads baked in IR-microwave combination oven were found to be dependent on gum type and the highest value was obtained for formulation containing κ-carrageenan.

1.7.3 Main problems in microwave baked products

Microwave-baked products have not been fully accepted by customers yet although microwave baking has some advantages of time, energy and space saving and nutrient retension. Common quality problems of these products are firm and tough texture, rapid staling, dryness and lack of color, flavor and crust formation.

One of the reasons for these problems is that physicochemical changes and interactions of major ingredients, which would normally occur over a lengthy period in a conventional system, cannot always be completed during the short baking period of microwave system (Hegenbert, 1992). Another reason is the specific interactions of each component in the formulation with microwave energy (Goebel et al., 1984). Therefore, the studies in recent years have been aimed to improve the product quality by changing the product formulation and oven design to obtain the same quality as conventionally baked products (Sumnu and Sahin, 2005).

In conventional baking, heat is transferred to the product mainly by convection from the heating media and by radiation from oven walls to the product surface followed by conduction to the center. The baking conditions which affect the final product quality are the rate and the amount of heat application, humidity level in a baking oven and baking time (Therdthai and Zhou, 2003). On the other hand, in microwave baking, food is surrounded by air at ambient temperature which is not heated by microwaves. The heat generated inside the food due to ionic conduction and dipolar rotation mechanisms is conducted through the food material. As a result of this fast heat generation, there may not be enough time for completion of baking reactions such as starch gelatinization, starch conversion by enzymes, enough expansion of dough/batter into a rigid crumb structure during microwave baking.

The most significant difference between microwave and conventional baking is the inability of microwave ovens to induce browning and crust formation. The cool ambient temperature inside a microwave oven causes surface cooling of microwave-baked products, which prevents formation of Maillard reaction products responsible for flavor and color (Decareau, 1992; Hegenbert, 1992). Even though the food samples are heated in microwave oven for longer periods, they become dry and brittle but never brown.

Breads baked in microwave oven stale faster compared to ones baked in conventional oven and this behavior can be explained by “Higo Effect” (Higo et al., 1983), which is the hypothesis that more amylose is leached out of starch granules during microwave heating of breads. This amylose was found to be more disoriented and contain less bound water than in conventionally baked bread. Upon cooling, the surrounding amylose molecules align and contribute to crumb firmness. The ability of amylose to realign into a more crystalline structure is better in microwave-heated bread than conventionally heated one, resulting in a harder texture (Sumnu, 2001).

In microwave baking, and relatively larger amounts of interior heating results in increased moisture vapor generation inside the food material, which creates significant interior pressure and concentration gradients. This results in higher rate of moisture losses during microwave heating (Datta, 1990). Breads and cakes baked in microwave oven were shown to lose more moisture as compared to conventionally baked ones (Sumnu et al, 2005; Zincirkiran et al., 2002; Seyhun, 2002; Keskin et al., 2004; Demirekler et al., 2004; Demirkol, 2007). Combining microwave with IR or hot air may be a solution to reduce the problems in microwave baked products.

1.7.4 IR heating mechanism

IR radiation shown in the electromagnetic spectrum in Figure 1.6 is predominantly responsible for the heating effect of sun (Ranjan et al., 2002). IR radiation found between the visible light and radio waves (0.76-1000 µm) can be divided into three different categories, namely, near-infrared radiation (NIR, 0.75-3 µm), mid-infrared radiation (MIR, 3-25 µm) and far-infrared radiation (FIR, 25-100 µm).

The infrared radiation source has often a high temperature (500-3000 ^{o}C). Heat transfer by convection cannot be ignored in infrared heating. IR lamps as well as hot rods and plates can be used as infrared sources (Mujumdar and Ratti, 2007). Interactions of food materials in the near- and mid- infrared range of electromagnetic waves primarily involve vibrational energy levels of molecules whereas in the far-infrared range, their interaction primarily involves rotational energy levels of molecules. As infrared heating has poor penetration due to higher frequency range, it has an impact only on the surface of the body and heat transfer through the body proceeds by conduction, convection or radiation (Sepuldeva and Barbosa-Canovas, 2003).

Penetration depth of infrared radiation can vary significantly for different foods since foods are complex mixtures of biochemical molecules, inorganic salt and water. The penetration depth of infrared radiation determines how much the surface temperature increases or the level of surface moisture that builds up over time. Datta and Ni (2002) showed that as the penetration depth decreased, that is as infrared energy absorbed closer to the surface, the surface temperature of the products increased.

Some of the advantages of infrared radiation as compared to conventional heating are reducing heating time, equipment compactness, rapid processing, decreased probability of flavor loss, preservation of vitamins in food products, and absence of solute migration from inner to outer regions (Ranjan et al., 2002). Sumnu et al. (2005) and Keskin et al. (2004) studied microwave, infrared and infrared-microwave combination baking of cakes and breads and they found that, it was not desirable to bake breads and cakes by using only IR heating since the product had a very thick crust. In addition, IR heating did not provide any advantage in reducing the baking time significantly and they concluded that it was possible to improve the quality of microwave baked cakes when IR heating was combined with microwave heating.

Temperature and moisture profiles for the foods heated by hot-air assisted-microwave and infrared radiation were studied by Datta and Ni (2002), using a multiphase porous media transport model for energy and moisture in the food. Il'yasov and Krasnikov (1991) provided detailed discussion of infrared absorption in their study but did not focus on energy or mass transport. Sandu (1986) provided qualitative descriptions of temperature and moisture profiles in foods during infrared heating. The infrared heating of foods, especially drying was studied by various researchers recently. In the study of Zhu et al (2010), the effects of three processing parameters, such as product surface temperature, slice thickness and processing time, on blanching and dehydration characteristics of apple slices exposed to simultaneous infrared dry-blanching and dehydration (SIRDBD) with intermittent heating. In the study of Das et al. (2009), both heating and drying of high moisture paddy using vibrating platform coupled with infrared heating source and the Page Model was found suitable to explain the infrared drying behavior of the high moisture paddy under vibrating condition.

1.8 Structural analysis of foods

Most of the quality properties of foods are derived from their unique macro and micro-structures. The physicochemical (rheology, optical, stability), sensory (texture, appearance, flavor), nutritional (bioavailability) and transport properties of foods are largely dependent on the type of components present, the interactions among them, and the structural organization (McClements, 2007). Quantification of structural features using images provides understanding basic mechanisms of physicochemical changes.

Cake crumb structure is one of the major quality attributes and it can be a determinant of the volume and the texture. The baking process, in which the sponge-like crumb texture occurs, creates a hierarchical structure of the gas cells resulting in a wide spectrum of cell sizes, from macro to micro-scale. Therefore, having knowledge on the macro and micro-structure of cakes may be useful to predict quality of cakes.

1.8.1 Macrostructure of bakery products

In recent years, image analysis methods have been applied for quantitative evaluation of morphology and macro/micro-structure of foodstuffs. Image processing techniques usually consist of five steps (Du and Sun, 2004), which are (1) image capture, (2) pre-processing, (3) image segmentation, (4) feature extraction and (5) classification. Quantitative examination of cake crumb, such as determining gas cell sizes and their distribution, can be done by image analysis to provide information on structural system.

Image analysis and quantification of relative features is the basis of modern food microscopy. The extracted information from image analysis is useful to translate the food system complexity to numerical data that will be analyzed to improve the understanding of structure-function relationships of complex systems, such as food and biological materials (Chanona-Perez et al., 2008). The major applications of image analysis in the area of cereal research is the differentiation of bread brands (Zayas, 1993), investigation of the crumb grain structure of baked goods (Noll and Kuhn, 1997; Perez-Nieto et al., 2010), comparison of crumb microstructure from pound cakes baked in a microwave and conventional oven (Sanchez-Pardo et al., 2008) and investigation of the effects of gums on macro and micro-structure of breads baked in different ovens (Ozkoc et al., 2009). Moreover, a mathematical method was proposed by Bertrand et al. (1992) to characterize the appearance of bread crumb by using digital images. Zghal et al. (2002) examined the effect of structural parameters and structural heterogeneity, quantified by digital image analysis, on mechanical properties of fresh bread crumb. Datta et al. (2007) demonstrated that more representative data on the pore size distribution of breads can be obtained from image analysis.

1.8.2 Microstructure of bakery products

Improvements on the quality of existing foods and the creation of new products to satisfy expanding consumer's demand during this 21st century are based largely on inventions at the microscopic level since majority of elements that critically participate in transport, physical and sensory properties of foods are below 100 µm range (Aguilera, 2005). The forces that act on the microstructural level are physical interactions (colloidal van der Waals, electrostatic, hydrogen bonding and hydrophobic forces), gravity, electrical forces and mechanical forces (McClements, 2007).

The imaging system in analyzing microstructure of foods determines the kind of information possible to obtain from the samples. The most widely used imaging techniques used in micro structural food research are light microscopy (LM), transmission electron microscopy (TEM), and scanning electron microscopy (SEM). SEM is a common and important method for understanding the microstructure of bakery products. SEM is capable of performing microstructural analysis at the magnifications ranging from 20 to 10000, combining best attributes of LM and TEM. Whole samples can be observed and both surface and internal structure can be analyzed. Sample preparation in SEM is relatively easy and introduces fewer artifacts than LM since no sectioning is required and a wide spectrum of food structures can be viewed (Sanchez-Pardo et al., 2008). When the electron beam strikes an ultra-fine sample section (100 nm), some of the incident electrons are transmitted to form an image with the impression of three dimensions (Aguilera and Stanley, 1999; Bozzola and Russell, 1991). However, coating the surface of samples with a conductive material such as gold is required to avoid surface charging (Aguilera and Germain, 2007). Recently, new techniques have been developed to make the SEM analysis easier, such as environmental scanning electron microscope (ESEM), Cryo-SEM and variable-pressure scanning electron microscope (VPSEM), etc. VPSEM instrument allows the examination of surfaces of almost any specimen, wet or dry, because the environment around the specimen no longer has to be at high vacuum (Goldstein et al., 2003).

The studies on the microstructure of bakery products are limited. Studies are mostly on breads rather than cakes. SEM studies have shown qualitative relationships between a bread's mechanical properties and the size and distribution of gas cells in the crumb (Zayas, 1993; Hayman et al., 1998). Microstructure changes during baking of breads have been studied by Freeman and Shelton (1991) and Datta et al. (2007). The effect of composition on microstructure of conventionally baked breads was studied by Hayman et al. (1998), Rojas et al. (2000) and Ahmad et al. (2001). Datta et al. (2007) examined the porous structure for different methods (liquid extrusion porosimetry, image analysis, volume displacement method and SEM) during baking of breads in different ovens to obtain comprehensive and quantitative information on pore characteristics of samples.

Quantitative information obtained by SEM is important to understand the structural and transport properties of food products. As a quantitative study, Alamilla et al. (2005) investigated the morphological changes of maltodextrin particles along spray drying by using SEM for image capturing and box counting method. In another quantitative study of Impoco et al. (2007) SEM was used to understand the microstructural properties of cheese by the help of Image J software.

1.9 Optimization by Response Surface Methodology (RSM)

Response surface methodology (RSM) is a collection of statistical and mathematical techniques useful for developing, improving, and optimizing processes. RSM has important applications in the design, development, and formulation of new products, as well as in the improvement of existing product designs (Myers and Montgomery, 2002). It is used to examine the relationship between one or more response variables and a set of quantitative experimental variables or factors. The objective of application of this method is optimization of these responses. If the response (y) is to be maximized in a two variables (x_1, x_2) system;

$$y = f(x_1,x_2) + \varepsilon \tag{1.8}$$

where ε represents the noise or error observed in the response y. If we denote the expected response by $E(y) = f(x_1,x_2) = \eta$, then the surface represented by;

$$\eta = f(x_1,x_2) \tag{1.9}$$

is called a response surface.

Response surfaces are usually represented graphically, where η is plotted versus the levels of x_1 and x_2 (Figure 1.7-a). The contour plot (Figure 1.7-b) may be plotted to help visualize the shape of the response surface. In the contour plot, lines of constant response are drawn in the x_1-x_2 plane and each contour corresponds to a particular height of the response surface.

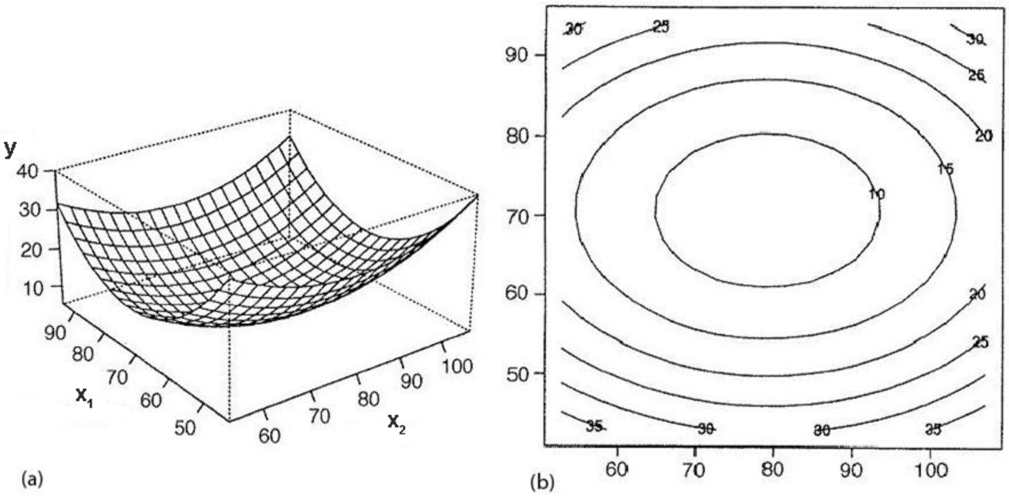


Figure 1.7 a) A three dimensional response surface showing the response as a function of x_1 and x_2 and b) a contour plot of a response surface.

In most RSM problems, the first step is to find a suitable approximation for the true functional relationship between y and the set of independent variables. If the response is well modeled by a linear function of the independent variables, then the approximating function is the first order model;

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k + \varepsilon \qquad (1.10)$$

If there is curvature in the system, then a polynomial higher degree should be used, such as the second-order model;

$$y = \beta_0 + \sum_{i=1}^{k} \boldsymbol{\beta}_i x_i + \sum_{i=1}^{k} \boldsymbol{\beta}_{ii} x_{ii} + \sum_{i<j} \sum \boldsymbol{\beta}_{ij} x_i x_j + \varepsilon \qquad (1.11)$$

For estimating the parameters in approximating polynomials, the method of least squares is used. The response surface analysis is then performed using the fitted surface. Designs for fitting surfaces are called response surface designs.

Fitting and analyzing response surfaces are greatly facilitated by the proper choice of an experimental design. Some of the important characteristics of an appropriate experimental design are (Myers and Montgomery, 2002);

i. Result in a good fit of the model to the data.
ii. Give sufficient information to allow a test for lack of fit.
iii. Allow models of increasing order to be constructed sequentially.
iv. Provide an estimate of "pure" experimental error.
v. Be insensitive (robust) to the presence of outliers in the data.
vi. Be robust to errors in control of design levels.
vii. Be cost-effective.
viii. Allow for experiments to be done in blocks.
ix. Provide a check on the homogeneous variance assumption.
x. Provide a good distribution of $Var[y(x)]/\sigma^2$

There are orthogonal first-order designs to minimize the variance of the regression coefficients in first-order models. The class of orthogonal first-order designs includes the 2^k factorial and fractions of the 2^k series in which main effects are not aliased with each other. In using these designs, it is assumed that the low and high levels of the k factors are coded to the usual ±1 levels. Another orthogonal first-order design is the simplex. The simplex is a regularly sided figure with k+1 vertices in k dimensions. Thus, for k = 2 the simplex design is an equilateral triangle and for k = 3 is it a regular tetrahedron.

Minimum conditions for fitting a second order model are;

i. at least three levels of each design variable
ii. at least $1 + 2k + k(k-1)/2$ distinct design points

Box and Behnken developed a family of efficient three-level designs for fitting second-order response surfaces. The class of designs is based on the construction of balanced incomplete block designs. For example, a balanced incomplete block design with three treatments and three blocks is given by (Myers and Montgomery, 2002);

	Treatment		
	1	2	3
Block 1	X	X	
Block 2	X		X
Block 3		X	X

In the response surface setting, the pairing together of treatments 1 and 2 symbolically implies that design variables x_1 and x_2 are paired together in a 2^2 factorial (scaling ±1) while x_3 remains fixed at the center ($x_3 = 0$). The same applies for blocks 2 and 3, with a 2^2 factorial being represented by each pair of treatments while the third factor of remains fixed at 0. As a result, the k = 3 Box-Behnken design (BBD) is given by;

x1	x2	x3
-1	-1	0
-1	1	0
1	-1	0
1	1	0
-1	0	-1
-1	0	1
1	0	-1
1	0	1
0	-1	-1
0	-1	1
0	1	-1
0	1	1
0	0	0

Researchers are inclined to require three evenly spaced levels in many scientific studies that require RSM. Therefore, BBD is an efficient option and indeed an important altenative to the central composite design. There is sufficient information available for testing lack of fit. It turns out that the BBD does not substantially deviate from rotatability. Another important characteristic of the BBD is that it is a spherical design. For example, in the k = 3 case that all of the points are so-called “edge points”, that is points that are on the edges of the cube; in this case, all edge points are a distance $2^{1/2}$ from the design center. The spherical nature of the BBD, combined with the fact that the designs are rotatable or near-rotatable, suggests that ample center runs should be used. Center runs are necessary to avoid singularity. The use of three to five center runs is recommended for the BBD.

RSM has been widely used in baking studies. RSM was used in the study of Rubenthaler et al. (1990) to determine the best combinations of sugar, yeast and fermentation and proof time to give the highest quality steamed bread. In the study of Frye and Setser (1991), RSM models were used to optimize textural attributes of a yellow layer cake with reduced calories. Toufelli et al. (1994) studied the effects of methylcellulose, egg albumen, and gum arabic on the sensory properties of gluten-free pocket-type flat bread by using RSM in the study of Gan et al. (2007). In the study of Sumnu et al. (2000), RSM was used to optimize the formulation of microwave-baked cakes. Proportions of corn starch, cassava starch, and rice flour were optimized for production of gluten-free bread to maximize specific volume, crumb grain score and bread score in the study of Sanchez et al. (2002). In another study, RSM was used to optimize gluten-free bread fortified with soy flour and dry milk (Sanchez et al., 2004). In the study of Sevimli et al. (2005), IR-microwave combination baking of cakes was optimized by using RSM. The optimum formulation for production of a cassava cake was determined by RSM. A fibre-enriched gluten-free bread formulation based on corn starch, rice flour and hydroxypropylmethyl cellulose was optimized by Sabanis et al. (2009). There is no study in literature on optimization of gluten free cakes to be bakes in IR-microwave combination oven.

1.10 Objectives of the study

A lifelong gluten-free diet is essential for patients having celiac disease. Gluten replacement is nowadays one of the most challenging issues for food science and technology. There are ongoing studies to improve quality of gluten-free products and to develop new gluten-free products. New and different technologies have recently been growing for developing alternative products with higher quality and reasonable price. IR-microwave baking is a novel technology that combines the time saving advantage of microwave and browning advantage of infrared heating. The main objective of this study was to develop new gluten-free cake formulations to be baked in IR-microwave combination oven. In addition, the effects of different gums on rheological and dielectric properties, gelatinization enthalpy of cake batter, macro and microstructure and quality of gluten-free rice cakes were studied. Moreover, the quality of gluten-free cakes baked in IR-microwave combination oven were compared with that of conventional oven.

Rheological information is valuable in product development. There is no study on rheological properties of gluten-free rice cake batter and the relationship between these properties and the quality of baked cakes in the literature. Dielectric properties, which depend on food composition and temperature, are the physical properties of food that affect microwave heating. Studies on dielectric properties and gelatinization enthalpy of cake batter are helpful in order to understand heating patterns during microwave baking. Dielectric properties and gelatinization enthalpy of gluten-free rice cake batters have not been studied, yet.

Having knowledge on the macro and micro-structure of cakes may be useful to predict many of the quality properties of cakes since the physicochemical, sensory and transport properties of foods are largely dependent on the type of components present, the interactions among them, and the structural organization. There are many studies for obtaining qualitative information for structure of foods by SEM in the literature. However, the structural studies on bakery products are limited. Moreover, there is no study in literature, which gives quantitative information on SEM images of baked products.

Response surface methodology, which is a collection of statistical and mathematical techniques, is a useful and common tool for development, improvement and optimization of processes. Many researchers have used this method in optimization of bakery products. On the other hand, optimization of conditions in IR-microwave combination oven and formulation of gluten-free rice cakes have not been studied yet. For this reason, it was aimed to optimize the baking conditions and formulations of rice cakes to be baked in IR-microwave combination oven.

CHAPTER 2

MATERIALS AND METHODS

2.1 Materials

Rice flour having 10% moisture, 6% protein and 0.6% ash (Knorr-Çapamarka, Istanbul, Turkey), sugar (sucrose), salt, baking powder (Bağdat Baharat, Ankara, Turkey) and shortening (Becel, Unilever, Turkey) containing vegetable oil, water, non-fat pasteurized milk, emulsifier blend (vegetable mono/diglycerides, soy lecithin), salt, lactic acid, potassium sorbate, vitamins (E, B6, Folic acid, A, D and B12), butter aroma and color additive (beta carotene) are bought from local markets. Egg white powder containing 8% moisture, 82% protein and 4% carbohydrate is obtained from Igreca (Seiches Sur le Loir, France). The emulsifier blend, Purawave™ (G-5568), which is composed of lecithin, soy protein, mono/diglycerides, and vegetable gums, is supplied from Puratos (Belgium). Xanthan gum (Xanthomonas campestris), the galactomannans, guar gum and locust bean gum are obtained from Sigma-Aldrich (Steinheim, Germany). κ-carrageenan (Viscarin XP 3480) and HPMC (Methocel F4M FG) are supplied from FMC biopolymer (Pennsylvania, USA) and Dow Chemical Company (Michigan, USA), respectively.

2.2 Methods

2.2.1 Preparation of cake batter

A cake batter recipe containing 100% rice flour, 100% sugar, 25% shortening, 9% egg white powder, 3% salt and 5% baking powder (all percentages are given on a flour weight basis) was used in the experiments. On a general basis, cake batter recipe contains 30.12% rice flour, 30.12% sugar, 7.53% shortening, 2.71% egg white powder, 0.90% salt and 1.51% baking powder. The amount of water added to the batter was 27.11% of the overall formulation. Gums (xanthan gum, guar gum, xanthan–guar gum, xanthan–carragenan gum, locust bean gum, κ-carregeenan, and HPMC) were added in the formulation as 1%, which was determined by preliminary experiments. Xanthan-guar gum and xanthan-κ-carrageenan gum blends were prepared by mixing these gums in equal proportions. To investigate the effect of emulsifier blend, 3% Purawave^{TM} was added to the batter formulations. A cake batter containing no gum and no emulsifier blend was used as control. During preparation of the cake, firstly, dry ingredients (rice flour, baking powder, salt and gum blend) were mixed thoroughly. In a separate cup, sugar and egg white powder were mixed, and then melted shortening was added and mixed for 1 min at 85 rpm by using a mixer (Kitchen Aid, 5K45SS, St. Joseph, MI, USA). When emulsifier blend was used, it was added to the melted shortening. Then, dry ingredient mix and water at 25^{o}C were added simultaneously to this mixture and mixed first for 2 min at 85 rpm, then for 1 min at 140 rpm and finally for 2 min at 85 rpm.

2.2.2 Physical properties of rice flour and gum powders

Bulk densities of hydrocolloids and rice flour were measured by using a cup with known volume. The cup was completely filled with the sample by tapping and then weighed. Bulk density (g/cm^3) was calculated by dividing the weight of the sample by the volume of the cup.

Dielectric properties of the powder forms of gums and rice flour were determined at 2450 MHz at 25^{o}C by using cavity resonator method (Regier, 2003). A constructed partially filled transversal electric (TE) 011 resonator was connected to a Network Analyzer (Hewlett Packard Co. 8753 D, Santa Rosa, CA), which was able to work between the frequencies of 30 kHz and 6 GHz. A computer program written by Regier (2003) was used to calculate the dielectric constant and dielectric loss factor values analytically at 2450 MHz.

2.2.3 Analysis of cake batter

Specific gravity, emulsion stability, rheological, dielectric and gelatinization properties of rice cake batter were determined.

2.2.3.1 Determination of specific gravity of cake batter

Specific gravity of cake batter was determined by dividing the weight of a certain volume of cake batter by the weight of the same volume of water. A cup whose volume was known was used in the measurements.

2.2.3.2 Determination of emulsion stability of cake batter

Freshly prepared cake batters were centrifuged (RC5C, Sorvall Instruments, Germany) at 6000 rpm for 20 min at 25 ^{o}C. The supernatant (fat) that was separated after the centrifugation was weighed. The ratio of the fat separated to the total fat in the batter was subtracted from 1 and multiplied by 100 to express as percentage of emulsion stability.

2.2.3.3 Determination of rheological properties

Steady shear properties were obtained at constant temperature (25 ^{o}C) by using a parallel-plate rheometer (Haake Model CV20, Karlsruhe, Germany). The samples were prepared just before the experiments. The gap between the plates was 1 mm. Shear rate, which was increased linearly between 1 and 200 s^{-1}, was applied to 2–3 g sample for 5 min. Throughout the tests, shear rate-shear stress and shear rate-apparent viscosity data were collected.

For time-dependency determination, 150 s^{-1} constant shear was applied to each sample for 10 min. Time versus apparent viscosity data were collected throughout the tests. Measurements were done in three replications.

2.2.3.4 Determination of dielectric properties of cake batter

The dielectric properties were measured by using a network analyzer (HP 8753 D, Hewlett Packard Co., Santa Rosa, CA) with an open ended coaxial line connected to a dielectric probe in a frequency range 2000-3000 MHz. The dielectric properties at 2450 MHz were taken into consideration. The network analyzer was calibrated with air, metallic short and distilled water at 25°C.

Dielectric properties of cake batters were measured between the temperatures of 25°C and 90°C immediately after the batters were prepared. A temperature controlled oil bath was used to reach the desired temperature. All measurements were done in triplicate.

2.2.3.5 Determination of gelatinization enthalpy of cake batter

Gelatinization enthalpies of the batters were determined using a differential scanning calorimeter (Jade, Perkin Elmer, Waltham, Massachusetts, USA) that was previously calibrated with indium. For the measurement, a batter sample (25-30 mg) was placed in hermetically sealed stainless steel pans. An empty pan was used as reference. The samples were heated from 7 to 140 °C using a scanning rate of 10 °C / min.

During thermal analysis of rice cake batters, onset, peak and conclusion temperatures and enthalpy changes were determined for each type of batter sample containing different gum types.

2.2.4 Baking

Cakes were baked in conventional and IR-microwave combination oven. Baking experiments were replicated twice.

2.2.4.1 Conventional baking

Conventional baking was performed in a commercial electric oven (9411FT, Arcelik, Bolu, Turkey). Two cake samples (100 g each) were baked at each time at 175 ^{o}C for 30 min. No emulsifier was added to the cakes baked conventionally.

2.2.4.2 IR-microwave combination baking

Cake samples of 100 g were baked in IR-microwave combination oven (Advantium oven^{TM}, General Electric Company, Louisville, KY, USA) at 70% upper and lower IR power and 40% microwave power for 7.5 min. This oven, which combines microwave heating and infrared heating, includes three halogen lamps each having 1500 W power. Two of the lamps are located at the top of the oven and at the bottom of the turntable. According to the IMPI test, microwave power of the oven was found to be 706 W (Buffler 1993). One cake was baked at a time. Previous studies showed that breads baked in this oven lost a significant amount of moisture (Keskin et al., 2004). Therefore, four beakers each containing 400 ml water were placed in the corners of the oven during baking.

2.2.5 Analysis of cakes

Weight loss, specific volume, porosity, volume index, texture profile and color of the cakes baked in different ovens were determined.

2.2.5.1 Determination of weight loss

The percentage of weight loss of the cakes was calculated by measuring the weights of the cake samples before and after the baking process.

2.2.5.2 Determination of specific bulk volume and porosity

Cake bulk volume was determined by the rape seed displacement method (AACC, 2000a). This value was divided by the weight of the cake for determination of specific bulk volume ($\overline{V}_b$). Solid volume of the same cake was also determined by rape seed displacement method after compressing the freshly baked, hot cake until no pore left in the sample (Sumnu et al., 2007) and this value was divided by the weight of the cake for determination of specific solid volume ($\overline{V}_s$). Then, total porosity was calculated from the following equation;

$$\text{Porosity} = (\overline{V}_b - \overline{V}_s) / \overline{V}_b \quad (2.1)$$

2.2.5.3 Determination of volume index

Volume index of cake samples were measured by using AACC template method (AACC, 2000b). In this method, cake was cut vertically through the center and the heights of the cake samples were measured at three different points (B, C, D) along the cross-sectioned cakes using the template (Figure 2.1). According to this method volume index was determined by the following equation;

$$\text{Volume index} = B + C + D \quad (2.2)$$

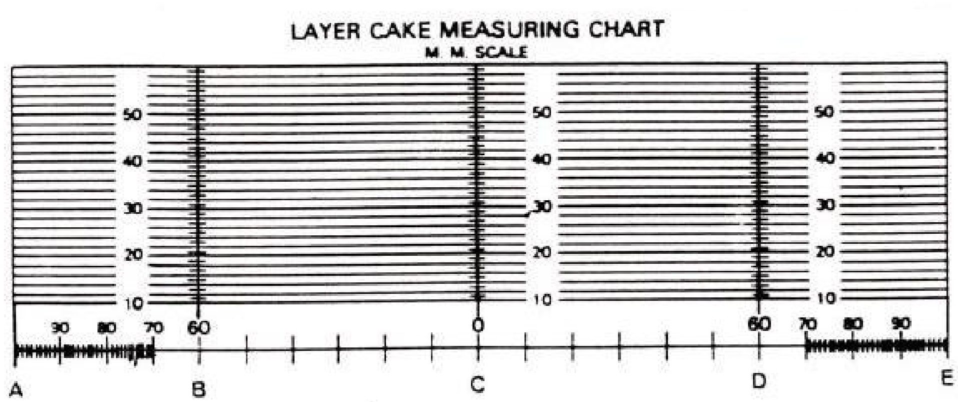


Figure 2.1 AACC Layer cake measuring chart (AACC, 2000b).

2.2.5.4 Texture profile analysis

Crumb firmness, cohesiveness, springiness, chewiness and gumminess were measured using a universal testing machine (TA Plus, Llyod Instruments, UK) after the cake samples had been cooled for 1h. Center of cake samples were cut into cubic shapes having dimensions of 25mm x 25mm x 25mm and were compressed to 25% of their original thickness at a speed of 55mm/min. A cylindirical probe and a load cell of 50 N were used (Sevimli et al., 2005). Measurements were done in duplicate.

2.2.5.5 Determination of color

The surface color of the cakes were measured by using Minolta Color Reader (CR-10, Japan) and expressed using CIE L^*, a^* and b^* color scale. Five measurements were made at different positions from the surface of the cakes at room temperature. The mean values were reported. Cake batter was selected as reference point and its color values were represented as L_0^*, a_0^* and b_0^*.Then, color change during baking was calculated from equation 2.3;

$$\Delta E = [(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2]^{1/2} \qquad (2.3)$$

2.2.6 Pore structure of cakes

The effects of different gums on macro and micro structures of gluten-free rice cakes baked in conventional and IR-microwave combination ovens were investigated by using the images obtained by scanner and scanning electron microscopy (SEM).

2.2.6.1 Scanning of cakes

Rice cakes formulated with different gums baked in different ovens were cut into two halves vertically by a razor blade. The cut side of one of the halves was placed over the glass of a scanner (Canoscan 3200F, Tokyo, Japan). Scanning was performed with a resolution of 300 dpi.

2.2.6.2 SEM analysis

Baked cake samples were frozen (-80 ^{o}C) and freeze dried before SEM analysis, which was carried out using JSM-6400 scanning electron microscope (JEOL, Tokyo, Japan). Prior to examination, samples were sputter coated with gold-palladium to render them electrically conductive by using HUMMLE VII Sputter Coating Device (Anatech Electronucs, Garfield, N.J., USA). The micrographs were taken at magnifications of 30x and 500x for the crumb parts of the cakes.

