INVESTIGATION OF QUALITY AND STALING OF BREADS WITH DIFFERENT GUM FORMULATIONS BAKED IN DIFFERENT OVENS

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INVESTIGATION OF QUALITY AND STALING OF BREADS WITH DIFFERENT GUM FORMULATIONS BAKED IN DIFFERENT OVENS

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ABSTRACT

INVESTIGATION OF QUALITY AND STALING OF BREADS WITH DIFFERENT GUM FORMULATIONS BAKED IN DIFFERENT OVENS

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The objective of this study was to determine the effects of different gums and their combination on quality and staling of breads baked in different ovens.

In the first part of the study, the effects of gums (xanthan, guar, κ-carrageenan, hydroxypropyl methylcellulose, locust bean gum and their blends) on quality of breads baked in infrared-microwave combination and conventional ovens were investigated. In addition, macro and micro-structure,

dielectric and thermal properties and acrylamide content of breads were studied.

Xanthan-guar blend addition improved bread quality with increasing specific volume and porosity values and decreasing hardness values of samples. More homogeneous closed-cell structure for conventionally baked control breads and channel formed cell structure for breads baked in infrared-microwave combination oven were observed. Dielectric properties of breads were found to be a function of gum type. No acrylamide was formed in microwave baked breads. Breads baked in infrared-microwave combination oven had similar acrylamide content with conventionally baked ones.

The second part of the study focused on staling. The hardness, retrogradation enthalpy, set back viscosity, FTIR outputs and crystallinity values of microwave-baked samples were found to be the highest. Infrared-microwave combination heating made it possible to produce breads with similar staling degrees as conventionally baked ones and reduced the conventional baking time of breads by about 39%. Addition of xanthan-guar blend decreased hardness, retrogradation enthalpy and crystallinity values of breads. According to hardness data, in the presence of xanthan-guar blend staling of breads baked in all types of ovens was delayed for 1 day.

Keywords: Bread baking, Gum, Infrared, Microwave, Staling

ÖZ

FARKLI GAM FORMÜLASYONLARIYLA FARKLI FIRINLARDA PİŞİRİLEN EKMEKLERİN KALİTE VE BAYATLAMALARININ İNCELENMESİ

Özkoç, Semin Özge
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Bu çalışmanın amacı, farklı gamların ve gam karışımlarının farklı fırınlarda pişirilen ekmeklerin kalite ve bayatlamaları üzerine olan etkilerinin belirlenmesidir.

Çalışmanın ilk kısmında, gamların (ksantan, guar, κ-carrageenan, hidroksipropilmetilselüloz, keçiboynuzu gamı ve bu gamların karışımları) kızılötesi-mikrodalga kombinasyon ve konvansiyonel fırınlarda pişirilen ekmeklerin kalitelerine olan etkileri incelenmiştir. Ayrıca ekmeklerin makro ve

mikro yapıları, dielektrik ve ısıl özellikleri ve akrilamid içerikleri araştırılmıştır.

Ksantan-guar karışımı ilavesi, ekmeklerin özgül hacim ve gözeneklilik değerlerini arttırıp, iç sertlik değerlerini azaltarak ekmek kalitesini iyileştirmiştir. Konvansiyonel fırında pişirilen kontrol ekmekleri için daha homojen kapalı-hücre gözenek yapısı, kızılötesi-mikrodalga kombinasyon fırında pişirilen kontrol ekmekleri için ise kanal yapısında gözenekler gözlenmiştir. Ekmeklerin dielektrik özelliklerinin gam tipinin bir fonksiyonu olduğu bulunmuştur. Mikrodalga fırında pişirilen ekmeklerde akrilamid oluşmamıştır. Kızılötesi-mikrodalga kombinasyon fırında pişirilen ekmeklerin, konvansiyonel fırında pişirilenlere benzer akrilamid içeriğine sahip olduğu görülmüştür.

Çalışmanın ikinci kısmında bayatlama üzerine odaklanılmıştır. Mikrodalga ile pişirilen örneklerin iç sertlik, retrogradasyon entalpisi, katılaşma viskozitesi, FTIR çıktılarının ve kristalinite değerlerinin en yüksek olduğu bulunmuştur. Kızılötesi-mikrodalga kombinasyon ısıtmanın kullanılması, konvansiyonel fırında pişirilen ekmeklere benzer bayatlama derecelerine sahip ekmek üretimini mümkün kılmış ve ekmeklerin konvansiyonel pişirme süresini yaklaşık % 39 oranında azaltmıştır. Ksantan-guar karışımının ilave edilmesi, ekmeklerin iç sertlik, retrogradasyon entalpisi ve kristalinite değerlerini azaltmıştır. İç sertlik verilerine göre bütün fırınlarda pişirilen ekmeklerin bayatlaması, ksantan-guar karışımının varlığında 1 gün gecikmiştir.

Anahtar sözcükler: Bayatlama, Ekmek pişirme, Gam, Kızılötesi, Mikrodalga

To My Family

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LIST OF ABBREVIATIONS

AACC	American Association of Cereal Chemists
AOAC	Association of Official Agricultural Chemists
APCI	Atmospheric Pressure Chemical Ionisation
ATAL	Anakara Test Analysis Laboratory
ATR-FTIR	Attenuated Total Reflection Fourier Transform Infrared
CIE	Commission Internationale d'Eclairage (International Commission on Illumination)
DSC	Differential Scanning Calorimetry
DTA	Differential Thermal Analysis
ΔE	Total color change (Euclidean distance in CIE *L*a*b** space)
FIR	Far-InfraRed
FTIR	Fourier Transform Infrared
GC	Gas Chromatography
ΔH	Enthalpy change
HPLC	High Performance Liquid Chromatography
HPMC	Hydroxypropyl Methylcellulose
ICC	International Association for Cereal Science and Technology
IR	InfraRed
LC-MS	Liquid Chromatography-Mass Spectrometry

LC-MS/MS	Liquid Chromatography-Double Mass Spectrometry
MC	Methylcellulose
MIR	Mid-InfraRed
NIR	Near-InfraRed
NMR	Nuclear Magnetic Resonans
RVA	Rapid ViscoAnalyser
SIM	Selective Ion Monitoring
TC	Total mass Crystallinity grade
TPA	Texture Profile Analysis
UV	Ultra-Violet
v	Volume
w	Weight
2θ	Scattering angle
WAXS	Wide-Angle X-ray Diffraction

CHAPTER 1

INTRODUCTION

1.1 IR-microwave Combination Heating of Foods

In IR-microwave combination heating, the time saving advantage of microwave heating is combined with the browning and crisping advantages of infrared heating (Keskin et al., 2004a). In IR-microwave combination heating, 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., 2005a). The selectivity of the combination heating can also be used to improve moisture distribution inside the food, by heating the surface of a food faster, which can help removing moisture easily from the surface and keeping it crisp (Datta et al., 2005a).

Since there is limited information about the IR-microwave combination heating in literature, in order to understand its mechanism, it is important to review the mechanisms of microwave and infrared heating separately.

1.1.1 Mechanism of microwave heating

Microwaves are electromagnetic waves having wavelength between radio and infrared waves on the electromagnetic spectrum and are generated by a device called “magnetron” (Giese, 1992).

A material interacts with microwave energy in three ways: reflection, transmission, or absorption (Figure 1.1) (Engelder and Buffler, 1991).

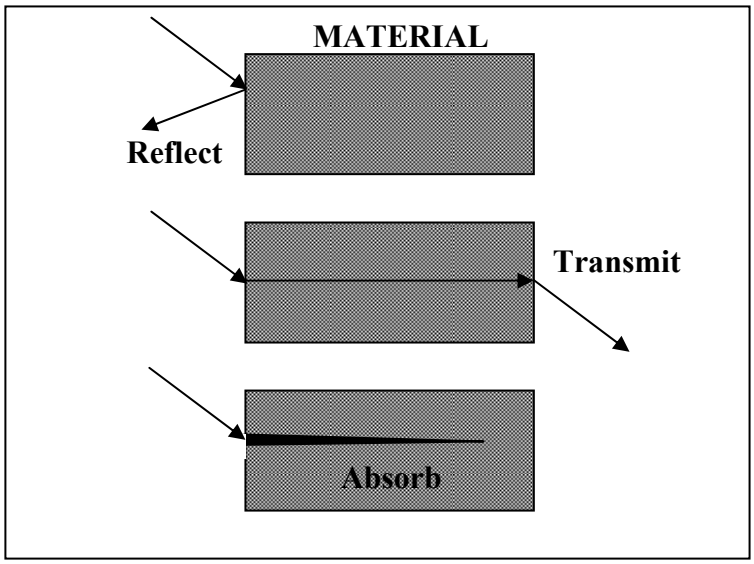

Figure 1.1 Three interaction ways (reflection, transmission, or absorption) of materials with microwave energy (Engelder and Buffler, 1991)

The major mechanisms of microwave heating of foods involve dipolar re-orientation and ionic conduction (Datta et al, 2005b), which can be seen in Figure 1.2. Heat is generated due to molecular friction, resulting from dipolar rotation of polar solvents and the conductive migration of dissolved ions (Oliveira and Franca, 2002). Primary food components that absorb microwaves, such as the water and the ions, lead to volumetric heating of foods (Datta, 2001).

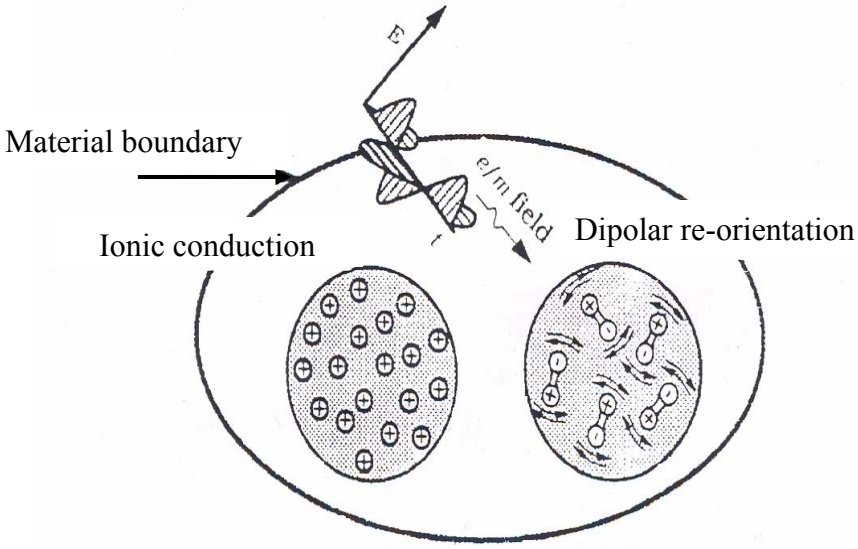

Figure 1.2 Schematic representations of dipolar rotation and ionic conduction mechanisms (Adapted from Datta et al., 2005b)

The energy equation includes a heat generation term in microwave heating:

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

where T is temperature, t is time, α is thermal diffusivity, ρ is density, C_p is specific heat of the material and Q is the rate of heat generated per unit volume of material.

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

$$Q = 2\pi\varepsilon_0\varepsilon'' fE^2 \quad (1.2)$$

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

The driving forces for heat and mass transfer in a microwave-heated food differ from conventionally heated ones. In microwave heating, time-temperature profiles within the product are caused by internal heat generation owing to the absorption of electrical energy from the microwave field and heat transfer by conduction, convection and evaporation (Mudgett, 1982). The surface temperature of a food heated by microwave energy is cooler than the interior because of the lack of ambient heat and the cooling effects of evaporation (Decareau, 1992). A porous media was found to be hotter in the inside when heated by microwaves and hotter on the outside when heated by convection (Wei et al., 1985a, 1985b).

Compared to conventional heating, moisture flow is uniquely and significantly altered during microwave heating. Relatively large amounts of internal heating may result in increased moisture vapor generation inside the food material, creating significant internal pressure and concentration gradients in microwave heating (Datta, 1990).

The advantages of microwave heating as compared to conventional heating can be summarized as less start-up time, faster heating, energy efficiency, space savings, precise process control, selective heating and final product formation with higher nutritive value (Decareau and Peterson, 1986).

The interaction of foods with microwaves is controlled by dielectric properties. Dielectric properties are the physical properties of food that affect the behaviour of the product during microwave heating, which may be helpful in understanding the microwave heating patterns of foods. The importance of

dielectric properties of food materials increased as microwave processing and new combination processing technologies is adapted to be used in food industry. Information about the dielectric properties of food materials provide knowledge about the heating patterns during microwave and microwave-assisted (i.e. IR-microwave combination heating) heating of foods, and provide assistance in developing product, process and equipment with consistent and predictable properties (Datta et al., 2005b). The dielectric properties represent a material's ability to absorb, transmit and reflect electromagnetic energy (Ryynänen, 1995). Dielectric properties are dielectric constant and dielectric loss factor, which depend on composition of a substance (moisture, oil, salt content, etc.), and processing conditions (temperature and frequency) (Calay et al., 1995).

There is limited dielectric data in literature during baking of breads and cakes in microwave and microwave assisted ovens (Sumnu et al., 2007; Sakiyan et al., 2007). Sumnu et al. (2007) found that dielectric properties of breads decreased sharply within the first 2-3 min of baking and then remained constant. They demonstrated that the dielectric properties of samples during baking were dependent on moisture content and porosity. Sakiyan et al. (2007) showed that dielectric properties of cake samples were dependent on formulation, baking time, and temperature. It was found that the increase in baking time and temperature decreased dielectric properties of all formulations but fat content increased dielectric properties of cakes (Sakiyan et al., 2007).

1.1.2 Mechanism of IR heating

Infrared (IR) radiation is the part of electromagnetic spectrum that is predominantly responsible for the heating effect of the sun (Ranjan et al., 2002). Infrared radiation is found between the visible light and radiowaves (0.76-1000μm) (Sepulveda and Barbosa-Canovas, 2003) and can be divided into three different categories, namely, near-infrared radiation (NIR), mid-

infrared radiation (MIR) and far-infrared (FIR) radiation (Ranjan et al., 2002) (Figure 1.3).

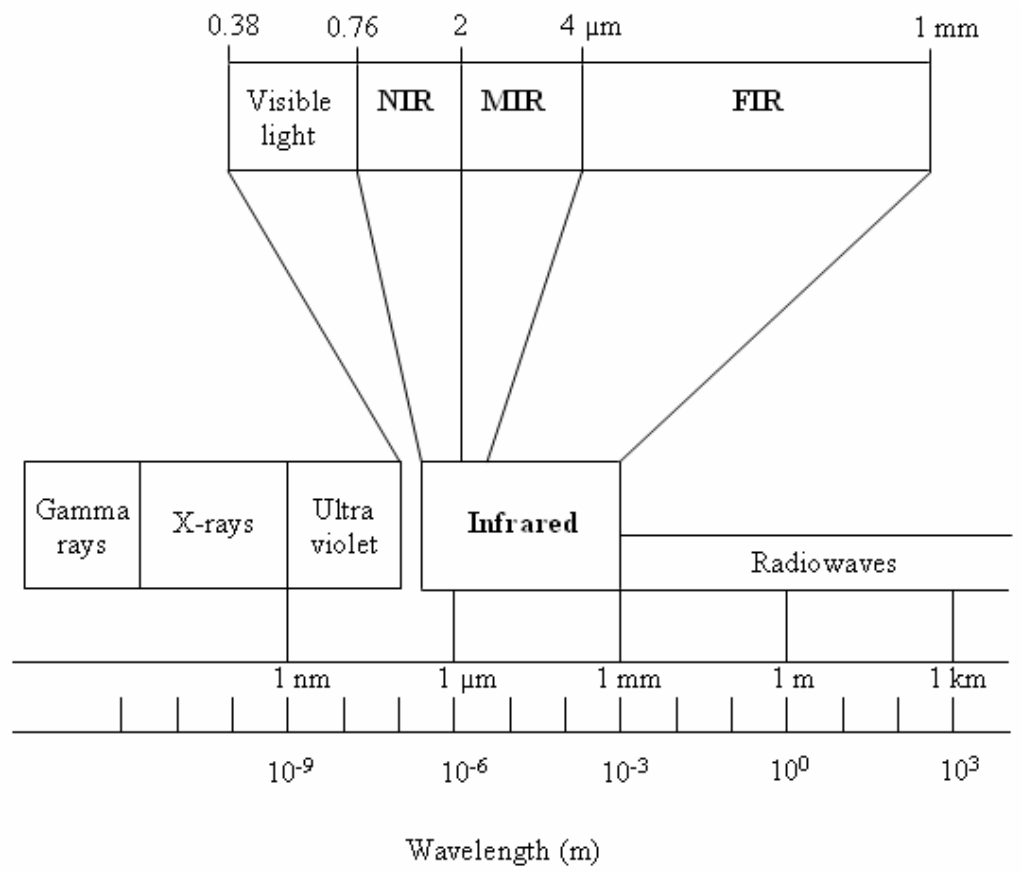

Figure 1.3 The electromagnetic spectrum

Infrared heating is one of the heating methods that heat is transferred by radiation. The infrared source has often a high temperature (500-3000 °C). In IR heating, heat transfer by convection is also taking place and can not be ignored. As infrared heating has poor penetration, it has an impact only on the surface of the body and heat transfer through the body proceeds by conduction or convection (Sepulveda and Barbosa-Canovas, 2003). The penetration depth of infrared radiation determines how much the surface temperature increases or

the level of surface moisture that builds up over time. Penetration depth of infrared radiation can vary significantly for various food materials. Datta and Ni (2002) showed that as the penetration depth decreased, that is as infrared energy was absorbed closer to the surface, the surface temperature of the products increased.