2.2.6.3 Image analysis

The scanned images and SEM micrographs at a magnification of 30x were analyzed using the software Image J (http://rsb.info.nih.gov/ij/) that uses the contrast between two phases (pores and solid part) in the image. 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 scanned images was cropped. The area of these cropped images, on which this analysis was performed, was 5.47x2.74 cm for each image. In the case of SEM micrographs, the whole area was analyzed without any cropping. The method and software used in the study of Impoco et al. (2007) was used for the examination of the pore distribution in rice cakes. This software is in the form of a plug-in for Image J. The plugin encompasses two commands: BinariseSEM and ComputeStats.

BinariseSEM segments the input image into “holes” and “structure”. The command ComputeStats employs the output of the previous application BinariseSEM to perform image statistics about the distribution of pores. In our study, pore area fraction, pore size distribution and mean roundness values of the rice cakes were calculated by this software. The formula of the roundness is given in the following equation;

$$\text{Roundness} = \frac{4A}{\pi D_{max}^{2}} \quad (2.4)$$

where A is net area and D_{max} is the maximum diameter of the pore.

2.2.7 Optimization by RSM

RSM was used as an optimization tool to relate the quality parameters to emulsifier content and baking conditions.

2.2.7.1 Experimental Design

In experimental design, Box-Behnken design is used. There are three independent variables each having three levels, which were emulsifier content (X_1; 0, 3, and 6%), upper halogen lamp power (X_2; 50, 60, and 70 %), and baking time (X_3; 7.0, 7.5, and 8.0 min). The levels of these variables were determined by preliminary experiments. For convenience, the actual values were converted into coded values. The uncoded and coded independent variables and the experimental design were given in Table 2.1. In this design, the experiments were randomized to minimize the effects of extraneous variables. Gum types of xanthan and xanthan-guar gum blens were chosen as qualitative variables. The design was replicated for each qualitative variable.

Table 2.1 Experimental design

Exp. No	Factors					
	X1 (%)		X2 (%)		X3 (min)	
	coded	uncoded	coded	uncoded	coded	uncoded
1	0	0	-1	50	0	7.5
2	1	6	-1	50	0	7.5
3	-1	0	1	70	0	7.5
4	1	6	1	70	0	7.5
5	-1	0	0	60	-1	7
6	1	6	0	60	-1	7
7	-1	0	0	60	1	8
8	1	6	0	60	1	8
9	0	3	-1	50	-1	7
10	0	3	1	70	-1	7
11	0	3	-1	50	1	8
12	0	3	1	70	1	8
13	0	3	0	60	0	7.5
14	0	3	0	60	0	7.5
15	0	3	0	60	0	7.5

For comparison, rice cake batter having the optimum formulation according to the results of IR-microwave combination baking was baked in conventional oven at 175 ^{o}C for 30 min.

The quality parameters, which were dependent variables, were weight loss, specific bulk volume, firmness and color. These parameters were determined by the methods explained in sections of 2.2.5.1, 2.2.5.2, 2.2.5.4 and 2.2.5.5 respectively.

2.2.7.2 Optimization

Multiple regression analysis was performed to fit second-order models to dependent variables by using Minitab Release 14 (Minitab Inc. State College PA, USA). The models were used to plot contour surfaces and optimum conditions were determined by performing multiple optimization by using response optimizer in Minitab release 14 software.

2.2.8 Statistical Analysis

Analysis of variance (ANOVA) was performed to determine whether statistically significant effect of gum type, emulsifier addition and oven types ($p \leq 0.05$). Variable means were compared by Duncan's multiple comparison test by using SAS statistics program (SAS 9.1 for Windows).

CHAPTER 3

RESULTS AND DISCUSSION

In the first part of the study, the effects of different gum types and the addition of emulsifier blend on some physical properties of gluten-free rice cake batters were investigated. Specific gravity, emulsion stability, steady shear and time dependency properties, dielectric constant and loss factor, gelatinization properties of cake batters were determined.

As a second part of the study, physical properties of the rice cakes baked in conventional and IR-microwave combination ovens such as weight loss, specific volume and textural properties were determined. Macro and micro-structures of rice cakes containing different types of gums baked in conventional and IR-microwave ovens were investigated by using image analysis and SEM. Quantitative analysis was performed on both scanned images and SEM micrographs.

In the last part of the study, RSM was used to optimize the IR-microwave combination baking conditions and formulation of gluten-free rice cakes. The relationships between the responses of specific volume, total color change, firmness and weight loss and independent variables, which were emulsifier content, upper halogen lamp power and baking time were examined by using second order models obtained statistical software of Minitab 14.

3.1 Physical Properties of Rice Cake Batters

Specific gravity, rheological properties, emulsion stability, dielectric properties and gelatinization enthalpy of the rice cake batters containing different types of gums and emulsifier blend were investigated.

3.1.1 Effects of different types of gums and emulsifier blend on specific gravity of rice cake batters

Low specific gravity is a desired property in cake batter since it indicates that more air is incorporated into the batter. Figure 1 shows the specific gravities of cake batters having different formulations. Control cake batter had specific gravity of 1.26. Most of the batter formulations had lower specific gravity than the control cake batter, which showed that more air was incorporated in the presence of gums and emulsifier blend. As shown in Figure 1, emulsifier blend addition into the batters decreased the specific gravity values significantly ($p \leq 0.05$). According to ANOVA results (Table A.1), it was observed that both gum type and emulsifier blend addition affected specific gravity of cake batter significantly ($p \leq 0.05$). The formation and stabilization of foams benefit from the addition of emulsifiers, which help aeration by lowering the surface tension between liquid and gas phases, thus reducing the amount of energy required to generate a larger interfacial area (Sahi and Alava, 2003). The highest specific gravity values in the presence of emulsifier blend were obtained when locust bean gum was added to the formulation, which indicated that the lowest air inclusion into the cake batter was obtained by addition of this gum type.

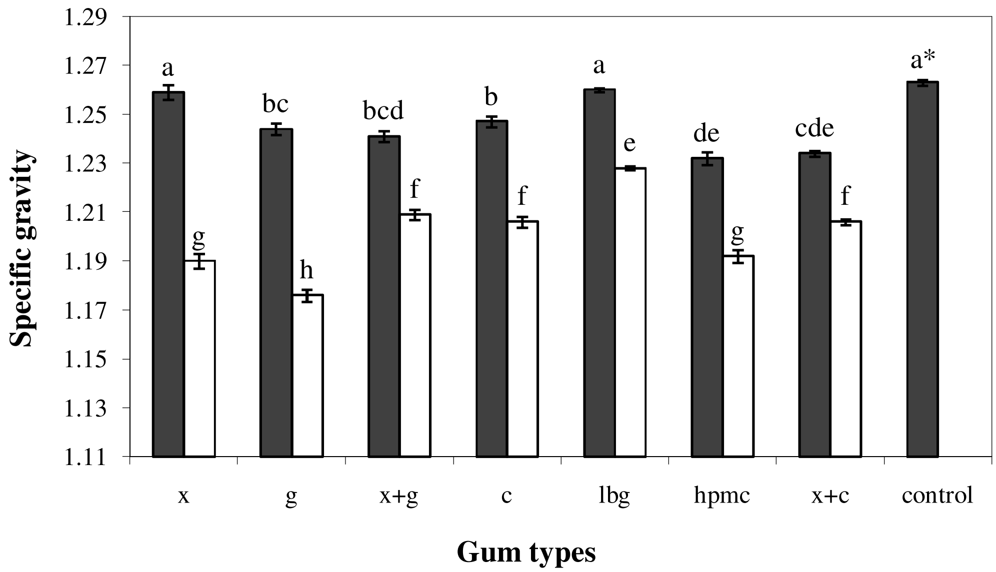


Figure 3.1 Effects of gum types with or without emulsifier blend on specific gravities of rice cake batters. x: xanthan, g: guar, x+g: xanthan + guar, c: κ-carrageenan, lbg: locust bean gum, hpmc: hydroxypropyl methylcellulose, x+c: xanthan + κ-carrageenan. ■ 0% emulsifier, □ 3% emulsifier. * Bars with different letters are significantly different.

3.1.2 Effects of different types of gums and emulsifier blend on rheological properties of rice cake batters

According to steady shear flow data obtained from parallel-plate viscometer at 25 ^{0}C, all the formulations containing different types of gums and emulsifier blend showed shear-thinning (pseudoplastic) behavior, which means that apparent viscosity decreases as the shear rate increases (Figures 3.2-3.5). Shear-thinning behavior can be explained by the alignment of microstructure with the flow direction as shear rate increases, thus apparent viscosity decreases (Song et al., 2006).

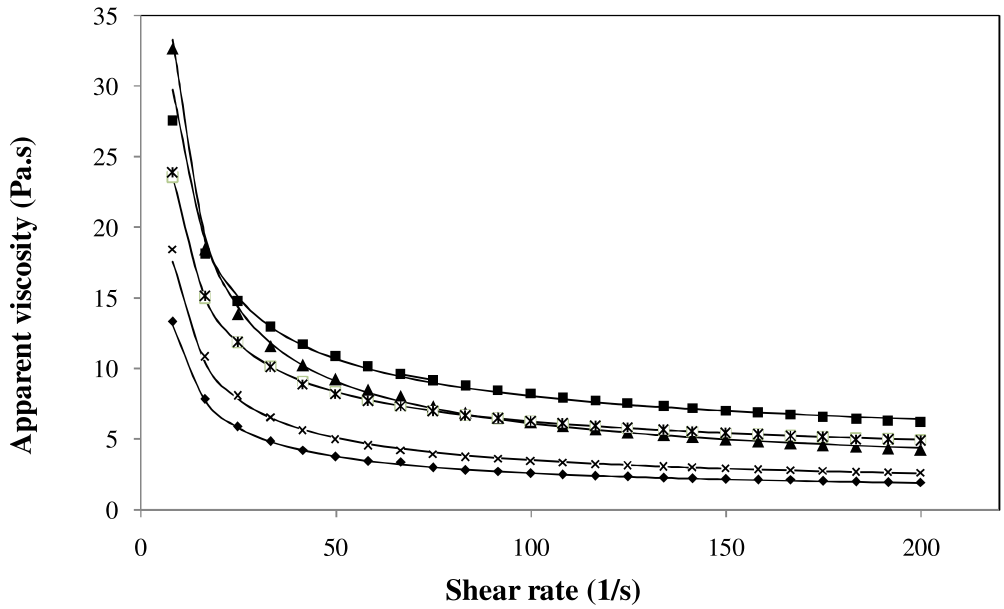


Figure 3.2 Shear rate versus apparent viscosity values of rice cake batters containing different types of gums and no emulsifier. ♦ control, ■ xanthan, ▲ guar, x carrageenan, * xanthan+carrageenan, — Casson model.

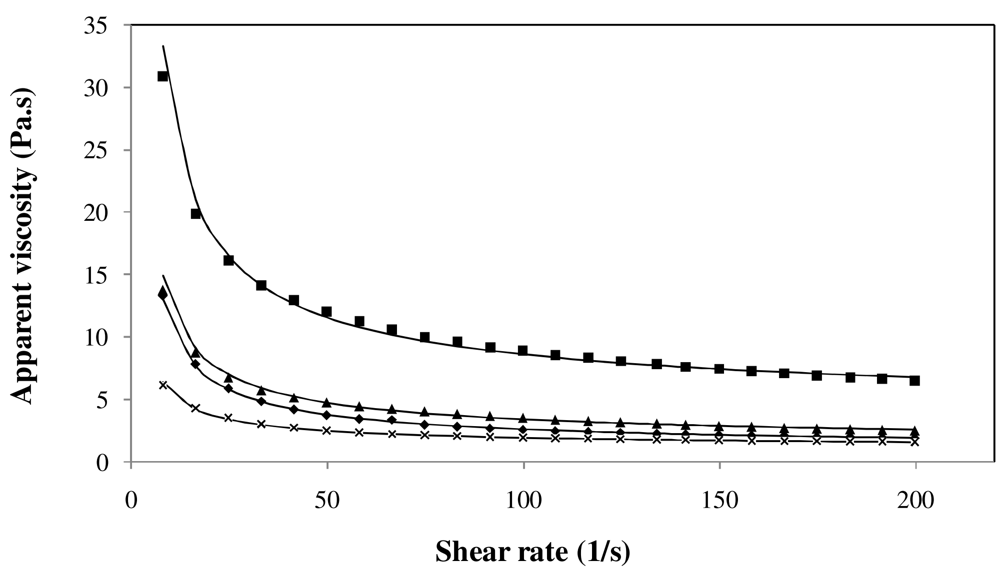


Figure 3.3 Shear rate versus apparent viscosity values of rice cake batters containing different types of gums and no emulsifier. ♦ control, ■ xanthan+guar gum, ▲ locust bean gum, x HPMC, — Casson model.

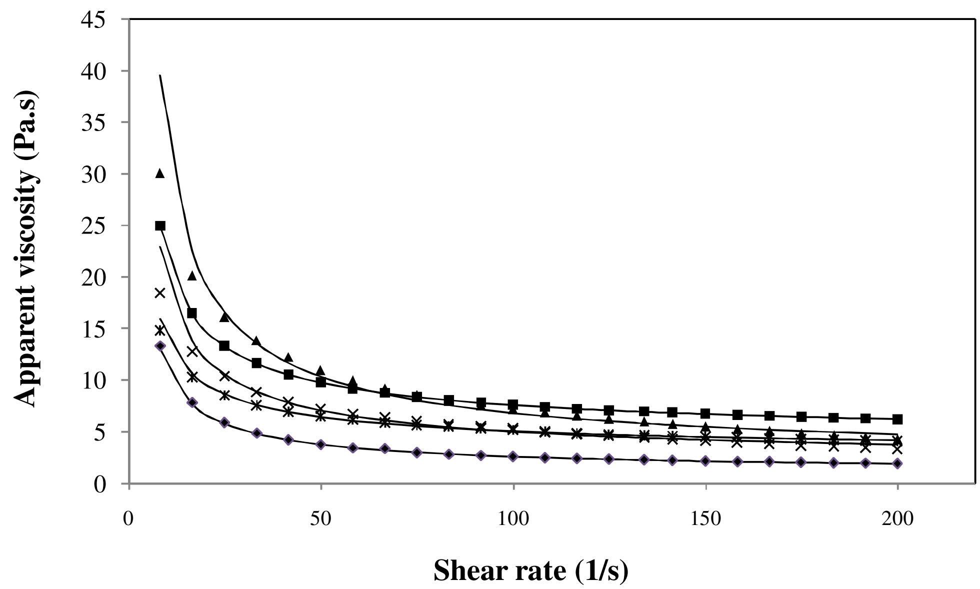


Figure 3.4 Shear rate versus apparent viscosity values of rice cake batters containing different types of gums and emulsifier. ♦ control, ■ xanthan, ▲ guar, x carrageenan, * xanthan+carrageenan, — Casson model.

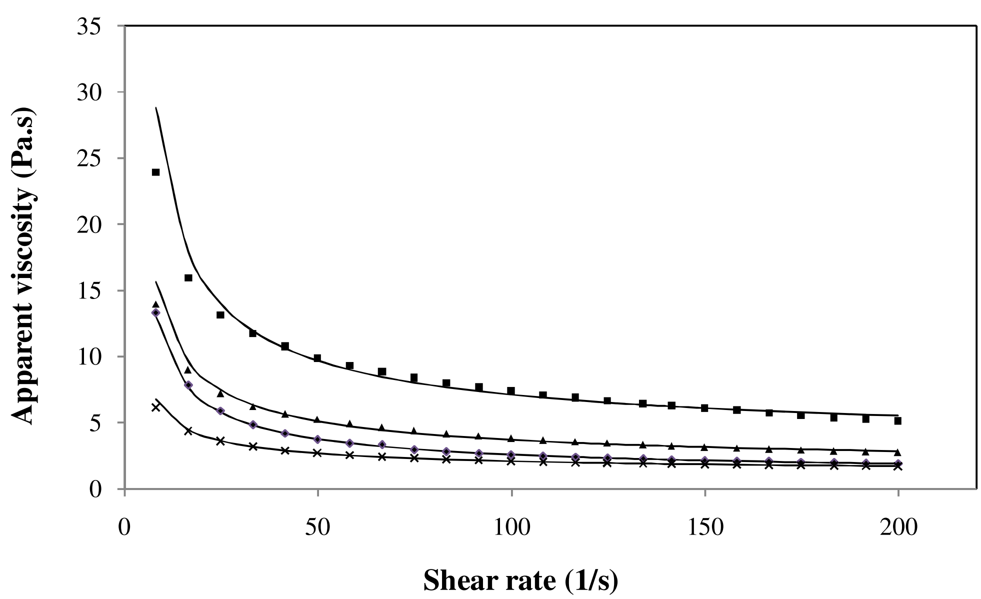


Figure 3.5 Shear rate versus apparent viscosity values of rice cake batters containing different types of gums and emulsifier. ♦ control, ■ xanthan+guar gum, ▲ locust bean gum, x HPMC, — Casson model.

The shear stress (τ) versus shear rate ($\dot{\gamma}$) data obtained from the viscometer for rice cake batters were fitted to the well-known rheological models, which are Power Law model (Equation 3.1) and Casson (Equation 3.2) models;

$$\tau = K_{cp}(\dot{\gamma})^{n} \tag{3.1}$$

where τ is the shear stress (Pa) and $\dot{\gamma}$ is the shear rate (1/s). K_{cp} is consistency index (Pa s^{n}) and n_p is the flow behavior index for Power law model;

$$\tau^{1/2} = K_{oc} + K_c\,(\dot{\gamma})^{1/2} \tag{3.2}$$

Casson yield stress (τ_0) was determined as the square of the intercept (K_{oc}) and consistency coefficient (K_c) was obtained from linear regression of the square roots of shear rate–shear stress data.

Table 3.1 shows Power Law and Casson model constants. Both of the models were fitted well with high coefficient of determination values (r^2 = 0.965-0.997 for Power Law Model and r^2 = 0.945-0.999 for Casson Model) in the shear rate range of 0-200 1/s. Flow behavior index values for Power Law Model (n_p) of cake batters ranged from 0.399 to 0.623. Batter containing HPMC gum had the lowest consistency index. When the Casson model constants were investigated (Table 3.1), the lowest Casson yield stress was found for HPMC containing batters. Sivaramakrishnan et al. (2004) found that HPMC addition into the rice flour dough resulted in a very sticky and cohesive dough showing high shear-thinning behavior. Fitting the data into Casson model also showed that the shear stress was the smallest for composite flour having short grain rice flour and HPMC. Casson Model is a structure based model and used in cooked rice flour dispersions (Chun and Yoo, 2004), rice starch dispersions (Yoo, 2006). Rice-blackgram suspensions

(Bhattacharya and Bhat, 1997) and high concentrations of steamed rice flour (Latha et al., 2002) also showed shear-thinning behavior and exhibited yield stress.

The highest apparent viscosities at 150 s^{-1} constant shear rate were obtained for batters containing xanthan and xanthan-guar gum blend as can be observed from Figures 3.6 and 3.7. This result may be due to xanthan's unique, rod-like conformation, which is responsive to shear than a random-coil conformation (Urlackern and Noble, 1997).

When locust bean gum was used in the formulations, higher apparent viscosity values were obtained as compared to the HPMC containing batters, but lower values were obtained as compared to the guar gum containing batters (Figure 3.6 and 3.7). Guar gum has a higher molecular weight than locust bean gum; therefore, its solution showed a higher viscosity than solution of locust bean gum (Casas et al., 2000).

The lowest apparent viscosity values were obtained for HPMC containing batters (Figures 3.6 and 3.7). This result was also correlated with the specific gravity results since HPMC gave the lowest specific gravity values (Figure 3.1), meaning more air inclusion, which resulted in lower apparent viscosity. The consistency of batters, like specific gravity, is a very important physical property affecting the product quality since it represents retain of the small bubbles, which are initially incorporated into the batter during the mixing time. If the viscosity is too low, the bubbles in the batter can easily rise to the surface and are lost to the atmosphere during baking.

Table 3.1 Power-law and Casson model constants for rice cake batters with different formulations.

	Power law model			Casson model		
Formulation	n_p	K_{cp} (Pa.s^n)	r^2	σ_{oc} (Pa)	K_c (Pa.s)$^{1/2}$	r^2
Control	0.421	38.356	0.977	63.03	0.817	0.999
Xanthan	0.563	61.87	0.997	107.848	1.798	0.997
Guar	0.399	100.524	0.987	170.459	1.171	0.997
Xanthan+guar	0.552	69.58	0.994	126.293	1.811	0.992
Carrageenan	0.418	52.568	0.965	84.339	0.957	0.997
Locust bean gum	0.496	35.73	0.994	63.915	1.047	0.994
HPMC	0.596	12.898	0.991	20.025	0.952	0.999
Xanthan+carrageenan	0.541	53.091	0.986	86.902	1.569	0.999
Xanthan+emulsifier	0.61	46.98	0.997	78.711	1.871	0.997
Guar+emulsifier	0.399	111.83	0.991	213.131	1.149	0.949
Xanthan+guar+emulsifier	0.545	59.377	0.997	114.833	1.595	0.981
Carrageenan+emulsifier	0.495	52.74	0.996	102.394	1.227	0.975
Locust bean gum+emulsifier	0.513	35.71	0.997	65.398	1.113	0.993
HPMC+emulsifier	0.611	12.78	0.997	20.994	0.983	0.999
Xanthan+carrageenan+emulsifier	0.623	29.52	0.997	47.967	1.557	0.999

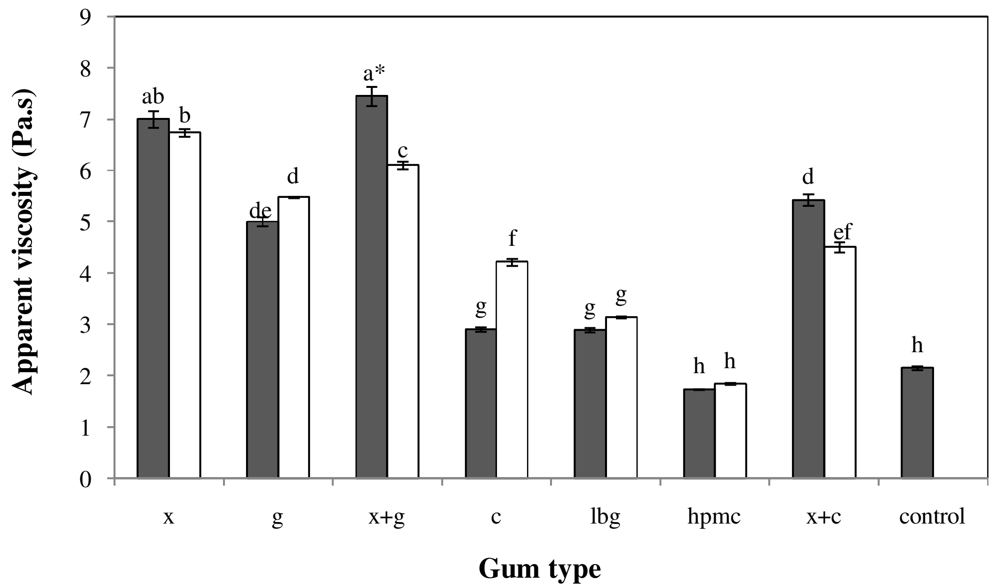


Figure 3.6 Apparent viscosities (Pa.s) of formulations at 150 s^{-1} constant shear rate according to Casson model. x: xanthan, g: guar, x+g: xanthan+guar, c: carrageenan, lbg: locust bean gum, hpmc: hydroxy propyl methyl cellulose, x+c: xanthan+carrageenan. ■ 0% emulsifier, □ 3% emulsifier. * Bars with different letters are significantly different.

κ- carrageenan also gave low values of apparent viscosity (Figures 3.6 and 3.7), although it is used in bread making as texture improver (Rosell et al., 2001). In the study of Shalini and Laxmi (2007), in which the effects of different hydrocolloids on the rheological properties of chapatti were investigated, the lowest values were obtained from κ- carrageenan containing bread.

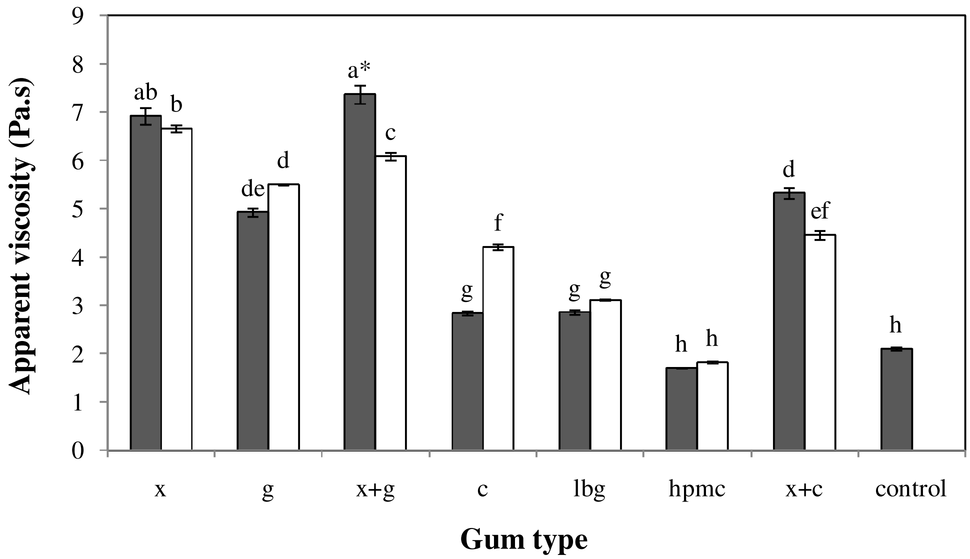


Figure 3.7 Apparent viscosities (Pa.s) of formulations at 150 s^{-1} constant shear rate according to Power law model. x: xanthan, g: guar, x+g: xanthan+guar, c: carrageenan, lbg: locust bean gum, hpmc: hydroxy propyl methyl cellulose, x+c: xanthan+carrageenan. ■ 0% emulsifier, □ 3% emulsifier. * Bars with different letters are significantly different.

Addition of emulsifier blend affected the viscosity of different batter formulations depending on the gum type (Figures 3.6 and 3.7). The two-way ANOVA results (Tables A.2 and A.3) for apparent viscosities for both Casson and Power law models indicated that in general, the effect of emulsifer blend was not significant ($p \leq 0.05$). However, addition of emulsifier blend to xanthan-guar gum blend and xanthan-κ-carrageenan blend decreased the apparent viscosity of cake batters significantly (Figures 3.6 and 3.7). The effect of emulsifier on apparent viscosity was a function of the type of the gum used in the formulation, which could be supported by the significant interaction ($p \leq 0.05$) of emulsifier blend-gum type.

Sample graphs showing time dependency data for some types of gum containing batters are shown in Figures 3.8 and 3.9. Most of the formulations including the control batter showed time-independent behavior. Guar gum containing formulations showed time-dependent thixotropic behavior, in which the apparent viscosity decreased with time. The decrease in viscosity with respect to time under constant shear can be explained by the loss of structure. On the contrary, apparent viscosity of xanthan containing batters increased with time (known as rheopectic behavior), which may be explained by building up the structure (Figure 3.8). Molecular conformation of xanthan gum contains a linear (1-4) linked β-D-glucose backbone with a trisaccharide side chain on every other glucose at C-3, containing, a D-glucuronic acid unit between 2-D-mannose units resulting in a five-fold helix (Sworn, 2000). The trisaccharide side chain in this conformation wraps around the backbone and protects the β-(1-4) linkages from attack. The stability of xanthan gum under adverse conditions is due to this protection. Rheopectic behavior under constant shear of 150 1/s, which can be accepted as an adverse condition, might be due to this protection.

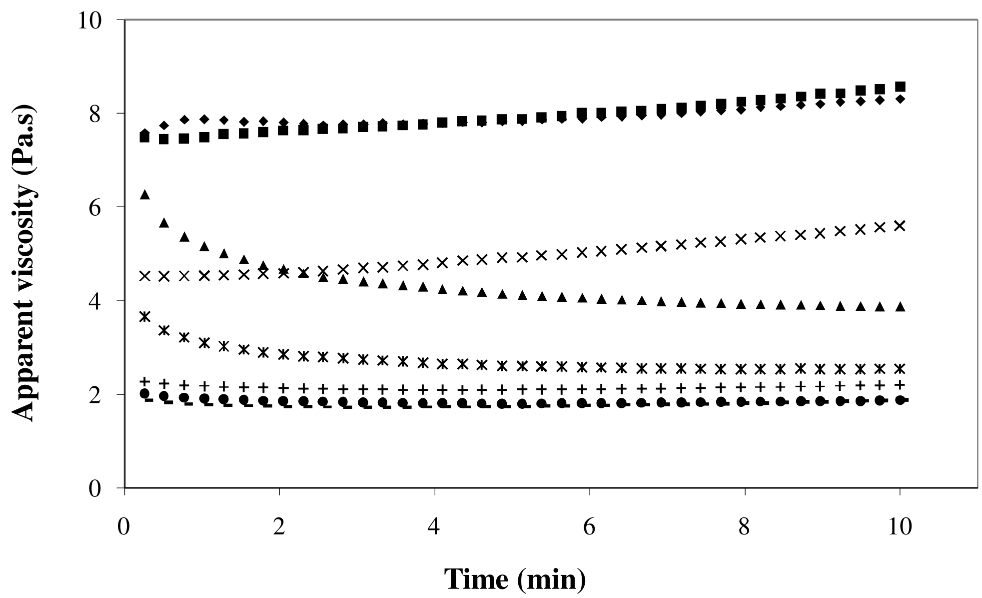


Figure 3.8 Time dependency of rice cake batters containing different types of gums and no emulsifier. ● control, ■ xanthan, ▲ guar, ♦ xanthan+guar gum, + κ-carrageenan, – HPMC, × xanthan-carrageenan, * locust bean gum.

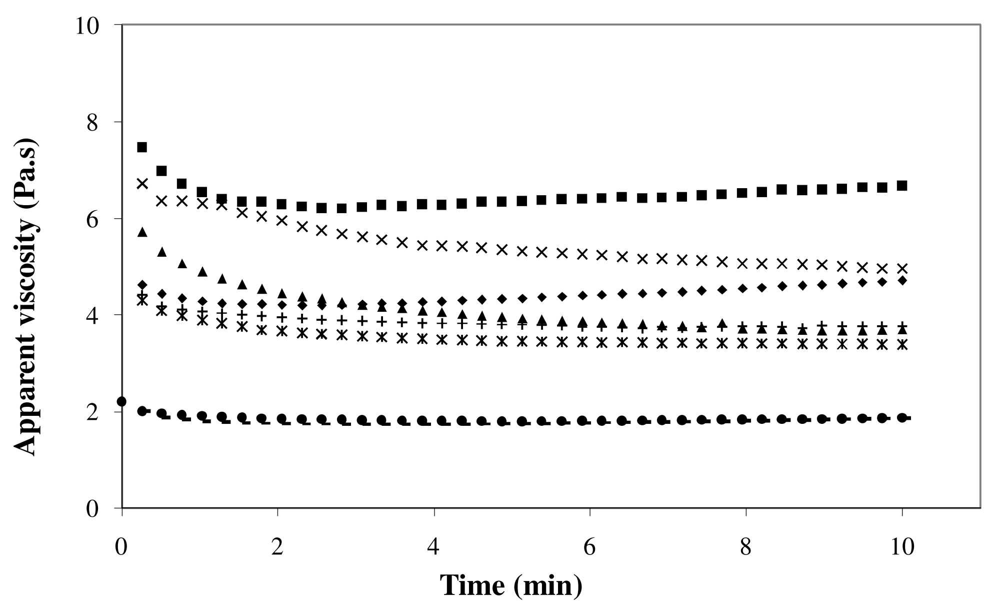


Figure 3.9 Time dependency of rice cake batters containing different types of gums and emulsifier. ● control, ■ xanthan, ▲ guar, ♦ xanthan+guar gum, + κ-carrageenan, – HPMC, × xanthan-carrageenan, * locust bean gum.

3.1.3 Effects of Different Types of Gums and Emulsifier Blend on Emulsion Stability of Rice Cake Batters

Emulsion stability, which is a measure of the rate at which an emulsion creams, flocculates or coalesces (Huang et al., 2001), can be measured by determining the size and distribution of oil droplets in the emulsion. Most hydrocolloids and also gums can act as stabilizers (stabilizing agents) of oil-in-water emulsions, but only a few can act as emulsifiers (emulsifying agents) (Dickinson, 2003).

Figure 3.10 shows the emulsion stabilities of batters with different formulations. Emulsion stabilities of the batter containing HPMC without emulsifier blend and of control batter were the lowest. HPMC is a water soluble gum at low temperatures. On the other hand, it forms gels when heated and then return to its original liquid viscosity when cooled and therefore, it shows an inverse solubility character (Huang et al., 2001). If the low viscosity mixture of HPMC is heated and hydration is delayed, a stable emulsion can be obtained having smaller size oil particles. In this study, emulsion stability experiments were performed at room temperature. Therefore, HPMC gave low values of stability due to this lack of gel formation inside the batter.

All other gums increased the emulsion stability of cake batter as compared to control cake batter. Although gums are mostly hydrophilic components, which do not exhibit significant surface activity in the emulsions, some of the gums were found to migrate slowly to the air-water and oil-water interfaces and exhibit some surface and interfacial activities as a stabilizer (Reichman, 1992; Grover, 1993; Garti 1999). According to ANOVA results (Table A.4), only gum type affected the emulsion stability values and addition of emulsifier blend did not change these values significantly except batters containing xanthan and xanthan-guar gum blend. The highest emulsion stability values were obtained from the guar gum containing cake batters. Guar gum is a rather rigid, hydrophilic biopolymer with a polymannose backbone and grafted galactose units and widely used in food industry as thickening, water-holding and stabilizing agent (Dickinson, 2003). There are statements in the literature (Garti, 1999; Garti and Reichman, 1993, 1994) that guar gum has the capacity to emulsify oils and stabilize fairly coarse emulsions. In these studies, these authors showed that this surface activity of guar gum is an intrinsic property of the polysaccharide itself, not due to the presence of any protein attached to the structure. On the study of Garti and Reichman (1994), in which the guar gum was purified down to 0.8 % protein, it was still found a similar degree of surface activity and emulsification ability. Based on this result, it can be acceptable that this gum may confer some emulsion stabilizing property due to the slight hydrophobicity of the polymannose backbone in the structure (Dickinson, 2003).

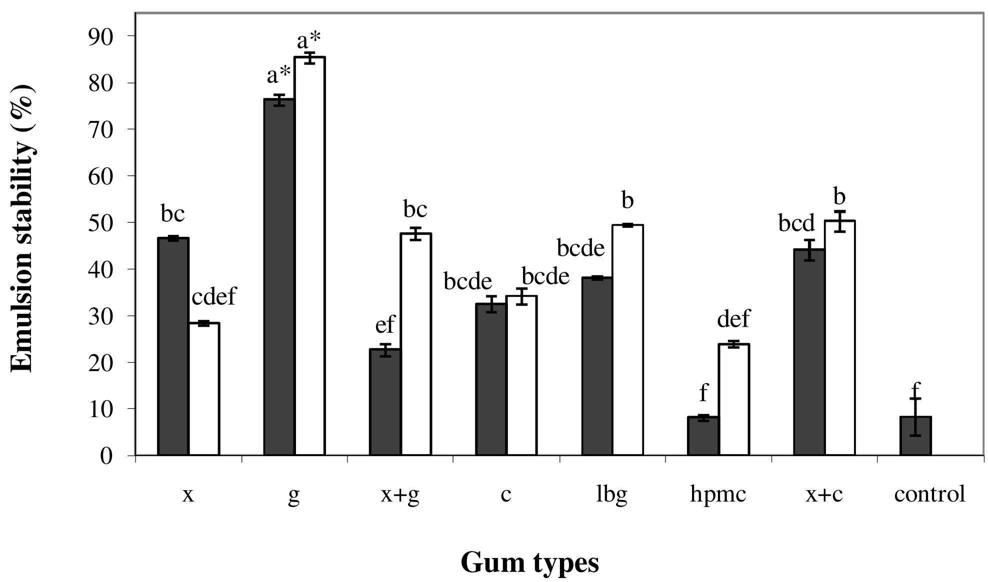


Figure 3.10 Emulsion stabilities of rice cake batters. x: xanthan, g: guar, x+g: xanthan + guar, c: κ-carrageenan, lbg: locust bean gum, hpmc: hydroxypropyl methylcellulose, x+c: xanthan + κ-carrageenan. ■ 0% emulsifier, □ 3% emulsifier. * Bars with different letters are significantly different.

3.1.4 Effects of different types of gums and emulsifier blend on dielectric properties of rice cake batters

Different types of gums were found to be significantly effective on the dielectric constant and loss factor of the cake batter samples (Tables A.5 and A.6). On the other hand, addition of emulsifier blend was found to be significant on dielectric constant but not significant on dielectric loss factor as can be seen at Tables A.5 and A.6.

When dielectric constants of rice cake batters at 25°C were considered (Figure 3.11), batters containing xanthan and guar gum gave the highest results. There was no significant difference between xanthan, guar and xanthan-guar blend containing batters without emulsifier blend (Table A.5). Dielectric constant values of HPMC and locust bean gum containing cake batters were lower than the other batters in the presence of no emulsifier blend (Figure 3.11). This may be due to the low dielectric constant values of these gums in powder form (Figure 3.12). As can be seen in Table 3.2, HPMC and locust bean gum had the lower bulk density than the others. In the study of Ndife et al (1998), a positive correlation between bulk densities and dielectric properties of starches in granular form was shown.

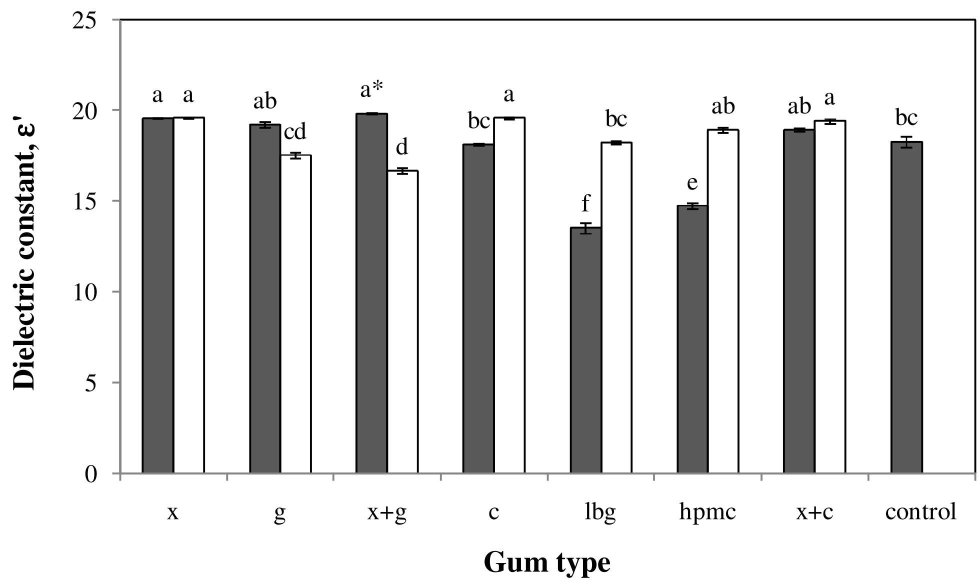


Figure 3.11 Dielectric constant values of rice cake batters at 25^0C. x: xanthan, g: guar, x+g: xanthan + guar, c: κ-carrageenan, lbg: locust bean gum, hpmc: hydroxypropyl methylcellulose, x+c: xanthan + κ-carrageenan. ■ 0% emulsifier, □ 3% emulsifier * Bars with different letters are significantly different.

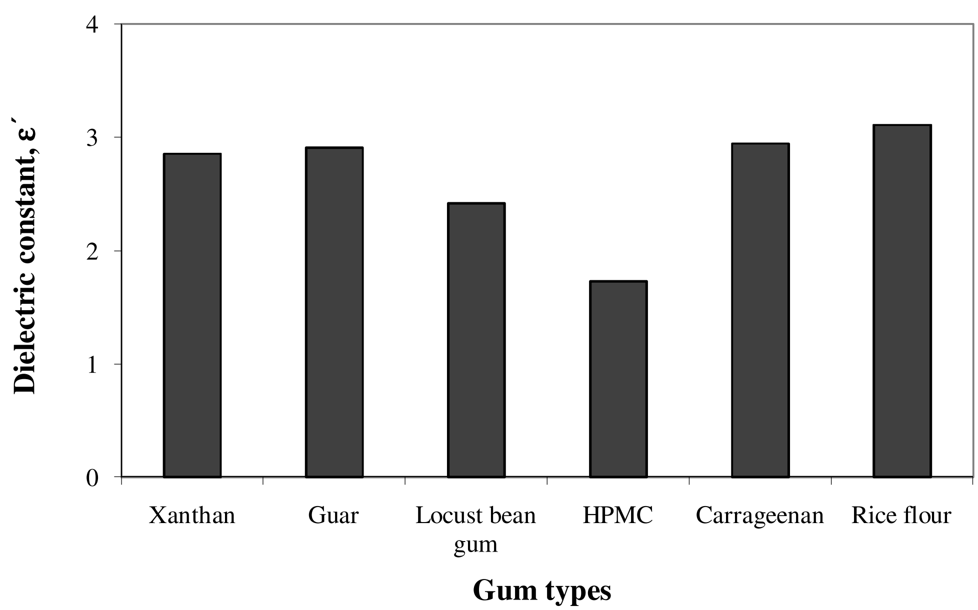


Figure 3.12 Dielectric constants of gum types in powder form

Table 3.2 Bulk densities of hydrocolloids in powder form and rice flour

Powder type	Bulk density (g/cm3)
Xanthan	0.862
Guar	0.628
Locust bean	0.620
HPMC	0.460
Carrageenan	0.907
Rice flour	0.810

According to two-way ANOVA, emulsifier blend addition was found to be significant with respect to dielectric constant ($p \leq 0.05$) (Table A.5). The addition of emulsifier blend reduced the dielectric constant of guar and xanthan-guar containing cake batters. The significant decrease in dielectric constant may be due to the decrease in free water and/or increase in air inclusion.

Dielectric constant values of batters containing locust bean gum, HPMC and κ-carrageenan increased with the addition of emulsifier blend (Figure 3.11). Although locust bean gum is a galactomannan like guar gum, it has lower molecular weight with a less branched structure than guar gum because of its lower galactose content (17-26 %) (Wielinga, 2000). Therefore, interaction of locust bean gum with emulsifier blend in the batter may not be as strong as guar gum and it may not bind as much free water to its structure as guar gum. More free water available in the structure resulted in higher dielectric constant. HPMC is a modified cellulose structure and three main factors influence the properties of modified celluloses. These are the type of substitution of the cellulose, the degree of polymerization and the degree of substition of the chain (Murray, 2000). Emulsifier blend used in formulations also contains some modified cellulose and interaction between HPMC and emulsifier blend may cause structure change by changing the degree of polymerization and substitution. This might result in more free water, which could not bind to the chains in the polymeric structure and this might increase the dielectric constant value of cake batter.

κ-carrageenan's ionic nature may be the reason for increase of dielectric constant by addition of emulsifier blend. It is an anionic sulphated polysaccharide, which forms thermoreversible gels in the presence of cations (Baeza et al., 2002). κ-carrageenan's interaction with proteins has been studied by many researchers. Soy protein, which presents in the emulsifier blend may interact with κ-carrageenan gum. This interaction of anions of κ-carrageenan with cations in the soy protein might be the reason of both an increase of free water in the system and dielectric constant value.

When dielectric loss factors of cake batters at 25°C were considered (Figure 3.13), like dielectric constant values, locust bean gum and HPMC containing cake batters gave the lowest values. Addition of emulsifier blend was not significant on dielectric loss factor ($p \leq 0.05$) (Tables A.6). In the study of Sakiyan et al. (2007), addition of Purawave emulsifier blend into the cake batter formulation did not affect dielectric loss factor.

HPMC in powder form also showed the lowest dielectric loss factor value according to Figure 3.14. Bulk density of this gum was the lowest (Table 3.2).

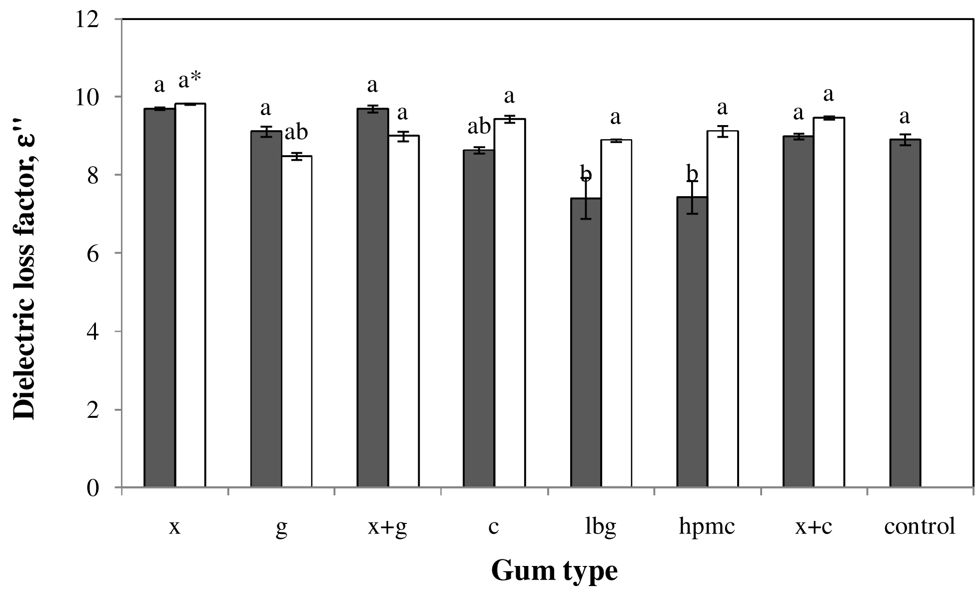


Figure 3.13 Dielectric loss factor values of rice cake batters at 25^{0}C. x: xanthan, g: guar, x+g: xanthan + guar, c: κ-carrageenan, lbg: locust bean gum, hpmc: hydroxypropyl methylcellulose, x+c: xanthan + κ-carrageenan. ■ 0% emulsifier, □ 3% emulsifier * Bars with different letters are significantly different.

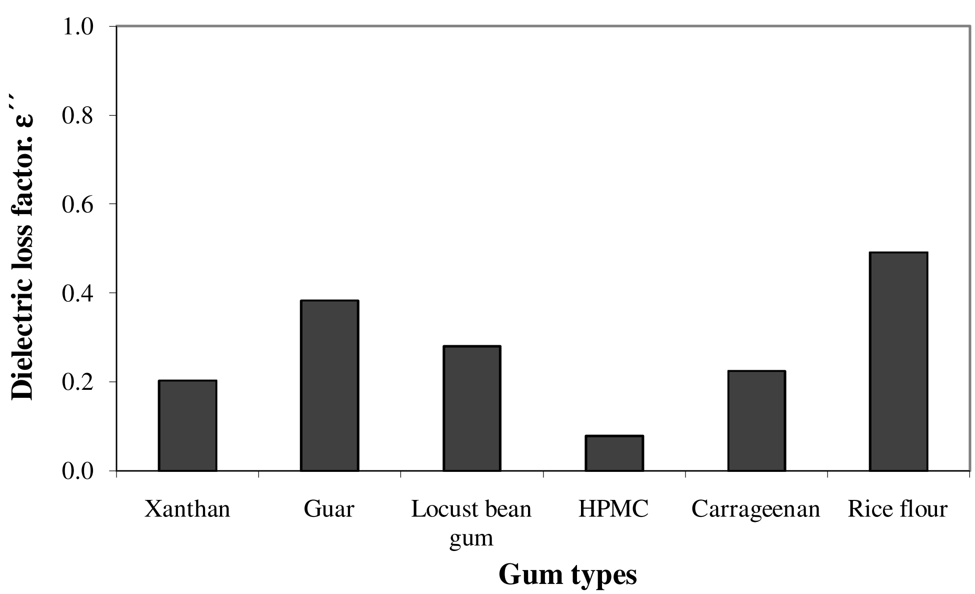


Figure 3.14 Dielectric loss factors of gum types in powder form

Figures 3.15-3.18 show the variation of dielectric constant and loss factors of cake batters as a function of temperature. It can be observed that in all figures, the values were nearly constant for almost all gum types until temperature of 85°C. Then there was a sharp increase. This sharp increase in dielectric properties after 75-80°C could be associated with starch gelatinization. In the study of Ahmed et al (2007), in which the dielectric properties of Indian Basmati rice flour slurries were investigated, there was a deviation in dielectric properties above 70°C, which could be associated with the gelatinization behaviour of starch that affected the availability of free water. Gelatinized starch binds less water to its structure; therefore, more water is free to respond to the alternating field (Roebuck and Goldblith, 1972). The addition of emulsifier blend did not shift the sharp increase in dielectric constant.

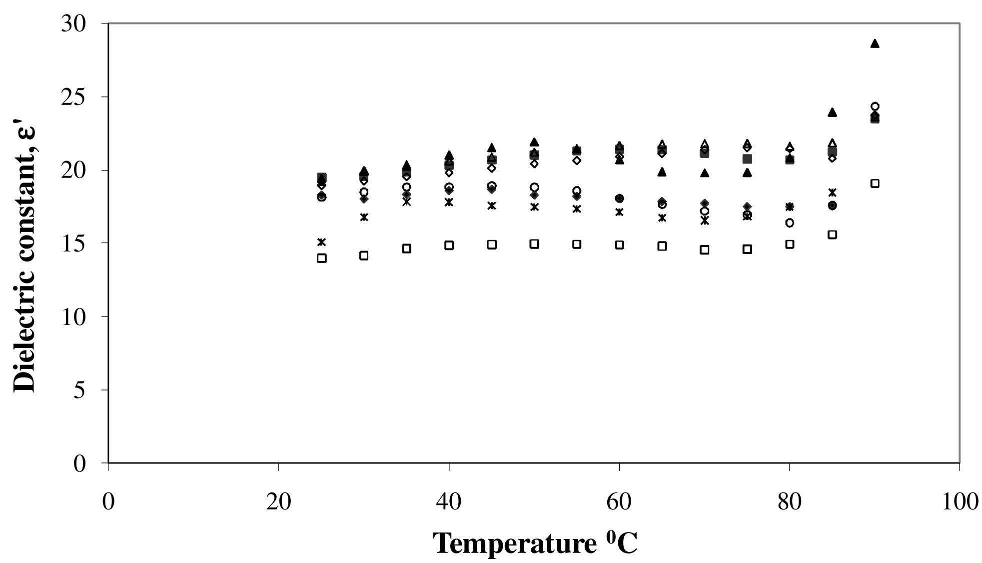


Figure 3.15 Effect of temperature change on dielectric constant values of rice cake batters containing no emulsifier (♦: control, ■ : xanthan gum, ▲: guar gum, Δ :xanthan - guar gum, □ : locust bean gum, * : HPMC, ○ : carrageenan, ◊: xanthan - carrageenan).

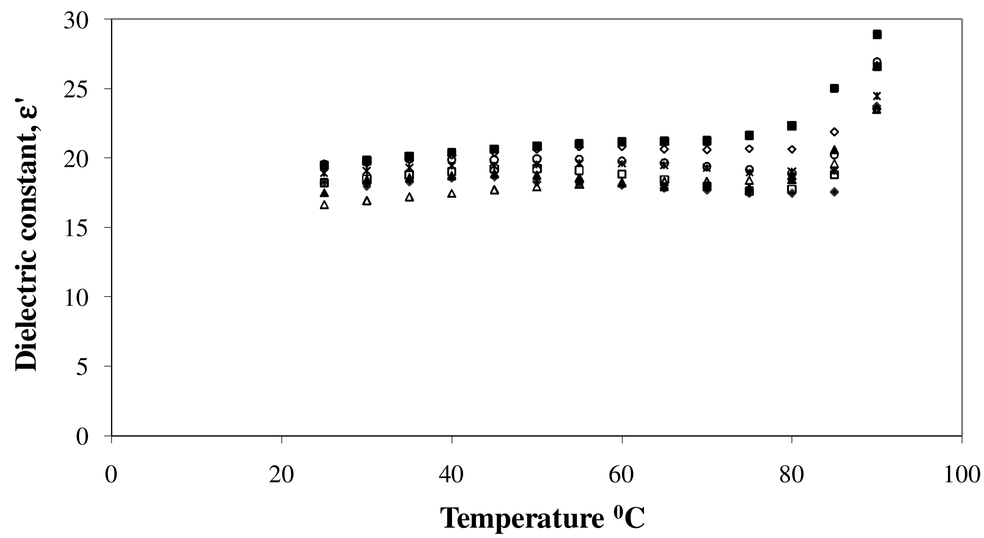


Figure 3.16 Effect of temperature change on dielectric constant values of rice cake batters containing 3% emulsifier (♦: control, ■ : xanthan gum, ▲: guar gum, Δ :xanthan - guar gum, □ : locust bean gum, * : HPMC, ○ : carrageenan, ◊: xanthan - carrageenan)

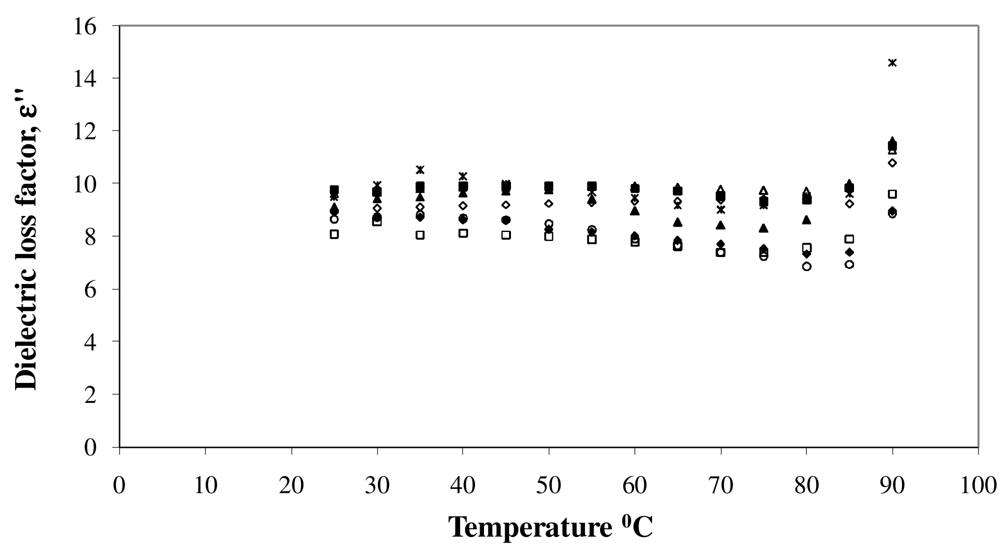


Figure 3.17 Effect of temperature change on dielectric loss factor values of rice cake batters containing no emulsifier (♦: control, ■ : xanthan gum, ▲: guar gum, Δ :xanthan - guar gum, □ : locust bean gum, * : HPMC, ○ : carrageenan, ◊: xanthan - carrageenan).

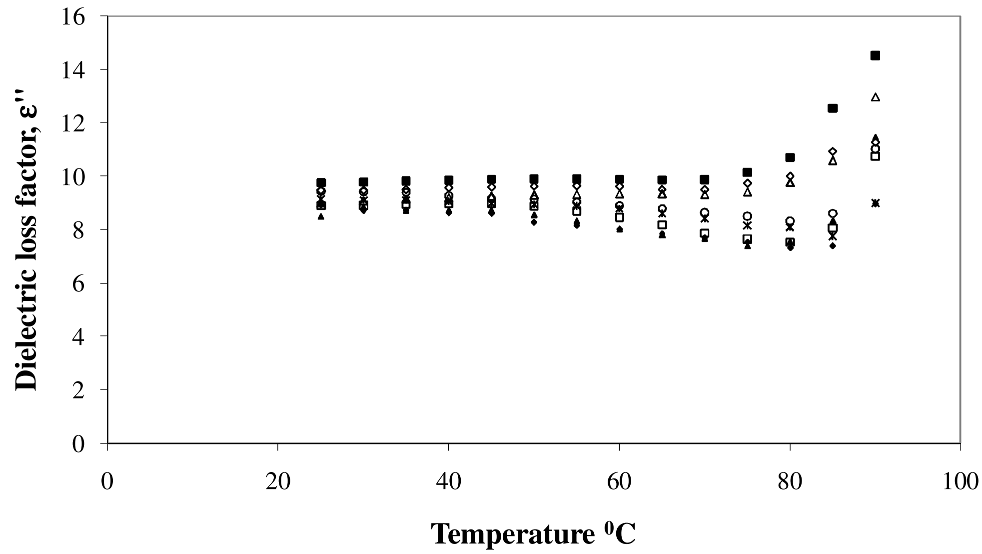


Figure 3.18 Effect of temperature change on dielectric loss factor values of rice cake batters containing 3% emulsifier (♦: control, ■ : xanthan gum, ▲: guar gum, Δ :xanthan - guar gum, □ : locust bean gum, * : HPMC, ○ : carrageenan, ◊: xanthan - carrageenan).

3.1.5 Gelatinization properties of rice cake batters containing different types of gums

Gum addition affected gelatinization temperatures of cake batters differently depending on the gum type (Table 3.3). DSC thermograms can be seen in Appendix B. In the study of Rojas et al. (1999), it was found that hydrocolloids may interact with the starch to produce an increase or decrease of the temperature gelatinization ranges, depending on the hydrocolloid. When gelatinization enthalpies are investigated, it can be seen that addition of gums increased the gelatinization enthalpies of cake formulations, which means more energy will be needed for starch gelatinization (Figure 3.19). The reason for this can be the water binding ability of the gum types. There will not be enough water for rice starch for gelatinization in the presence of gums, therefore, more energy will be needed for starch gelatinization.

Thus, the gelatinization enthalpy values of gum containing cake formulations were higher than control cakes.

Table 3.3 Onset, peak and conclusion temperatures of gelatinization of the rice cake batters.

Formulation	T_o (°C)	T_p (°C)	T_c (°C)
Control	97	110.14	126
Xanthan	91	110.67	130
Guar	92	108.92	132
Xanthan+Guar	94	108.30	126
Locust Bean	91	106.66	125
HPMC	95	107.76	126
Carrageenan	97	109.66	130
Xanthan+Carrageenan	90	108.78	129

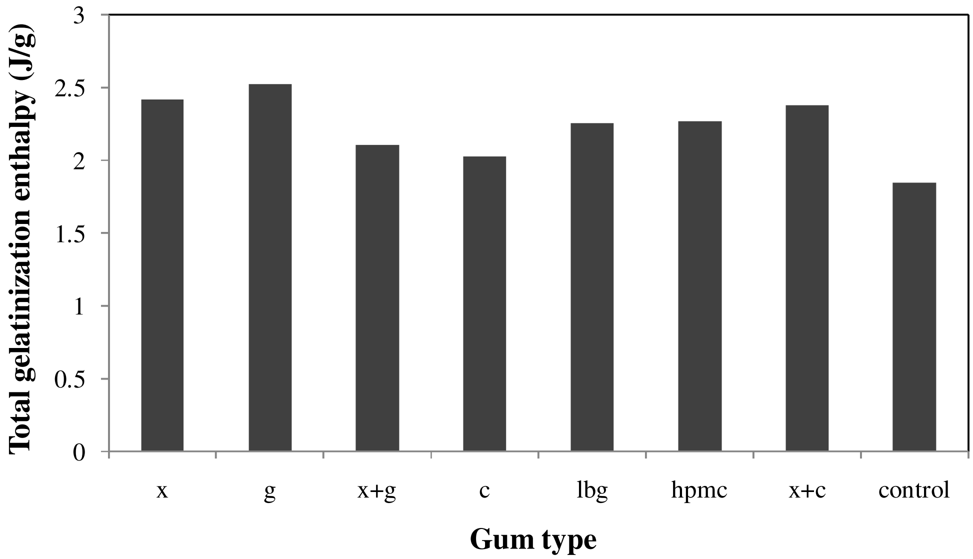


Figure 3.19 Total gelatinization enthalpies of gluten-free rice cake batters. x: xanthan, g: guar, x+g: xanthan + guar, c: κ-carrageenan, lbg: locust bean gum, hpmc: hydroxypropyl methylcellulose, x+c: xanthan + κ-carrageenan.

3.2 Physical Properties of Rice Cakes Baked in IR-microwave Combination Oven

Physical properties of the rice cakes containing different types of gums and emulsifier blend baked in IR-microwave combination oven were determined. These physical properties were specific volume, porosity, volume index, textural properties and weight loss.

Voluminous structure in cakes is a desirable property. According to the specific volume results shown in Table 3.4, the highest volume values were obtained by xanthan and emulsifier blend containing batters. Moreover, cake batters containing this gum had the highest porosity and volume index. The higher viscosity values of xanthan containing batters (Figures 3.6 and 3.7) improved cake structure and this resulted in higher volumes. In the study of Miller and Hoseney (1990), it was shown that xanthan gum significantly improved the cake volume. In Table 3.4, it can be seen that cakes prepared using gums other than xanthan gum collapsed in the oven, which can be seen by the smaller C values than B and D. This may be explained by the difference in the dielectric properties of different batter formulations. Xanthan gum containing batters had higher dielectric properties (Figures 3.11 and 3.13). Since dielectric properties are known to be highly related to the ability to interact with microwaves, higher dielectric properties of xanthan may affect faster gelatinization and can be effective on the final structure and volume properties by providing non-collapsing rice cakes. The cake collapse observed in the presence of HPMC and locust bean gum may be due to the lowest viscosities (Figures 3.6 and 3.7) and low dielectric properties of their cake batters (Table 3.4).

κ-carrageenan containing rice cakes also collapsed like HPMC containing ones. This may also be the result of low viscosity of the cake batter containing κ-carrageenan. Carrageenans are sulphated gum types, which form thermoreversible gels in the presence of gel-promoting cations; especially K^+ for κ-carrageenan type. In dairy desserts, carrageenan gelation is importantly affected by the presence of milk proteins (Verbeken et al., 2006). Therefore, in this study, κ-carrageenan containing cakes could not give desirable volume properties due to the lack of enough proteins in the batters.

According to ANOVA results, both gum types and addition of emulsifier blend significantly affected all the volume properties of rice cakes ($p \leq 0.05$) (Tables A.7-9). Two-way ANOVA results in Tables A.7-9 also show that there is significant interactions between gum types and emulsifier blend.

Table 3.4 Specific volume, porosity, volume index and height of different positions of cakes with different formulations baked in IR-microwave combination oven.

Formulation	Specific volume (ml/g)	Porosity	B (mm)	C (mm)	D (mm)	Volume index (mm)
Xanthan	1.51±0.057 bc *	0.64±0.041 a	31.50	31.50	31.50	94.50±1.121 bc
Guar	1.08±0.085 h	0.44±0.004 f	26.00	24.00	26.00	76.00±1.556 gh
Xanthan+guar	1.22±0.099 fg	0.47±0.051 ef	29.50	29.50	29.50	88.50±1.980 d
κ-carrageenan	1.22±0.057 fg	0.50±0.018 def	29.50	25.00	29.50	84.00±2.828 e
Locust bean gum	1.14±0.028 gh	0.44±0.055 f	28.00	25.50	28.00	81.50±1.273 ef
HPMC	1.20±0.042 g	0.61±0.047 ab	26.00	25.50	27.00	78.50±3.253 g
Xanthan+κ-carrageenan	1.38±0.028 de	0.53±0.027 bcde	32.00	30.50	32.00	94.50±2.970 bc
Xanthan+emulsifier	1.72±0.057 a	0.60±0.055 abc	36.50	36.50	36.50	109.50±2.263 a
Guar+emulsifier	1.33±0.028 ef	0.51±0.025 def	31.00	26.50	31.00	88.50±2.404 d
Xanthan+guar+emulsifier	1.66±0.057 a	0.59±0.008 abc	36.00	36.00	36.00	108.00±1.131 a
κ-carrageenan+emulsifier	1.40±0.042 cde	0.51±0.025 def	31.00	29.00	31.00	91.00±2.121 cd
Locust bean gum+emulsifier	1.44±0.042 bcde	0.54±0.010 bcde	34.00	30.00	34.00	98.00±0.707 b
HPMC+emulsifier	1.49±0.014 bcd	0.52±0.027 cdef	31.00	28.00	31.00	90.00±1.414 cd
Xanthan+κ-carrageenan+emulsifier	1.53±0.028 b	0.57±0.021 abcd	36.00	36.00	36.00	108.00±0.849 a
Control	1.11±0.042 gh	0.48±0.028 ef	25.00	23.50	25.00	73.50±0.849 h

* Columns with different letters are significantly different.

C is the height of the cake at the center point and B and D are the heights of the cake at the points 2.5 cm away from the center towards the left and right sides of the cake, respectively.