Use of different types of electromagnetic waves, for heating food and preservation of food has been reported by various researchers. Heating of foods by microwave heating has been examined in detail but by infrared heating to some extent (Datta and Ni, 2002). The infrared heating of foods were studied by Ginzburg (1969); Sandu (1986); Il'yasov and Krasnikov (1991); Sakai and Hanzawa (1994); Ratti and Mujumdar (1995); Datta and Ni (2002). Ginzburg (1969) predicted temperature profiles and infrared penetration depth of foodstuffs (e.g.wheat dough, wheat bread, carrot, tomato paste, potato, apple) for infrared heating. Il'yasov and Krasnikov (1991) provided detailed discussions of infrared energy absorption in foods but did not focus on energy or mass transport. Sakai and Hanzawa (1994) reviewed the applications and advances in far-infrared heating in Japan. Sandu (1986) provided qualitative descriptions of temperature and moisture profiles in foods during infrared 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.

Some of the advantages of infrared radiation as compared to conventional heating are reduced 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).

1.1.3 Mechanisms of IR-microwave combination heating

IR-microwave combination heating implies two different heating mechanisms together. There are limited studies on IR-microwave combination heating in the literature (Demirekler et al., 2004; Keskin et al., 2004a; Sumnu et al., 2005; Keskin et al., 2005; Demirkol, 2007; Datta et al., 2007; Sumnu et al., 2007). These studies are about the investigation of the effect of this heating method on quality (texture, volume and color) of breads (Keskin et al, 2004a; Demirekler et al, 2004), cakes (Sumnu et al, 2005; Demirkol, 2007) and cookies (Keskin et al., 2005). Breads baked in IR-microwave combination oven had comparable quality with conventionally baked ones in terms of color, textural characteristics, specific volume and porosity (Demirekler et al., 2004). Cakes baked in IR-microwave combination oven had similar color and firmness values with conventionally baked ones (Sumnu et al., 2005).

Some combination heating methods were studied to be an alternative to conventional heating, such as infrared and hot air assisted microwave heating (Datta and Ni, 2002), microwave-hot air combination heating (Kudra et al., 1990; Riva et al., 1991; Lu et al., 1998; Ren and Chen, 1998), and microwave-impingement combination heating (Smith, 1979, 1983, 1986; Walker and Li, 1993; Sumnu et al., 2007). Several patents have been developed to provide surface browning and crispness by adding either hot air circulation (August, 1987; Eke, 1987; Maiellano and Sklenak, 1991; Thorneywork and Jelly, 1994) or infrared heat (Eck and Buck, 1980; Fujii and Tsuda, 1987; Jung and Lee, 1992) to microwaves. These patents do not describe the engineering basics of combination heating processes. Datta and Ni (2002) studied modeling of heat and moisture transport during microwave heating of foods in the presence of infrared or hot air to microwaves. They suggested that the transport processes were modified during microwave heating of foods due to internal pressures developed from evaporation and such pressure-driven flow was affected by the

parameters, such as structure and properties of the food material and microwave power level. When infrared was added to microwave heating, the already complex transport processes were also modified significantly. They demonstrated that the power level and penetration of infrared energy were significant parameters in such a process and they identified the effect of these parameters on transport characteristics in quantitative engineering terms.

1.2 Baking of Bread

The major processing steps of bread manufacture, each of which has equal significance in producing an acceptable end product are dough making, fermentation, and baking (Pomeranz and Shellenberger, 1971).

Dough making step includes:

- mixing of flour and water together with yeast, salt, and other specified ingredients in appropriate ratios, to obtain homogeneous mass,
- development of gluten structure (hydrated proteins) through the application of energy during kneading,
- incorporation of air bubbles within the dough during mixing,
- continued development of gluten structure, referred as ripening or maturing, in order to modify the rheological properties of dough and improve its gas holding capacity (Cauvain, 1999).

In fermentation step, the products of microbial metabolism modify the dough, which are essential for production of light, well aerated, and appetizing bread. Fermentation process includes two main events, which are fermentation of carbohydrates into carbon dioxide, alcohol, and small amounts of other compounds that act as flavor precursors, and modification of the proteinaceous matrix for optimum dough development and gas retention during the baking stage. As fermentation continues, more gas is produced and the gas cells in the

dough become larger and larger. 60% of total gas produced is lost during fermentation, punching, molding and proofing of the dough. After punching, the dough is molded.

Baking is the final and key step in breadmaking, in which the raw dough piece is transformed into a light, porous, readily digestible and flavorful product, under the influence of heat. Bread production requires a carefully controlled baking process to reach the quality attributes required. The parameters having vital influence on final product quality can be summarized as the rate and amount of heat applied, the humidity level in the baking chamber and baking time (Therdthai et al., 2002).

The reactions that take place during baking are film formation, gas expansion, gas solubility reduction, alcohol evaporation, yeast action, carbon dioxide formation, starch gelatinization, gluten denaturation, sugar caramelization and browning. These reactions must take place in order, at the specified temperature, in the correct time and in the proper atmosphere (Matz, 1960).

1.2.1 Changes in starch structure during baking

In the dough stage, starch is in the native form. During processing of bread dough, granule organization and structure of starch change severely through gelatinization during baking and retrogradation during storage of bread.

Native starch granules are insoluble in cold water but, when heated in an aqueous medium, they absorb water and swell. Initially, swelling is reversible but it becomes irreversible as temperature is increased, which result in significant variation in the granule structure. As temperature increases, the starch polymers vibrate vigorously, breaking intermolecular bonds and

allowing their hydrogen bonding sites to engage more water molecules. The penetration of water leads to an increased separation of starch chains resulting in increase in randomness and decrease in number and size of crystalline regions. Continued heating causes complete loss of crystallinity. At this stage the viscosity of the system is very close to that of a near-solid system, since the melting temperature value exceeded. This point is regarded as the gelatinization temperature (Pateras, 1999). The gelatinization temperature of starch is greatly influenced by the binding forces within the granule that varies with granule size, ratio of amylose to amylopectin and species (Zallie, 1988). The term gelatinization refers to the physical changes, such as loss of molecular (double-helical) order, melting of crystallites, granular swelling and disruption and starch solubilization, taking place upon heating of starch in water (Atwell et al., 1988; Biliaderis, 1998; Hug-Iten, 2000). Moreover, the digestibility of starch is improved due to gelatinization (Ranhotra and Bock, 1988).

In a fresh-baked product such as bread or cake, the starch granules are swollen, some of the amylose has migrated into the aqueous phase, and more of the amylose is at the granule surface, as are the portions of some of the amylopectin molecules (Stauffer, 2000). Several factors influence the gelatinization phenomenon, including the presence of water, sugar, fat, proteins, and emulsifiers.

It is known that there is a minimum starch-water ratio in order to achieve complete gelatinization (Biliaderis, 1990). The effect of proteins on starch gelatinization is through forming complexes with starch molecules on the granule surface and preventing escape of exudate from the granules and as a result, increasing gelatinization temperature of starch (Olkku and Rha, 1978).

Sugars also raise gelatinization temperature and delay gelatinization of starch (Spies and Hoseney, 1982; Eliasson, 1992; Kim and Walker, 1992a).

Sugars achieve this by limiting water availability, lowering water activity and forming sugar bridges between starch chains (Kim and Walker, 1992b).

Fats and emulsifiers also retard starch gelatinization by delaying the transport of water into the starch granule through amylose-lipid complex formation (Eliasson, 1985; Kim and Walker, 1992a).

Starch gelatinization is required for producing a baked good with desirable quality. The variation in the rates of moisture loss under microwave baking conditions can result in different degrees of starch gelatinization (Yin and Walker, 1995). This should be taken into consideration while developing microwave baked products.

1.2.2 Problems in microwave baking

Microwave-baked products have some quality problems, such as having dense or gummy texture, crumb hardness and undesirable moisture gradient inside (Bell and Steinke, 1991). One of the reasons for these problems is that physicochemical changes and interactions of major ingredients, which would normally occur over a lengthy baking period in a conventional system, can not always be completed during the short baking period of a microwave system (Hegenbert, 1992). Other reasons may be summarized as specific interactions of each component in the formulation with microwave energy (Goebel et al., 1984).

The biggest difference between convection and microwave ovens is the inability of the microwave ovens to induce browning. 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). Brown surfaces, produced by the Maillard reaction and caramelization of sugars, are a

result of high temperatures accompanied by dehydration (Burea et al., 1987). When the samples are heated in microwave oven for a longer period, they become dry and brittle but never brown. In order to eliminate the crust color problem, Lorenz et al. (1973) emphasized the importance of bread formulation by using relatively dark doughs (rye, whole-wheat). Hybrid or multimedia ovens combining impingement and infrared with microwaves have been introduced so as to overcome the problem related to crustless or unacceptable color of products baked using microwaves (Smith, 1986; Walker and Li, 1993; Keskin et al., 2004a; Sumnu et al., 2007). Susceptors which consist of a metallized plastic film laminated to paperboard on top of which, or within which, the sample is placed and have the property of absorbing microwave energy and converting it to heat, which is transferred to the sample by conduction or radiation can also be used to achieve effective browning and crispness (Zuckerman and Miltz, 1992; Zincirkiran et al., 2002).

The short microwave baking time may also influence flavor development, that the flavor compounds may not be formed as under conventional baking conditions. Different flavor components may be completely volatilized at different rates and in different proportions in microwave heating than in conventional heating. Moreoever, it was also found that different chemical reactions took place during microwave cooking when compared to conventional cooking, resulting in different flavor formation (Sumnu, 2001).

In microwave heating, moisture flows due to concentration and pressure gradients. 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., 1999; Zincirkiran et al., 2002; Seyhun, 2002; Keskin et al., 2004a; Demirekler et al., 2004: Demirkol, 2007).

When bread or bread-like doughs were produced by conventional formulations and then baked in microwave oven, unacceptable textures were obtained (Lorenz et al., 1973; Ovadia and Walker, 1996). It was identified that the exterior parts of the microwave-baked products are rubbery and tough and the interior parts of them are firm and difficult to chew (Shukla, 1993). The firmness problem of bread interiors is associated with the large diameter, preswollen starch granules. Addition of fat and emulsifiers were shown to reduce the firmness of microwave baked breads (Ozmutlu et al., 2001a,b). More amylose was shown to leach out during microwave baking of breads and cakes as compared to conventional baking (Higo and Naguchi, 1987; Seyhun, 2002). This also explained why the initial texture of microwave baked breads was firmer. On the other hand, the interaction of gluten with microwaves has an adverse effect on firmness and toughness of microwave baked breads (Yin and Walker, 1995). Breads with low gluten content baked in microwave oven were found to be softer than the ones with high gluten content (Ozmutlu et al., 2001b).

Breads baked in microwave oven stale faster compared to the ones baked in conventional ovens. This behavior is known as “Higo Effect” (Higo et al., 1983). The Higo Effect 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 contained less bound water than in conventionally heated 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 (Ovadia, 1994). In order to form microwave-baked products with comparable volume, texture and eating quality as those associated with conventionally prepared ones, new

product development is required. Conventional formulations can be improved or a new formulation can be designed by using some additives to solve the problem of toughness or firmness in microwave baked breads. Processing conditions and mechanisms can also be adjusted to decrease the firmness in microwave-baked breads. Combination heating and addition of different food additives, such as gums, emulsifiers, may be alternative solutions to improve the quality of microwave baked products.

1.2.3 Structure of bread

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 their structural organization (McClements, 2007). When it was looked from the structural organization point, bread crumb structure is one of the major quality attributes of bread. The relationship between crumb structure and crumb appeareance may be self-evident, but crumb structure is also a determinant of loaf volume (Zghal et al., 1999), texture (Pyler, 1988) and the taste (Baker, 1939). Therefore, it may be concluded that having knowledge on the structure of breads may be helpful to predict many of the quality properties of bread (Scanlon and Zghal, 2001).

The baking process, which sets the sponge-like crumb texture in bread, creates a hierarchical structure of the gas cells resulting in a wide spectrum of cell sizes, from macro to micro-scale within bread crumb (Liu and Scanlon, 2003).

1.2.3.1 Macrostructure of bread

Quantitative examination, such as determining gas cell sizes and their distribution, can be done by image analysis in providing information on the structural hierarchy within the bread crumb.

Computer vision systems are used for automatic inspection based on camera-computer technology. The aim is to quickly get information about different features of products in relation with their quality. Computer vision is a non-destructive, automated, and cost-effective solution for quality inspection, and is increasingly finding application area in food industry (Aguilera and Germain, 2007). The main advantages of this image analysis technique are the generation of precise descriptive data, the reduction of human involvement in the analysis, its speed and objectivity. Some applications of computer image analysis in characterizing structure properties of foods can be listed as meat, fish, pizza, cheese and bread (Brosnan and Sun, 2004).

Characterization of bread structure using image analysis has been done on bread crumb in the literature (Bertrand et al., 1992; Zghal et al., 2002; Datta et al., 2007). A mathematical method was proposed by Bertrand et al. (1992), to characterize the appearance of bread crumb from 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 for materials having large pores, such as bread, in terms of covering pore sizes outside the range of typical porosimetry apparatus, can be obtained from scanned image based information.

1.2.3.2 Microstructure of bread

Some of the microstructural elements contributing to identity and quality of bakery products can be listed as starch granules, protein assemblies, polymer networks, oil droplets, gas bubbles, etc. (Aguilera, 2005). The forces that act on the microstructural level (below the 100 μm range) are physical interactions (colloidal van der Waals, electrostatic, hydrogen bonding and hydrophobic forces), gravity, electrical forces, mechanical forces (McClements, 2007).

In analyzing microstructure of foods, multiple factors affect the decision in choosing the imaging technique suitable for the particular study. The imaging system determines the kind of information possible to obtain from the samples. The most widely used imaging techniques used in microstructural food research are Light microscopy (LM), transmission electron microscopy (TEM), and scanning electron microscopy (SEM). 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. However, coating the surface of samples with a conductive material (e.g. 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 (cryo scanning electron microscope) and variable-pressure scanning electron microscope (VPSEM), etc.

The variable-pressure SEM (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). Since VPSEM instrument is capable of operating in a

low vacuum mode, an electrically conductive coating does not need to be applied, which is the case in conventional SEM's.