When the firmness values of the cakes were investigated (Figure 3.20), xanthan-guar gum blend and emulsifier blend containing cakes were the softest as compared to ones prepared with other formulations (Table A.10). HPMC and κ-carrageenan (with/without xanthan gum) containing cakes were softest when no emulsifier blend was used. On the other hand, in the absence of emulsifier blend, cakes containing xanthan-guar gum blend were the firmest. Xanthan may thicken the crumb walls by surrounding the air spaces and cause more compact structure (Rosell et al., 2001). Moreover, Gomez et al. (2007) showed that guar gum resulted in the hardest wheat cakes. In the study of Mandala and Sotirakoglou (2005), it was indicated that the breads containing xanthan and guar gum showed higher failure force than control breads at puncture tests. Gum concentration is also an important criteria for texture of baked products. In the study of Köksel (2009), as guar gum concentration increased from 0.3 to 1%, the firmness values increased significantly.

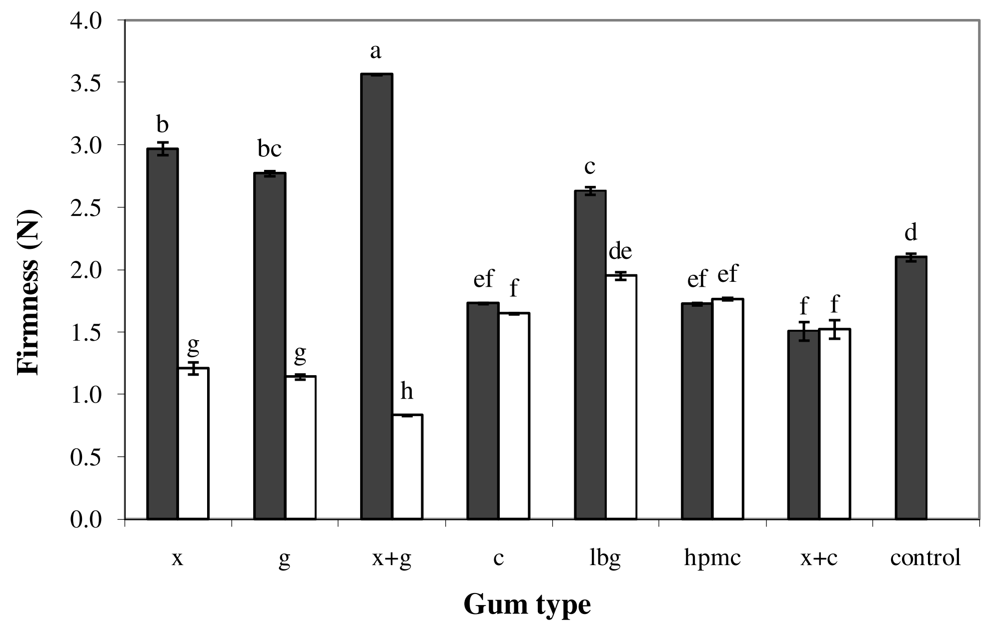


Figure 3.20 Firmness of the rice cakes baked in IR-microwave combination oven. x: xanthan, g: guar, x+g: xanthan + guar, c: κ-carrageenan, lbg: locust bean gum, hpmc: hydroxypropyl methylcellulose, x+c: xanthan + κ-carrageenan. ■ 0% emulsifier, □ 3% emulsifier * Bars with different letters are significantly different.

In Table 3.5, the effect of gums and emulsifier blend on the parameters obtained from texture profile analysis, such as springiness, gumminess and chewiness can be seen. Springiness is attributed to elasticity and plastic recovery from deformation and gumminess/chewiness are related to pastiness and breakdown (Bourne, 2002). Chewiness is described with the common terms of tender, chewy or tough. On the other hand, gumminess, which is generally described as common terms of short, mealy, pasty and gummy (Szczesnaik, 1995).

Springiness, gumminess and chewiness values were affected by both the gum type and emulsifier blend addition significantly ($p \leq 0.05$) (Tables A.11-13). All gum types gave higher springiness values than control cake (Table 3.5), which resulted in more elastic cakes. The highest springeness values were obtained in cakes containing xanthan and emulsifier blend, which also gave highest specific volume value (Table 3.4). This result is reasonable that higher air inclusion into the cakes cause higher springiness and elasticity in the structure.

Gummy or sticky texture in cakes is not a desirable property like firm structure. On the other hand, addition of emulsifier decreased the gumminess values for all gum types and less gummy cakes were obtained as compared to control cake. Firmness and gumminess values gave similar trend since gumminess is one of the texture parameters dependent on firmness values (Figure 3.20 and Table 3.5) . Gums that gave higher firmness values than control cake without emulsifier addition also gave higher gumminess values. These gums were xanthan, guar, xanthan-guar gum blend and locust bean gum. High chewiness values, like gumminess, is not a pleasing textural propery either and it is also related to the firmness values. Xanthan, guar and xanthan-guar gum blend cakes showed lower chewiness values (Table 3.5) than control cake after addition of emulsifier content.

Table 3.5 Textural profile of the rice cakes containing different types of gums and emulsifier blend baked in IR-microwave combination oven.

Formulation	Springiness (mm)	Gumminess (N)	Chewiness (N.mm)
Xanthan	5.11±0.050 ab *	1.65±0.054 b	8.41±0.361 b
Guar	4.78±0.027 bcd	1.51±0.065 bc	7.23±0.350 c
Xanthan+guar	5.27±0.005 a	1.86±0.007 a	9.78±0.344 a
κ-carrageenan	4.21±0.008 ef	0.95±0.078 de	4.02±0.485 ef
Locust bean gum	4.54±0.008 cde	1.49±0.046 c	6.76±0.341 c
HPMC	4.52±0.024 cde	0.93±0.115 def	4.19±0.276 ef
Xanthan+κ-carrageenan	4.60±0.019 cde	0.83±0.099 ef	3.83±0.608 f
Xanthan+emulsifier	5.38±0.020 a	0.67±0.003 g	3.59±0.186 fg
Guar+emulsifier	4.44±0.000 de	0.63±0.029 g	2.81±0.058 g
Xanthan+guar+emulsifier	4.39±0.003 de	0.43±0.109 h	1.91±0.587 h
κ-carrageenan+emulsifier	5.09±0.019 ab	0.94±0.056 de	4.77±0.014 de
Locust bean gum+emulsifier	5.24±0.003 ab	1.06±0.065 d	5.53±0.412 d
HPMC+emulsifier	5.15±0.012 ab	0.96±0.085 de	4.94±0.780 de
Xanthan+κ-carrageenan+emulsifier	4.97±0.023 abc	0.77±0.050 fg	3.84±0.067 f
Control	3.87±0.014 f	1.10±0.072 d	4.23±0.080 ef

* Columns with different letters are significantly different.

According to Table 3.6, which shows the weight loss of rice cakes containing different types of gums and emulsifier blend baked in IR-microwave combination oven, no significant difference was found between all the cake formulations ($p \leq 0.05$) (Table A.14).

Table 3.6 Weight loss (%) of rice cakes containing different types of gums and emulsifier blend baked in IR-microwave combination oven.

Formulation	0% emulsifier	3% emulsifier
Xanthan	12.80±0.051 a	13.29±0.075 a
Guar	13.30±0.115 a	13.28±0.102 a
Xanthan+Guar	12.97±0.085 a	13.25±0.133 a
Carrageenan	12.91±0.029 a	13.43±0.065 a
Locust Bean	13.29±0.170 a	14.22±0.023 a
HPMC	13.61±0.194 a	13.36±0.174 a
Xanthan+Carrageenan	12.97±0.038 a	13.29±0.008 a
Control	13.48±0.162 a	

3.3 Physical Properties of Rice Cakes Baked in Conventional Oven

Physical properties of the rice cakes containing different types of gums baked in conventional oven were determined. These physical properties were specific volume, textural properties and weight loss.

It can be seen in Figure 3.21 that the highest specific volume was obtained for xanthan containing rice cake similar to the results of IR-microwave baked cakes (Table 3.4). The lowest specific volume values were shown by the cakes containing galactomannans of guar and locust bean gums. Specific volume of the cakes containing other types of gums were not significantly different than control cake ($p \leq 0.05$) (Table A.15). When conventional and IR-microwave combination ovens were compared, specific volume values of the cakes baked in conventional oven were lower than cakes baked in IR-microwave combination oven (Figure 3.21 and Table 3.4). This may be due to the difference in baking mechanisms. In IR-microwave combination baking, internal heat generation results in higher internal pressure in a very short time, which may cause looser and more porous structure than conventional baking. Therefore, conventionally baked cakes had lower specific volumes than IR-microwave baked ones.

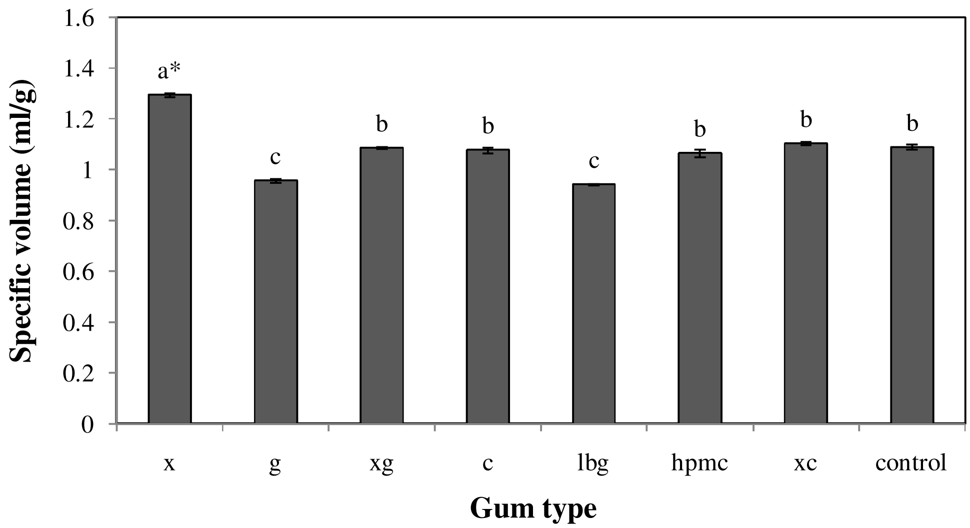


Figure 3.21 Specific volume of the rice cakes without emulsifier baked in conventional oven. x: xanthan, g: guar, xg: xanthan + guar, c: κ-carrageenan, lbg: locust bean gum, hpmc: hydroxypropyl methylcellulose, xc: xanthan + κ-carrageenan.

According to texture profile analysis, all gum types showed lower firmness values than control cake except guar gum (Figure 3.22). Guar gum cake, which also gave significantly lower specific volume value than control cake (Figure 3.21), might give firmer structure due to the lower air inclusion into its structure. In Table 3.7, springiness, gumminess and chewiness of the cakes can be seen. Gum addition did not affect the springiness values of conventionally baked cakes ($p \leq 0.05$) (Table A.17). On the other hand, gum addition affected both gumminess and chewiness values significantly (Tables A.18 and 19). Cake containing guar gum gave the highest gumminess and chewiness values among all the cakes baked in conventional oven. These results show that the gummy and tough structure of guar gum cake can be correlated with the results of specific volume (Figure 3.21) and firmness results (Figure 3.22). In the study of Köksel (2009), 1% guar gum containing cakes gave the highest firmness, gumminess and chewiness values. Cakes containing xanthan gum and HPMC had the softest as well as lowest gumminess and chewiness values.

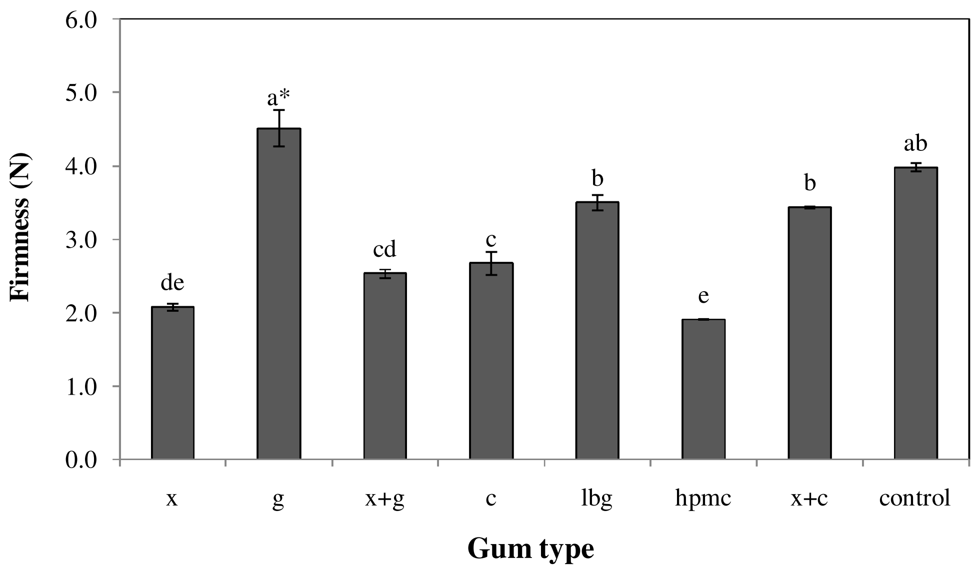


Figure 3.22 Firmness of the rice cakes without emulsifier baked in conventional oven. x: xanthan, g: guar, xg: xanthan + guar, c: κ-carrageenan, lbg: locust bean gum, hpmc: hydroxypropyl methylcellulose, xc: xanthan + κ-carrageenan.

Table 3.7 Textural profile of the rice cakes containing different types of gums baked in conventional oven

Formulation	Springiness (mm)	Gumminess (N)	Chewiness (N.mm)
Xanthan	3.91±0.046 a *	1.16±0.047 cd	4.51±0.189 cd
Guar	3.97±0.015 a	2.59±0.136 a	10.25±0.505 a
Xanthan+guar	3.94±0.049 a	1.42±0.023 c	5.60±0.164 c
Carrageenan	3.86±0.023 a	1.45±0.114 c	5.59±0.409 c
Locust bean gum	3.81±0.009 a	1.91±0.081 b	7.26±0.296 b
HPMC	3.73±0.077 a	1.02±0.012 d	3.80±0.074 d
Xanthan+carrageenan	3.94±0.089 a	2.00±0.032 b	7.88±0.096 b
Control	4.11±0.020 a	2.42±0.022 a	9.95±0.142 a

* Columns with different letters are significantly different.

When baking methods were compared in terms of firmness values, conventionally baked cakes were firmer than IR-microwave combination baked cakes except the ones containing xanthan and xanthan-guar gum blend (Figures 3.20 and 3.22). In the study of Demirkol (2007), conventionally baked cakes for 28 minutes showed higher firmness values than cakes containing emulsifier baked in IR-microwave combination oven. The difference in the behaviors of gum types in different ovens showed the interaction between gum type and baking method in terms of textural properties.

All the gum types gave lower weight loss than the control cake (Figure 3.23) due to . Weight loss of cakes baked in conventional oven was lower than the cakes baked in IR-microwave oven due to the higher moisture loss of microwave baking (Table 3.6). High pressure gradient inside the cake due to the larger internal heat generation in the microwave oven caused higher moisture loss in IR-microwave baked cakes than the conventionally baked cakes. In recent studies, it was shown that breads and cakes baked in microwave oven lost more moisture as compared to conventionally baked ones (Sumnu et al, 2005; Zincirkiran et al., 2002; Seyhun, 2002; Keskin et al., 2004; Demirekler et al., 2004; Demirkol, 2007)

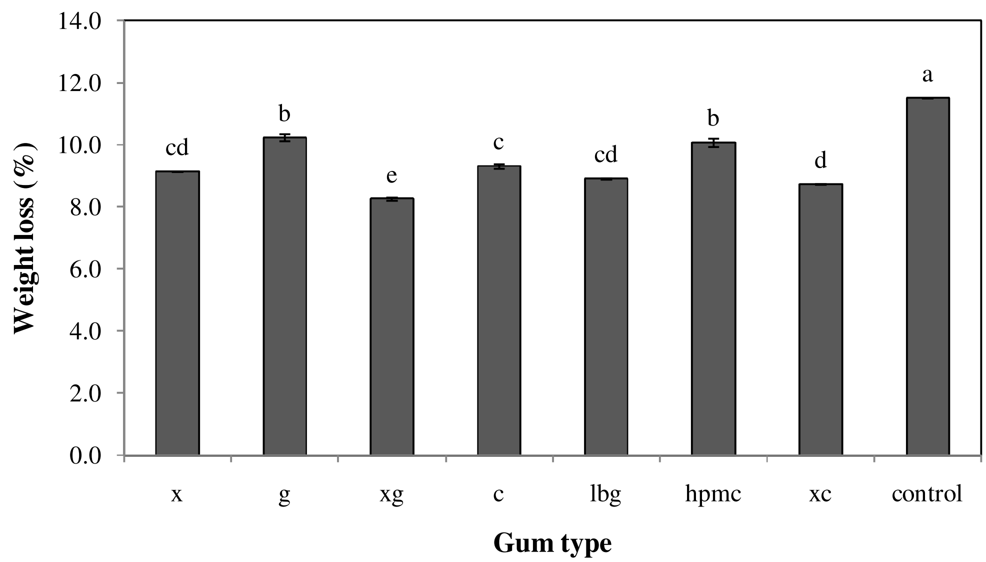


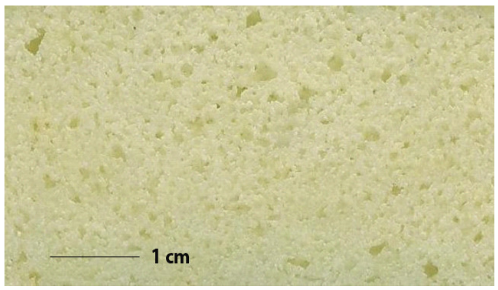
Figure 3.23 Weight loss of the rice cakes without emulsifier baked in conventional oven. x: xanthan, g: guar, xg: xanthan + guar, c: κ-carrageenan, lbg: locust bean gum, hpmc: hydroxypropyl methylcellulose, xc: xanthan + κ-carrageenan.

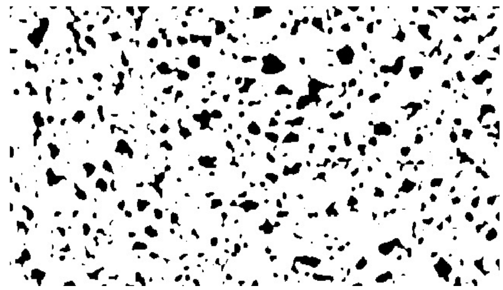
3.4 Macro and Micro-structure of Rice Cakes

Macro and micro-structures of the crumbs of gluten-free rice cakes containing different types of gums were analyzed. Quantitative information on macro-structure of the cakes in terms of area-based pore size distribution and pore area fraction were obtained by the help of image analysis. Qualitative information on micro-structure of the cakes were obtained by SEM analysis.

3.4.1 Effects of different types of gums on macro-structure of rice cakes baked in conventional and IR-microwave combination ovens

Figure 3.24a shows the sample graph of scanned image of a rice cake containing xanthan gum. The binarised image that was obtained by the Image J software can be seen in Figure 3.24b. Binarised images were used for quantitative analysis of pores. Pore area fractions of cakes containing different gums and baked in different ovens were shown in Figure 3.25. Two-way ANOVA (Table A.21) showed that both gum type and baking mode were found to be significantly effective on the pore area fractions of cake crumbs ($p \leq 0.05$).





(a) **(b)**

Figure 3.24 (a) Scanned image of rice cake containing xanthan gum. (b) Binarised image of this cake.

Higher pore area fraction values mean that cakes were more porous. Cakes containing xanthan and xanthan-guar gum blend gave higher pore area fractions than the other gums when they were baked in IR-MW combination oven (Figure 3.25). Xanthan and xanthan-guar gum blend containing cakes were shown to have higher volume index, specific volume and porosity values (Table 3.4). These results can be related to the rheological properties of the rice cake batters. Apparent viscosity of rice cake batters containing xanthan and xanthan-guar gum were found to be higher than the batters containing guar, locust bean and κ-carrageenan (Figures 3.6 and 3.7). Higher apparent viscosity might help entrapment of air into the cake batters and cause higher volumes and porosity values. In low apparent viscosity batters such as containing galactomannans such as guar and locust bean gums or κ-carrageenan, air bubbles could easily rise to the surface and be lost into the atmosphere. For conventional baking mode, the galactomannans, guar and locust bean gums gave the lowest pore area fraction. This result was correlated with the specific volume values of rice cakes baked in conventional oven, which were shown in Figure 3.21.

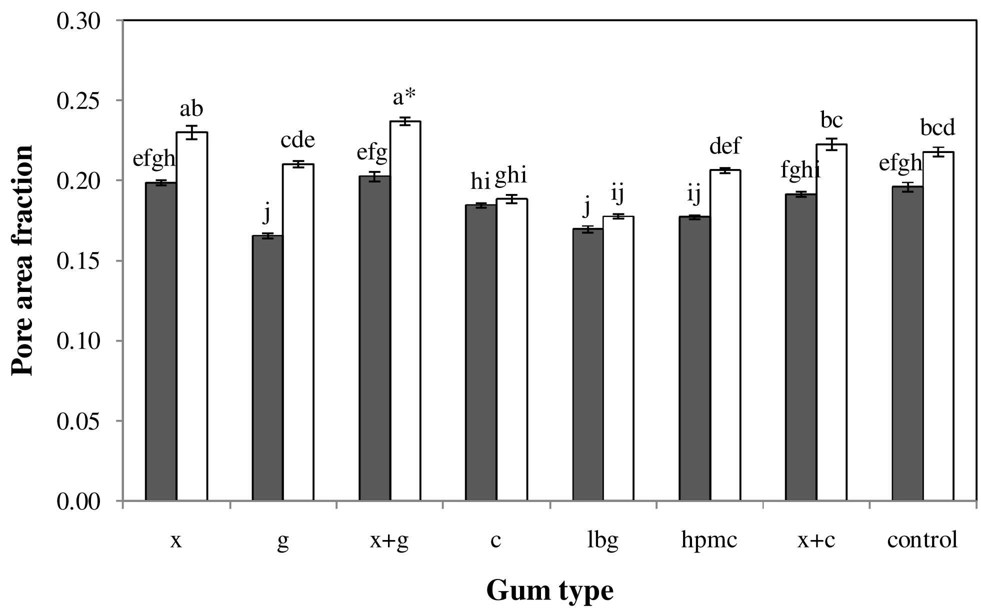


Figure 3.25 Effects of gum types and baking modes on pore area fractions of rice cakes. x: xanthan, g: guar, x+g: xanthan + guar, c: κ-carrageenan, lbg: locust bean gum, hpmc: hydroxypropyl methylcellulose, x+c: xanthan + κ-carrageenan. ■ Conventional oven, □ IR-microwave combination oven. * Bars with different letters are significantly different.

When the baking modes were compared, IR-microwave combination provided cakes with higher pore area fraction values than conventional baking (Figure 3.25). The reason for this significant difference between baking methods can be the difference in baking mechanisms. Larger amounts of interior heating in microwave baking results in increased moisture vapor generation inside the food, which creates high pressure gradient. Higher pressure gradient occurring inside the cakes during microwave heating as compared to conventional heating can cause looser and more porous structures in cakes. Ozkoc et al. (2009) obtained similar results for breads baked in different ovens in their study.

The roundness values of the pores of the cakes were shown in Figure 3.26. No significant difference between gum types was found in terms of roundness values according to ANOVA results (Table A.22). The roundness values of 1 means that pores are in circular shape. The roundness values in this study were found between 0.45-0.50, which means the pore structures in cakes were not circular.

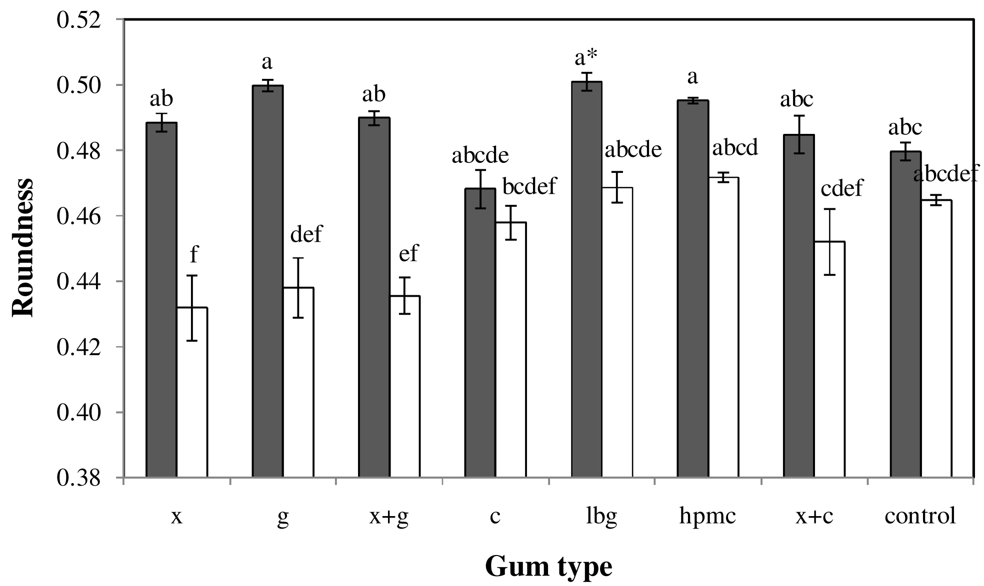


Figure 3.26 Effects of gum types and baking modes on roundness values of pores of rice cakes. x: xanthan, g: guar, x+g: xanthan + guar, c: κ-carrageenan, lbg: locust bean gum, hpmc: hydroxypropyl methylcellulose, x+c: xanthan + κ-carrageenan. ■ Conventional oven, □ IR-microwave combination oven. * Bars with different letters are significantly different.

Table 3.8 Pore area distributions of rice cakes with different gums baked in different ovens

		Number of Pores							
Range of pore area (mm^2)	Oven type	Gum Type							
		Control	X	G	X-G	C	LBG	HPMC	X-C
0-0.5		228	353	166	250	276	170	138	202
0.5-1		65	89	63	67	75	35	37	64
1-5	Conventional	97	118	98	116	115	83	79	127
5-10		11	6	5	6	8	10	13	8
10-15		0	0	0	0	0	0	1	0
Total number of pores		401	566	332	439	474	298	267	401
0-0.5		223	381	299	288	232	190	245	264
0.5-1		51	89	86	65	56	63	74	75
1-5	IR-microwave	103	135	119	115	100	111	114	144
5-10		15	15	6	16	17	9	11	6
10-15		3	1	1	2	2	1	2	1
Total number of pores		395	621	511	486	406	374	446	490

X: xanthan, G: guar, X-G: xanthan + guar, C: κ-carrageenan, LBG: locust bean gum, HPMC: hydroxypropyl methylcellulose, X-C: xanthan + κ-carrageenan.

In Table 3.8, pore area distributions of the cakes baked in both conventional and IR-microwave combination oven can be seen. It can be seen that IR-microwave baked cakes gave higher number of pores than conventionally baked ones except control and κ-carrageenan cakes. Additionally, IR-microwave combination baking increased the number of small-sized (0-0.5 mm^2) pores again except the cakes containing no gum or κ-carrageenan. Thus, it can be concluded that IR-microwave combination baking could generally improve the uniformity in pore structures. IR-microwave baking increased the pore area fraction values for all gum types, which can be seen in Figure 3.25. When small size pores (0-0.5 mm^2) were considered, xanthan containing cakes gave higher pore numbers.

Some qualitative and quantitative information on macro-structure of the cakes baked in conventional and IR-MW combination oven were also obtained by performing SEM analysis on cake crumbs with 30 x magnification (Figures 3.27 and 3.28). According to these micrographs, coalescence of the pores and formation of channel like structures were observed in the cakes. The method used in the study of Impoco et al. (2007) was used for obtaining quantitative information on SEM micrographs. The maximum pore area obtained from these micrographs was less than 5.82 mm^2 in an image having a total area of 12.66 mm^2. This was for xanthan guar gum blend containing cake baked in IR-MW combination oven. In figure 3.29, pore area fraction values of the cakes based on SEM images which were analyzed by image analysis can be seen. Both gum type and baking method were found to be significantly effective on pore area fractions ($p \leq 0.05$) (Table A.23). Like in the scanned images of cakes, cakes containing xanthan gum and xanthan-guar gum blend and baked in IR-microwave oven had higher pore area fractions as compared to other formulations. The difference in the dielectric properties of gums may affect the porosity in cake crumbs. When the dielectric properties of the batters are high, more interaction between the cake batters and microwaves can occur. By this way, higher gelatinization can be obtained. This can be the reason of higher porosity of cakes containing xanthan that had higher dielectric properties than other gums (Figures 3.11 and 3.13). On the other hand, guar gum had also high dielectric properties but resulted in lower pore area fraction values (Figure 3.25) than xanthan gum. Low apparent viscosity given by this gum may be the reason of low pore area fraction. In Table 3.4, it can be seen that guar gum containing cakes baked in IR-microwave combination oven gave lower specific volume and porosity results as compared to other gum types.

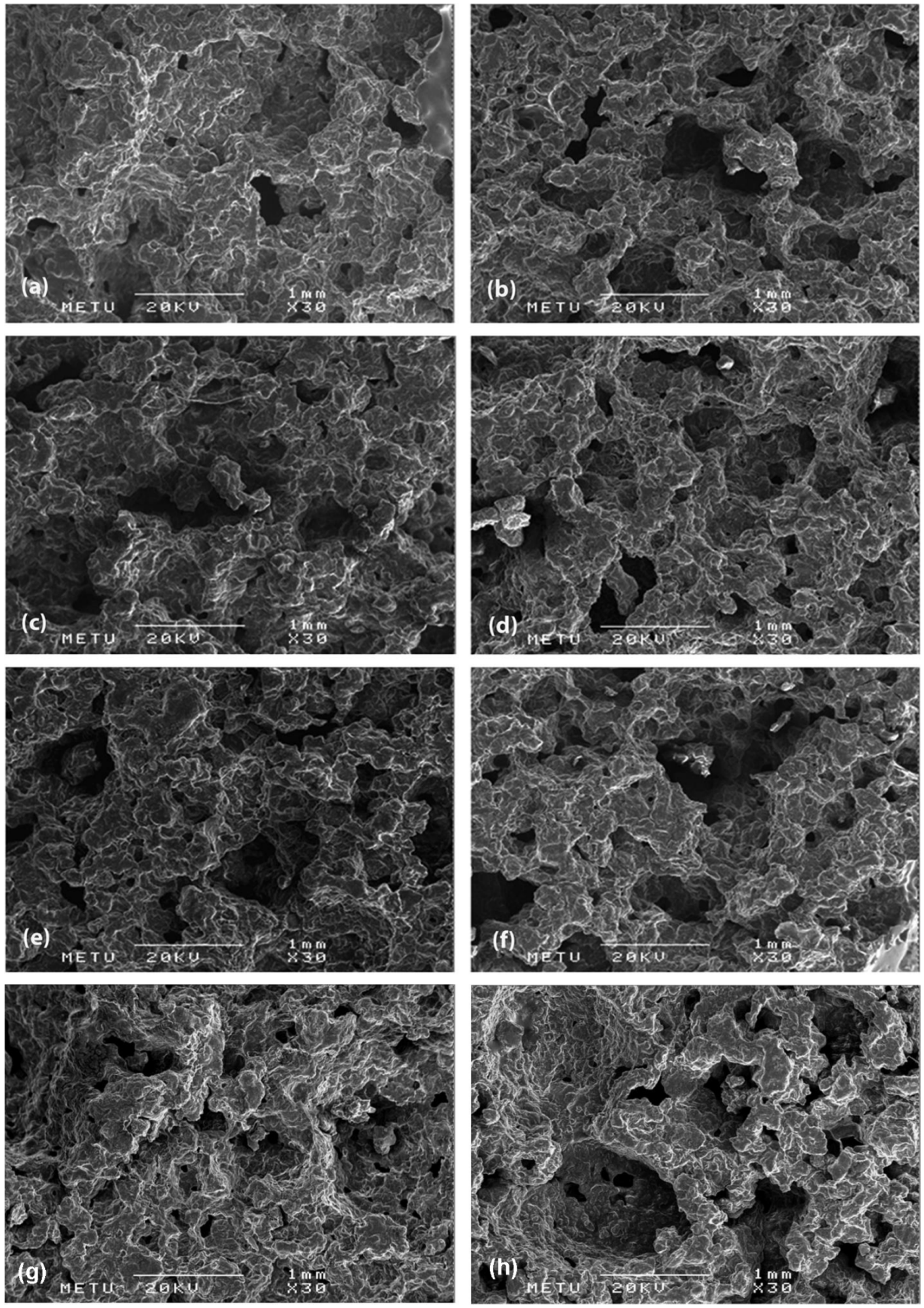


Figure 3.27 SEM micrographs (30X) for cakes baked in conventional oven (a. control, b.xanthan, c. guar, d. xanthan-guar, e. locust bean, f. κ-carrageenan, g. xanthan-κ-carrageenan, h. HPMC)

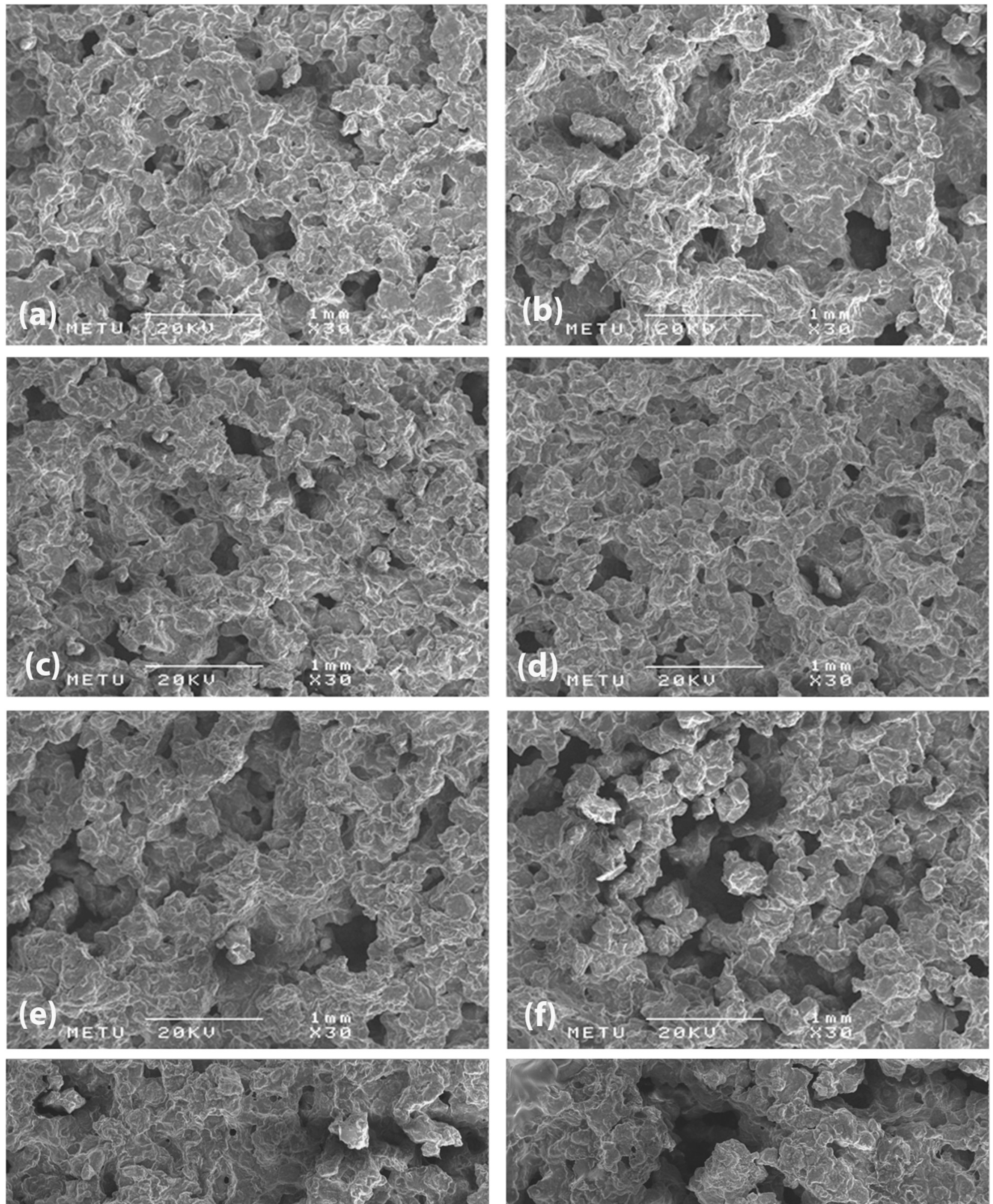


Figure 3.28 SEM micrographs (30X) for cakes baked in IR-microwave combination oven (a. control, b.xanthan, c. guar, d. xanthan-guar, e. locust bean, f. κ-carrageenan, g. xanthan-κ-carrageenan, h. HPMC)

More uniform structures were obtained when gums were added into the cake formulations (Figures 3.27 and 3.28). Control cake had both small and large pores and the distribution was not homogeneous, which was also concluded according to the pore distribution results shown in Table 3.8. Xanthan-guar gum blend containing cakes gave the most uniform and homogeneous pore distributions.

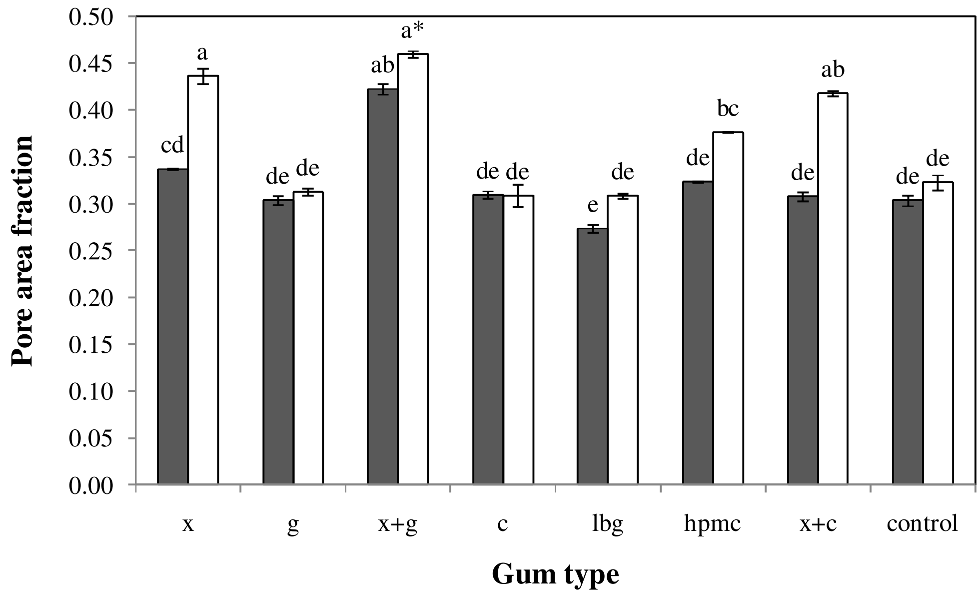


Figure 3.29 Effects of gum types and baking modes on pore area fractions of rice cakes based on SEM images x: xanthan, g: guar, x+g: xanthan + guar, c: κ-carrageenan, lbg: locust bean gum, hpmc: hydroxypropyl methylcellulose, x+c: xanthan + κ-carrageenan. ■ Convetional oven, □ IR-MW combination oven. * Bars with different letters are significantly different.

3.4.2 Effects of different types of gums on micro-structure of rice cakes baked in conventional and IR-microwave combination ovens

In Figures 3.30 and 3.31, the images obtained at 500X magnifications of the cakes baked in conventional and IR-microwave combination oven were shown, respectively. In conventional baking, more deformation of the starch granules can be seen. Gelatinized starch granules were dispersed on the surface of the baked cakes and they seemed as continuous sheets. On the other hand, in cakes baked in IR-microwave combination oven, granular residues and deformed starch structure were observed together. All starch granules did not lose their identity and did not disintegrate completely. In microwave heating, incomplete gelatinization may occur due to shorter processing time and higher pressure-gradient, which causes higher moisture loss. In the study of Sakiyan et al. (2010), it was also found that in IR-microwave baked cakes; gelatinization was lower than that in conventional baking. Therefore, in SEM analysis of cakes baked in IR-microwave combination oven, less deformed starch granules were observed.

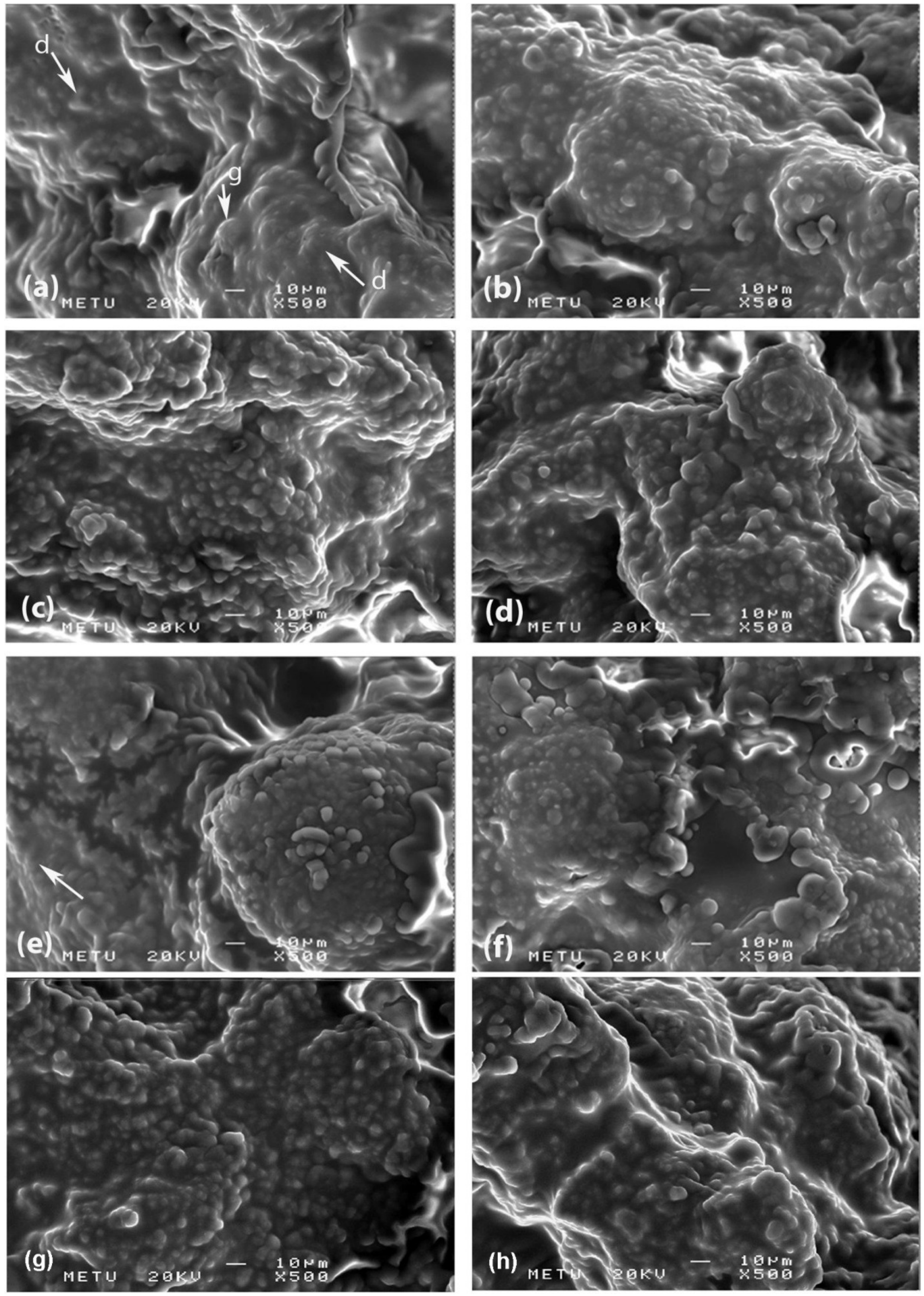


Figure 3.30 SEM micrographs (500X) for cakes baked in conventional oven (a. control, b.xanthan, c. guar, d. xanthan-guar, e. locust bean, f. κ-carrageenan, g. xanthan-κ-carrageenan, h. HPMC) (d: Deformed starch, g: granular starch)

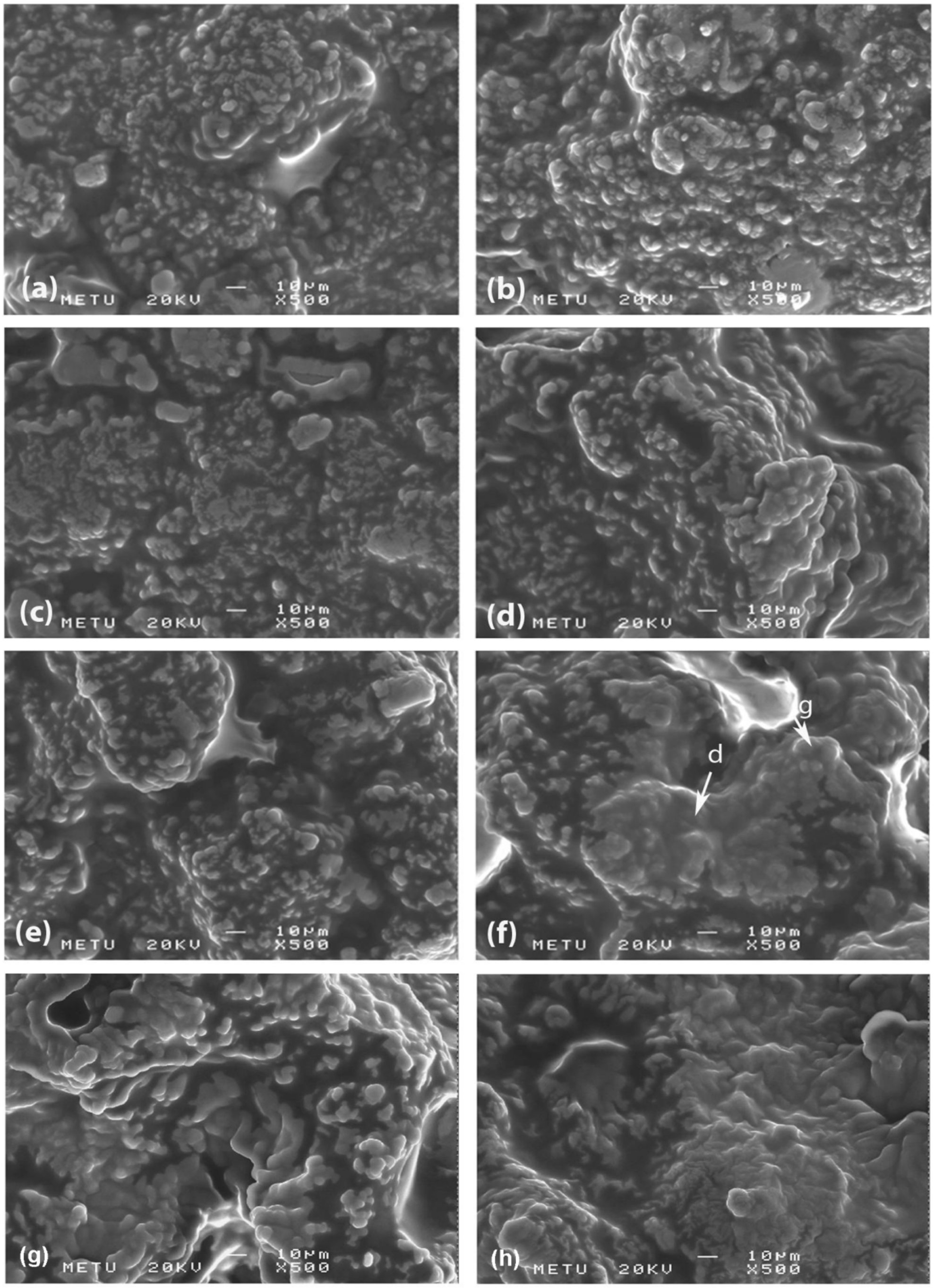


Figure 3.31 SEM micrographs (500X) for cakes baked in IR-microwave combination oven (a. control, b.xanthan, c. guar, d. xanthan-guar, e. locust bean, f. κ-carrageenan, g. xanthan-κ-carrageenan, h. HPMC) (d: Deformed starch, g: granular starch)

3.5 Optimization of Baking of Rice Cakes in IR-microwave Combination Oven by Response Surface Methodology

RSM was used to design the optimum IR-microwave combination baking conditions and formulation of gluten-free rice cake. The relationships between the responses of specific volume, total color change, firmness and weight loss and independent variables of emulsifier content, upper halogen lamp power and baking time were examined by using second order models obtained. Two types of cake formulations containing xanthan and xanthan-guar gum blend, which gave the most desirable results in the batter and cake quality analysis, were used in the experiments. Experimental data used in RSM are given in Table C.1 and Table C.2.

Second-order model equation (Equation 3.3) was used to fit the independent and dependent variables and it was examined for goodness to fit.

$$Y=b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_1^2 + b_5X_2^2 + b_6X_3^2 + b_7X_1X_2 + b_8X_1X_3 + b_9X_2X_3 \quad (3.3)$$

In this equation, X_i s are the independent variables (X_1 is emulsifier blend content, X_2 is upper halogen lamp power level, and X_3 is baking time), b_i s are the model constants, and Y is the dependent variables (specific volume, total color change, firmness and weight loss).

The model constants and coefficient of determination values of each dependent variable were shown in Table 3.9. The equations for each response could be derived from the predicted values of each response variable. Coefficient of determination (r^2) is the proportion of variation in the response attributed to the model rather than to the random error. For good fit models, at least r^2 of 80% is suggested (Gan et al., 2007). The results in our study (Table 3.9) showed that the models for all the response variables were adequate since they had satisfactory r^2 of more than 90%, and there was also insignificant lack of fit for all response variables.

The lack of fit test is a measure of the failure of a model to represent data in the experimental domain at which points were not included in the regression (Varnalis et al., 2004).

Table 3.9 Regression equations for baked cakes containing xanthan guar gum blend and xanthan gum.

Quality parameter	Gum Type	Equation	r^2	Lack of fit (F)
Specific volume	Xanthan-guar gum blend	$Y_1 = 1.491^{***} + 0.104^{***} X_1 - 0.012^{ns} X_2 - 0.023^{ns} X_3 - 0.049^{*} X_1^2 - 0.011^{ns} X_2^2 - 0.009^{ns} X_3^2 + 0.013^{ns} X_1X_2 + 0.016^{ns} X_1X_3 - 0.041^{ns} X_2X_3$	96.7	1.92^{ns}
	Xanthan gum	$Y_1 = 1.490^{***} - 0.009^{ns} X_1 - 0.012^{ns} X_2 - 0.026^{**} X_3 + 0.152^{***} X_1^2 + 0.004^{ns} X_2^2 + 0.008^{ns} X_3^2 - 0.013^{ns} X_1X_2 + 0.026^{*} X_1X_3 - 0.017^{ns} X_2X_3$	98.7	0.62^{ns}
Total color change	Xanthan-guar gum blend	$Y_2 = 28.267^{***} + 4.525^{***} X_1 + 5.275^{***} X_2 + 2.425^{***} X_3 - 2.596^{***} X_1^2 + 0.154^{ns} X_2^2 + 0.004^{ns} X_3^2 - 1.925^{*} X_1X_2 - 0.425^{ns} X_1X_3 - 0.025^{ns} X_2X_3$	98.5	0.28^{ns}
	Xanthan gum	$Y_2 = 30.733^{***} + 6.750^{***} X_1 + 6.525^{***} X_2 + 4.075^{***} X_3 - 4.117^{***} X_1^2 + 0.433^{ns} X_2^2 + 0.133^{ns} X_3^2 - 0.500^{ns} X_1X_2 - 0.750^{ns} X_1X_3 + 1.550^{ns} X_2X_3$	99.0	17.78^{ns}
Firmness	Xanthan-guar gum blend	$Y_3 = 3.216^{***} - 0.426^{***} X_1 + 0.045^{ns} X_2 + 0.228^{ns} X_3 + 0.255^{ns} X_1^2 - 0.297^{ns} X_2^2 + 0.456^{*} X_3^2 - 0.427^{ns} X_1X_2 + 0.221^{ns} X_1X_3 + 0.036^{ns} X_2X_3$	92.3	0.47^{ns}
	Xanthan gum	$Y_3 = 3.065^{***} + 0.276^{***} X_1 + 0.198^{***} X_2 + 0.087^{ns} X_3 - 0.486^{***} X_1^2 - 0.163^{ns} X_2^2 + 0.161^{ns} X_3^2 + 0.190^{*} X_1X_2 + 0.029^{ns} X_1X_3 - 0.113^{ns} X_2X_3$	96.6	14.59^{ns}
Weight loss	Xanthan-guar gum blend	$Y_4 = 13.857^{***} + 0.536^{ns} X_1 + 0.855^{ns} X_2 + 1.334^{*} X_3 - 0.213^{ns} X_1^2 - 0.367^{ns} X_2^2 + 0.238^{ns} X_3^2 + 0.018^{ns} X_1X_2 + 0.180^{ns} X_1X_3 - 0.212^{ns} X_2X_3$	96.7	1.18^{ns}
	Xanthan gum	$Y_4 = 12.922^{***} + 0.214^{ns} X_1 + 0.541^{**} X_2 + 1.592^{***} X_3 - 0.121^{ns} X_1^2 - 0.221^{ns} X_2^2 + 0.359^{ns} X_3^2 + 0.345^{ns} X_1X_2 - 0.099^{ns} X_1X_3 - 0.003^{ns} X_2X_3$	98.5	0.92^{ns}

ns Not significant, X_1, emulsifier content, X_2 upper halogen lamp power level, X_3 baking time (coded values)

* Significant at $p \leq 0.05$, ** Significant at $p \leq 0.01$, *** Significant at $p \leq 0.001$.

Dependent variables at different experimental conditions were also predicted using the model. Predicted values were compared with the experimental values of cakes containing both xanthan-guar gum blend and xanthan gum (Figures 3.32a-d and 3.33a-d, respectively). As can be seen in these figures, the coefficient of determination showing the relationship between predicted and experimental data were high. This indicates that the experimental data fits the model well.

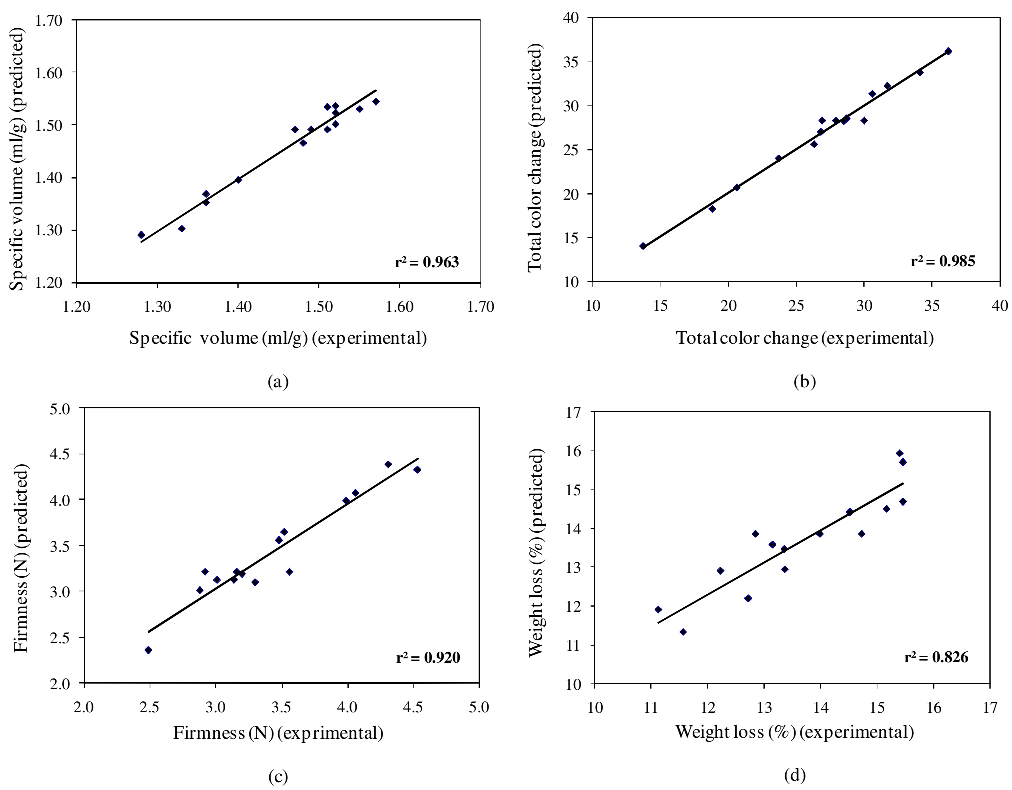


Figure 3.32 Comparison of predicted and experimental values of dependent variables for cakes formulated with xanthan-guar gum blend. (a) Specific volume, (b) Total color change, (c) Firmness, (d) Weight loss

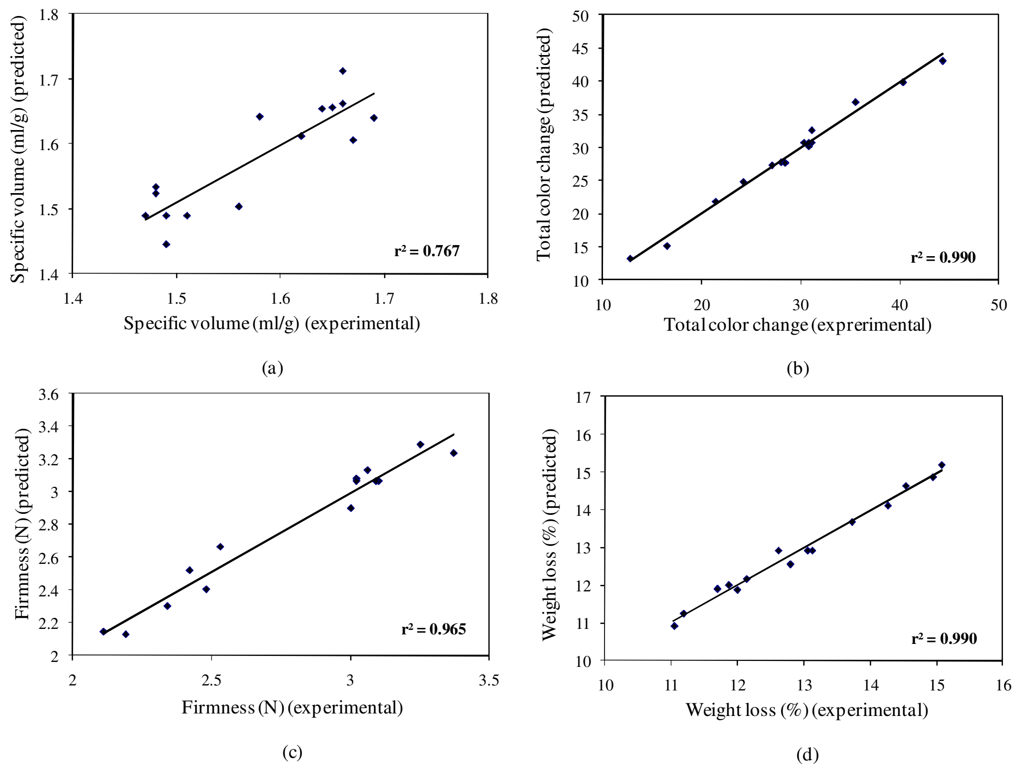


Figure 3.33 Comparison of predicted and experimental values of dependent variables for cakes formulated with xanthan gum. a Specific volume, b Total color change, c Firmness, d Weight loss

Emulsifier blend content was found to be the only significant main factor ($p\leq0.01$) in affecting the specific volume of the cakes containing xanthan-guar gum blend according to the multiple regression analysis. When emulsifier blend content increased, specific volume of the cakes increased (Figure 3.34a). According to this figure, for cakes baked for 7 minutes, the increase in emulsifier blend content from 0 to 6% increased the specific volume of the cakes by 12.3%. Emulsifier blend addition is known to improve the gas retention and to increase resistance of the cake to collapse, which can also be seen from the specific volume results shown in Table

3.4 in Section 3.2. Thus, the increase in emulsifier blend content improved the specific volume of the cakes containing xanthan-guar gum blend. In the study of Mohamed and Hamid (1998), volume expansion was found to be correlated positively with emulsifier content for the rice cakes.

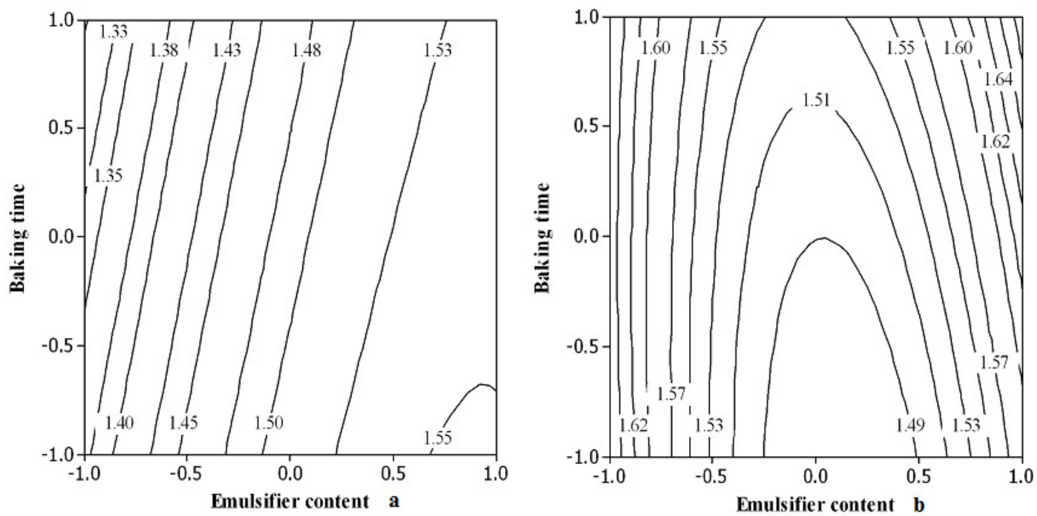


Figure 3.34 Effects of emulsifier blend content (X_1) and baking time (X_3) on specific volume (ml/g) of cakes (X_2=0). a Xanthan-guar gum blend, b Xanthan gum.

The increase in baking time decreased the specific volume of the cake, which may be explained by the shrinkage of cakes within the studied range of baking time. It can be seen that for the 0% level of emulsifier blend content, when the baking time was increased from 7 to 8 minutes, the specific volume of cakes decreased from 1.38 to 1.33 ml/g (Figure 3.34a).

There was an optimum emulsifier blend concentration, which was about 6% of emulsifier blend content for 7 minutes baking time (Figure 3.34b), to obtain voluminous cakes. Figure 3.34b also shows that the effect of baking time on volume was a function of emulsifier blend content. Emulsifiers have the ability of improving gas retention in the cake structure. Baking time is also important to prevent the collapse of cakes in the oven. Emulsifier content is dependent on baking time on affecting the volume of cakes and this explains the significant interaction between the baking time and emulsifier blend content (Table 3.9).

When Figures 3.34a and b were examined, it can be observed that xanthan gum containing cakes had higher specific volume values than the cakes containing xanthan-guar gum blend. In Table 3.4, it may also be observed that specific volume of xanthan containing cakes were higher than xanthan-guar gum blend containing cakes baked in IR-microwave combination oven. Cakes containing xanthan-guar gum blend had specific volumes of 1.33-1.55 ml/g and cakes containing only xanthan gum had specific volumes of 1.48-1.64 ml/g according to the contour plots shown in Figures 3.38a and b. It was known that xanthan had higher viscosities when it was used with guar gum because of the synergistic effect of the gums (Casas et al., 2000) and this can also be seen in Figures 3.6 and 3.7. The viscosity is an important physical property of cake batter to obtain cakes with high volume and there is an optimum viscosity of cake batter to obtain cakes with high volume. If the viscosity of the batter is too low, batter cannot hold air bubbles inside and cake collapses in the oven. Although, a highly viscous batter can hold the air bubbles inside, the expansion of this batter is restricted because of its high viscosity (Sahi and Alava, 2003). Thus, the cakes with lower volume are obtained. In this study, cakes containing xanthan gum had higher specific volume than the cakes containing xanthan-guar gum blend, as cake batter containing only xanthan gum had lower viscosity than the one containing xanthan-guar gum blend.