The studies done on the microstructure of bread are limited (Khoo et al., 1975; Pomeranz et al., 1977; Pomeranz et al., 1984; Freeman and Shelton, 1991; Zayas, 1993; Brennan et al., 1996; Hayman et al., 1998; Rojas et al., 2000; Ahmad et al., 2001; Datta et al., 2007). Scanning electron microscopy (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 Khoo et al. (1975), Pomeranz et al. (1984), Freeman and Shelton, (1991), Datta et al. (2007). The effect of composition on microstructure of conventionally baked breads was studied by Pomeranz et al. (1977), Brennan et al. (1996), Hayman et al. (1998), Rojas et al. (2000), Ahmad et al. (2001), Datta et al. (2007) examined the porous structure with four different methods (liquid extrusion porosimetry (LEP), image analysis, volume displacement method and SEM) during baking of breads in novel combination microwave heating ovens to obtain comprehensive and quantitative information on pore characteristics of samples.

1.2.4 Acrylamide

Acrylamide (CH_2=CH-CO-NH_2; 2-propenamide) is a reactive molecule with a molecular weight of 71.08 g/mol. The detection of acrylamide in food by Swedish researchers in April 2002, caused to spotlight this topic worldwide because of its known adverse effects on health and its classification as a probable carcinogen in humans (IARC, 1994; Lingnert et al., 2002). Investigations immediately started to get information about the acrylamide formation mechanism, development of suitable analytical methods to determine it, acrylamide content in foods for exposure estimates and the possible ways for its reduction.

The Maillard reaction was found to be responsible for the formation of acrylamide in heated foods. Recent studies suggested that acrylamide in foods is largely derived from heat-induced reactions between the amino group of the free amino acid asparagine and the carbonyl group of reducing sugars during processing. Bråthen & Knutsen, (2005) demonstrated that, in starch based and cereal systems, asparagine played an important role more than reducing sugars.

Even though the formation of acrylamide in foods is via the reaction between asparagine and reducing sugars, there are also other minor suggested routes, which can be seen in Figure 1.4.

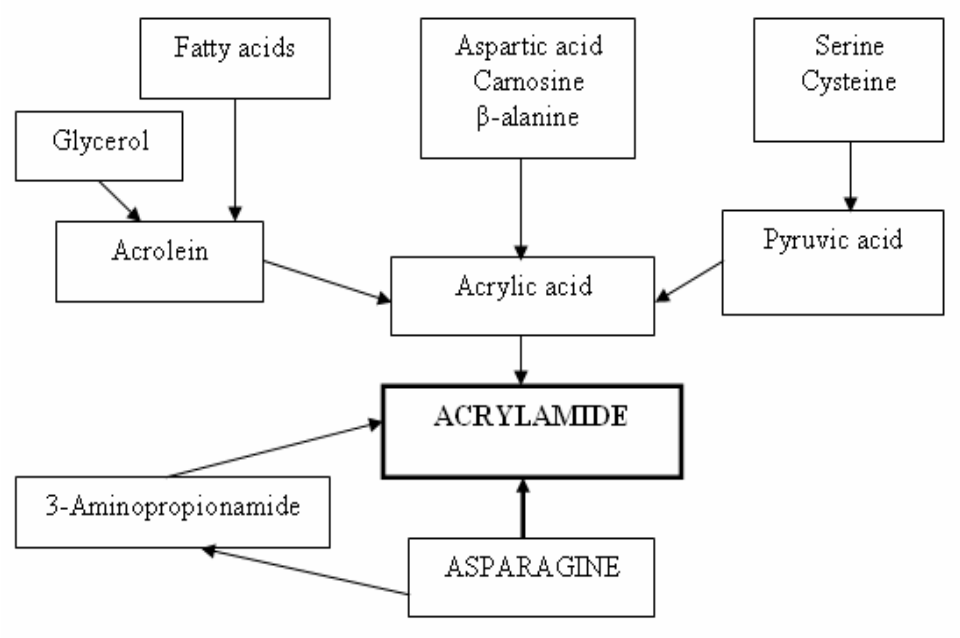

Figure 1.4 Formation routes of acrylamide (Adapted from Eriksson, 2005)

Acrolein is suggested to be formed from dehydration of glycerol when animal and vegetable fats are heated (Umano and Shibamoto, 1987). Moreover, it is found to be produced by polyunsaturated fatty acids in lipid oxidation processes. The possible formation routes of acrylamide through acrolein has been proposed by Yasuhara et al. (2003) in oil and fats.

Amino acids, such as aspartic acid, carnosine, and β-alanine can go through acrylic acid during their thermal decomposition in combination with available ammonia to produce acrylamide (Stadler et al., 2003; Yaylayan et al., 2004; Yaylayan et al., 2005).

3-aminopropionamide was first identified as a transient intermediate product during acrylamide formation from asparagine (Zyzak et al., 2003) and it was found to be a very effective precursor of acrylamide formation under certain reaction conditions (Eriksson, 2005). Additionally, 3-aminopropionamide can be formed in reactions between asparagine and pyruvic acid (Stadler et al., 2004).

The proposed pathway for acrylamide formation through pyruvic acid may be reduction of pyruvic acid into lactic acid, and further dehydration into acrylic acid (Eriksson, 2005). In model studies with lactic acid it was demonstrated that such transformations were possible in the presence of ammonia. Mixtures of lactic acid and ammonia salts produced lactamide, acrylic acid and acrylamide when pyrolyzed (Yaylayan et al., 2005).

Bread crust, crisp bread, and various bakery products and cereal formulations are the widely consumed processed foods with high acrylamide contents. However, because of variations in the amount of precursors present and the processing conditions (e.g., temperature, time, nature of food matrix), wide variations in acrylamide content of products were observed in different food categories as well as in different brands of the same food category (Zhang et al., 2005).

Although bread contains trace amount of acrylamide (in the low part per billion range) it may contribute significantly to the overall dietary intake significantly due to its high consumption (Taeymans et al., 2004; Grob, 2007).

There have been various studies in recent years, aiming to investigate and to decrease acrylamide formation in bread (Fredriksson et al., 2004; Surdyk et al., 2004; Brathen and Knutsen, 2005; Bråthen et al., 2005; Mustafa et al., 2005; Claus et al., 2006; Ahrne et al., 2007). Fredriksson et al. (2004) examined the effect of raw material, fermentation time, flour particle size and sourdough content of doughs in reducing free asparagine during dough making. They suggested that prolonged yeast fermentation reduced free asparagine in dough and acrylamide content in bread. Surdyk et al. (2004) investigated the effects of asparagine and fructose on acrylamide content of yeast leavened white bread. They found that the increase in baking temperatures, mainly above 200 °C, and baking time caused an increase in acrylamide content in crust. Significant correlation between color and acrylamide content in crust was observed at different baking conditions with constant recipe. Additionally, they found that although the addition of asparagine increased acrylamide content, it did not affect the color of breads. Brathen and Knutsen (2005) studied the effects of baking time and temperature on acrylamide formation in dry starch systems, freze-dried rye based flat bread doughs, flat bread and breads. They found that acrylamide content of bread crusts increased with both baking time and temperature in the interval they studied. Brathen et al. (2005) reported that glycine addition to the formulation significantly reduced the acrylamide in both flat breads and bread crusts. Mustafa et al. (2005) examined the effect of addition of acrylamide precursors (fructose, asparagine) and oat-bran concentrate on acrylamide and color of whole grain rye crisp breads. They described that while added asparagine had a significant effect on acrylamide formation in rye bread, added fructose and oat-bran concentrate did not influence acrylamide content. Claus et al. (2006) suggested that lowering the pH of dough, by adding consumable acids, such as citric acid or by lactic acid fermentation, as applied during sourdough preparation, may be one possible way to reduce acrylamide content in bread. Ahrne et al. (2007) investigated the effect of crust temperature and water content on acrylamide formation during baking of white bread. They found that crust temperature together with water

content affected the acrylamide formation in bread crusts significantly and higher temperatures caused high acrylamide content. However, at very high temperatures and lower water contents they observed a decrease in acrylamide content of crusts with unacceptable color.

Recently, a great number of methods have been developed to quantify the acrylamide in foodstuffs. Classical methods based on HPLC or GC technique alone were found to be not sufficient to quantify the acrylamide in heat-treated foods at trace levels, such as bread, because of the complexity of food matrices. For this reason, acrylamide determination methods used in the studies are mainly based on MS as the determinative technique, coupled with a chromatographic step either by LC or GC with and without derivatization of the analyte (Zhang et al., 2005). Ros´en and Hellenas (2002), firstly reported the analysis of acrylamide in different heat-treated foods using the isotope dilution LC–MS technique. The choice as being LC–MS is due to the hydrophilic properties of acrylamide, and MS for its high selectivity (Zhang et al., 2005).

1.3 Staling of Bread

Bread staling refers to all changes that occur in bread after baking. Staling makes the product less acceptable to a consumer. Although different approaches have been brought up to clarify the staling mechanism and to prevent it, the phenomenon of staling is still not completely understood (Stampfli and Nerste, 1995). When it was contemplated from the economical point of view, staling has considerable economic importance for the baking industry since it limits the shelf life of baked products (Maarel et al., 2002).

Characterization of bread and starch-gel systems from macro- to nanoscale as illustrated in Figure 1.5 is required to obtain information about the staling mechanism. Different mechanical, microscopic and physicochemical

methods were applied by many researchers to display the staling mechanism clearly.

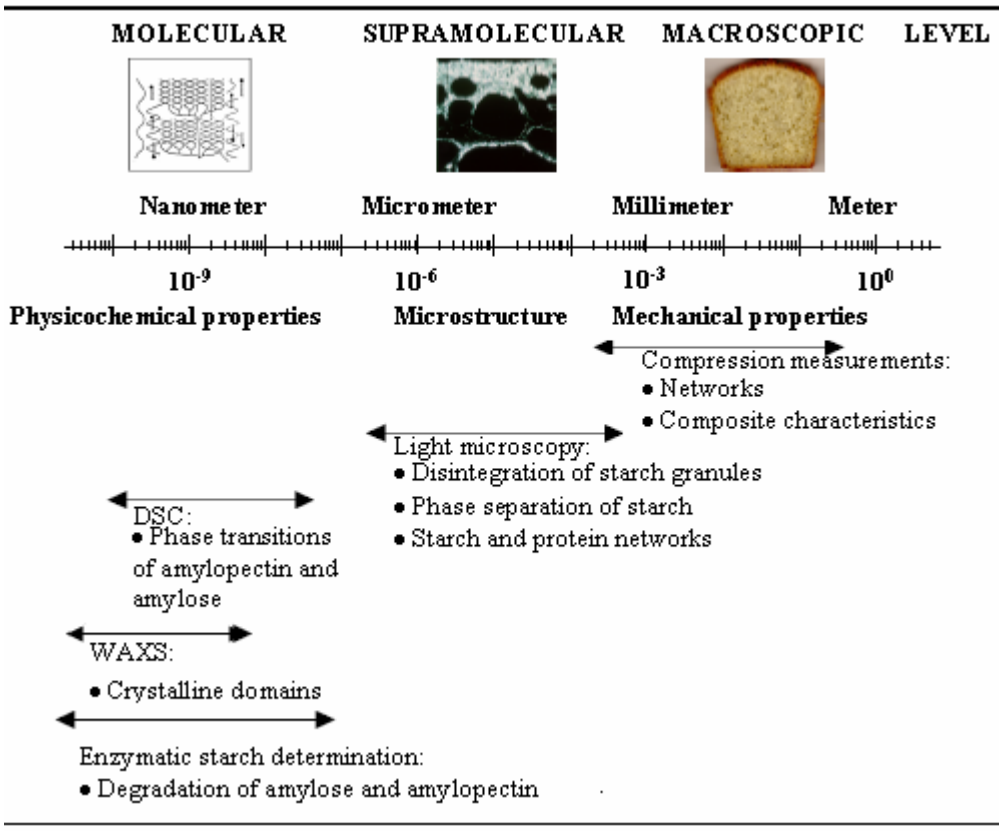

Figure 1.5 Overview on characterization of structures of starch in bread and bread model systems from macro- to nano- scale (Adapted from Hug-Iten, 2000)

When investigating the staling phenomena considering macroscopic, microscopic and molecular levels, the mechanical properties, microstructure and physicochemical properties have been measured respectively, by the help of compression measurements, microscopic monitoring methods SEM, DSC and X-ray analysis (Hug-Iten, 2000).

Bread staling is a very complex process that cannot be explained by a single effect. It involves amylopectin retrogradation, reorganization of

polymers within the amorphous region, loss of moisture content, distribution of water between the amorphous and crystalline zone (Martin and Hoseney, 1991; Martin et al., 1991). Changes occur in both crumb and crust of the bread (D'Appolonia and Morad, 1981). Stampfli and Nerste (1995) emphasized that consumers associate staling with some typical sensorial changes in the bread such as loss of flavor, loss of crispness in the crust, increased crumbliness and crumb firmness.

Bread crumb firming is probably the change most widely associated with staling. Studies on bread staling demonstrated that changes in starch structure, such as gelatinization and retrogradation of starch, contribute to firm texture (Bloksma and Bushuk, 1988).

Schoch and French (1947) proposed a model that describes bread staling through gradual association of amylopectin within the swollen granules. They suggested that amylose quickly associated in bread immediately after baking, affecting initial firmness, but played no further role in crumb firming. On the other hand, according to Ghiasi et al. (1984), firming was not solely a result of amylopectin retrogradation. Factors other than amylopectin retrogradation have been considered as possible contributors to bread staling. It was suggested that bread staling may be due to progressive cross binding between protein and swollen residues of starch granules, mediated by amylose molecules leached out during baking (Martin, 1989; Martin et al., 1991; Martin and Hoseney, 1991). Similarly, Inagaki and Seib (1992) found that firming occurred even when the starch contained no amylose and therefore, they proposed that interaction between swollen starch granules and the gluten matrix might occur during aging of bread. Overall, Zobel and Kulp (1996) concluded that the proteins act as diluent of the starch component and the basic firming mechanism is caused by the increase of order in starch fraction.

It is necessary to understand the staling mechanism of breads baked in microwave oven. It has been shown that the staling rate of microwave baked breads and cakes were higher than conventionally baked ones (Keskin, 2003; Seyhun et al., 2003).

1.3.1 Changes in starch structure during staling

Gelatinized starch mixtures exist in forms of gels. During storage, crystalline aggregates increase gradually resulting from the breaking of hydrogen bonds between amylose molecules. These amylose molecules, through their linearity, reassociate into a more orderly form constituting new hydrogen bonds, which is refered as "retrogradation" (Zallie, 1988; Mc Williams, 1989). The reason of emphasizing retrogradation phenomenon is due to its effects on quality, acceptability and shelf-life of starch-containing foods (Biliaderis, 1991).

There are different approaches in explaining the staling phenomenon in terms of starch retrogradation. The most common one is that amylopectin retrogradation is part of the staling process and thus, there is a correlation between amylopectin retrogradation/recrystallization and staling, but amylopectin retrogradation is not solely responsible for the observed changes in texture (Gray and Bemiller, 2003).

Starch retrogradation is mostly affected by two factors: temperature and moisture content of the baked product (Stauffer, 2000). Retrogradation is negatively correlated with temperature that it accelerates as temperature decreases. Reheating might partially reverse starch retrogradation but when cooled again, it was seen that the rate of retrogradation increased (Cauvain, 1998). Studies showed that starch retrogradation slowed down when the moisture content of the starch gel was high (Stauffer, 2000).

Starch retrogradation, or partial recovery of the ordered structures, takes place on cooling and during aging. It is known that retrogradation involves two distinct events; gelation of amylose solubilized during gelatinization and amylopectin recrystallization within the gelatinized granules. Amylose gelation covers a rapid network development, occurring in less than one day, via chain entanglement; while amylopectin is responsible for slow development of the crystallinity in the polymer-rich regions, which may continue for weeks (Leon et al., 2006). These mechanisms are important because retrogradation is thought to be the main reason for staling of bakery goods. The gelation of amylose is followed by a slow crystallization in the B-type form (Ring, 1987). Similarly recrystallized amylopectin structures also show a B-type pattern in contrast to native wheat starch, where crystalline amylopectin is ordered in the A-type form (Miles et al., 1985). Thus, no differences are found between amylose and amylopectin regarding the crystalline pattern after retrogradation. During baking, amylose forms complexes with endogenous wheat lipids as well as added lipids, showing a V-type pattern (Zobel, 1988).

1.3.2 Methods for measuring staling

The most obvious attribute of staling of baked goods is crumb firming. A correlation coefficient of 0.98 was found between firmness level and taste panel assessment of staleness, validating the use of firmness to monitor staling (Axford et al., 1968). Firmness or rigidity of the product increases markedly with the retrogradation of starch (Collison, 1968). Firmness of breads and cakes can be quantified by compressing the sample and measuring the force necessary to attain a predetermined penetration. As the staling increases, the force required to compress the product increases, therefore, a relationship between firmness and storage time may be developed (Gil et al., 1999).

Instrumental texture profile analysis (TPA) has been widely adapted to the study of starch retrogradation in actual food and model starch gel systems.

In a TPA test, a sample of specific dimensions is compressed uniaxially. Several parameters may be obtained from TPA tests, such as hardness, fracturability, stickiness, etc. (Karim et al., 2000).

The tendency of a starch to retrograde can also be studied from its pasting behaviour, usually by observing changes in viscosity using a variety of instruments including Brabender Amyloviscograph (Karim et al., 2000) and Rapid Viscoanalyser (Karim et al., 2000; Patel et al., 2005). Viscosity curves are used as fingerprints of the hydration and cooking characteristics of starchy materials. Changes in viscosity profiles give idea about the effect of new processes on starch properties. They are extremely useful in measuring variation among starch-based ingredients, and can be used to indicate changes in retrogradation during baking, drying, frying and other unit operations. Staling of products is related to amylopectin retrogradation and can be followed by viscosity changes (Huang and Rooney, 2001). D' Appolonia and Morad (1981) demonstrated that viscosity changes resembled firming curves and other measures that have been related to starch crystallization. Moreover, it was stated that viscosity measurements can also be used to determine the effects of other ingredients in the formula on cooking and hydration properties (Huang and Rooney, 2001). Rapid Visco^{TM} Analyser (RVA) is a computer-integrated mixer viscometry developed to determine the viscous properties of cooked starch, grain, batter and other foods. It consists of a molded plastic stirring paddle attached to an electric motor whose shaft rotates at constant speed and the current required to drive it is constantly monitored by a microprocessor, where the apparent viscosity of samples is continuously measured under variable conditions of shear and temperature.

Among the thermoanalytical methods, differential scanning calorimetry (DSC) has proven to be most useful one in providing basic information on starch retrogradation (Karim et al., 2000). In the case of retrograded starch, the value of ΔH (retrogradation enthalpy) provides a quantitative measure of the

energy transformation that occurs during the melting of recrystallized amylopectin as well as precise measurements of the transition temperatures of this endothermic event (Karim et al., 2000). Endothermic peak temperatures vary from about 50°C to 60°C, depending on the storage temperature, starch concentration, and aging times (Zobel and Kulp, 1996). There are various studies on measuring starch retrogradation in bread by the help of DSC analysis. Some of them are Fearn and Russell, (1982); Zeleznak and Hoseney, (1986); Czuchajowska and Pomeranz, (1989); Schiraldi et al (1996); Leon et al (1997); Jagannath et al (1998); Defloor and Delcour, (1999); Hug-Iten, (2000); Rasmussen and Hansen, (2001); Barcenas et al (2003); Ribotta et al (2004); Barcenas and Rosell., (2006); Katina et al (2006); Patel et al (2005); Primo-Martin et al (2007), but there is no DSC study on retrogradation of starch in breads baked in microwave and IR-microwave combination oven.

Soluble starch of the samples can also be used as staling indicating parameters (Kim and D' Appolonia, 1977; Morad and D' Appolonia, 1980; Giovanelli et al., 1997, Seyhun, 2002). Morad and D' Appolonia (1980) stated that the amount of soluble starch decreased as storage time increased.

The ordering of the starch fraction was followed by different methods in terms of molecular level. One of the methods is the X-ray diffraction technique, where extensive information on the role of starch in bread staling has been obtained (Dragsdorf and Varriano-Marston, 1980; Varriano-Marston et al., 1980; Pisesookbunterng et al., 1983; Zeleznak and Hoseney, 1987; Hug-Iten, 2000; Ribotta et al., 2004). Starch in freshly baked bread is mostly amorphous but slowly recrystallizes during storage. Changes in crystallinity during aging are shown in the X-ray diffraction patterns (Karim et al., 2000). Crystallization of amorphous starch into B-type crystalline structure is observed during bread aging. V-type crystalline structure which is the indicative of amylose complexing with fatty acids, remains unchanged during storage (Leon et al., 2006). The A-type crystal contains 8 water molecules,

whereas the B-type crystal contains 36 water molecules. As a result, in breads amylopectin recrystallization forms B-type crystalline regions and the crumb is firmer because more water has migrated into the crystalline region. Since water participates in crystal formation, the plasticizing effect of water in starch-gluten matrix is no longer available, resulting in firmer bread and drier mouth feel (Slade and Levine, 1987). On the other hand, it was stated in the literature that in the case of bread, changes in crystallinity of the starch component may not necessarily parallel the development of firmness associated with staling since the different types of crystals influence the distribution of water within the crumb differently (Dragsdorf and Varriano-Marston, 1980; Zobel and Senti, 1959).

Non invasive methods of Fourier Transform Infrared (FTIR) spectroscopy and Near-infrared (NIR) spectroscopy have been also used to monitor staling in bread (Wilson et al., 1991). FTIR spectroscopy measures the degree of short-range ordering in a system. Conformational changes brought by starch retrogradation can be monitored by analyzing the band-narrowing, which is caused by a reduction in the range of conformations and smaller distribution of bond energies since the system becomes more ordered upon staling (Wilson et al., 1991; Karim et al., 2000). The spectral region 1200-800 cm^{-1} has been shown to be sensitive to the degree of molecular order in starch (Ottenhof et al, 2005). The modification with ageing of the absorption values in this spectral region, consisting in the variation of the relative intensities of overlapped bands at ~ 1000 cm^{-1}, has been observed by other researchers (Cocchi et al., 2005), relating it to the progressive ordering of the amylopectin polymer present in bread. Peaks at 1047 cm^{-1} are related to crystalline regions of starch (Karim et al., 2000).

NMR is based on the ability of nuclei with magnetic dipole moments to absorb electromagnetic energy (Vodovotz et al., 1996). NMR has long been used in the study of water in foods and other biological materials. The

technique most frequently applied to the study of food systems is low resolution ^{1}H NMR which is capable of elucidating physical structure from analysis of the NMR decay signal (Ablett, 1992). As bread stales, starch changes from amorphous state to the more stable crystalline state. During storage, the solid-like signal is gradually increased with storage time (Karim et al., 2000). Moreover, the molecular mobility during storage of the bread system is also determined by the NMR techniques (Vodovotz et al., 1996; Kulik and Haverkamp, 1997). The dynamic state of water is a further important factor in the staling process (Kulp and Ponte, 1981). Recently, NMR has been applied to study changes in mobility and micro-distribution of water during staling (Leung et al., 1983; Kim-Shin et al., 1991; Chen et al., 1997).

1.3.3 Retardation of staling of breads

Strategies, in commercial bread production, to extend bread freshness can be summarized as formulation modifications, variation of production parameters and use of various processing methods (Zobel and Kulp, 1996). The mostly used strategy in retarding the staling of breads is modification of formulation.

Ingredients have different effects on bread staling, such as emulsifiers, sugars, shortening, enzymes and gums. But since bread is a complex medium and all the ingredients interact with each other, it is difficult to estimate their specific effects on bread texture. Maleki et al. (1981) investigated the effects of emulsifiers, sugar and shortening levels on the staling of bread. Many researchers have shown that monoglycerides of higher fatty acids are effective softening agents for bread (Bechtel, 1955).

Different enzymes are currently added to the bread making process for improving dough handling, fresh bread quality and also the shelf life (Haros et al., 2002; Keskin et al., 2004b). α-amylases have been found to be effective in

reducing staling by many researchers (Martin and Hoseney, 1991; Akers and Hoseney, 1994). Xylanases were found to have an anti-staling action during bread storage (Haros et al., 2002). It has been observed that addition of specific lipases in combination with triglycerides also improves loaf volume, crumb softness and staling rate (Gil et al., 1999). Keskin et al. (2004b) demonstrated that all of the enzymes (fungal α-amylase, xylanase, lipase, protease) were effective in reducing the initial firmness and increasing the specific volume of breads baked in microwave and IR-microwave combination ovens. However, in conventional baking, it was seen that the enzymes on crumb firmness were mostly effective during storage.

Starches, either native or modified, have been applied to improve food texture and to retard firming after storage (Moore et al., 1984). The effects of starches on retarding the firming of breads have been investigated by several researchers (Johnson and Miller, 1959; Jankowski and Jankiewiez, 1961; Herz, 1965; Moore et al., 1984; Snyder, 1984).

The softening effect of hydrocolloids should be attributed to their water retention capacity, a possible inhibition of the amylopectin retrogradation, and in consequence prevention of starch-gluten interactions (Guarda et al., 2004). Hamer (1995) demonstrated that hydrocolloids like xanthan and guar gums retarded firming. Use of gums (xanthan gum, guar gum and methylcellulose (MC)) retarded staling of microwave-baked cakes (Seyhun et al., 2003). The effect of hydrocolloids (sodium alginate, κ- carrageenan, xanthan gum and hydroxypropyl methylcellulose (HPMC)) on fresh bread quality and bread staling were studied by Guarda et al (2004) and they found that bread quality was improved with the usage of these hydrocolloids. In addition, all hydrocolloids were found to be effective in reducing the loss of moisture content during storage.

The baking temperature of breads has been shown to affect bread staling (Giovanelli et al., 1997). The staling rate was lowered by decreasing the baking temperature both in terms of crumb hardening and starch retrogradation.

1.4 Gums

Hydrocolloids are water-soluble polysaccharides with high molecular weights (up to 1 million). Gums act as texture improvers, emulsifiers, fat reducers, binding agents, film formers, stabilizers, shelf-life extenders (Gurkin, 2002). Since they can function at very low concentrations, their use may be helpful to achieve cost reductions and their properties make them suitable for use in a wide variety of applications in the food industry (Ward and Andon, 2002). In addition, hydrocolloids are edible, biodegradable, high in soluble dietary fiber, and readily available in natural or unmodified versions. Synergies between hydrocolloids enable to improve or create modified functional properties by using two or more gums together (Ward and Andon, 2002). The function of the gum is very application-sensitive. The function of gums in some applications may be successful, while it may not be effective in other applications (Heflich, 1996).

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).

Gums have been widely used in food industry in order to increase moisture retention and to improve food texture (Armero and Collar, 1996a, 1996b), slow down the retrogradation of the starch (Davidou et al., 1996; Smith et al., 2004), extend the overall quality of the product (Rojas et al., 1999).

Gums are used in baked goods primarily to enhance final product moistness. The gums (guar, xanthan, agar, pectin, etc.) absorb several times their weight in water (up to 6 x). However, the overall increase in dough water absorption due to the addition of a gum is relatively small because of being used at low amounts (typically from 0.01 % to 0.5 % total formula basis). The additional water may be insignificant, but the viscous, slippery mouth feel that the gums retain even after baking can be perceived as a beneficial increase in product moistness (Heflich, 1996).

The gums can make the baked crumb rubbery and elastic. This may be perceived as softer or fresher at sufficiently low levels, and also as tough or chewy at elevated levels (Heflich, 1996).

Some of the gums (for example, agar and pectin) are not preferred to be used in dough formulations because of their cost. Xanthan and guar can sufficiently function at very low levels to be cost-effective. Guar is functional at levels of 0.1-0.35 % total formula basis and may cause a rubbery crumb at the high level in some products. The use of guar is restricted to 0.35% total basis in baked goods by the FDA (U.S. Code of Federal Regulations, 21: 184.1339) (Heflich, 1996).

Gums are considered to be soluble dietary fiber and have low caloric value (0 to 2 calories per gram) due to partial metabolism by microorganisms in the human intestine. Aside from its excellent thickening properties, guar gum has been reported to help reducing LDL cholesterol (Wilson et al., 1998). Many other hydrocolloids (e.g., locust bean gum, gum arabic, xanthan gum, pectin, konjac mannan) have been denoted to reduce blood cholesterol levels and others (e.g., inulin, gum arabic) have been denoted to have prebiotic effects (Williams and Phillips, 2005).

Diverse studies have shown that the use of hydrocolloids in breadmaking produces a significant improvement in the bread quality (Rao et al., 1985; Mettler et al., 1992; Mettler and Seibel, 1993; Armero and Collar, 1998; Rosell et al., 2001, Barcenas et al., 2004; Guarda et al., 2004). The hydrocolloids are added to bakery products for improving their shelf life by keeping the moisture content and retarding the staling (Twillman and White, 1988; Davidou et al., 1996; Collar et al., 1999; Rojas et al., 1999).

There are studies in literature about the effects of different hydrocolloids on quality of conventionally baked breads (Rosell et al., 2001; Azizi and Rao, 2004; Guarda et al., 2004; Ribotta et al., 2005). Rosell et al (2001), investigated the effects of different hydrocolloids (sodium alginate, κ-carrageenan, xanthan gum and HPMC) on the final quality of breads. They demonstrated that hydrocolloids increased the specific volume, except alginate, as well as moisture retention and water activity. Azizi and Rao (2004) studied the effect of surfactants (sodium stearoyl-2-lactylate; distilled glycerol monostearate; glycerol monostearate; diacetyl tartaric acid esters of monoglyceride) and gums (xanthan, guar, karaya, locust bean gum) on dough rheology and quality of bread. They found that gums in combination with surfactants improved bread quality. When gums were used alone, it was seen that the improvement in quality of breads in terms of texture and specific volume was statistically insignificant. The effect of hydrocolloids (sodium alginate, κ- carrageenan, xanthan gum and HPMC) on fresh bread quality and bread staling were studied by Guarda et al (2004), and it was found that bread quality was improved with the usage of these hydrocolloids. Additionally, they found that all hydrocolloids were able to reduce the loss of moisture content during storage. Ribotta et al (2005) investigated the effects of hydrocolloids (low molecular weight sodium alginate, carob gum, guar gum, xanthan gum, high metoxyl pectin and carrageenan isoforms) on bread quality and demonstrated that all hydrocolloids decreased the initial bread crumb firmness and chewiness. The effects of gums (xanthan and guar) at different

concentrations on fresh and frozen microwave-reheated breads were studied by Mandala (2005). It was seen that both hydrocolloid type and concentration influenced the physical properties and final quality of the fresh bread samples in a different extent. Gavilighi et al (2006), examined the effect of hydrocolloids (guar gum, xanthan gum, locust bean gum, carboxymethylcellulose) on staling of bread (Lavash bread). They found that all gums used in the study decreased staling rates and improved quality of bread samples.

1.4.1 Xanthan gum

Xanthan gum is a polysaccharide derived from *Xanthomonas campestris*, a bacterium commonly found on leaves of plants of the cabbage family (BeMiller and Whistler, 1996). Xanthan gum has a β-D-glucose backbone like cellulose, but every second glucose unit is attached to a trisaccharide consisting of mannose, glucuronic acid, and mannose (Figure 1.6).