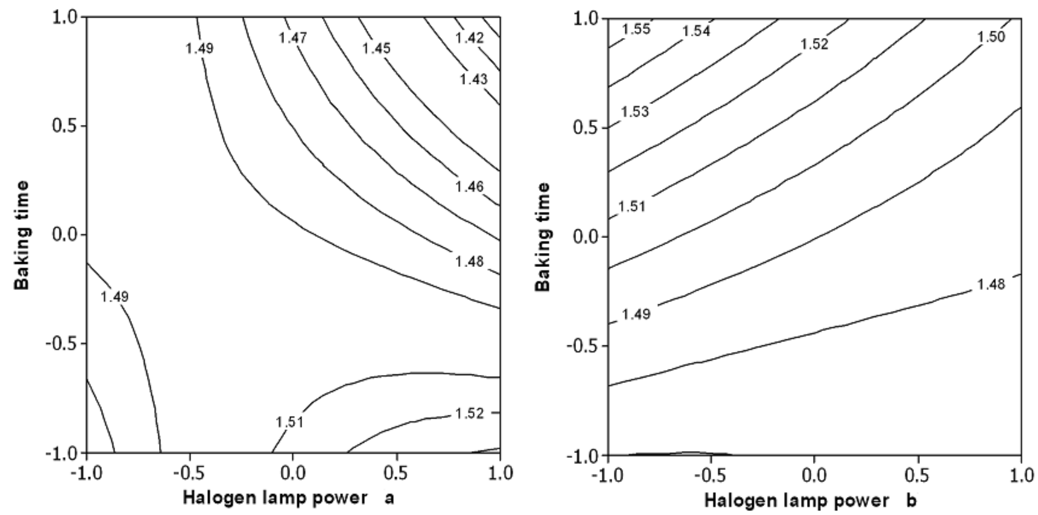


Figure 3.35 Effects of halogen lamp power (X_2) and baking time (X_3) on specific volume (ml/g) of cakes (X_1=0). a Xanthan-guar gum blend, b Xanthan gum.

The increase in halogen lamp power decreased the volume of xanthan-guar gum blend containing cakes for longer baking times (Figure 3.35a). For all baking times, the increase in halogen lamp power decreased the volume of only xanthan gum containing cakes (Figure 3.35b). The reason for these decreases is that the thicker crust formed on the cakes compressed the structure more and resulted in lower volumes (Sevimli et al., 2005).

All the independent variables were found to be significantly effective on the total color change of cakes containing both xanthan-guar gum blend and xanthan gum ($p \leq 0.001$) (Table 3.9). The effects of emulsifier blend content and baking time on total color change can be seen in Figure 3.36a and b. Increase in both independent variables increased the total color change that is desirable for cake baking process. Ingredients such as carbohydrates and proteins have main effects on Maillard reactions, which are the reactions between amino acids and reducing sugars, requiring the addition of heat. In Maillard reactions, the reactive carbonyl group of the sugar interacts with the nucleophilic amino group of the amino acid. Since the emulsifier blend used in this study contains soy protein, higher colour change values were obtained as emulsifier blend content was increased.

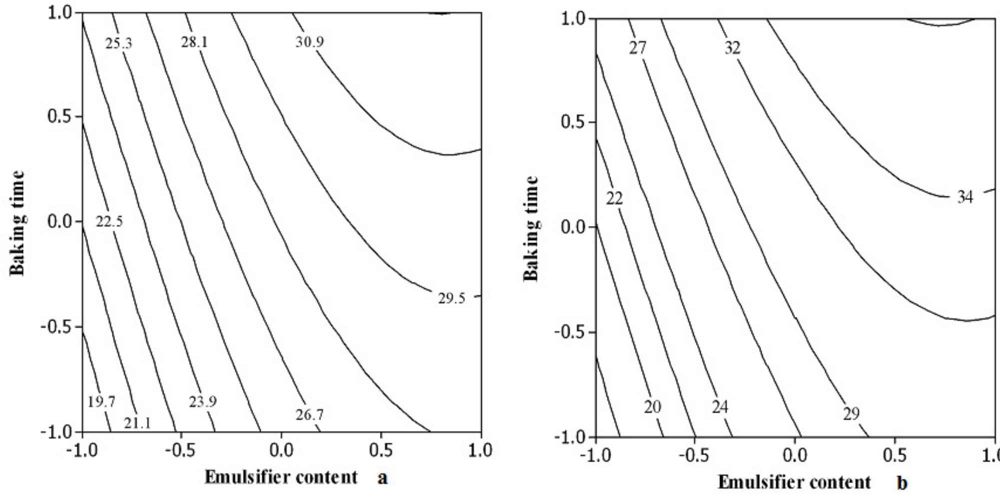


Figure 3.36 Effects of emulsifier blend content (X_1) and baking time (X_3) on total color change of cakes (X_2=0). a Xanthan gum, b Xanthan-guar gum blend.

When Figure 3.37a and b are examined, it can be seen that the increase in both baking time and halogen lamp power caused an increase in total color change. In the study of Sevimli et al. (2005), in which a wheat flour cake was baked in IR-microwave combination oven, similar results were obtained. Higher halogen lamp power means higher temperature, which enhances Maillard reactions. Color change on the surface increased as halogen lamp power increased due to these reactions. No significant difference was found between the gum types with respect to total color change.

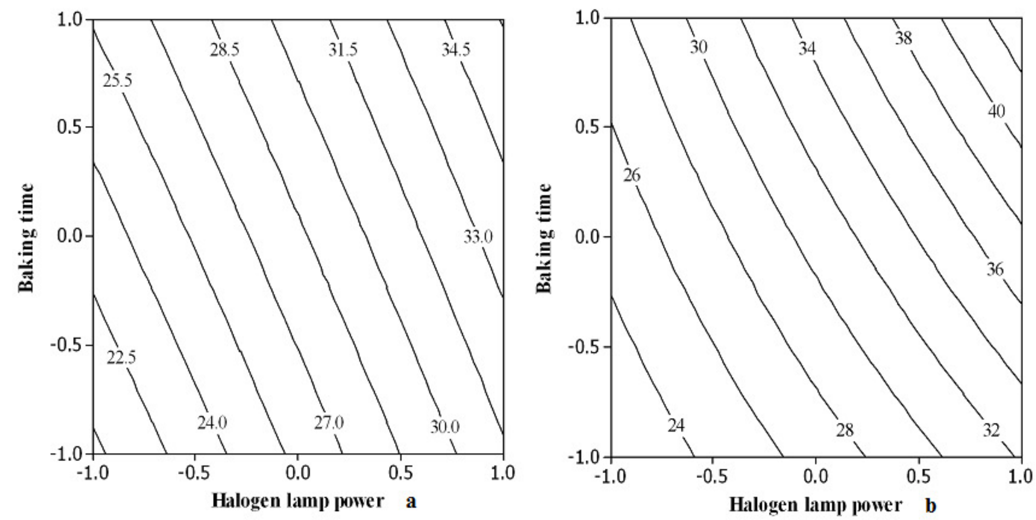


Figure 3.37 Effects of halogen lamp power (X_2) and baking time (X_3) on total color change of cakes (X_1=0). a Xanthan-guar gum blend, b Xanthan gum.

Only the emulsifier blend content was found to be significantly effective in affecting the firmness of cakes containing xanthan-guar gum blend ($p \leq 0.001$) (Table 3.9). As emulsifier blend content increased, the firmness of the cakes decreased and softer cakes were obtained (Figure 3.38a). For cakes baked for 7 minutes and containing xanthan-guar gum blend, the increase in the emulsifier blend content from 0 to 6% decreased the firmness of the cakes from 4.07 to 3.07 N. It can be observed that the baking time was not as significant as the emulsifier blend content in affecting firmness of the cakes.

For the cakes containing xanthan gum only, emulsifier blend content and halogen lamp power were found to be significant in affecting the firmness values ($p \leq 0.01$) (Table 3.9). The effect of baking time on firmness was observed to be a function of emulsifier content (Figure 3.38b). This trend is also similar to the results obtained for specific volume results. For all baking times the variation of firmness of cakes remained constant after an emulsifier concentration of about 4.8 % (coded value of 0.6).

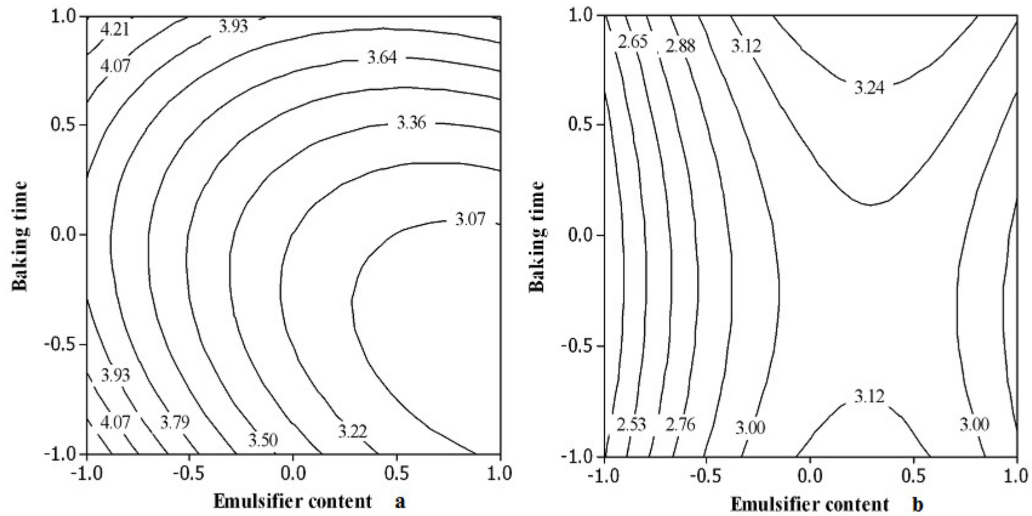


Figure 3.38 Effects of emulsifier blend content (X_1) and baking time (X_3) on firmness of cakes (X_2=0). a Xanthan gum, b Xanthan-guar gum blend.

The effect of halogen lamp power on the firmness can be observed in Figures 3.39a and b. Halogen lamp power was not significant in affecting the firmness for cakes containing xanthan guar gum blend. (Figure 3.39a and Table 3.9). According to the Fig.6b, for most of the baking times, as the halogen lamp power increased, the firmness of the cakes increased. Higher halogen level meant higher moisture loss resulting in a firmer cake. Since moisture loss is a function of baking time, as the baking time increased, the moisture loss and therfore firmness of cakes increased. There was also a significant difference between the gum types with respect to firmness. Only xanthan gum containing cakes were softer than xanthan-guar gum blend containing cakes.

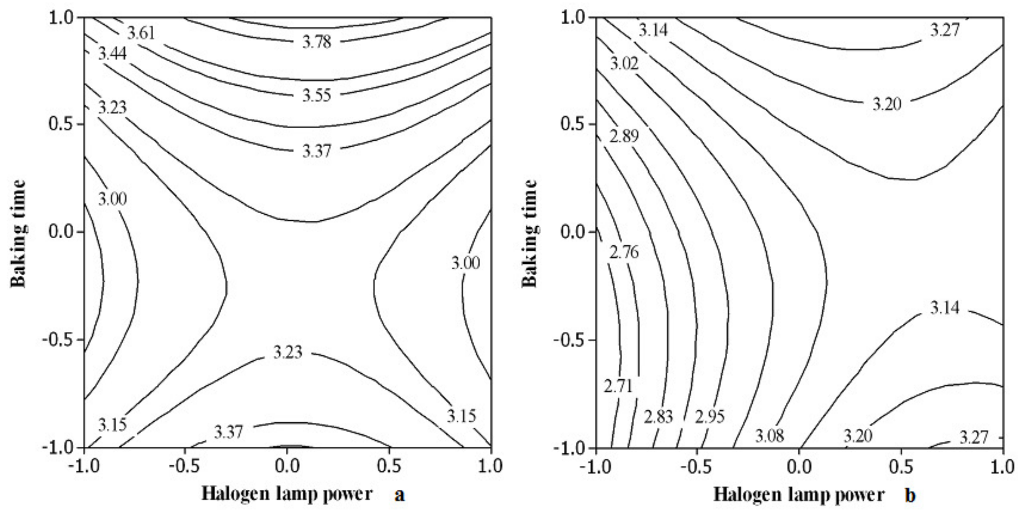


Figure 3.39 Effects of halogen lamp power (X_2) and baking time (X_3) on firmness of cakes (X_1=0). a Xanthan-guar gum blend, b Xanthan gum.

Emulsifier blend content did not affect the weight loss of the cakes significantly (Figure 3.40). It can be seen in Figure 3.41 that upper halogen lamp power and baking time increased, weight loss of the cakes containing xanthan-guar gum blend and xanthan gum increased as in the study of Sevimli et al. (2005). For the cakes containing xanthan-guar gum blend, which were baked using halogen lamp of 50%, the increase in baking time increased from 7 to 8 minutes, increased weight loss from 11.6 to 14.4%. For the same conditions, weight loss increase of cakes containing xanthan gum was from 11 to 14.2%. Higher moisture loss occurred as baking time and halogen lamp power increased, therefore, weight loss increased. No significant difference was found between the gum types on affecting the weight loss.

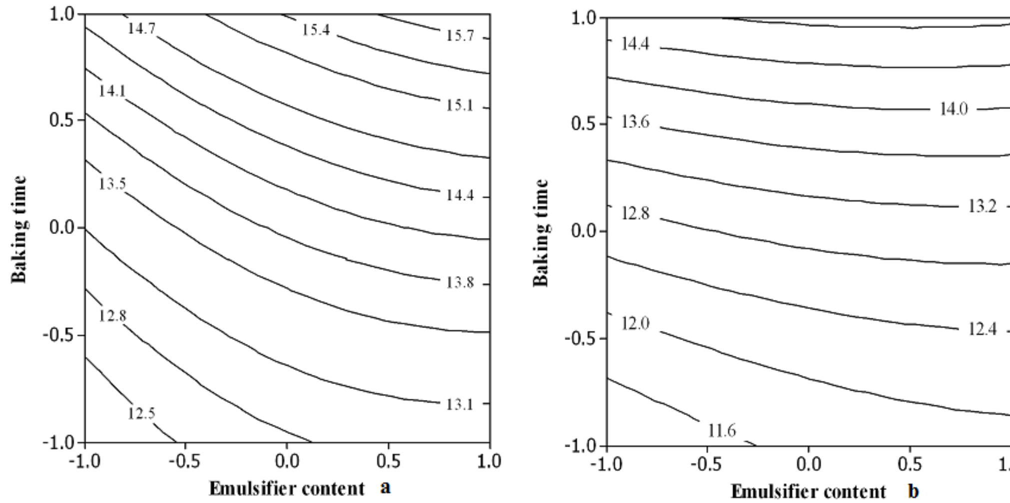


Figure 3.40 Effects of emulsifier blend content (X_1) and baking time (X_3) on weight loss of cakes (X_2=0). a Xanthan gum, b Xanthan-guar gum blend.

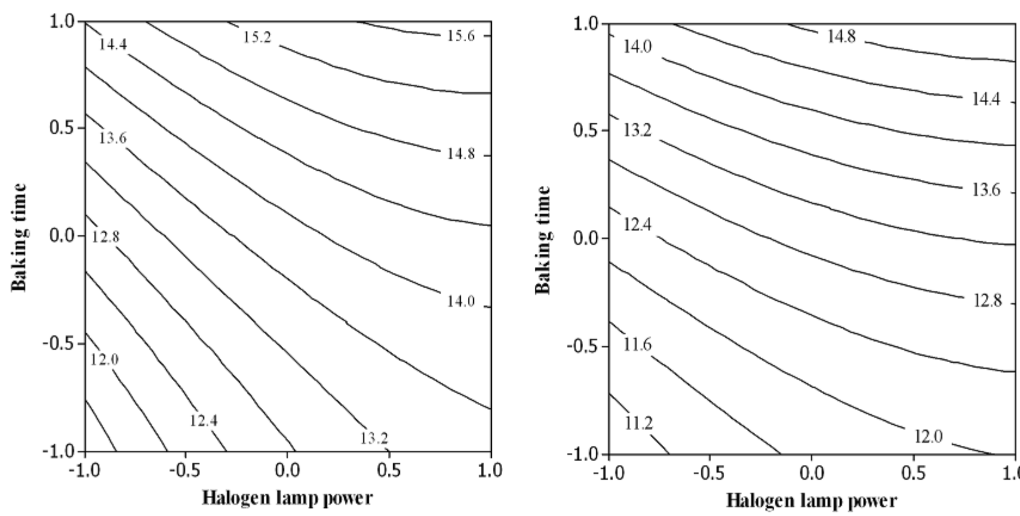


Figure 3.41 Effects of halogen lamp power (X_2) and baking time (X_3) on weight loss of cakes (X_1=0). a Xanthan-guar gum blend, b Xanthan gum.

The optimum baking conditions for rice cakes containing xanthan guar gum blend and xanthan gum baked in IR-microwave combination oven were found by multiple optimization by using the response optimizer in Minitab release 14 statistical software. Maximum specific volume, maximum color change, minimum firmness and minimum weight loss were considered in determination of these optimum conditions. Optimum points can be seen as coded and uncoded values in Table 3.10. When the optimum points were examined, 70% halogen lamp power was found to be optimum for cakes containing xanthan-guar gum blend while 60% halogen lamp power was optimum for xanthan gum containing cakes. Since the viscosity of the xanthan gum containing batter was lower than that of xanthan-guar gum blend (Casas et al, 2000), gas produced inside the batter might not be held in the cake structure when the rate of heating was higher.

Table 3.10 Optimum formulations and baking conditions in IR-microwave combination oven for rice cakes containing xanthan guar gum blend and xanthan gum

	Xanthan-guar gum blend		Xanthan gum	
	Coded	Uncoded	Coded	Uncoded
Emulsifier content (%)	0.56	4.68	0.88	5.28
Halogen lamp power (%)	1.00	70	0.08	60
Baking time (min)	-1.00	7	-0.99	7

Values for the quality charateristics, which are specific volume, total color change, firmness and weight loss, were calculated at these optimum conditions and shown in Table 3.11. Cakes formulated by xanthan or xanthan-guar blend and by optimum concentration of emulsifier blend were also baked in conventional oven for comparison. Cakes baked by using infrared-microwave combination ovenhad similar colour and firmness values to those of conventional oven (Table 3.11). IR-microwave combination baking resulted in cakes with higher volume but lower moisture content. Since IR-microwave combination baking decreased conventional baking time by 77 %, it may be recommended to be used in production of rice cakes. Using only xanthan gum in cakes gave better results with respect to specific volume and firmness (Table 3.11). On the other hand, in terms of total color change and weight loss of cakes, there were no significant difference between the gum types.

Table 3.11 Quality characteristics of the cakes baked in conventional oven and at optimum conditions of IR-microwave combination oven

	IR-microwave combination baking		Conventional baking	
	Xanthan-guar blend	Xanthan gum	Xanthan-guar blend	Xanthan gum
Specific volume (ml/g)	1.57	1.75	1.30	1.38
Total color change (ΔE)	32.18	30.56	26.43	25.34
Firmness (N)	2.58	2.32	2.35	2.13
Weight loss (%)	13.69	11.94	10.65	7.70

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS

Rice cake batters formulated with different gums with and without emulsifier blend showed shear-thinning behavior. Both Power law and Casson model were suitable to explain the rheological behavior of rice cake batters. Xanthan containing cake batters gave the highest apparent viscosity values. All gums except HPMC increased the emulsion stability of cake batter. Understanding the physical and rheological properties of rice cake will be helpful in gluten-free product development.

It was observed that addition of different types of gums could change the dielectric properties of rice cake batters. Temperature dependence of dielectric properties of cake batters was significant only after 85 ^{0}C, which can be due to gelatinization and significant structure change at this temperature. Addition of gums caused an increase in the gelatinization enthalpy values. Xanthan and guar gum containing batters had the highest dielectric properties. As long as dielectric properties are concerned, it can be concluded that cake batters containing xanthan and guar gum can be heated and gelatinize faster in microwave processing. Therefore, usage of these gum types alone or in blended form can be recommended for a gluten-free rice cake batter for baking in microwave or microwave-assisted ovens. Information on dielectric and gelatinization properties of rice cake batters will be helpful for modeling of a microwavable gluten free baked product.

IR-microwave combination baked cakes had higher specific volume values than conventional ones. Emulsifier blend addition increased the specific volume and porosity of the cakes baked in IR-microwave combination oven and decreased the firmness values. Xanthan and emulsifier blend containing cakes had the highest volume, porosity and lowest firmness. They did not collapse in the oven as well.

Macro and micro-structure analysis of rice cakes showed that addition of different types of gums affected the pore area fraction and total number of pores of the rice cakes. These results also showed that more porous cakes were obtained when xanthan and xanthan-guar gum blend were used. Thus, both xanthan and xanthan-guar gum blend can be recommended to be used in gluten-free cakes. Baking method was found to be important in affecting porosity and pore size distribution of cakes. The micro-structure of cakes baked in different ovens was also different. There were more deformed starches in conventionally baked cakes as compared to the cakes baked in IR-MW combination oven. This study also showed that it was possible to analyze SEM micrographs quantitatively.

Optimization of the formulation and baking conditions of gluten free rice cakes baked in IR-microwave combination oven was performed by applying RSM successfully. Generally, the increase in emulsifier content increased the surface color but decreased the firmness of the cakes. The increase in halogen lamp power decreased specific volume but increased firmness, weight loss and surface color. As baking time increased, surface of cakes became darker and cakes lost more moisture.

It could be possible to produce high quality rice cakes for celiac patients using xanthan gum and emulsifier blend. IR-microwave combination baking may be an alternative of conventional baking to produce rice cakes, which reduces the baking time significantly.

As a future work, determination of dielectric properties of rice cakes during baking in IR-microwave oven may be recommended. Temperature distribution inside the cake during baking in IR-microwave combination oven may be helpful in understanding the relationship between cake batter and microwaves better and can be used in modelling studies.

In the optimization experiments, both microwave and halogen lamp modes of the oven were operated at the same time. In a future study, the modes of microwave and halogen lamp can be operated at different times so that the effect of mode sequence on the quality of cakes can be observed.

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APPENDIX A

ANOVA and DUNCAN TEST TABLES

Table A.1 ANOVA and Duncan Single Range Test for specific gravities of rice cake batters containing different types of gums and emulsifier blend.

Cake formulations: 1: xanthan cake containing no emulsifier, 2: guar cake containing no emulsifier, 3: xanthan-guar blend cake containing no emulsifier, 4: κ-carrageenan cake containing no emulsifier, 5: locust bean gum cake containing no emulsifier, 6: HPMC cake containing no emulsifier, 7: xanthan- κ-carrageenan blend cake containing no emulsifier, 8: xanthan cake containing emulsifier, 9: guar cake containing emulsifier, 10: xanthan-guar blend cake containing emulsifier, 11: κ-carrageenan cake containing emulsifier, 12: locust bean gum cake containing emulsifier, 13: HPMC cake containing emulsifier, 14: xanthan- κ-carrageenan blend cake containing emulsifier, 15: control cake containing no gum and no emulsifier.

1-Way ANOVA

The SAS System

The GLM Procedure

Class Level Information

Class	Levels	Values
X	15	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Number of Observations Read 75

Number of Observations Used 75

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	0.05393699	0.00385264	58.84	<.0001
Error	60	0.00392840	0.00006547		
Corrected Total	74	0.05786539			

R-Square	Coeff Var	Root MSE	Y Mean
0.932111	0.660097	0.008092	1.225813

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X	14	0.05393699	0.00385264	58.84	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X	14	0.05393699	0.00385264	58.84	<.0001

Duncan's Multiple Range Test for Y

Alpha	0.05
Error Degrees of Freedom	60
Error Mean Square	0.000065

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X
A	1.263	5	15
A	1.260	5	5
A	1.259	5	1
B	1.247	5	4
B C	1.244	5	2
B C D	1.241	5	3
C D E	1.234	5	7
D E	1.232	5	6
E	1.228	5	12
F	1.209	5	10
F	1.206	5	11
F	1.206	5	14
G	1.192	5	13
G	1.190	5	8
H	1.176	5	9

2-Way ANOVA

Class	Levels	Values
X1	7	1 2 3 4 5 6 7
X2	2	1 2

Number of Observations Read 70

Number of Observations Used 70

Source	DF	SS	MS	F	P
X1	6	0.0075323	0.0012554	20.90	0.000
X2	1	0.0345432	0.0345432	575.17	0.000
Interaction	6	0.0042931	0.0007155	11.91	0.000
Error	56	0.0033632	0.0000601		
Total	69	0.0497318			

S = 0.007750 R-Sq = 93.24% R-Sq(adj) = 91.67%

Table A.2 ANOVA and Duncan Single Range Test for apparent viscosities (Casson model) of rice cake batters containing different types of gums and emulsifier blend.

Cake formulations: 1: xanthan cake containing no emulsifier, 2: guar cake containing no emulsifier, 3: xanthan-guar blend cake containing no emulsifier, 4: κ-carrageenan cake containing no emulsifier, 5: locust bean gum cake containing no emulsifier, 6: HPMC cake containing no emulsifier, 7: xanthan- κ-carrageenan blend cake containing no emulsifier, 8: xanthan cake containing emulsifier, 9: guar cake containing emulsifier, 10: xanthan-guar blend cake containing emulsifier, 11: κ-carrageenan cake containing emulsifier, 12: locust bean gum cake containing emulsifier, 13: HPMC cake containing emulsifier, 14: xanthan- κ-carrageenan blend cake containing emulsifier, 15: control cake containing no gum and no emulsifier.

1-Way ANOVA

The SAS System

The GLM Procedure

Class Level Information

Class	Levels	Values
X	15	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Number of Observations Read 45

Number of Observations Used 45

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	155.4628839	11.1044917	98.14	<.0001
Error	30	3.3945516	0.1131517		
Corrected Total	44	158.8574355			

R-Square	Coeff Var	Root MSE	Y Mean
0.978631	7.577798	0.336380	4.439024

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X	14	155.4628839	11.1044917	98.14	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X	14	155.4628839	11.1044917	98.14	<.0001

Duncan's Multiple Range Test for Y

Alpha	0.05
Error Degrees of Freedom	30
Error Mean Square	0.113152

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X
A	7.447	3	3
A B	7.001	3	1
B	6.737	3	8
C	6.100	3	10
D	5.483	3	9
D	5.428	3	7
D E	5.004	3	2
E F	4.506	3	14
F	4.215	3	11
G	3.143	3	12
G	2.904	3	4
G	2.890	3	5
H	2.151	3	15
H	1.843	3	13
H	1.734	3	6

2-Way ANOVA

Class	Levels	Values
X1	7	1 2 3 4 5 6 7
X2	2	1 2

Number of Observations Read 42

Number of Observations Used 42

Source	DF	SS	MS	F	P
X1	6	131.493	21.9154	183.15	0.000
X2	1	0.031	0.0315	0.26	0.612
Interaction	6	7.108	1.1846	9.90	0.000
Error	28	3.350	0.1197		
Total	41	141.982			

S = 0.3459 R-Sq = 97.64% R-Sq(adj) = 96.54%

Table A.3 ANOVA and Duncan Single Range Test for apparent viscosities (Power-law model) of rice cake batters containing different types of gums and emulsifier blend.

Cake formulations: 1: xanthan cake containing no emulsifier, 2: guar cake containing no emulsifier, 3: xanthan-guar blend cake containing no emulsifier, 4: κ-carrageenan cake containing no emulsifier, 5: locust bean gum cake containing no emulsifier, 6: HPMC cake containing no emulsifier, 7: xanthan- κ-carrageenan blend cake containing no emulsifier, 8: xanthan cake containing emulsifier, 9: guar cake containing emulsifier, 10: xanthan-guar blend cake containing emulsifier, 11: κ-carrageenan cake containing emulsifier, 12: locust bean gum cake containing emulsifier, 13: HPMC cake containing emulsifier, 14: xanthan- κ-carrageenan blend cake containing emulsifier, 15: control cake containing no gum and no emulsifier.

1-Way ANOVA

The SAS System

The GLM Procedure

Class Level Information

Class	Levels	Values
X	15	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Number of Observations Read 45

Number of Observations Used 45

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	153.6182368	10.9727312	95.15	<.0001
Error	30	3.4594377	0.1153146		
Corrected Total	44	157.0776745			

R-Square	Coeff Var	Root MSE	Y Mean
0.977976	7.729241	0.339580	4.393446

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X	14	153.6182368	10.9727312	95.15	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X	14	153.6182368	10.9727312	95.15	<.0001

Duncan's Multiple Range Test for Y

Alpha 0.05

Error Degrees of Freedom 30

Error Mean Square 0.115315

Means with the same letter are not significantly different.

Duncan Grouping		Mean	N	X
A		7.370	3	3
A	B	6.922	3	1
B		6.666	3	8
C		6.089	3	10
D		5.499	3	9
D		5.324	3	7
D	E	4.926	3	2
E	F	4.456	3	14
F		4.210	3	11
G		3.117	3	12
G		2.858	3	4
G		2.841	3	5
H		2.104	3	15
H		1.820	3	13
H		1.702	3	6

2-Way ANOVA

Class	Levels	Values
X1	7	1 2 3 4 5 6 7
X2	2	1 2

Number of Observations Read	42
Number of Observations Used	42

Source	DF	SS	MS	F	P
X1	6	129.653	21.6089	177.07	0.000
X2	1	0.002	0.0016	0.01	0.911
Interaction	6	7.114	1.1857	9.72	0.000
Error	28	3.417	0.1220		
Total	41	140.186			

S = 0.3493   R-Sq = 97.56%   R-Sq(adj) = 96.43%

Table A.4 ANOVA and Duncan Single Range Test for emulsion stabilities of rice cake batters containing different types of gums and emulsifier blend.

Cake formulations: 1: xanthan cake containing no emulsifier, 2: guar cake containing no emulsifier, 3: xanthan-guar blend cake containing no emulsifier, 4: κ-carrageenan cake containing no emulsifier, 5: locust bean gum cake containing no emulsifier, 6: HPMC cake containing no emulsifier, 7: xanthan- κ-carrageenan blend cake containing no emulsifier, 8: xanthan cake containing emulsifier, 9: guar cake containing 3% emulsifier, 10: xanthan-guar blend cake containing emulsifier, 11: κ-carrageenan cake containing emulsifier, 12: locust bean gum cake containing emulsifier, 13: HPMC cake containing emulsifier, 14: xanthan- κ-carrageenan blend cake containing emulsifier, 15: control cake containing no gum and no emulsifier.

1-Way ANOVA

The SAS System

The GLM Procedure

Class Level Information

Class	Levels	Values
X	15	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Number of Observations Read 30

Number of Observations Used 30

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr >
Model	14	12999.70659	928.55047	12.62	<.0001
Error	15	1104.06060	73.60404		
Corrected Total	29	14103.7671			

R-Square	Coeff Var	Root MSE	Y Mean
0.921719	21.60882	8.579280	39.70267

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X	14	12999.70659	928.55047	12.62	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X	14	12999.70659	928.55047	12.62	<.0001

Duncan's Multiple Range Test for Y

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	73.60404

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X
A	85.260	2	9
A	76.335	2	2
B	50.265	2	14
B	49.470	2	12
B C	47.600	2	10
B C	46.635	2	1
B C D	44.125	2	7
B C D E	38.125	2	5
B C D E	34.150	2	11
B C D E	32.560	2	4
C D E F	28.040	2	8
D E F	23.920	2	13
E F	22.675	2	3
F	8.295	2	15
F	8.085	2	6

2-Way ANOVA

Class	Levels	Values
X1	7	1 2 3 4 5 6 7
X2	2	1 2

Number of Observations Read	28
Number of Observations Used	28

Source	DF	SS	MS	F	P
X1	6	9419.5	1569.92	19.98	0.000
X2	1	359.5	359.50	4.57	0.051
Interaction	6	1106.9	184.48	2.35	0.088
Error	14	1100.2	78.58		
Total	27	11986.1			

S = 8.865   R-Sq = 90.82%   R-Sq(adj) = 82.30%

Table A.5 ANOVA and Duncan Single Range Test for dielectric constants of rice cake batters containing different types of gums and emulsifier blend.

Cake formulations: 1: xanthan cake containing no emulsifier, 2: guar cake containing no emulsifier, 3: xanthan-guar blend cake containing no emulsifier, 4: κ-carrageenan cake containing no emulsifier, 5: locust bean gum cake containing no emulsifier, 6: HPMC cake containing no emulsifier, 7: xanthan- κ-carrageenan blend cake containing no emulsifier, 8: xanthan cake containing emulsifier, 9: guar cake containing emulsifier, 10: xanthan-guar blend cake containing emulsifier, 11: κ-carrageenan cake containing emulsifier, 12: locust bean gum cake containing emulsifier, 13: HPMC cake containing emulsifier, 14: xanthan- κ-carrageenan blend cake containing emulsifier, 15: control cake containing no gum and no emulsifier.

1-Way ANOVA

The SAS System

The GLM Procedure

Class Level Information

Class	Levels	Values
X	15	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Number of Observations Read 45

Number of Observations Used 45

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	145.4597180	10.3899799	30.46	<.0001
Error	30	10.2323339	0.3410778		
Corrected Total	44	155.6920519			

R-Square	Coeff Var	Root MSE	Y Mean
0.934278	3.219508	0.584019	18.14000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X	14	145.4597180	10.3899799	30.46	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X	14	145.4597180	10.3899799	30.46	<.0001

Duncan's Multiple Range Test for Y

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	0.341078

Means with the same letter are not significantly different.

Duncan Grouping		Mean	N	X
A		19.830	3	3
A		19.578	3	11
A		19.572	3	8
A		19.561	3	1
A		19.404	3	14
A	B	19.218	3	2
A	B	18.929	3	13
A	B	18.924	3	7
B	C	18.273	3	15
B	C	18.232	3	12
B	C	18.128	3	4
C	D	17.530	3	9
D		16.665	3	10
E		14.742	3	6
F		13.517	3	5

2-Way ANOVA

Class	Levels	Values
X1	7	1 2 3 4 5 6 7
X2	2	1 2

Number of Observations Read	42
Number of Observations Used	42

Source	DF	SS	MS	F	P
X1	6	62.958	10.4930	39.74	0.000
X2	1	7.689	7.6886	29.12	0.000
Interaction	6	74.757	12.4594	47.18	0.000
Error	28	7.394	0.2641		
Total	41	152.797			

S = 0.5139   R-Sq = 95.16%   R-Sq(adj) = 92.91%

Table A.6 ANOVA and Duncan Single Range Test for dielectric loss factors of rice cake batters containing different types of gums and emulsifier blend.

Cake formulations: 1: xanthan cake containing no emulsifier, 2: guar cake containing no emulsifier, 3: xanthan-guar blend cake containing no emulsifier, 4: κ-carrageenan cake containing no emulsifier, 5: locust bean gum cake containing no emulsifier, 6: HPMC cake containing no emulsifier, 7: xanthan- κ-carrageenan blend cake containing no emulsifier, 8: xanthan cake containing emulsifier, 9: guar cake containing emulsifier, 10: xanthan-guar blend cake containing emulsifier, 11: κ-carrageenan cake containing emulsifier, 12: locust bean gum cake containing emulsifier, 13: HPMC cake containing emulsifier, 14: xanthan- κ-carrageenan blend cake containing emulsifier, 15: control cake containing no gum and no emulsifier.

1-Way ANOVA

The SAS System

The GLM Procedure

Class Level Information

Class	Levels	Values
X	15	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Number of Observations Read 45

Number of Observations Used 45

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	22.32229714	1.59444980	2.87	0.0076
Error	30	16.69149679	0.55638323		
Corrected Total	44	39.01379393			

R-Square	Coeff Var	Root MSE	Y Mean
0.572164	8.340774	0.745911	8.942947

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X	14	22.32229714	1.59444980	2.87	0.0076

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X	14	22.32229714	1.59444980	2.87	0.0076

Duncan's Multiple Range Test for Y

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	0.556383

Means with the same letter are not significantly different.

Duncan Grouping		Mean	N	X
A		9.818	3	8
A		9.705	3	1
A		9.702	3	3
A		9.474	3	14
A		9.434	3	11
A		9.130	3	13
A		9.112	3	2
A		8.998	3	10
A		8.996	3	7
A		8.910	3	15
A		8.893	3	12
A	B	8.638	3	4
A	B	8.489	3	9
B		7.437	3	6
B		7.409	3	5

2-Way ANOVA

Class	Levels	Values
X1	7	1 2 3 4 5 6 7
X2	2	1 2

Number of Observations Read	42
Number of Observations Used	42

Source	DF	SS	MS	F	P
X1	6	12.0769	2.01281	3.50	0.010
X2	1	2.2451	2.24509	3.90	0.058
Interaction	6	7.9968	1.33280	2.32	0.061
Error	28	16.1029	0.57510		
Total	41	38.4217			

S = 0.7584 R-Sq = 58.09% R-Sq(adj) = 38.63%

Table A.7 ANOVA and Duncan Single Range Test for specific volumes of rice cakes containing different types of gums and emulsifier blend baked in IR-microwave combination oven.

Cake formulations: 1: xanthan cake containing no emulsifier, 2: guar cake containing no emulsifier, 3: xanthan-guar blend cake containing no emulsifier, 4: κ-carrageenan cake containing no emulsifier, 5: locust bean gum cake containing no emulsifier, 6: HPMC cake containing no emulsifier, 7: xanthan- κ-carrageenan blend cake containing no emulsifier, 8: xanthan cake containing emulsifier, 9: guar cake containing emulsifier, 10: xanthan-guar blend cake containing emulsifier, 11: κ-carrageenan cake containing emulsifier, 12: locust bean gum cake containing emulsifier, 13: HPMC cake containing emulsifier, 14: xanthan- κ-carrageenan blend cake containing emulsifier, 15: control cake containing no gum and no emulsifier.

1-Way ANOVA

The SAS System

The GLM Procedure

Class Level Information

Class	Levels	Values
X	15	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Number of Observations Read	30
Number of Observations Used	30

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	1.10248000	0.07874857	29.24	<.0001
Error	15	0.04040000	0.00269333		
Corrected Total	29	1.14288000			

R-Square	Coeff Var	Root MSE	Y Mean
0.964651	3.810377	0.051897	1.362000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X	14	1.10248000	0.07874857	29.24	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X	14	1.10248000	0.07874857	29.24	<.0001

Duncan's Multiple Range Test for Y

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	0.002693

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X
A	1.720	2	8
A	1.660	2	10
B	1.530	2	14
B C	1.510	2	1
B C D	1.490	2	13
B C D E	1.440	2	12
C D E	1.400	2	11
D E	1.380	2	7
E F	1.330	2	9
F G	1.220	2	4
F G	1.220	2	3
G	1.200	2	6
G H	1.140	2	5
G H	1.110	2	15
H	1.080	2	2

2-Way ANOVA

Class	Levels	Values
X1	7	1 2 3 4 5 6 7
X2	2	1 2

Number of Observations Read 28

Number of Observations Used 2

Source	DF	SS	MS	F	P
X1	6	0.4372	0.072867	26.43	0.000
X2	1	0.4732	0.473200	171.63	0.000
Interaction	6	0.0560	0.009333	3.39	0.028
Error	14	0.0386	0.002757		
Total	27	1.0050			

S = 0.05251 R-Sq = 96.16% R-Sq(adj) = 92.59%

Table A.8 ANOVA and Duncan Single Range Test for porosities of rice cakes containing different types of gums and emulsifier blend baked in IR-microwave combination oven.

Cake formulations: 1: xanthan cake containing no emulsifier, 2: guar cake containing no emulsifier, 3: xanthan-guar blend cake containing no emulsifier, 4: κ-carrageenan cake containing no emulsifier, 5: locust bean gum cake containing no emulsifier, 6: HPMC cake containing no emulsifier, 7: xanthan- κ-carrageenan blend cake containing no emulsifier, 8: xanthan cake containing emulsifier, 9: guar cake containing emulsifier, 10: xanthan-guar blend cake containing emulsifier, 11: κ-carrageenan cake containing emulsifier, 12: locust bean gum cake containing emulsifier, 13: HPMC cake containing emulsifier, 14: xanthan- κ-carrageenan blend cake containing emulsifier, 15: control cake containing no gum and no emulsifier.

1-Way ANOVA

The SAS System

The GLM Procedure

Class Level Information

Class	Levels	Values
X	15	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Number of Observations Read	30
Number of Observations Used	30

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	0.10374667	0.00741048	6.12	0.0006
Error	15	0.01815000	0.00121000		
Corrected Total	29	0.12189667			

R-Square	Coeff Var	Root MSE	Y Mean
0.851103	6.559093	0.034785	0.530333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X	14	0.10374667	0.00741048	6.12	0.0006

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X	14	0.10374667	0.00741048	6.12	0.0006

Duncan's Multiple Range Test for Y

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	0.00121

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X
A	0.640	2	1
A B	0.605	2	6
A B C	0.600	2	8
A B C	0.595	2	10
A B C D	0.565	2	14
B C D E	0.545	2	12
B C D E	0.530	2	7
C D E F	0.520	2	13
D E F	0.510	2	11
D E F	0.510	2	9
D E F	0.504	2	4
E F	0.480	2	15
E F	0.465	2	3
F	0.445	2	2
F	0.440	2	5

2-Way ANOVA

Class	Levels	Values
X1	7	1 2 3 4 5 6 7
X2	2	1 2

Number of Observations Read 28

Number of Observations Used 28

Source	DF	SS	MS	F	P
X1	6	0.056093	0.0093488	7.54	0.001
X2	1	0.006604	0.0066036	5.33	0.037
Interaction	6	0.035621	0.0059369	4.79	0.007
Error	14	0.017350	0.0012393		
Total	27	0.115668			

S = 0.03520 R-Sq = 85.00% R-Sq(adj) = 71.07

Table A.9 ANOVA and Duncan Single Range Test for volume index of rice cakes containing different types of gums and emulsifier blend baked in IR-microwave combination oven.

Cake formulations: 1: xanthan cake containing no emulsifier, 2: guar cake containing no emulsifier, 3: xanthan-guar blend cake containing no emulsifier, 4: κ-carrageenan cake containing no emulsifier, 5: locust bean gum cake containing no emulsifier, 6: HPMC cake containing no emulsifier, 7: xanthan- κ-carrageenan blend cake containing no emulsifier, 8: xanthan cake containing emulsifier, 9: guar cake containing emulsifier, 10: xanthan-guar blend cake containing emulsifier, 11: κ-carrageenan cake containing emulsifier, 12: locust bean gum cake containing emulsifier, 13: HPMC cake containing emulsifier, 14: xanthan- κ-carrageenan blend cake containing emulsifier, 15: control cake containing no gum and no emulsifier.

1-Way ANOVA

The SAS System

The GLM Procedure

Class Level Information

Class	Levels	Values
X	15	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Number of Observations Read 30

Number of Observations Used 30

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	3667.866667	261.990476	64.98	<.0001
Error	15	60.480000	4.032000		
Corrected Total	29	3728.346667			

R-Square	Coeff Var	Root MSE	Y Mean
0.983778	2.208194	2.007984	90.93333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X	14	3667.866667	261.990476	64.98	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X	14	3667.866667	261.990476	64.98	<.0001

Duncan's Multiple Range Test for Y

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	4.032

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X
A	109.500	2	8
A	108.000	2	10
A	108.000	2	14
B	98.000	2	12
B C	94.500	2	1
B C	94.500	2	7
C D	91.000	2	11
C D	90.000	2	13
D	88.500	2	9
D	88.500	2	3
E	84.000	2	4
E F	81.500	2	5
F G	78.500	2	6
G H	76.000	2	2
H	73.500	2	15

2-Way ANOVA

Class	Levels	Values
X1	7	1 2 3 4 5 6 7
X2	2	1 2

Number of Observations Read 28

Number of Observations Used 28

Source	DF	SS	MS	F	P
X1	6	1619.36	269.89	63.23	0.000
X2	1	1302.89	1302.89	305.23	0.000
Interaction	6	94.36	15.73	3.68	0.021
Error	14	59.76	4.27		
Total	27	3076.37			

S = 2.066 R-Sq = 98.06% R-Sq(adj) = 96.25%

Table A.10 ANOVA and Duncan Single Range Test for firmness values of rice cakes containing different types of gums and emulsifier blend baked in IR-microwave combination oven.

Cake formulations: 1: xanthan cake containing no emulsifier, 2: guar cake containing no emulsifier, 3: xanthan-guar blend cake containing no emulsifier, 4: κ-carrageenan cake containing no emulsifier, 5: locust bean gum cake containing no emulsifier, 6: HPMC cake containing no emulsifier, 7: xanthan- κ-carrageenan blend cake containing no emulsifier, 8: xanthan cake containing emulsifier, 9: guar cake containing emulsifier, 10: xanthan-guar blend cake containing emulsifier, 11: κ-carrageenan cake containing emulsifier, 12: locust bean gum cake containing emulsifier, 13: HPMC cake containing emulsifier, 14: xanthan- κ-carrageenan blend cake containing emulsifier, 15: control cake containing no gum and no emulsifier.

1-Way ANOVA

The SAS System

The GLM Procedure

Class Level Information

Class	Levels	Values
X	15	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Number of Observations Read 30

Number of Observations Used 30

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	15.71622037	1.12258717	71.35	<.0001
Error	15	0.23601680	0.01573445		
Corrected Total	29	15.95223717			

R-Square	Coeff Var	Root MSE	Y Mean
0.985205	6.472099	0.125437	1.938120

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X	14	15.71622037	1.12258717	71.35	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X	14	15.71622037	1.12258717	71.35	<.0001

Duncan's Multiple Range Test for Y

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	0.015734

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X
A	3.564	2	3
B	2.970	2	1
B C	2.771	2	2
C	2.633	2	5
D	2.100	2	15
D E	1.951	2	12
E F	1.766	2	13
E F	1.729	2	4
E F	1.726	2	6
F	1.649	2	11
F	1.523	2	14
F	1.507	2	7
G	1.210	2	8
G	1.141	2	9
H	0.833	2	10

2-Way ANOVA

Class	Levels	Values
X1	7	1 2 3 4 5 6 7
X2	2	1 2

Number of Observations Read 28

Number of Observations Used 28

Source	DF	SS	MS	F	P
X1	6	1.9726	0.32876	23.17	0.000
X2	1	6.6586	6.65857	469.22	0.000
Interaction	6	7.0291	1.17151	82.55	0.000
Error	14	0.1987	0.01419		
Total	27	15.8589			

S = 0.1191 R-Sq = 98.75% R-Sq(adj) = 97.58%

Table A.11 ANOVA and Duncan Single Range Test for springiness values of rice cakes containing different types of gums and emulsifier blend baked in IR-microwave combination oven.

Cake formulations: 1: xanthan cake containing no emulsifier, 2: guar cake containing no emulsifier, 3: xanthan-guar blend cake containing no emulsifier, 4: κ-carrageenan cake containing no emulsifier, 5: locust bean gum cake containing no emulsifier, 6: HPMC cake containing no emulsifier, 7: xanthan- κ-carrageenan blend cake containing no emulsifier, 8: xanthan cake containing emulsifier, 9: guar cake containing emulsifier, 10: xanthan-guar blend cake containing emulsifier, 11: κ-carrageenan cake containing emulsifier, 12: locust bean gum cake containing emulsifier, 13: HPMC cake containing emulsifier, 14: xanthan- κ-carrageenan blend cake containing emulsifier, 15: control cake containing no gum and no emulsifier.

1-Way ANOVA

The SAS System

The GLM Procedure

Class Level Information

Class	Levels	Values
X	15	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Number of Observations Read 30

Number of Observations Used 30

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	5.53960747	0.39568625	9.47	<.0001
Error	15	0.62691750	0.04179450		
Corrected Total	29	6.16652497			

R-Square	Coeff Var	Root MSE	Y Mean
0.898335	4.284963	0.204437	4.771033

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X	14	5.53960747	0.39568625	9.47	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X	14	5.53960747	0.39568625	9.47	<.0001

Duncan's Multiple Range Test for Y

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	0.041795

Means with the same letter are not significantly different.

Duncan Grouping			Mean	N	X
A			5.384	2	8
A			5.271	2	3
A	B		5.238	2	12
A	B		5.146	2	13
A	B		5.111	2	1
A	B		5.094	2	11
A	B	C	4.971	2	14
B	C	D	4.781	2	2
C	D	E	4.599	2	7
C	D	E	4.542	2	5
C	D	E	4.520	2	6
D	E		4.441	2	9
D	E		4.392	2	10
E	F		4.211	2	4
F			3.868	2	15

2-Way ANOVA

Class	Levels	Values
X1	7	1 2 3 4 5 6 7
X2	2	1 2

Number of Observations Read	28
Number of Observations Used	28

Source	DF	SS	MS	F	P
X1	6	1.03551	0.172585	4.07	0.014
X2	1	0.37886	0.378859	8.93	0.010
Interaction	6	2.37780	0.396300	9.34	0.000
Error	14	0.59415	0.042439		
Total	27	4.38632			

S = 0.2060   R-Sq = 86.45%   R-Sq(adj) = 73.88%

Table A.12 ANOVA and Duncan Single Range Test for gumminess values of rice cakes containing different types of gums and emulsifier blend baked in IR-microwave combination oven.

Cake formulations: 1: xanthan cake containing no emulsifier, 2: guar cake containing no emulsifier, 3: xanthan-guar blend cake containing no emulsifier, 4: κ-carrageenan cake containing no emulsifier, 5: locust bean gum cake containing no emulsifier, 6: HPMC cake containing no emulsifier, 7: xanthan- κ-carrageenan blend cake containing no emulsifier, 8: xanthan cake containing emulsifier, 9: guar cake containing emulsifier, 10: xanthan-guar blend cake containing emulsifier, 11: κ-carrageenan cake containing emulsifier, 12: locust bean gum cake containing emulsifier, 13: HPMC cake containing emulsifier, 14: xanthan- κ-carrageenan blend cake containing emulsifier, 15: control cake containing no gum and no emulsifier.

1-Way ANOVA

The SAS System

The GLM Procedure

Class Level Information

Class	Levels	Values
X	15	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Number of Observations Read	30
Number of Observations Used	30

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	4.57071647	0.32647975	67.01	<.0001
Error	15	0.07308250	0.00487217		
Corrected Total	29	4.64379897			

R-Square	Coeff Var	Root MSE	Y Mean
0.984262	6.639064	0.069801	1.051367

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X	14	4.57071647	0.32647975	67.01	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X	14	4.57071647	0.32647975	67.01	<.0001

Duncan's Multiple Range Test for Y

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	0.004872

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X
A	1.857	2	3
B	1.647	2	1
B C	1.513	2	2
C	1.489	2	5
D	1.096	2	15
D	1.056	2	12
D E	0.956	2	13
D E	0.953	2	4
D E	0.939	2	11
D E F	0.931	2	6
E F	0.831	2	7
G F	0.775	2	14
G	0.667	2	8
G	0.634	2	9
H	0.432	2	10

2-Way ANOVA

Class	Levels	Values
X1	7	1 2 3 4 5 6 7
X2	2	1 2

Number of Observations Read	28
Number of Observations Used	28

Source	DF	SS	MS	F	P
X1	6	0.61342	0.10224	21.05	0.000
X2	1	2.02073	2.02073	416.14	0.000
Interaction	6	1.93239	0.32207	66.33	0.000
Error	14	0.06798	0.00486		
Total	27	4.63452			

S = 0.06968   R-Sq = 98.53%   R-Sq(adj) = 97.17%

Table A.13 ANOVA and Duncan Single Range Test for chewiness values of rice cakes containing different types of gums and emulsifier blend baked in IR-microwave combination oven.

Cake formulations: 1: xanthan cake containing no emulsifier, 2: guar cake containing no emulsifier, 3: xanthan-guar blend cake containing no emulsifier, 4: κ-carrageenan cake containing no emulsifier, 5: locust bean gum cake containing no emulsifier, 6: HPMC cake containing no emulsifier, 7: xanthan- κ-carrageenan blend cake containing no emulsifier, 8: xanthan cake containing emulsifier, 9: guar cake containing emulsifier, 10: xanthan-guar blend cake containing emulsifier, 11: κ-carrageenan cake containing emulsifier, 12: locust bean gum cake containing emulsifier, 13: HPMC cake containing emulsifier, 14: xanthan- κ-carrageenan blend cake containing emulsifier, 15: control cake containing no gum and no emulsifier.

1-Way ANOVA

The SAS System

The GLM Procedure

Class Level Information

Class	Levels	Values
X	15	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Number of Observations Read 30

Number of Observations Used 30

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	128.2849198	9.1632086	58.74	<.0001
Error	15	2.3401310	0.1560087		
Corrected Total	29	130.6250508			

R-Square	Coeff Var	Root MSE	Y Mean
0.982085	7.810857	0.394979	5.056800

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X	14	128.2849198	9.1632086	58.74	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X	14	128.2849198	9.1632086	58.74	<.0001

Duncan's Multiple Range Test for Y

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	0.156009

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X
A	1.857	2	3
B	1.647	2	1
C	1.513	2	2
C	1.489	2	5
D	1.096	2	12
D E	1.056	2	13
D E	0.956	2	11
E F	0.953	2	15
E F	0.939	2	6
E F	0.931	2	4
E F	0.831	2	14
F	0.775	2	7
G F	0.667	2	8
G	0.634	2	9
H	0.432	2	10

2-Way ANOVA

Class	Levels	Values
X1	7	1 2 3 4 5 6 7
X2	2	1 2

Number of Observations Read	28
Number of Observations Used	28

Source	DF	SS	MS	F	P
X1	6	19.395	3.2325	19.39	0.000
X2	1	40.471	40.4713	242.79	0.000
Interaction	6	66.959	11.1598	66.95	0.000
Error	14	2.334	0.1667		
Total	27	129.159			

S = 0.4083   R-Sq = 98.19%   R-Sq(adj) = 96.52%

Table A.14 ANOVA and Duncan Single Range Test for weight loss values of rice cakes containing different types of gums and emulsifier blend baked in IR-microwave combination oven.

Cake formulations: 1: xanthan cake containing no emulsifier, 2: guar cake containing no emulsifier, 3: xanthan-guar blend cake containing no emulsifier, 4: κ-carrageenan cake containing no emulsifier, 5: locust bean gum cake containing no emulsifier, 6: HPMC cake containing no emulsifier, 7: xanthan- κ-carrageenan blend cake containing no emulsifier, 8: xanthan cake containing emulsifier, 9: guar cake containing emulsifier, 10: xanthan-guar blend cake containing emulsifier, 11: κ-carrageenan cake containing emulsifier, 12: locust bean gum cake containing emulsifier, 13: HPMC cake containing emulsifier, 14: xanthan- κ-carrageenan blend cake containing emulsifier, 15: control cake containing no gum and no emulsifier.

1-Way ANOVA

Class	Levels	Values
X	15	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Number of Observations Read 28

Number of Observations Used 28

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	3.232	0.231	1.24	0.344
Error	15	2.802	0.187		
Corrected Total	29	6.034			

S = 0.4322 R-Sq = 53.56% R-Sq(adj) = 10.22%

Table A.15 ANOVA and Duncan Single Range Test for specific volumes of rice cakes containing different types of gums baked in conventional oven.

Cake formulations: 1: xanthan cake baked in conventional oven, 2: guar cake baked in conventional oven, 3: xanthan-guar blend cake baked in conventional oven, 4: κ-carrageenan cake baked in conventional oven, 5: locust bean gum cake baked in conventional oven, 6: HPMC cake baked in conventional oven, 7: xanthan- κ-carrageenan blend cake baked in conventional oven, 8: control cake baked in conventional oven

1-Way ANOVA

The SAS System

The GLM Procedure

Class Level Information

Class	Levels	Values
X	8	1 2 3 4 5 6 7 8

Number of Observations Read 16

Number of Observations Used 16

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	0.16174144	0.02310592	37.77	<.0001
Error	8	0.00489450	0.00061181		
Corrected Total	15	0.16663594			

R-Square	Coeff Var	Root MSE	Y Mean
0.970628	2.295444	0.024735	1.077563

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X	7	0.16174144	0.02310592	37.77	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X	7	0.16174144	0.02310592	37.77	<.0001

Duncan's Multiple Range Test for Y

Alpha	0.05
Error Degrees of Freedom	8
Error Mean Square	0.00612

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X
A	1.295	2	1
B	1.105	2	7
B	1.090	2	8
B	1.088	2	3
B	1.078	2	4
B	1.066	2	6
C	0.958	2	2
C	0.943	2	5

Table A.16 ANOVA and Duncan Single Range Test for firmness of rice cakes containing different types of gums baked in conventional oven.

Cake formulations: 1: xanthan cake baked in conventional oven, 2: guar cake baked in conventional oven, 3: xanthan-guar blend cake baked in conventional oven, 4: κ-carrageenan cake baked in conventional oven, 5: locust bean gum cake baked in conventional oven, 6: HPMC cake baked in conventional oven, 7: xanthan- κ-carrageenan blend cake baked in conventional oven, 8: control cake baked in conventional oven

1-Way ANOVA

The SAS System

The GLM Procedure

Class Level Information

Class	Levels	Values
X	8	1 2 3 4 5 6 7 8

Number of Observations Read 24

Number of Observations Used 24

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	18.03952421	2.57707489	24.01	<.0001
Error	16	1.71757053	0.10734816		
Corrected Total	23	19.75709474			

R-Square	Coeff Var	Root MSE	Y Mean
0.913066	10.63675	0.327640	3.080267

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X	7	18.03952421	2.57707489	24.01	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X	7	18.03952421	2.57707489	24.01	<.0001

Duncan's Multiple Range Test for Y

Alpha	0.05
Error Degrees of Freedom	16
Error Mean Square	0.107348

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X
A	4.515	3	2
A B	3.984	3	8
B	3.503	3	5
B	3.440	3	7
C	2.676	3	4
C D	2.535	3	3
D E	2.080	3	1
E	1.910	3	6

Table A.17 ANOVA and Duncan Single Range Test for springiness of rice cakes containing different types of gums baked in conventional oven.

Cake formulations: 1: xanthan cake baked in conventional oven, 2: guar cake baked in conventional oven, 3: xanthan-guar blend cake baked in conventional oven, 4: κ-carrageenan cake baked in conventional oven, 5: locust bean gum cake baked in conventional oven, 6: HPMC cake baked in conventional oven, 7: xanthan- κ-carrageenan blend cake baked in conventional oven, 8: control cake baked in conventional oven

1-Way ANOVA

The SAS System

The GLM Procedure

Class Level Information

Class	Levels	Values
X	8	1 2 3 4 5 6 7 8

Number of Observations Read 24

Number of Observations Used 24

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	0.26281717	0.03754531	1.91	0.1339
Error	16	0.31410537	0.01963159		
Corrected Total	23	0.57692253			

R-Square	Coeff Var	Root MSE	Y Mean
0.455550	3.585311	0.140113	3.907967

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X	7	0.26281717	0.03754531	1.91	0.1339

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X	7	0.26281717	0.03754531	1.91	0.1339

Table A.18 ANOVA and Duncan Single Range Test for gumminess of rice cakes containing different types of gums baked in conventional oven.

Cake formulations: 1: xanthan cake baked in conventional oven, 2: guar cake baked in conventional oven, 3: xanthan-guar blend cake baked in conventional oven, 4: κ-carrageenan cake baked in conventional oven, 5: locust bean gum cake baked in conventional oven, 6: HPMC cake baked in conventional oven, 7: xanthan- κ-carrageenan blend cake baked in conventional oven, 8: control cake baked in conventional oven

1-Way ANOVA

The SAS System

The GLM Procedure

Class Level Information

Class	Levels	Values
X	8	1 2 3 4 5 6 7 8

Number of Observations Read 24

Number of Observations Used 24

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	6.98650710	0.99807244	23.41	<.0001
Error	16	0.68226498	0.04264156		
Corrected Total	23	7.66877207			

R-Square	Coeff Var	Root MSE	Y Mean
0.911033	11.83201	0.206498	1.745252

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X	7	6.98650710	0.99807244	23.41	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X	7	6.98650710	0.99807244	23.41	<.0001

Duncan's Multiple Range Test for Y

Alpha	0.05
Error Degrees of Freedom	16
Error Mean Square	0.042642

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X
A	2.586	3	2
A	2.423	3	8
B	2.003	3	7
B	1.908	3	5
C	1.451	3	4
C	1.419	3	3
C D	1.155	3	1
D	1.018	3	6

Table A.19 ANOVA and Duncan Single Range Test for chewiness of rice cakes containing different types of gums baked in conventional oven.

Cake formulations: 1: xanthan cake baked in conventional oven, 2: guar cake baked in conventional oven, 3: xanthan-guar blend cake baked in conventional oven, 4: κ-carrageenan cake baked in conventional oven, 5: locust bean gum cake baked in conventional oven, 6: HPMC cake baked in conventional oven, 7: xanthan- κ-carrageenan blend cake baked in conventional oven, 8: control cake baked in conventional oven

1-Way ANOVA

The SAS System

The GLM Procedure

Class Level Information

Class	Levels	Values
X	8	1 2 3 4 5 6 7 8

Number of Observations Read 24

Number of Observations Used 24

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	121.0923980	17.2989140	28.46	<.0001
Error	16	9.7262376	0.6078899		
Corrected Total	23	130.8186356			

R-Square	Coeff Var	Root MSE	Y Mean
0.925651	11.37379	0.779673	6.854996

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X	7	121.0923980	17.2989140	28.46	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X	7	121.0923980	17.2989140	28.46	<.0001

Duncan's Multiple Range Test for Y

Alpha	0.05
Error Degrees of Freedom	16
Error Mean Square	0.60789

Means with the same letter are not significantly different.

Duncan Grouping		Mean	N	X
A		10.251	3	2
A		9.950	3	8
B		7.884	3	7
B		7.261	3	5
C		5.596	3	4
C		5.587	3	3
C	D	4.510	3	1
D		3.800	3	6

Table A.20 ANOVA and Duncan Single Range Test for weight loss of rice cakes containing different types of gums baked in conventional oven.

Cake formulations: 1: xanthan cake baked in conventional oven, 2: guar cake baked in conventional oven, 3: xanthan-guar blend cake baked in conventional oven, 4: κ-carrageenan cake baked in conventional oven, 5: locust bean gum cake baked in conventional oven, 6: HPMC cake baked in conventional oven, 7: xanthan- κ-carrageenan blend cake baked in conventional oven, 8: control cake baked in conventional oven

1-Way ANOVA

The SAS System

The GLM Procedure

Class Level Information

Class	Levels	Values
X	8	1 2 3 4 5 6 7 8

Number of Observations Read 16

Number of Observations Used 16

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	15.05564844	2.15080692	51.99	<.0001
Error	8	0.33093350	0.04136669		
Corrected Total	15	15.3865819			

R-Square	Coeff Var	Root MSE	Y Mean
0.978492	2.135882	0.203388	9.522438

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X	7	15.05564844	2.15080692	51.99	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X	7	15.05564844	2.15080692	51.99	<.0001

Duncan's Multiple Range Test for Y

Alpha	0.05
Error Degrees of Freedom	8
Error Mean Square	0.041367

Means with the same letter are not significantly different.

Duncan Grouping		Mean	N	X
A		11.505	2	8
B		10.235	2	2
B		10.081	2	6
C		9.316	2	4
C	D	9.140	2	1
C	D	8.909	2	5
D		8.733	2	7
E		8.262	2	3

Table A.21 ANOVA and Duncan Single Range Test for pore area fractions of scanner images rice cakes containing different types of gums and baked in conventional and IR-microwave combination ovens.

Cake formulations: 1: xanthan cake baked in conventional oven, 2: guar cake baked in conventional oven, 3: xanthan-guar blend cake baked in conventional oven, 4: κ-carrageenan cake baked in conventional oven, 5: locust bean gum cake baked in conventional oven, 6: HPMC cake baked in conventional oven, 7: xanthan- κ-carrageenan blend cake baked in conventional oven, 8: control cake baked in conventional oven, 9: xanthan cake baked in IR-microwave combination oven, 10: guar cake baked in IR-microwave combination oven, 11: xanthan-guar blend cake baked in IR-microwave combination oven, 12: κ-carrageenan cake baked in IR-microwave combination oven, 13: locust bean gum cake baked in IR-microwave combination oven, 14: HPMC cake baked in IR-microwave combination oven, 15: xanthan- κ-carrageenan blend cake baked in IR-microwave combination oven, 16: control cake baked in IR-microwave combination oven.

1-Way ANOVA

The SAS System

The GLM Procedure

Class Level Information

Class	Levels	Values
X	16	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

Number of Observations Read 64

Number of Observations Used 64

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	15	0.02726580	0.00181772	19.67	<.0001
Error	48	0.00443483	0.00009239		
Corrected Total	63	0.03170062			

R-Square	Coeff Var	Root MSE	Y Mean
0.860103	4.841866	0.009612	0.198520

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X	15	0.02726580	0.00181772	19.67	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X	15	0.02726580	0.00181772	19.67	<.0001

Duncan's Multiple Range Test for Y

Alpha	0.05
Error Degrees of Freedom	48
Error Mean Square	0.000092

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X
A	0.237	4	11
A B	0.230	4	9
B C	0.223	4	15
B C D	0.218	4	16
C D E	0.210	4	10
D E F	0.206	4	14
E F G	0.203	4	3
E F G H	0.199	4	1
E F G H	0.196	4	8
F G H I	0.191	4	7
G H I	0.189	4	12
H I	0.185	4	4
I J	0.178	4	13
I J	0.177	4	6
J	0.170	4	5
J	0.166	4	2

2-Way ANOVA

Class	Levels	Values
X1	8	1 2 3 4 5 6 7 8
X2	2	1 2

Number of Observations Read 64

Number of Observations Used 64

Source	DF	SS	MS	F	P
X1	7	0.0141149	0.0020164	21.82	0.000
X2	1	0.0105191	0.0105191	113.85	0.000
Interaction	7	0.0026319	0.0003760	4.07	0.001
Error	48	0.0044348	0.0000924		
Total	63	0.0317006			

S = 0.009612 R-Sq = 86.01% R-Sq(adj) = 81.64%

Table A.22 ANOVA and Duncan Single Range Test for roundness of scanner images rice cakes containing different types of gums and baked in conventional and IR-microwave combination ovens.