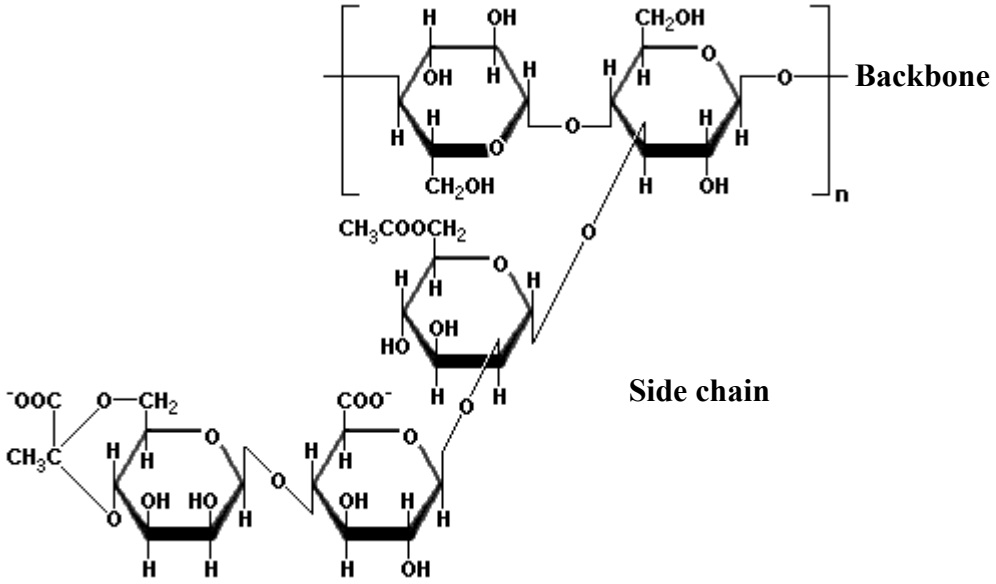

Figure 1.6 Structure of repeating unit of xanthan gum (BeMiller and Whistler, 1996)

Xanthan solutions display unique rheological properties and excellent mechanical, chemical and enzymatic stability, solubility in hot or cold water; high solution viscosity at low concentrations, solubility and stability in acidic systems, stable solution viscosity at temperature range from 0 to 100 °C may be some examples to its superior properties.

It is used as a thickening agent or as a stabilizer in food applications (BeMiller and Whistler, 1996). In addition to these, xanthan is used to improve quality (Rosell et al., 2001; Guarda et al., 2004; Mandala, 2005; Ribotta et al., 2005; Gavilighi et al., 2006) and to extend shelf-life (Guarda et al., 2004; Gavilighi et al., 2006) of breads baked in conventional ovens. In another study by Turabi et al. (2008), it was found that addition of xanthan gum to the formulation increased the apparent viscosity of cake batter and prevented collapse of the cakes baked in IR-microwave combination oven.

1.4.2 Guar gum

Guar gum is an important low-cost thickening polysaccharide for both food and non food applications. It has many uses as a food stabilizer, and as a source of dietary fiber. It is a cold-water soluble, nonionic, and salt-tolerant natural polysaccharide. Guar gum produces the highest viscosity of any natural, commercial gum. It is the ground endosperm of seeds from guar plant (*Cyamopsis tetragonoloba*). The main component of endosperm is a galactomannan. Galactomannans consist of a main chain of β-D-mannopyranosyl units joined by 1,4 bonds with single unit α-D-galactopyranosyl branches attached at O-6. The specific polysaccharide component of guar gum is guaran (Figure 1.7). In guaran, about one half of the D-mannopyranosyl main chain units contain a D-galactopyranosyl side chain (BeMiller and Whistler, 1996).

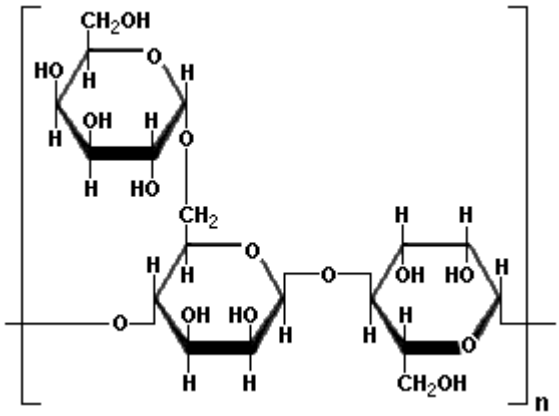

Figure 1.7 Guaran, specific polysaccharide component in guar gum (BeMiller and Whistler, 1996)

Guar gum is an excellent additive in salad dressings, ice cream mixes and bakery products because of its strong hydrophilic character (Berk, 1976). Guar gum was shown to improve quality of breads (Mandala et al. (2005),

Ribotta et al. (2005), and Gavilighi et al. (2006)). Additionally, Gavilighi et al. (2006) used it in retarding staling of Lavash breads.

Guar gum interact synergistically with xanthan. 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 intermolecular binding between xanthan and galactomannans suggests that destabilization of the xanthan helix facilitates xanthan and galactomannan binding (Cheetham and Mashimba, 1988, 1991). It was demonstrated by the researchers 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 results obtained in a recent study by 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. It was concluded by Wang et al (2002) that the stability of xanthan helical structure or xanthan chain flexibility played a critical role in its interaction with guar. Another model assumed that regularly substituted mannan chains with galactose units located on one side of the backbone are linked with the xanthan backbone. This model does not rule out the former model (the association of unsubstituted regions of galactomannan with the backbone of the xanthan helix) but provides an explanation for the interactions of xanthan with highly substituted galactomannans like guar gum (McCleary, 1979; McCleary et al., 1984; Schorsh et al., 1997). On the other hand, Bresolin et al (1997) reported that there were strong interactions between xanthan (whatever its conformation) and totally substituted galactomannan backbone, assuming different mechanisms were involved between the two polysaccharides. In another study by Schorsch et al (1997), the influence of 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 provided evidence that xanthan gum played a major role in the rheological behaviour of xanthan/galactomannan systems. They said that differences in the mechanism may exist according to the mannose/galactose ratio, xanthan/galactomannan ratio and the ionic strength.

1.4.3 Gum κ- carrageenan

The term carrageenan denotes a group or family of sulfated galactans extracted from red seaweeds. Carrageenans are linear chains of D-galactopyranosyl units joined with alternating (1,3)-α-D- and (1,4)- β-D-glycosidic linkages, with most sugar units having one or two sulfate groups esterified to a hydroxyl group at carbons 2 or 6 (BeMiller and Whistler, 1996). This gives a sulfate content ranging from 15 to 40%. Units often contain a 3,6-anhydro ring. The principal structures are termed kappa (κ) (Figure1.8), iota (ι), and lambda (λ). Carrageenans, as extracted, are mixtures of nonhomogeneous polysaccharides.

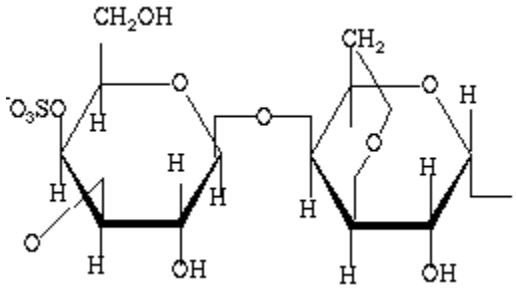

Figure 1.8 Idealized unit structure of κ- carrageenan (BeMiller and Whistler, 1996)

Highly viscous solutions can be obtained with carrageenan when added to the formulation. The synergistic effect between kappa-carrageenan and

locust bean gum was given in literature (BeMiller and Whistler, 1996). The combination of them produces rigid, brittle, syneresing gels.

The traditional uses for carrageenan are water gels and dairy applications, such as milk gels, frozen desserts, processed cheese, etc. (Imeson, 2000). Gum carrageenan has been studied for their effectiveness in frozen doughs (Sharadanant and Khan, 2003a, 2006) and has shown promising results in refrigerated cereal products, such as tortillas (Gurkin, 2002). Addition to these application areas, it can be used in improving quality and decreasing staling rate of breads (Rosell et al., 2001; Sharadanant and Khan, 2003b; Guarda et al., 2004; Ribotta et al., 2005).

1.4.4 Locust bean gum

Locust bean gum (LBG, also called carob gum, obtained from carob tree (*Ceratonia siliqua*), is a galactomannan as guar gum, having fewer branch units than does guar gum. Its structure is more irregular, and can form junction zones with its long "naked chain" sections (BeMiller and Whistler, 1996). LBG interacts with xanthan and carrageenan helices to form rigid gels.

The general use of locust bean gum (LBG) is in dairy and frozen dessert products. It is rarely used alone, but in combination with other gums, such as carboxymethylcellulose (CMC), carrageenan, xanthan, guar gum (BeMiller and Whistler, 1996). The other application area for locust bean gum is its use in baking studies to obtain improvement in quality of frozen doughs (Sharadanant and Khan, 2003a; 2006), breads (Azizi and Rao, 2004) and cakes (Gomez et al., 2007) and to extend shelf-life of breads (Sharadanant and Khan, 2003b; Gavilighi et al., 2006) and cakes (Gomez et al., 2007). Sharadanant and Khan (2003a) demonstrated that addition of locust bean gum to the formulation improved frozen dough quality. In another study by Azizi and Rao (2004), it was seen that locust bean gum addition in combination with surfactant gels to

the formulation improved the bread making quality of wheat flour to a maximum extent. On the other hand, Turabi et al. (2008) demonstrated that locust bean gum addition to the cake formulation did not provide improvement in specific volume of cakes. When the effects of gums (guar, xanthan, carboxymethylcellulose, and locust bean gum) on staling rate of Lavash breads were studied, locust bean gum addition resulted in highest retrogradation enthalpies which meant no improvement in retarding staling (Gavilighi et al., (2006)).

1.4.5 Hydroxypropyl methylcellulose

Hydroxypropyl methylcelluloses (HPMC) are made by reacting alkali cellulose with both propylene oxide and methyl chloride. They are cold-water soluble because of the presence of hydroxypropyl ether groups along the chains preventing the intermolecular association characteristic of cellulose (BeMiller and Whistler, 1996). Methylcelluloses, because of the ether groups, can easily stabilize emulsions and foams. They can also be used to reduce the amount of fat in food products via providing fat-like properties or reducing absorption of fat in fried products. Moreover, similar to other gum types (xanthan, guar, carrageenan, locust bean gum), hydroxypropyl methylcelluloses (HPMC) can be used in improving quality (Rosell et al., 2001; Guarda et al., 2004) and retarding staling (Guarda et al., 2004) of breads.

1.5 Objectives of the Study

The objective of this study was to determine the effects of different gums (guar, xanthan, κ- carrageenan, hydroxypropyl methylcellulose (HPMC), locust bean gum (LBG)) and their combination on the quality and staling of breads baked in different ovens (microwave, IR-microwave combination and conventional). It was also aimed to study the bread staling mechanism during microwave and IR-microwave combination baking.

Since crumb firmness and weight loss of breads baked in microwave and IR-microwave combination oven were found to be higher as compared to that of conventionally baked ones in previous studies (Keskin et al., 2004a), in this thesis, it was aimed to minimize this problem by modifying the bread formulation with the addition of different gums. The quality parameters and pore characterization of breads formulated with different gums baked in IR-microwave combination oven have not been studied yet.

Dielectric and thermal properties are the physical properties of food that affect the heating behaviour of the product during microwave baking. This may be helpful in understanding the microwave heating patterns of foods. In this research, the effects of different gums on dielectric and thermal properties of bread doughs and breads baked in IR-microwave combination oven were studied, since there are no studies about this topic in literature.

The detection of acrylamide in food by Swedish researchers in April 2002, caused to spotlight this topic worldwide because of its known neurotoxic and carcinogenic effects. Since food safety and consumer health are the most important concerns, the safety of finished product processed with novel technologies, such as microwave assisted combination baking, should be considered seriously. Data on acrylamide formation during microwave and IR-microwave combination baking are not available in literature. Therefore, in this study, it was aimed to investigate acrylamide formation during microwave, IR-microwave combination baking of breads and compare them with conventionally baked ones.

The staling mechanism in microwave baked products is not clear. Although, it is shown that microwave baked products stale faster than conventionally baked ones, there is no study in literature on investigation of staling of breads baked in IR-microwave combination oven. Since staling has considerable economic importance for the baking industry, it is important to

concentrate on this subject. In order to understand staling mechanisms of breads baked in microwave and IR-microwave combination ovens, degree of starch retrogradation in breads baked in these ovens was investigated by various methods (moisture content, hardness, soluble starch, DSC, RVA, X-ray, FTIR analysis).

CHAPTER 2

MATERIALS AND METHODS

2.1 Materials

Bread flour containing 30 % wet gluten, 13.5 % moisture and 0.54 % ash was obtained from Murat Un A.Ş. (Ankara, Turkey). Sugar, milk powder, salt, yeast, margarine were supplied from a local market. The gums used were guar gum (Guar Gum Powder HV-101 FCC, AEP Colloids Inc., NY, USA), xanthan gum (XAN-80 NF FCC, AEP Colloids Inc., NY, USA), κ-carrageenan (Calcium Carrageenan, AEP Colloids Inc., NY, USA), hydroxypropyl methylcellulose (HPMC) (Methocel F4M FG, FMC Biopolymer, Pennsylvania, USA), locust bean gum (LBG) (Sigma-Aldrich, Steinheim, Germany) and their blends.

2.2 Methods

2.2.1 Dough preparation

The dough was prepared according to the hamburger bread (bun) formulation, which is 100 % flour, 8 % sugar, 6 % milk powder, 2 % salt, 3 % yeast, 8 % margarine, 55 % water on flour weight basis. The gums were added to the dough formulation at 0.2, 0.5 and 1.0 % concentrations (on flour weight basis), except LBG and HPMC, which were added at 0.5% concentration only.

The gums were mixed at equal concentrations to obtain their blends. As a control, no gum was added to the formulation.

Dough was prepared by using straight dough method. First of all, the dry ingredients were mixed. Yeast was dissolved in water at 30 °C. Margarine was melted and added to the dry ingredients in liquid phase together with dissolved yeast. All the ingredients were mixed by a mixer (Kitchen Aid, 5K45SS, USA). After complete mixing of the dough, it was placed into the incubator (Nüve EN 400, Turkey) at 30 °C for fermentation. Total duration of the fermentation was 125 minutes. After the first 70 minutes, the dough was taken out of the incubator, punched and placed into the incubator again. A second punch took place after 35 minutes. After fermentation, the dough was divided into 50 g pieces. Each piece was shaped and placed into the incubator for the last time for 20 minutes under the same incubation conditions.

2.2.2 Baking

Samples were baked in conventional, microwave and IR-microwave combination ovens at the following baking conditions.

2.2.2.1 Conventional baking

Conventional baking was performed in a commercial electrical oven (Arçelik, İstanbul, Turkey). The prepared dough samples were baked at 200 ^{o}C for 13 minutes which was determined as the optimum baking condition for conventional baking previously (Keskin, 2003, 2004a). Four samples were baked at a time.

Dough samples were baked in conventional oven at 200° C for different baking times for determination of acrylamide formation during baking. Baking times which give similar color values in breads baked in conventional and IR-

microwave combination oven were selected for comparison of their acrylamide contents.

2.2.2.2 Microwave baking

The IR-microwave combination oven (Advantium oven^{TM}, General Electrics, USA) was used by only operating the microwave power. Dough samples were baked at 100 % power for 2 minutes which was determined by preliminary experiments. Four breads were baked at a time.

The power of microwave oven has been determined as 706W by using IMPI 2-L test (Buffler, 1993).

2.2.2.3 IR-microwave combination baking

Infrared-microwave baking was performed in IR-microwave combination oven (Advantium oven^{TM}, General Electric Company, Louisville, KY, USA). Two halogen lamps at the top and one at the bottom, each having 1500 W, were operated at the same power during halogen lamp baking. Four breads were baked at 70 % halogen lamp power and 20 % microwave power for 8 minutes which was determined by preliminary experiments.

Dough samples were baked in IR-microwave combination oven at 70% halogen lamp and 20% microwave power for 5, 7 and 8 minutes for determination of acrylamide content of samples during IR-microwave combination baking. Baking times which give similar color values in breads baked in conventional and IR-microwave combination oven were selected for comparison of their acrylamide contents.

Two beakers, each containing 400 ml water, were placed at the back corners of the oven to provide humidity during baking (Demirekler et al., 2004).

2.2.3 Determination of temperature profile

Fiber optic temperature probes were placed at the center of the dough and temperature was measured using a FISO real time measurement system (FISO Technologies, Inc., Quebec, Canada).

2.2.4 Storage of bread

After baking, breads were covered with stretch film, and kept in a plastic bag at 22±2°C for 120 h. Moisture content, hardness, soluble starch, RVA, DSC, X-ray and FTIR analysis of breads were performed at different storage times.

2.2.5 Analysis of dough and fresh bread

2.2.5.1 Determination of water binding capacity

The water binding capacities of mixture of dry ingredients of dough were measured using the method of Medcalf and Gilles (1965). 2.5 g of the mixture was mixed with 37.5 ml deionized water in a 50 ml centrifuge tube. The tube was then capped and agitated using an environmental incubator shaker for 1 hour. It was then centrifuged for 10 minutes at 2200×*g*. The water was decanted and the tube was tipped up and allowed to drain for 10 minutes. The tube was then weighed and the amount of water held by the sample determined by subtracting the initial weight of the sample from the weight of 'treated' sample. The water binding capacity was calculated from equation (2.1):

$$\text{WBC (w/w)} = \frac{(\text{Weight of treated sample} - \text{Initial weight of sample})}{\text{Initial weight of sample}} \qquad (2.1)$$

2.2.5.2 Determination of moisture content

Moisture contents of whole bread sample and only the crust portion (1mm thick section from the surface) were determined by drying the samples in an oven at 105°C until constant weight was obtained (AACC, 2000).

2.2.5.3 Determination of specific bulk volume and porosity

Bread specific bulk volume (V_b) was determined by the rape seed displacement method (AACC, 2000). Specific solid volume (V_s) of the same bread was also determined by rape seed method after compacting the bread to exclude all the pores. Then, total porosity was calculated from equation (2.2);

$$\varepsilon = (V_b - V_s) / V_b \qquad (2.2)$$

2.2.5.4 Determination of porous structure of bread

Macro and micro-structures of breads baked in different ovens (microwave, IR-microwave combination, and conventional) were investigated by the help of image and SEM analysis, respectively.

2.2.5.4.1 Image analysis

Breads formulated with different gums baked in different ovens (conventional and IR-microwave combination ovens) were cut into two halves vertically. The cut side of one of the halves was placed over the glass of a scanner (HP Scanjet 5470C, USA) having a resolution of 300 dpi. The scanned image was analyzed using the software Image J (http://rsb.info.nih.gov/ij/;

Abramoff, et al., 2004; Braadbaart and Van Bergen, 2005; Datta et al., 2007; Demirkol, 2007) that uses the contrast between the two phases (pores and solid part) in the image. The scanned color image is first converted to gray scale. Using bars of known lengths, pixel values are converted into distance units. The largest possible rectangular cross-section of the bread halves was cropped. After adjusting the threshold, area-based pore size distribution, and pore area as fraction of total area were determined using the software.

2.2.5.4.2 Scanning electron microscopy analysis

The bread samples for SEM analysis were frozen (-40°C) and freeze dried. The frozen bread crumb pieces having size of approximately 5 x 5 x 5 mm were then viewed and photographed with Zeiss EVO 50 XVP SEM (Germany & UK) in variable-pressure mode at Hacettepe University (Ankara, Turkey) at an accelerating voltage of 25 kV. The variable-pressure SEM (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). Since the instrument used in the analysis was capable of "low vacuum" operation (50 Pa), poor coating may give rise to charging on surfaces and misleading results, so that in this work, the samples were not coated and SEM in variable pressure mode was used. Scanning electron micrographs with appropriate magnifications (70x and 1000x) were selected for the presentation of results.

2.2.5.5 Texture profile analysis

The hardness, cohesiveness, springiness and chewiness of bread crumb were measured with Texture Analyser (TA Plus, Lloyd Instruments, UK) equipped with a 50 N load cell. The graphical representation of texture profile analysis can be seen in Figure 2.1.

Breads with the dimension of 20mm × 25mm × 15mm were compressed for 25% at a speed of 55 mm/min. A cylindrical probe with a diameter of 10 mm was used.

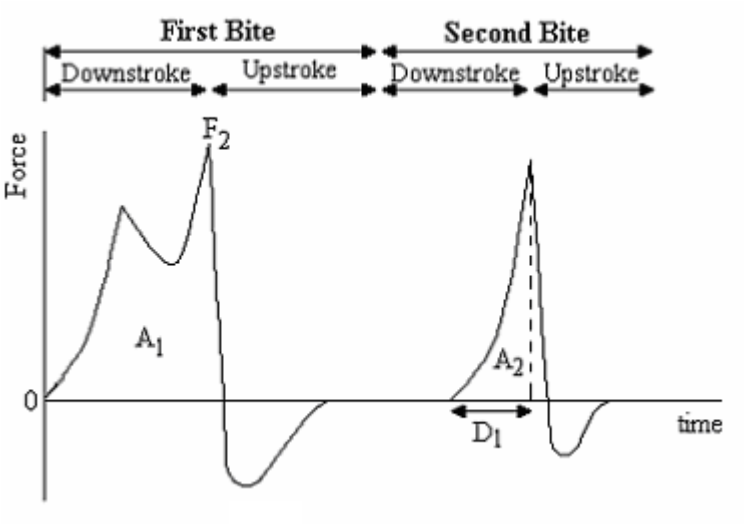

Figure 2.1 Graphical representation of texture profile analysis (Bourne, 2002)

Texture profile parameters were determined from:

Hardness: F2

Cohesiveness: A2/A1

Springiness: D1

Chewiness: hardness x cohesiveness x springiness: F2 x (A2/A1) x D1

The texture analysis of bread samples was performed after cooling 1h at room temperature.

2.2.5.6 Determination of color

The surface colors of breads were measured by using Minolta Color Reader (Minolta CR-10, Osaka, Japan). CIE L^*, a^*, b^* color scale was used for color measurements. The L^* value indicates lightness/darkness, the a^* value

represents the degree of redness/greenness and the b^* value represents the degree of blueness/yellowness. Total color difference (ΔE) was calculated from equation (2.3), where L_{ref}^*, a_{ref}^*, b_{ref}^* represents the L^*, a^*, b^* values of the dough ($L_{ref}^* = 80.9$, $a_{ref}^* = 3.1$, $b_{ref}^* = 32.8$):

$$\Delta E = [(L^* - L_{ref}^*)^2 + (a^* - a_{ref}^*)^2 + (b^* - b_{ref}^*)^2]^{1/2} \quad (2.3)$$

2.2.5.7 Determination of thermal conductivity

Thermal conductivity of dough and bread samples baked for different times at different ovens was measured at 23 °C using a Thermal Properties Analyzer (Model KD2, Decagon Devices, Inc., Pullman, WA, USA). This instrument consists of a hand-held readout and a single-needle sensor made of stainless steel and having a length and diameter of 60 mm and 1.28 mm, respectively. The needle contains both a heating element and a thermistor. The principle of measurement of thermal properties using this instrument is based on the dissipation of heat from a line heat source given a known voltage (3 V). In the case of bread samples, after baking, breads were left at ambient temperature for a while before covering with stretch film, and kept in a plastic bag until measurement.

2.2.5.8 Determination of dielectric properties

The open-ended coaxial probe method was used to measure dielectric properties of dough and bread samples. The dielectric measurement system includes HP85070 open ended coaxial high temperature probe (Agilent Technologies Inc., Palo Alto, CA, USA) and a S parameter network analyzer (Agilent 8722ES, Agilent Technologies, Inc., Palo Alto, CA, USA). Measurements were performed at 2450 MHz.

Dielectric properties of dough and bread samples were measured at 23°C. For the measurement of dielectric properties of dough, unfermented dough samples were prepared without yeast addition. Dielectric properties of dough were measured immediately after the dough was prepared. In the case of breads, samples were taken out of the oven, and left at ambient temperature for a while, before covering with stretch film, and kept in a plastic bag until measurement. Breads were sliced in the radial direction to have a thickness of 20 mm by using a razor blade for measuring dielectric properties of crumb. Probe was contacted to the cut bread surface at the central region.

2.2.5.9 Determination of acrylamide

Acrylamide analysis was performed in crust portion having 1mm thickness. Finely ground bread crusts (1 g) were weighed into a 10-mL glass centrifuge tube with cap. 9800 µL 0.2 mM acetic acid, 100 µL Carrez1 (Potassium ferricyanide) and 100 µLCarrez 2 (zinc sulfate) solutions were added. After mixing in a vortex mixer for 2 min, the mixture was centrifuged at 5000 rpm for 10 min at -5 °C. The clear supernatant was transferred into a vial with an injector and filtered through 0.45 µm nylon filter and analysed by chromatography/mass spectrometer (LC/MS). LC/MS analyses were performed in an Agilent 1100 HPLC system (Waldbronn, Germany) consisting of a binary pump, an autosampler and a temperature-controlled column oven, coupled to an Agilent 1100 MS detector equipped with an atmospheric pressure chemical ionisation (APCI) interface. Inertsil ODS-3 column (250 mm × 4.6 mm, 5 µm; HiChrom, Berkshire, UK) with an isocratic mixture of 0.01 mmol L^{-1} acetic acid in a 2 g L^{-1} aqueous solution of formic acid at a flow rate of 0.6 $mLmin^{-1}$ was used in the analytical separation. The separation was performed at 25 °C. The LC eluent was directed to the MS system after a delay time of 6.5 min using MSD software (Agilent, Waldbronn, Germany). Selective ion monitoring (SIM) mode with the following interface parameters was used for data acquisition: drying gas (N_2, 100 psig) flow rate 4 $Lmin^{-1}$,

nebuliser pressure 60 psig, drying gas temperature 325°C, vaporiser temperature 425°C, capillary voltage 4 kV, corona current 4 μA, fragmentor voltage 55 eV. Ions monitored were *m*/*z* 72 and 55 for the quantification of acrylamide in the samples. Full scan analyses were performed in the mass range *m*/*z* 50–210 for the spectral identification of acrylamide and sample coextractives, respectively (Gokmen and Senyuva, 2006).

2.2.5.10 Determination of reducing sugar content

Reducing sugar (glucose and fructose) content of bread crusts were determined by AOAC method, 979.23, using an Agilent 1100 high-performance liquid chromatography (HPLC) system (Waldbronn, Germany) with a Shodex Asahipak NH2P-50-2D column (150 mm × 2 mm; Agilent, Waldbronn, Germany) maintained at 35 °C. The mobile phase was 750 gL^{-1} acetonitrile at a flow rate of 0.2 $mLmin^{-1}$.

2.2.5.11 Determination of amino acid composition

The amino acids were extracted from the matrixes using acidified water. Simultaneous determination of underivatized amino acids was carried out by a liquid chromatography/mass spectrometry (LC/MS). The analyses were performed in an Agilent 1100 HPLC system with a Zorbax Bonus-RP analytical column (100 mm × 2.1 mm, 3.5 μm; Agilient, Waldbronn, Germany) using an isocratic mixture of 0.01 mmol L^{-1} acetic acid in a 2 g L^{-1} aqueous solution of formic acid at a flow rate of 0.2 mL min^{-1}. Selective ion monitoring (SIM) mode with the following interface parameters was used for data acquisition: drying gas (N_2) flow 4 L min^{-1}, nebuliser pressure 55 psig, drying gas temperature 320°C, vaporiser temperature 320°C, capillary voltage 3 kV, corona current 8 μA, fragmentor voltage 55 eV (Ozcan and Senyuva, 2006).

2.2.6 Staling analysis

Moisture content, hardness, soluble starch, DSC, RVA, X-ray and FTIR analysis were performed during storage of bread samples.

2.2.6.1 Determination of moisture content

The moisture content of samples was determined as in section 2.2.5.2.

2.2.6.2 Determination of hardness

The hardness of samples was determined as in section 2.2.5.5.

2.2.6.3 Determination of soluble starch

Soluble starch was determined colorimetrically by adding iodine solution to a water extract of bread crumb (Giovanelli et al., 1997). 2 g crumb was homogenized with 100 ml of deionized water. The suspension was centrifuged and 1 ml of supernatant was mixed with 10 ml of water and 1 ml of iodine solution (2 g of KI + 0.2 g of I_2 in 100 mL water). Absorbance at 590 nm was measured against a blank (11 mL of water + 1 mL of iodine solution) using UV spectrophotometer (Pharmacia, USA). Soluble starch concentration was calculated against a calibration curve built with a standard solution of soluble starch (Merck, USA).

2.2.6.4 Differential Scanning Calorimetry analysis

DSC analysis was performed to measure the retrogradation enthalpies of the breads in a Calorimeter (Perkin Elmer Jade DSC, Shelton, USA). 10 ± 1 mg of freeze-dried bread crumb samples were loaded into the pans and water was added at 1: 2 (w/v, sample: water ratio). The pans were hermetically sealed

and kept at room temperature for 1h. Then the samples were scanned by DSC from 10°C to 90 °C at a heating rate of 10°C/min.

2.2.6.5 Rapid Visco Analyser analysis

Rapid Visco^{TM} Analyzer (RVA) (Newport Scientiric PTY. Ltd., Warriewood, NSW, Australia) was used to study retrogradation of starch in different products. Samples were defatted by Soxhlet extraction with n-hexane for 6 hours prior to RVA analysis. The defatted samples were ground in a coffee grinder and sieved through a 212-μm screen. RVA was employed to investigate the pasting properties of the bread samples. In this assay, 4 g (14% moisture basis) defatted and ground sample of each bread was added to 25 g distilled water in an RVA sample canister. The heating and cooling cycles were programmed in the following manner. The samples were held at 50 °C for 1 min, heated to 95 °C within 3.5 min and then held at 95 °C for 2.5 min. It was subsequently cooled to 50 °C within 3.5 min and then held at 50 °C for 2 min. Typical RVA curve can be seen in Figure 2.2.

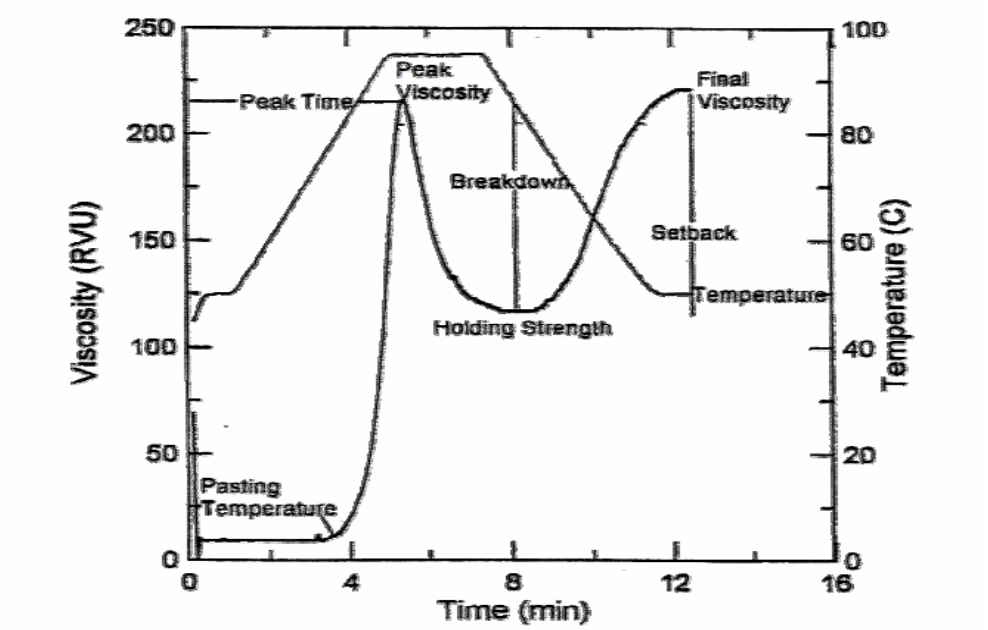

Figure 2.2 Typical RVA curve

The peak viscosity (the maximum viscosity during pasting), break down viscosity (the difference between the peak viscosity and the minimum viscosity during pasting), set back viscosity (the difference between the maximum viscosity during cooling and the minimum viscosity during pasting), final viscosity (the viscosity at the end of the RVA run) (Chaisawang and Suphantharika, 2006) were determined from the RVA plots using Termocline for Windows, Version 2.0.