Cake formulations: 1: xanthan cake baked in conventional oven, 2: guar cake baked in conventional oven, 3: xanthan-guar blend cake baked in conventional oven, 4: κ-carrageenan cake baked in conventional oven, 5: locust bean gum cake baked in conventional oven, 6: HPMC cake baked in conventional oven, 7: xanthan- κ-carrageenan blend cake baked in conventional oven, 8: control cake baked in conventional oven, 9: xanthan cake baked in IR-microwave combination oven, 10: guar cake baked in IR-microwave combination oven, 11: xanthan-guar blend cake baked in IR-microwave combination oven, 12: κ-carrageenan cake baked in IR-microwave combination oven, 13: locust bean gum cake baked in IR-microwave combination oven, 14: HPMC cake baked in IR-microwave combination oven, 15: xanthan- κ-carrageenan blend cake baked in IR-microwave combination oven, 16: control cake baked in IR-microwave combination oven.

1-Way ANOVA

The SAS System

The GLM Procedure

Class Level Information

Class	Levels	Values
X	16	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

Number of Observations Read 64

Number of Observations Used 64

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	15	0.03082384	0.00205492	4.38	<.0001
Error	48	0.02253638	0.00046951		
Corrected Total	63	0.05336022			

R-Square	Coeff Var	Root MSE	Y Mean
0.577656	4.605479	0.021668	0.470486

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X	15	0.03082384	0.00205492	4.38	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X	15	0.03082384	0.00205492	4.38	<.0001

Duncan's Multiple Range Test for Y

Alpha	0.05
Error Degrees of Freedom	48
Error Mean Square	0.00047

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X
A	0.501	4	5
A	0.500	4	2
A	0.495	4	6
A B	0.490	4	3
A B	0.489	4	1
A B C	0.485	4	7
A B C	0.480	4	8
A B C D	0.472	4	14
A B C D E	0.469	4	13
A B C D E	0.468	4	4
A B C D E F	0.465	4	16
B C D E F	0.458	4	12
C D E F	0.452	4	15
D E F	0.438	4	10
E F	0.436	4	11
F	0.432	4	9

2-Way ANOVA

Class	Levels	Values
X1	8	1 2 3 4 5 6 7 8
X2	2	1 2

Number of Observations Read 64

Number of Observations Used 64

Source	DF	SS	MS	F	P
X1	7	0.0048483	0.0006926	1.48	0.199
X2	1	0.0205385	0.0205385	43.74	0.000
Interaction	7	0.0054371	0.0007767	1.65	0.143
Error	48	0.0225364	0.0004695		
Total	63	0.0533602			

S = 0.02167 R-Sq = 57.77% R-Sq(adj) = 44.57%

Table A.23 ANOVA and Duncan Single Range Test for pore area fractions of rice cake SEM micrographs (30X) containing different types of gums and baked in conventional and IR-microwave combination ovens.

Cake formulations: 1: xanthan cake baked in conventional oven, 2: guar cake baked in conventional oven, 3: xanthan-guar blend cake baked in conventional oven, 4: κ-carrageenan cake baked in conventional oven, 5: locust bean gum cake baked in conventional oven, 6: HPMC cake baked in conventional oven, 7: xanthan- κ-carrageenan blend cake baked in conventional oven, 8: control cake baked in conventional oven, 9: xanthan cake baked in IR-microwave combination oven, 10: guar cake baked in IR-microwave combination oven, 11: xanthan-guar blend cake baked in IR-microwave combination oven, 12: κ-carrageenan cake baked in IR-microwave combination oven, 13: locust bean gum cake baked in IR-microwave combination oven, 14: HPMC cake baked in IR-microwave combination oven, 15: xanthan- κ-carrageenan blend cake baked in IR-microwave combination oven, 16: control cake baked in IR-microwave combination oven.

1-Way ANOVA

The SAS System

The GLM Procedure

Class Level Information

Class	Levels	Values
X	16	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

Number of Observations Read 32

Number of Observations Used 32

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	15	0.09924741	0.00661649	14.25	<.0001
Error	16	0.00742764	0.00046423		
Corrected Total	31	0.10667506			

R-Square	Coeff Var	Root MSE	Y Mean
0.930371	6.239548	0.021546	0.345313

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X	15	0.09924741	0.00661649	14.25	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X	15	0.09924741	0.00661649	14.25	<.0001

Duncan's Multiple Range Test for Y

Alpha	0.05
Error Degrees of Freedom	48
Error Mean Square	0.000092

Means with the same letter are not significantly different.

Duncan Grouping		Mean	N	X
A		0.460	2	11
A		0.436	2	9
A	B	0.423	2	3
A	B	0.418	2	15
B	C	0.376	2	14
C	D	0.337	2	1
D	E	0.324	2	6
D	E	0.323	2	16
D	E	0.313	2	10
D	E	0.310	2	4
D	E	0.309	2	12
D	E	0.309	2	13
D	E	0.308	2	7
D	E	0.304	2	2
D	E	0.304	2	8
E		0.274	2	5

2-Way ANOVA

Class	Levels	Values
X1	8	1 2 3 4 5 6 7 8
X2	2	1 2

Number of Observations Read 32

Number of Observations Used 32

Source	DF	SS	MS	F	P
X1	7	0.071487	0.0102125	22.00	0.000
X2	1	0.016335	0.0163353	35.19	0.000
Interaction	7	0.011425	0.0016321	3.52	0.018
Error	16	0.007428	0.0004642		
Total	31	0.106675			

S = 0.02155 R-Sq = 93.04% R-Sq(adj) = 86.51%

APPENDIX B

DSC THERMOGRAMS

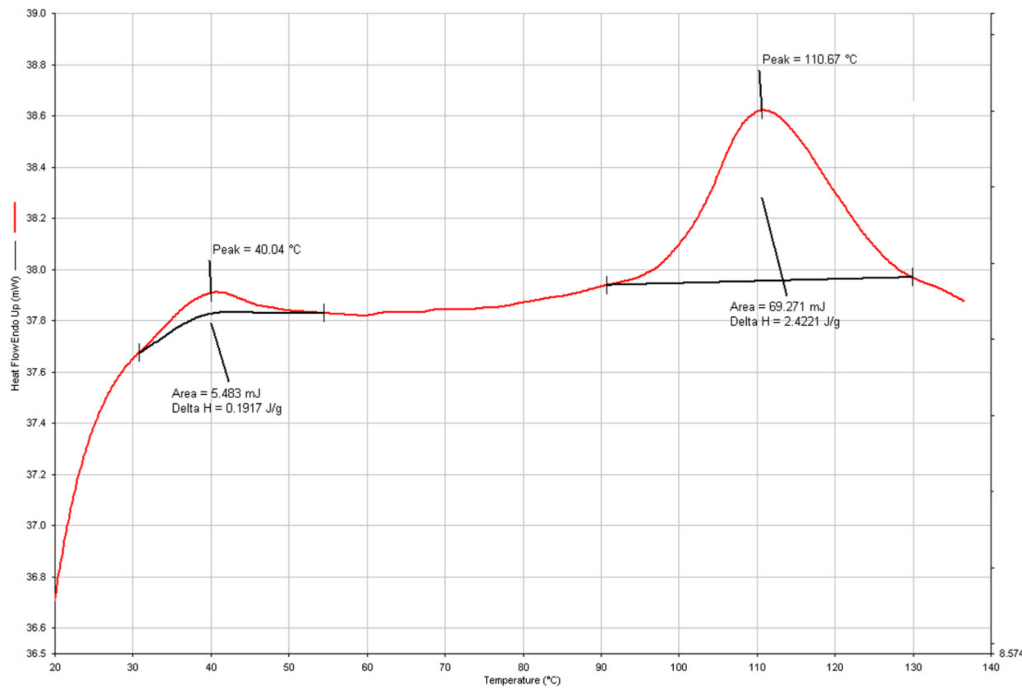

Figure B.1 DSC thermogram of rice cake batter containing xanthan gum.

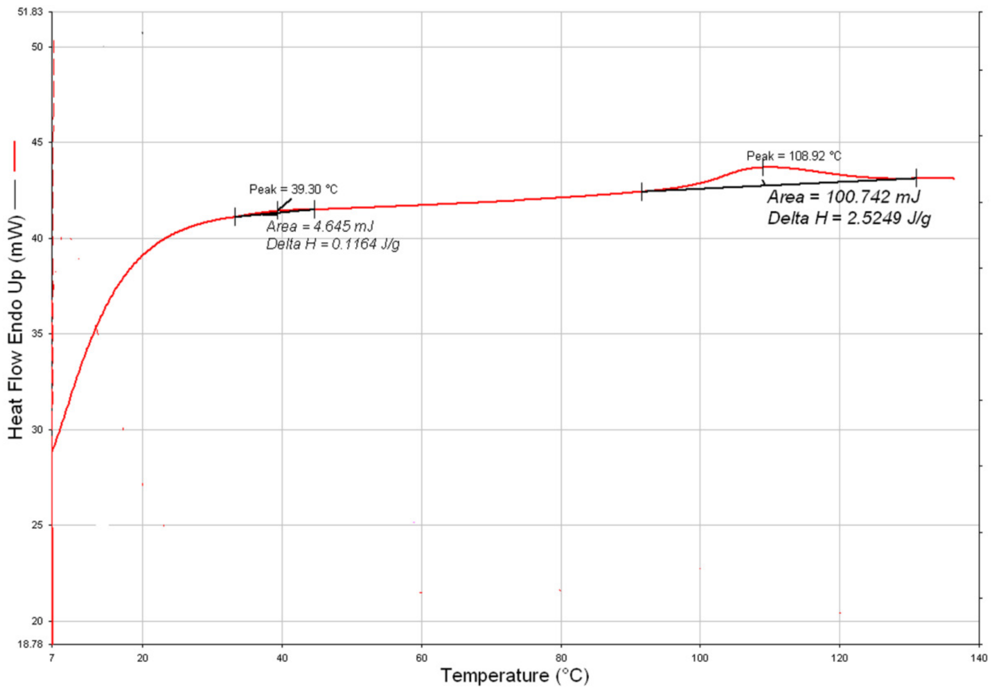

Figure B.2 DSC thermogram of rice cake batter containing guar gum.

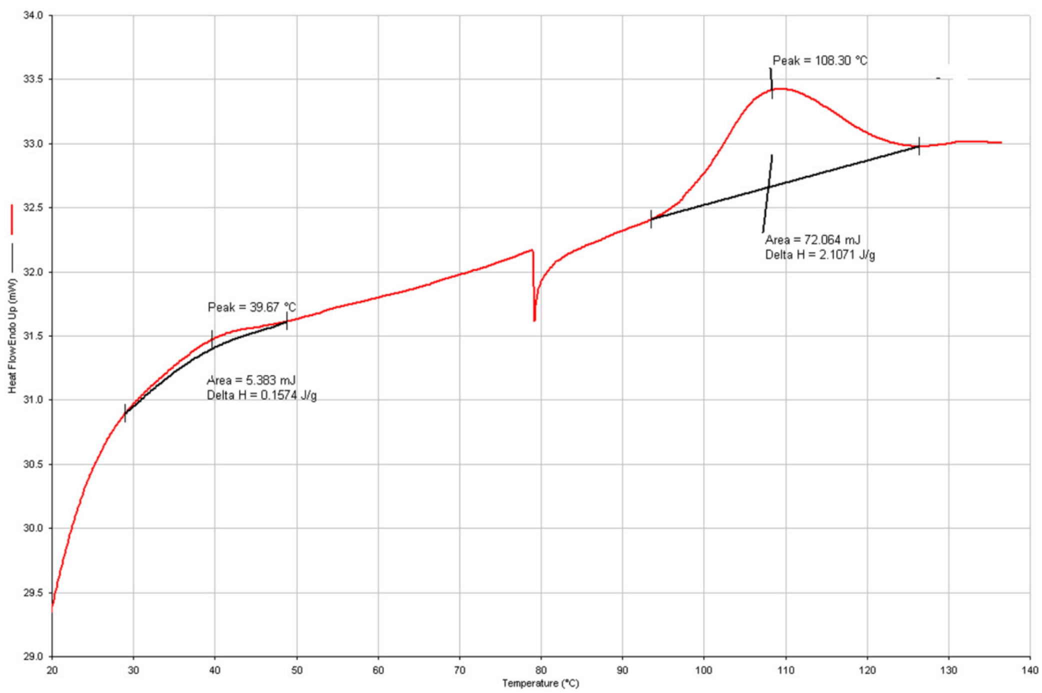

Figure B.3 DSC thermogram of rice cake batter containing xanthan-guar gum blend.

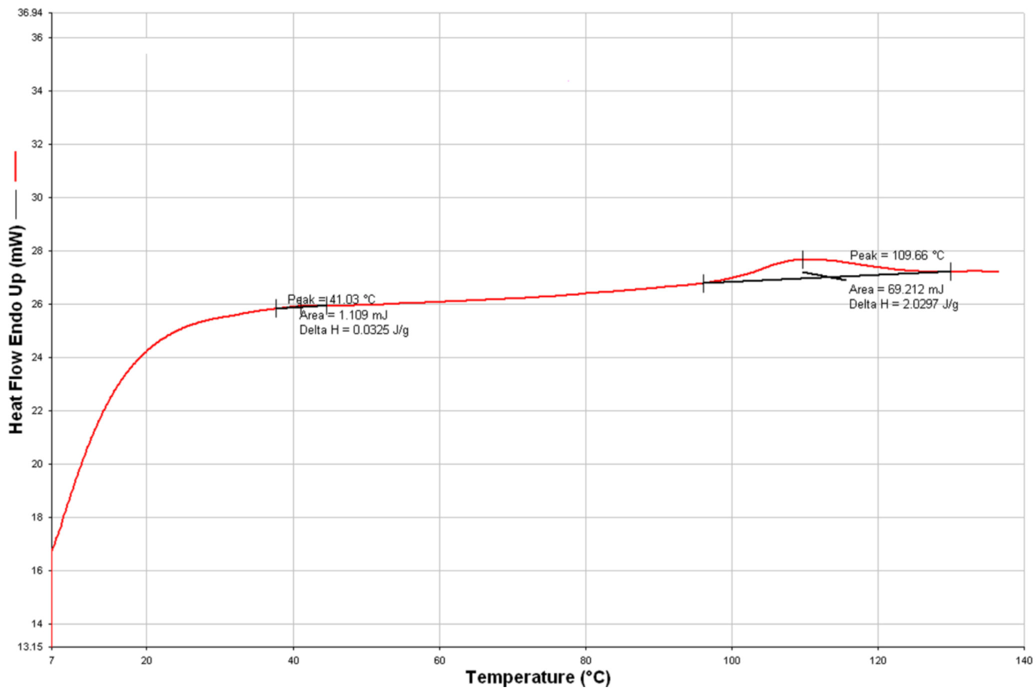

Figure B.4 DSC thermogram of rice cake batter containing κ-carrageenan gum.

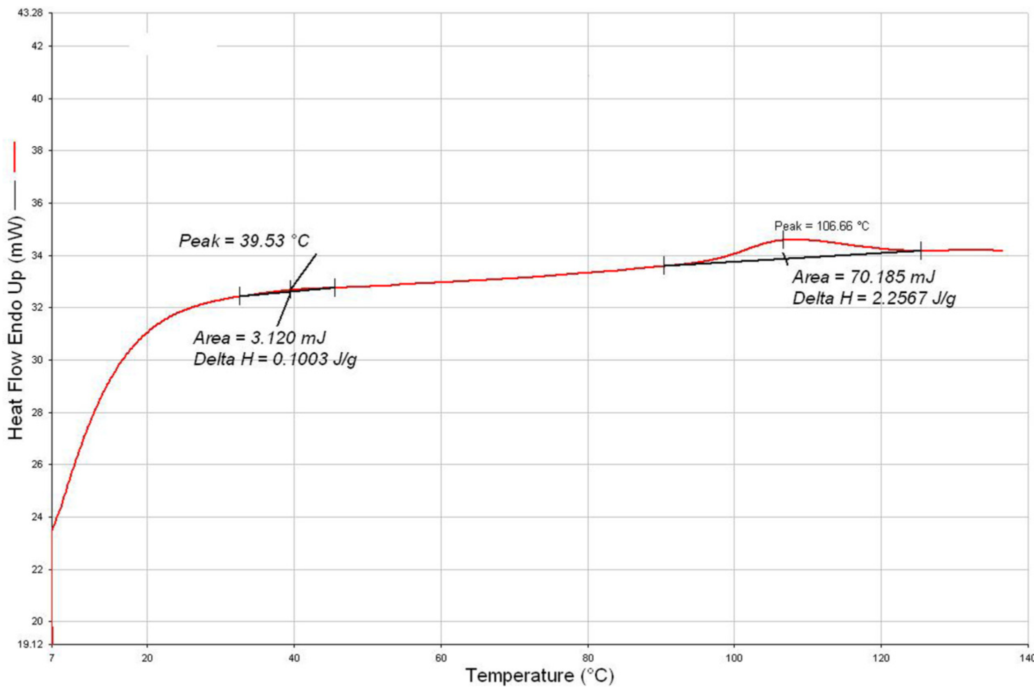

Figure B.5 DSC thermogram of rice cake batter containing locust bean gum.

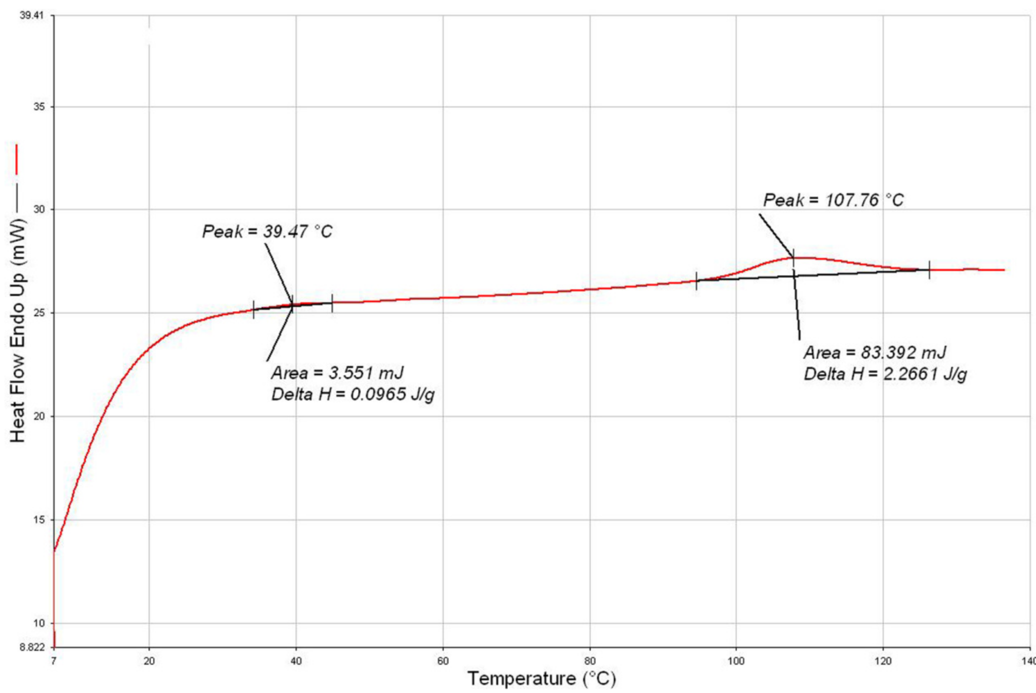

Figure B.6 DSC thermogram of rice cake batter containing HPMC.

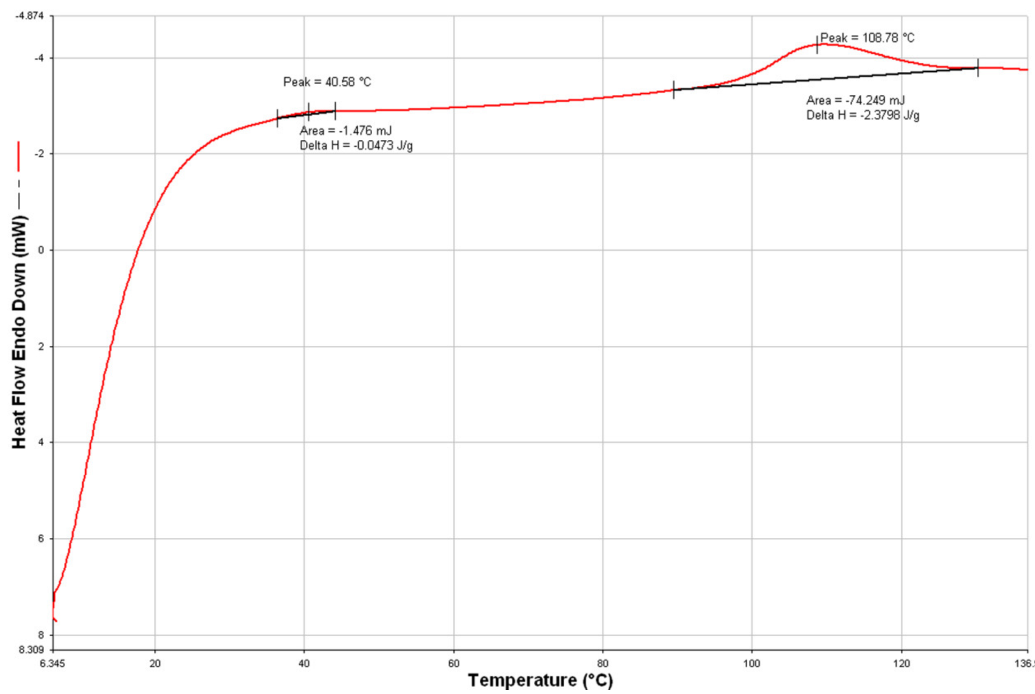

Figure B.7 DSC thermogram of rice cake batter containing xanthan- κ-carrageenan gum blend.

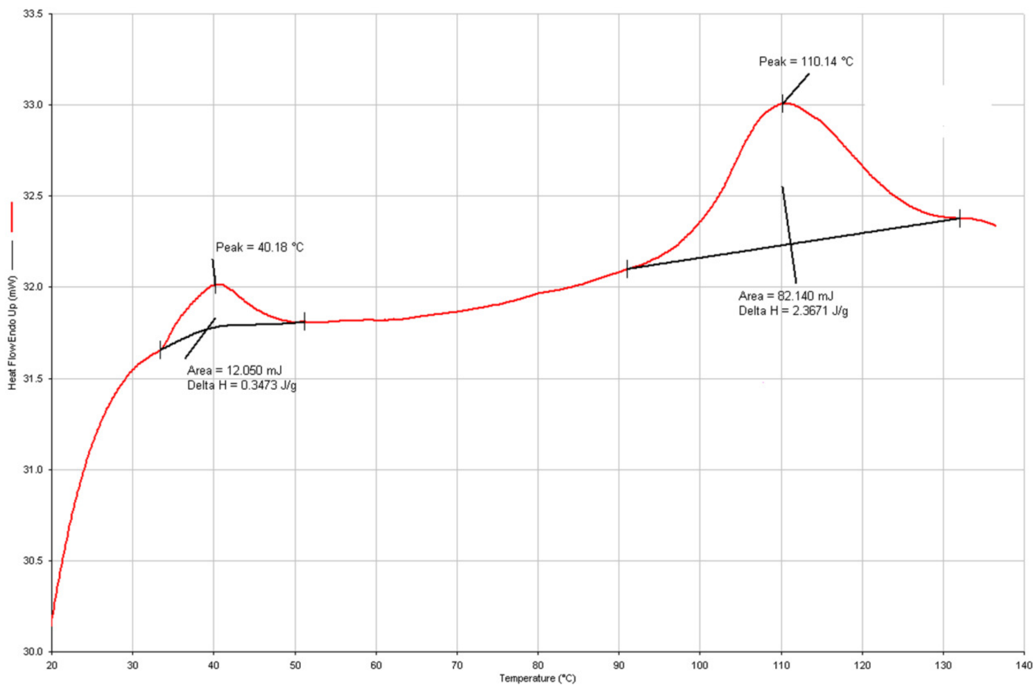

Figure B.8 DSC thermogram of control cake batter.

APPENDIX C

DATA USED IN RSM

Table C.1 Experimental data for rice cakes containing xanthan-guar gum blend

	Coded Factors			Experimental data			
Exp. No.	X1 (%)	X2 (%)	X3 (min)	Specific volume (ml/g)	Total color change (ΔE)	Firmness (N)	Weight loss (%)
1	-1	-1	0	1.36	13.70	3.01	11.13
2	1	-1	0	1.51	26.80	3.14	13.37
3	-1	1	0	1.33	28.70	4.06	13.15
4	1	1	0	1.52	34.10	2.49	15.46
5	-1	0	-1	1.36	18.80	4.31	12.72
6	1	0	-1	1.57	28.50	2.88	12.23
7	-1	0	1	1.28	23.70	4.53	15.17
8	1	0	1	1.55	31.70	3.99	15.40
9	0	-1	-1	1.48	20.60	3.30	11.57
10	0	1	-1	1.52	30.60	3.20	13.36
11	0	-1	1	1.52	26.30	3.48	14.52
12	0	1	1	1.40	36.20	3.52	15.46
13	0	0	0	1.47	27.90	3.16	13.99
14	0	0	0	1.49	30.00	3.56	14.73
15	0	0	0	1.51	26.90	2.92	12.85

Table C.2 Experimental data for rice cakes containing xanthan gum

	Coded Factors			Experimental data			
Exp. No.	X1 (%)	X2 (%)	X3 (min)	Specific volume (ml/g)	Total color change (ΔE)	Firmness (N)	Weight loss (%)
1	-1	-1	0	1.64	12.80	2.19	12.13
2	1	-1	0	1.66	28.00	2.34	11.69
3	-1	1	0	1.65	27.10	2.11	12.79
4	1	1	0	1.62	40.30	3.02	13.72
5	-1	0	-1	1.66	16.50	2.48	11.18
6	1	0	-1	1.58	30.80	3.00	11.99
7	-1	0	1	1.67	24.20	2.42	14.53
8	1	0	1	1.69	35.50	3.06	14.94
9	0	-1	-1	1.48	21.40	2.53	11.04
10	0	1	-1	1.48	31.10	3.25	11.86
11	0	-1	1	1.56	28.40	3.10	14.26
12	0	1	1	1.49	44.30	3.37	15.07
13	0	0	0	1.49	30.30	3.02	13.12
14	0	0	0	1.47	31.10	3.09	13.05
15	0	0	0	1.51	30.80	3.09	12.61

VITA

Elif Turabi was born in Bandırma, Turkey on April 17, 1980. She was graduated from Food Engineering Department of Middle East Technical University in 2003. She completed a minor degree of Quality Planning and Control at Industrial Engineering Department of the same university (2001-2003). She studied her Ph.D. on BS at Food Engineering Department for six years (February 2004-May 2010). She worked as a research assistant in Food Engineering Department of Middle East Technical University between September 2005-February 2010.

Her publications are listed below:

A. Full paper published in International Journals

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

Turabi, E., Regier, M., Sumnu G., Sahin, S., and Rother, M. (2010). Dielectric and thermal properties of rice cake formulations containing different gum types. International Journal of Food Properties. In print.

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Sumnu G., **Turabi E**. & Oztop M., (2005) Drying of carrots in microwave and halogen lamp–microwave combination ovens , LWT - Food Science and Technology,38,549-553.

B. Conference Papers (International)

Turabi E., Şumnu G. & Şahin S., Investigation of Macro-structure of Gluten-free Rice Cakes Baked in Infrared-microwave Combination Oven. Oral Presentation in 5th International Technical Symposium on Food Processing, Monitoring Technology in Bioprocesses and Food Quality Management, 31 August-2 September 2009, Potsdam, GERMANY.

Turabi E, Şumnu G. & Şahin S., A Study on the Micro-structure of Gluten-free Rice Cakes Baked in Conventional and IR-microwave Combination Ovens. Poster Presentation in International Microwave Power Institute's 43rd Annual Symposium, 8-10 JULY 2009, Washington DC , USA.

Turabi E, Şumnu G. & Şahin S., Thermal Analysis of Gluten-free Rice Cake Batters Containing Different Gum Types. Poster Presentation in Bosphorus 2008-ICC International Conference, 24-26 April, 2008, Istanbul, TURKEY.

Özkoc S. Ö., Şumnu G., Şahin S & **Turabi E.**, The Effect of Gum Addition on Starch Retrogradation of Breads Baked in Different Ovens. Poster Presentation in Bosphorus 2008-ICC International Conference, 24-26 April, 2008, Istanbul, TURKEY.

Turabi E, Şumnu G. & Şahin S., Dielectric Properties of Gluten-Free Rice Cake Batters Formulated with Different Gums. Oral Presentation in CIGR Section VI ınternational symposium, Food and Agricultural Products Processing and Innovations, 24-26 September 2007, Naples, ITALY

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Turabi E, Sumnu G & Sahin S., A Study on the Rheological Properties of Gluten-free Cake Batter containing Emulsifier and Different Types of Gums, Poster Presentation in AACC International Annual Meeting, September 11-14, 2005. Orlando, Florida,USA.

C. Conference Papers (National)

Turabi E., Şumnu G. & Şahin S, Konvansiyonel ve Kızıl-ötesi Mikrodalga Kombinasyonlu Fırınlarda Pişirilen Glutensiz Pirinç Keklerinin Makro-yapılarının İncelenmesi, Poster Sunumu, Gıda Mühendisliği Kongresi, 6-8 Kasım 2009, Kemer-Antalya, Türkiye.

Turabi E., Şumnu G. & Şahin S, Infrared-Mikrodalga Kombinasyonlu Fırında Pişirilen Glutensiz Pirinç Keklerinin Pişirme Şartlarının Optimizasyonu, Poster Sunumu, Hububat Urunleri Teknolojisi Kongresi, 7-8 Eylul 2006, Gaziantep, Turkiye

Turabi E., Şumnu G. & Şahin S, Infrared-Mikrodalga Kombinasyonlu Fırında Pişirilmiş Glutensiz Prinç Keklerinin Pişirme Şartlarının Optimizasyonu, 9. Türkiye Gıda Kongresi-Abant İzzet Baysal Üniversitesi, Poster Sunumu, 24-26 Mayıs 2006, Bolu, Türkiye

Turabi E., Şumnu G. & Şahin S, Farklı Gam Tipi ve Emülgatör Kullanımının Glutensiz Kek Hamurunun Reolojik Özellikleri Üzerindeki Etkileri, Ege Üniversitesi Mühendislik Fakültesi Gıda Mühendisligi Bölümü Gıda Kongresi, Poster Sunumu, 19-21 Nisan 2005, İzmir, Turkiye.

PROJECT WORK

Kızıl ötesi-Mikrodalga Kombinasyonlu Fırında Pişirilmeye Uygun Glutensiz Kek Formülasyonunun Optimizasyonu (Optimization of Gluten-free Cake Formulations for Baking in Infrared-Microwave Combination Oven), 2007-2009, TÜBİTAK-TOVAG 106O702, Researcher.

Design of gluten-free cake formulations for halogen lamp-microwave combination oven, 2005-2006, M.E.T.U Research Fund Project, Researcher, BAP-2005-03-14-04.

Investigation of alternative baking methods, 2005, OSTİM Endüstriyel Yatırımlar ve İşletme and Arçelik, Researcher.

HONORS-AWARDS-SCHOLARSHIPS

- Scholarship from KIT (Karlsruhe Institute of Technology), Process Engineering and Technology Network of Competence (Pro3) (October 2006-October 2007)
- Scholarship from TUBITAK (The Scientific and Technological Research Council of Turkiye) for PhD education (2004-2008)
- Scholarship from Turkish Prime Minister's Office for B.Sc. education, 1998-2003.
- Dean's High Honor (5 semesters) and Honor (3 semesters) Lists (1998-2003)