2.2.6.6 Wide angle X-ray diffraction analysis

X-ray diffraction analysis was done using Rigaku Miniflex (Rigaku Americas Corp., The Woodlands, USA) with CuKα (30kV, 15mA, λ=1.542Å) radiation. The scanning region of the diffraction angle (2θ) was 5°-40°, which covers all the significant diffraction peaks of starch crystallites, with the scanning speed of 1° /min. The curve fitting analysis were done by the help of PeakFit V4.12 software. The freeze-dried samples were compressed to thin disks of 1-2 mm thickness and a diameter of 13 mm.The pressed sample was mounted on a sample holder. The measurements were carried out at 22±2 °C.

Since starch crystallinity is influenced by the water content of the sample, all the samples must have the same water content. The same water content can be obtained by two options, which are freeze-drying the samples or equilibrating the samples to certain water content. The last option involves a long storage time (>1 day) of the samples at certain relative humidity up to equilibrium of the samples, that can result in starch retrogradation which will interfere with the quantification of crystallinity. Therefore, the study of starch crystallinity was performed using freeze-dried samples. Relative crystallinity values were used to minimize the possible effect of the freeze-drying process on the absolute crystallinity values, as all samples were subjected to the freeze-drying process (Primo-Martin et al., 2007).

Crystalline peaks were analysed as pseudo-Voight-form and the amorphous ones as Gaussian-form peaks (Ribotta et al., 2004). The crystallinity levels in samples were determined by the separation and integration of the areas under the crystalline and amorphous X-ray diffraction peaks (Zobel, 1988). The quantification of relative crystallinity was performed using the total mass crystallinity grade (TC), which is the ratio of area of the crystalline fraction to the area of crystalline fraction plus the amorphous fraction.

$$TC = \frac{I_c}{I_c + I_a} \tag{2.4}$$

where I_c is the integrated intensity of crystalline phase, and I_a is the integrated intensity of the amorphous phase (Ribotta et al., 2004).

2.2.6.7 Fourier Transform Infrared Spectroscopy analysis

ATR-FTIR experiments were conducted on a Bruker Vertex 70 Spectrometer using Diamond w/KRS-5 lens single reflection ATR plate (MIRacle ATR, Pike Technologies, Madison, WI, USA), operating in the middle-IR region, 600 – 4000 cm^{-1}. The measurements were done at a resolution of 2 cm^{-1} with 32 scans. For this assay, freeze-dried breads were used. The samples were placed onto the surface of the crystal and contact of ATR crystal with the sample was provided.

The curve fitting analysis was done by the help of PeakFit V4.12 software.

2.2.7 Statistical Analysis

Analysis of variance (ANOVA) was performed to determine whether there was significant difference between storage time, gum and oven types

($p \leq 0.05$). Variable means were compared by Tukey Single Range test by using Minitab statistics programme (MINITAB for Windows, Version 14, Minitab Inc., State College, Pa., USA).

CHAPTER 3

RESULTS AND DISCUSSION

In the first part of the study, effects of gums on quality parameters, dielectric and thermal properties, and macro and micro-structure of breads baked in IR-microwave combination oven were investigated. For comparison, conventional baking was used. Acrylamide formation during microwave, IR-microwave combination and conventional baking of breads was also studied. In the second part of the study, staling mechanism of breads baked in microwave and IR-microwave combination ovens was investigated by different methods (moisture content, hardness, soluble starch, DSC, RVA, X-ray and FTIR analysis). Additionally, the effects of gum addition on physicochemical properties of breads baked in microwave, IR-microwave combination and conventional ovens were determined.

3.1 Effects of Different Gums on Quality Parameters of Bread Samples Baked in Different Ovens

Xanthan, guar, carrageenan and locust bean gums and hydroxypropyl methylcellulose (HPMC) were selected to be used in this study since these gums were used in conventional baking studies (Rosell et al., 2001; Azizi and Rao, 2004; Guarda et al., 2004; Ribotta et al., 2005; Gavilighi et al., 2006). A preliminary study was done to determine the optimum gum concentration and gum type to be used in breads baked in IR-microwave combination oven. At

the beginning of the study, xanthan, guar and carrageenan gums were added to the formulation at 0.2, 0.5 and 1.0% concentrations. The effects of these gums at different concentrations on quality parameters of breads baked in IR-microwave combination oven can be seen in Table 3.1.

Table 3.1. The effect of gum type and concentration on the quality of breads baked in IR-microwave combination oven

	QUALITY PARAMETER			
GUM TYPE	**Gum concentration (%)**	**Moisture content (%)**	**Specific volume (ml/g)**	**Hardness (N)**
control (no gum)	0.0	35.98	1.93	0.79
xanthan	0.2	35.98	1.85	1.07
	0.5	36.07	1.89	0.96
	1.0	36.34	1.69	1.71
guar	0.2	35.77	1.92	0.81
	0.5	35.81	1.95	0.72
	1.0	35.89	1.78	1.04
xanthan-guar	0.2	35.93	1.93	0.86
	0.5	36.04	2.00	0.63
	1.0	36.15	1.82	0.97
κ-carrageenan	0.2	35.83	1.79	1.10
	0.5	35.78	1.85	0.94
	1.0	35.85	1.71	1.25

Gum concentration did not have a significant effect on moisture content of breads. Increasing gum concentration from 0.2% to 0.5% increased the volume and decreased the hardness of breads. When concentration of 1.0% was used, specific volume of breads decreased and breads became firmer. Mandala

and Sotirakoglou (2005) demonstrated in their studies that high concentration of xanthan or guar gum addition resulted in a decrease of the specific volume as compared to that of the control samples. Moreover, Rosell et al. (2001) designated that hydrocolloids, such as xanthan could thicken the crumb air cell walls and its high concentration could enhance this phenomenon leading to a more compact structure. Therefore, 0.5% concentration was selected as the optimum concentration. It was seen that addition of xanthan, guar and carrageenan gums to the formulation did not improve the quality of breads baked in IR-microwave combination oven significantly (Table 3.1 and Table A.1). On the other hand, breads formulated with xanthan-guar blend at 0.5% concentration had significantly higher specific volume and lower hardness values compared to control breads (Tables 3.1, A.1 and A.2, Figures 3.1 and 3.2). This can be explained by synergistic effect of these gums.

Synergistic effect of xanthan-guar blend were shown in literature (Sworn, 2000; Gurkin, 2002), which is explained by different models. One of the model 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 intermolecular binding between xanthan and galactomannans suggests that destabilization of the xanthan helix facilitates xanthan and galactomannan binding (Cheetham and Mashimba, 1988, 1991). It was demonstrated by the researchers 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 results obtained in a recent study by 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. Another model assumed that regularly substituted mannan chains with galactose units located on one side of the backbone are linked with the xanthan backbone. This model does not rule out the former model (the association of unsubstituted

regions of galactomannan with the backbone of the xanthan helix) but provides an explanation for the interactions of xanthan with highly substituted galactomannans like guar gum (McCleary, 1979; McCleary et al., 1984; Schorsh et al., 1997).

To investigate the effect of other blends, xanthan-carrageenan and guar-carrageenan, on bread quality, blends were added to the formulation at 0.5% concentration. It was seen that breads formulated with xanthan-guar blend provided the highest volume (Figure 3.1). The synergistic effect between xanthan and guar gums may be the reason of obtaining high volume breads. Guar gum may soften the thickening effect of xanthan gum, which prevents destruction of formed gas cells and formation of new uniform gas cells during proofing.

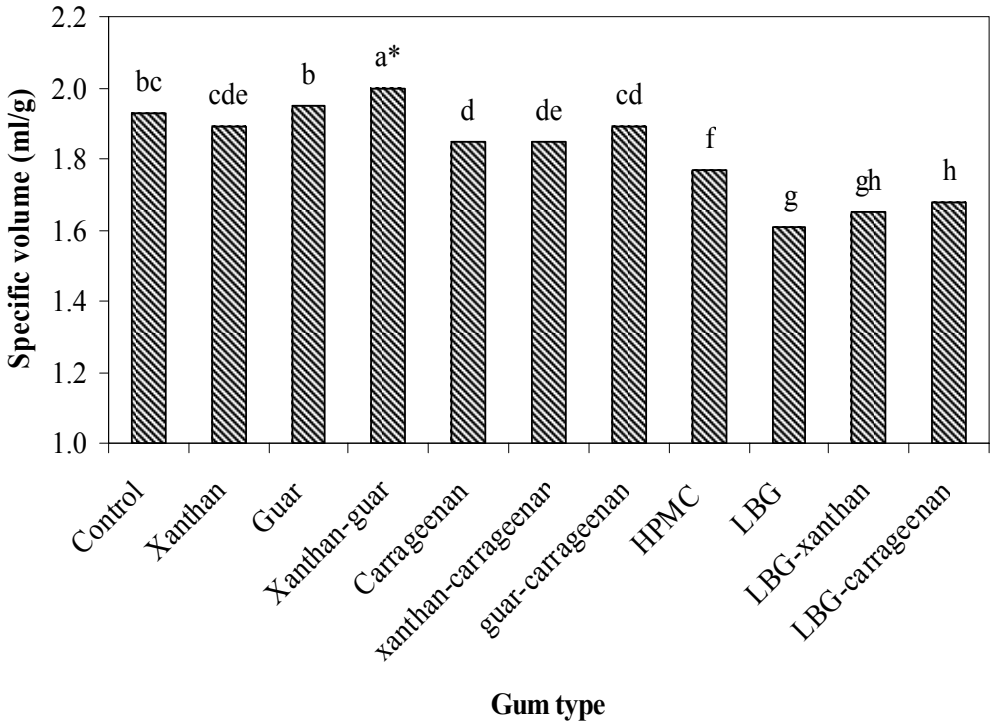

Figure 3.1 The effect of gum type (at 0.5% concentration) on specific volume of breads baked in IR-microwave combination oven (* means bars having different letters are significantly different, $p \leq 0.05$)

When the effect of gums added at 0.5% concentration on hardness of bread samples baked in IR-microwave combination oven was considered, the hardness of breads formulated with xanthan, guar, κ- carrageenan and guar-carrageenan blend were found to be not significanly different from that of control breads (Figure 3.2 and Table A.2). Similar results were obtained for κ-carrageenan gum in the study of Guarda et al (2004), which showed that κ-carrageenan did not produce any effect on hardness of breads. On the other hand, xanthan-guar blend addition to the formulation resulted in a significant decrease in hardness value of breads. Textural attributes could be correlated to structural characteristics of the crumb (specific volume and porosity) (Mandala and Sotirakoglou, 2005). Since the specific volume of breads formulated with xanthan-guar blend was the highest (Figure 3.1), obtaining the lowest hardness values was an expected result (Figure 3.2). Samples having low volume have more densely packed polymers in their structure which results in firm texture. This can be explained by having more entanglements and interactions occuring between the more densely packed polymers in samples (Leon et al., 2006). The addition of xanthan to the formulation did not reduce bread hardness at the studied concentration. Xanthan can thicken the crumb air cell walls (Rosell et al., 2001) and its high concentration can enhance this phenomenon leading to a more compact structure. Similar results were obtained in literature for conventionally baked breads (Guarda et al., 2004; Ribotta et al., 2005).

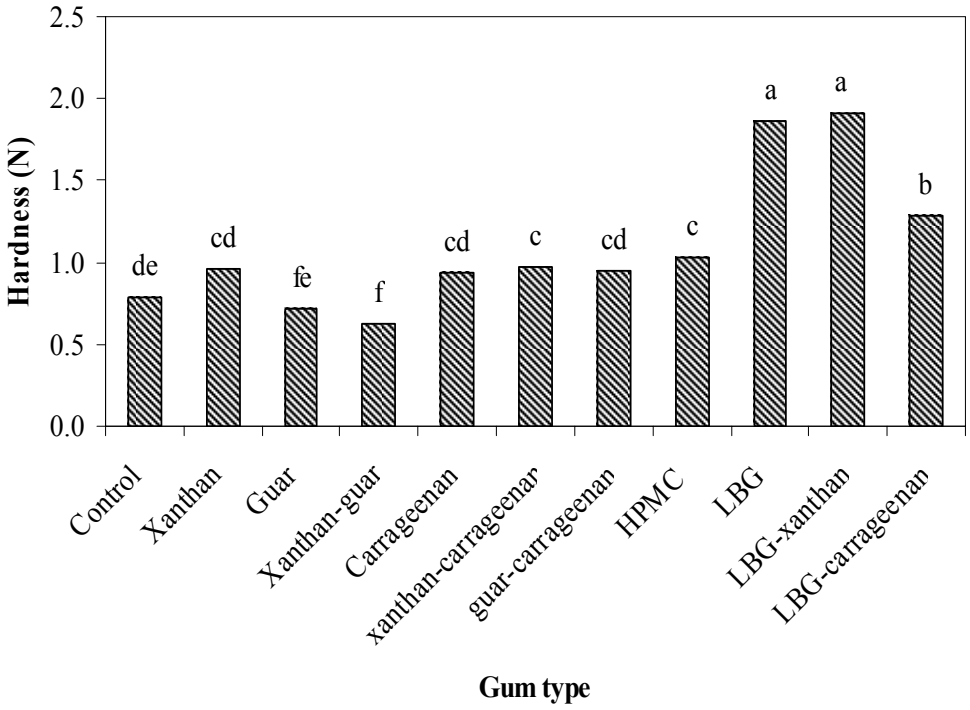

Figure 3.2 The effect of gum type (at 0.5% concentration) on hardness of breads baked in IR-microwave combination oven

It was decided to use xanthan, guar, carrageenan, and xanthan-guar blend at the rest of the first part of the study, since breads formulated with these gums were either softer than or not significantly different from control breads.

The effect of gums on the parameters obtained from texture profile analysis, such as cohesiveness, springiness, chewiness can be seen in Table 3.2. Cohesiveness is related to integrity, crumbliness and type/rate of breakdown terms; whereas springiness is attributed to elasticity and plastic recovery from deformation and chewiness is related to pastiness and breakdown (Bourne, 2002). Cohesiveness values were found to be dependent on gum type (Table A.3). There was slight decrease in cohesiveness values of xanthan and guar gum added samples compared to control ones. Springiness values were found to be independent of gum type (Table A.4). Since chewiness is one of the

texture profile analysis parameters dependent on hardness; it showed similar trend with the hardness data that is the presence of xanthan-guar blend in the formulation significantly decreased the chewiness values as compared to control breads (Table 3.2, Figure 3.2 and Table A.5).

Table 3.2. Texture profile of the breads formulated with different gums baked in IR-microwave combination oven

	GUM TYPE				
Texture Profile	**No gum**	**Xanthan**	**Guar**	**Xanthan-guar**	**κ-carrageenan**
Cohesiveness	0.56 ± 0.009^{a}	0.52 ± 0.010^{b}	0.52 ± 0.003^{b}	0.53 ± 0.007^{ab}	0.53 ± 0.015^{ab}
Springiness (mm)	3.36 ± 0.023^{a}	3.48 ± 0.030^{a}	3.50 ± 0.015^{a}	3.37 ± 0.035^{a}	3.45 ± 0.025^{a}
Chewiness (N.mm)	1.51 ± 0.025^{b}	1.74 ± 0.030^{a}	1.30 ± 0.032^{c}	1.11 ± 0.017^{d}	1.73 ± 0.040^{a}

(* means gums having different letters within each row are significantly different ($p \leq 0.05$)

The color values (ΔE) of breads baked in IR-microwave combination oven were not found to be dependent on gum type (Figure 3.3 and Table A.6).

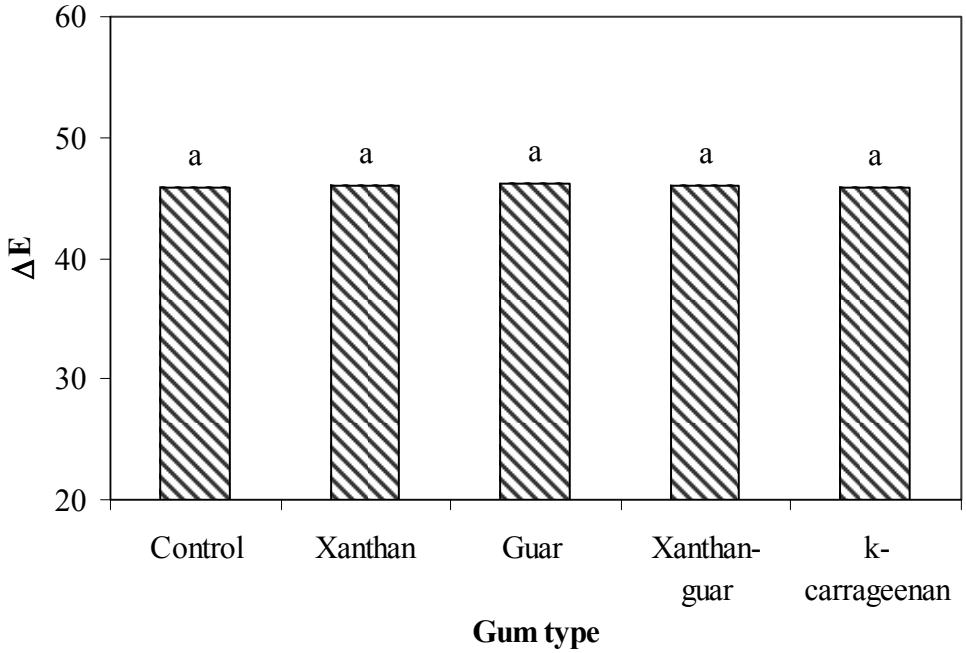

Figure 3.3 The effect of gum type on color of breads baked in IR-microwave combination oven

When the effects of gum addition at 0.5% concentration on the quality of breads baked in conventional oven were considered, similar results were obtained with the ones for IR-microwave combination oven. That is, xanthan-guar addition to the formulation at 0.5% concentration resulted in a significant increase in specific volume and a significant decrease in hardness values of breads (Figures 3.4 and 3.5, Tables A.7 and A.8). On the other hand, the specific volume and hardness of breads formulated with xanthan, guar, κ-carrageenan were found to be not significanly different from that of control bread (Figures 3.4 and 3.5). Similar results were obtained for κ- carrageenan gum in the study of Leon et. al. (2000), which showed that κ- carrageenan did not produce any effect on specific volume of breads, which may be explained by the interaction of gum carrageenan with gluten proteins.

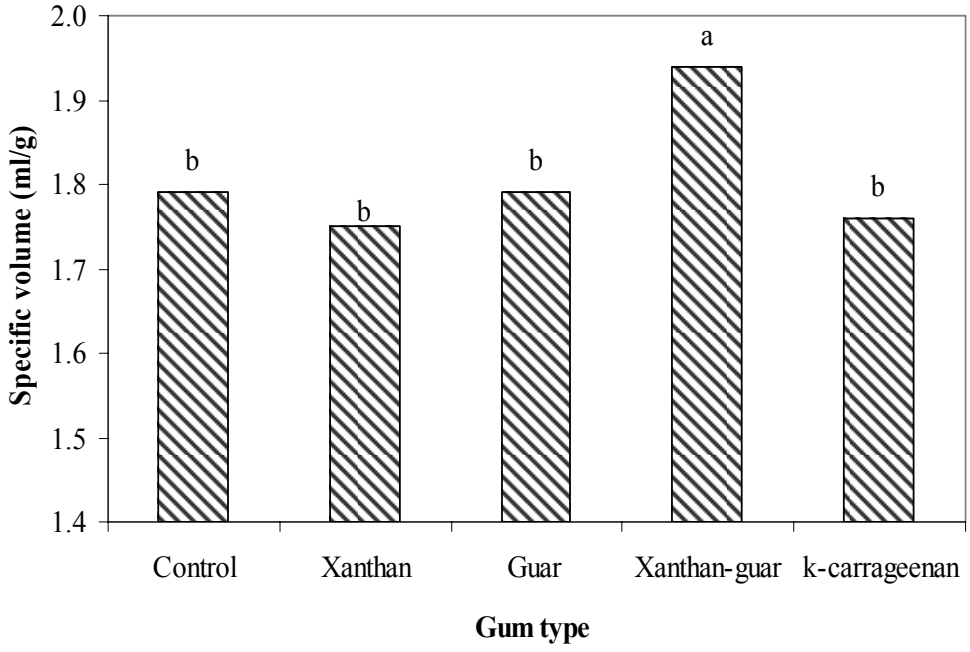

Figure 3.4 The effect of gum type (at 0.5% concentration) on specific volume of breads baked in conventional oven

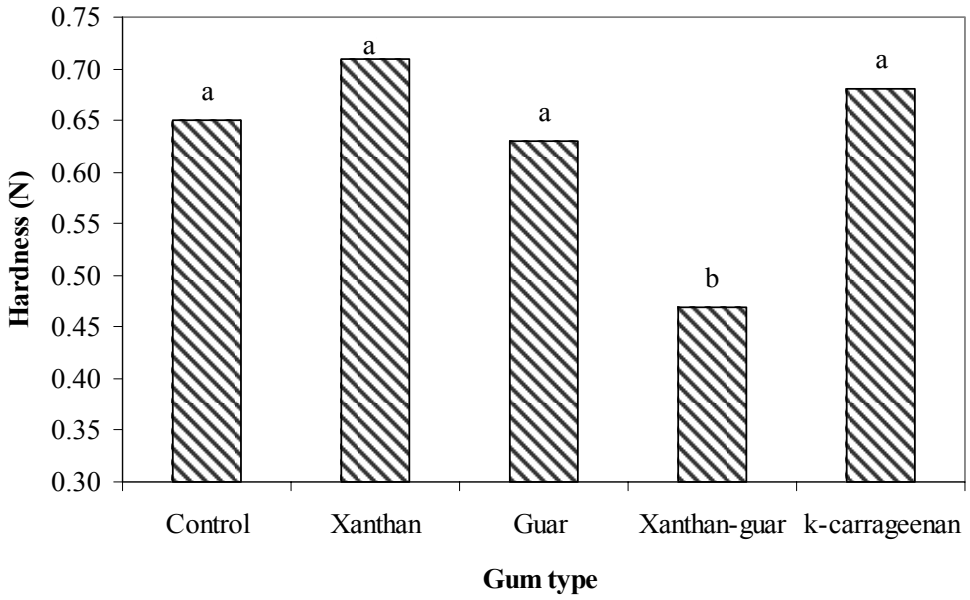

Figure 3.5 The effect of gum type (at 0.5% concentration) on hardness of breads baked in conventional oven

Table 3.3 demonstrates the texture profile analysis results other than hardness for the breads formulated with different gums baked in conventional oven. According to ANOVA results, it was found that the cohesiveness values of samples baked in conventional oven was not affected by gum addition, significantly (Table A.9). Gum addition, rather than xanthan-guar blend, was found to increase springiness values of samples significantly (Table A.10). Chewiness, which is related to hardness, also showed similar trend with the hardness data in the presence of xanthan-guar blend in the formulation that is chewiness values of xanthan-guar blend containing breads decreased as compared to control breads (Table 3.3 and Figure 3.5, Table A.11).

Table 3.3. Texture profile of the breads formulated with different gums baked in conventional oven

	GUM TYPE				
Texture Profile	**No gum**	**Xanthan**	**Guar**	**Xanthan-guar**	**κ-carrageenan**
Cohesiveness	0.52 ± 0.009^{a}	0.51 ± 0.006^{a}	0.51 ± 0.005^{a}	0.52 ± 0.009^{a}	0.51 ± 0.003^{a}
Springiness (mm)	3.18 ± 0.032^{c}	3.44 ± 0.021^{a}	3.32 ± 0.036^{b}	3.13 ± 0.019^{c}	3.31 ± 0.021^{b}
Chewiness (N.mm)	1.11 ± 0.014^{b}	1.38 ± 0.028^{a}	1.06 ± 0.023^{b}	0.75 ± 0.023^{c}	1.13 ± 0.033^{b}

When the texture profiles of samples baked in conventional and IR-microwave combination oven were compared, ANOVA results demonstrated that hardness, cohesiveness, springiness and chewiness values of samples were dependent on oven and gum types (Tables A.12, A.13, A.14 and A.15). The texture profile parameters of samples baked in IR-microwave combination oven were higher than that of conventionally baked ones (Figure 3.2, Figure 3.5; Table 3.2 and Table 3.3). Similar findings were obtained by Demirekler et al. (2004) that hardness, springiness, chewiness values of IR-microwave combination baked breads were higher than that of the conventionally baked ones. It was found that xanthan-guar addition to the formulation at 0.5% concentration resulted in a significant decrease in hardness and chewiness values of breads baked in conventional and IR-microwave combination ovens.

The color values (ΔE) of breads baked in conventional oven were not found to be dependent on gum type (Figure 3.6 and Table A.16).

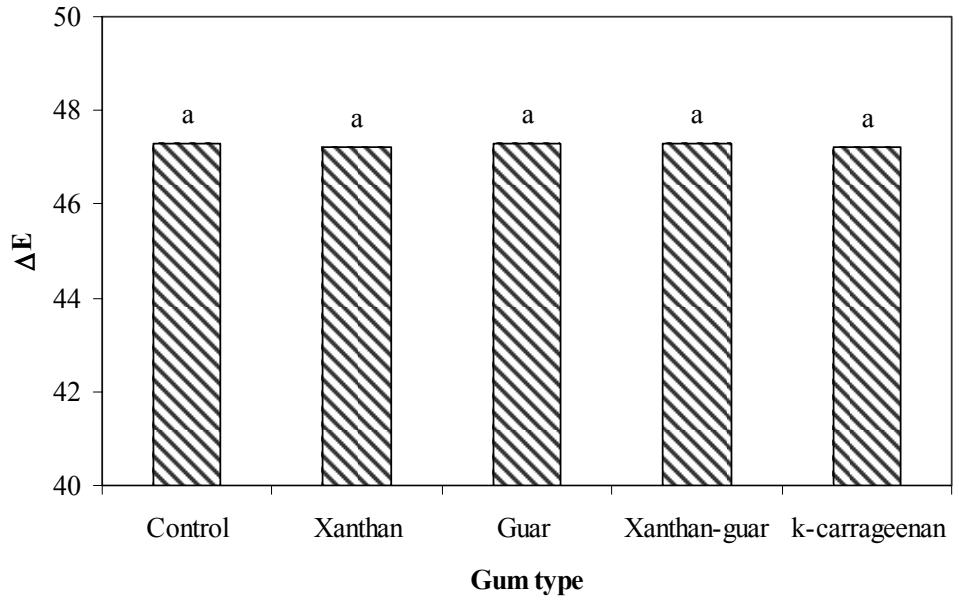

Figure 3.6 The effect of gum type on color of breads baked in conventional oven

When the porosity of samples baked in conventional and IR-microwave combination oven were compared, ANOVA results demonstrated that porosity of samples was dependent on gum and oven types (Table A.17). The porosity of breads formulated with xanthan-guar blend baked in conventional and IR-microwave combination ovens was the highest (Figure 3.7). The decrease in porosity value of conventionally baked breads formulated with xanthan or guar gums alone as compared to the control breads was also observed in other studies (Mandala 2005; Mandala and Sotirakoglou, 2005). Since porosity is related to specific volume results, it was not surprising that xanthan, guar and κ- carrageenan containing breads had low specific volume and porosity values. The thickening effect of xanthan gum may be the reason, resulting in compact structure, which causes prevention of destruction of formed gas cells and formation of new uniform gas cells during proofing.

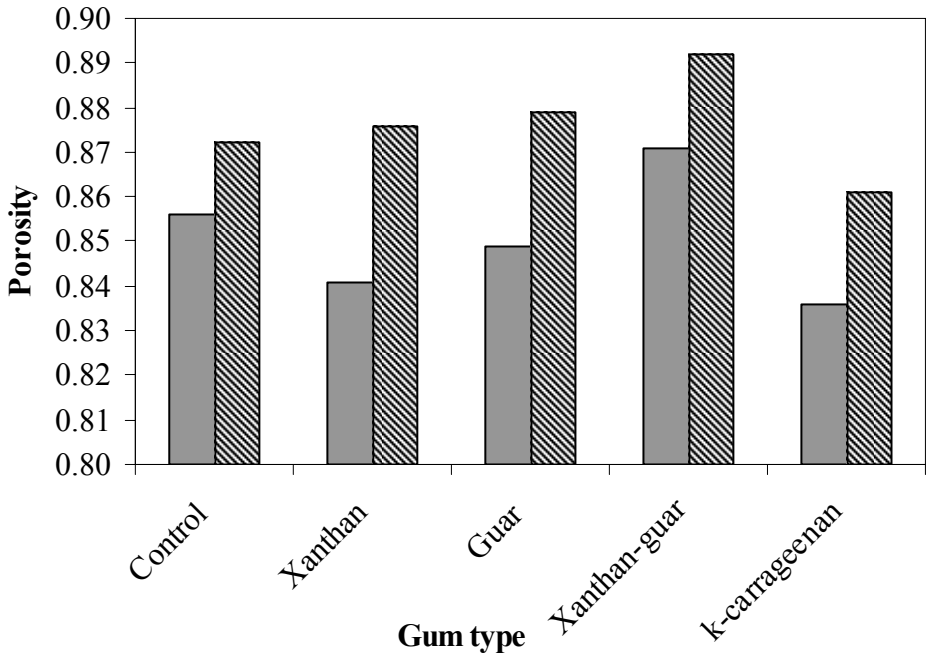

Figure 3.7 Variation in porosity values of breads formulated with different gums baked in conventional and IR-microwave combination ovens

Conventional IR-microwave

The porosity values of IR-microwave combination baked samples were found to be significantly higher than the conventionally baked ones, in accordance with the specific volume results (Figures 3.1, 3.4, 3.7) and early studies (Demirekler et al., 2004). The significant microwave-induced internal pressure formed during IR-microwave combination baking might result in a puffing effect leading to high volume and porous structure.

3.2 Effects of Different Gums on Macro and Micro- Structure of Bread Samples Baked in IR-Microwave Combination and Conventional Ovens

Macro and microstructure of the samples were obtained by Image and SEM analysis, respectively. By the help of macrostructure analysis quantitative data in terms of area-based pore size distribution and pore area as fraction of total area can be obtained, whereas characterization of microstructure provides qualitative observations about the pore characteristics.

3.2.1 Determination of pore area and cumulative pore area fraction of breads by image analysis

Macro-structure of the samples were obtained by the software, Image J It uses the contrast between the two phases (pores and solid part) in the image during the macro-structure analysis.

Figure 3.8a shows the scanned image of conventionally baked control breads. From that scanned image, pore areas are extracted by the software, Image J, an example of which is shown in Figure 3.8b and 3.8c, and cumulative pore area fractions are obtained (Figures 3.9 and 3.10).

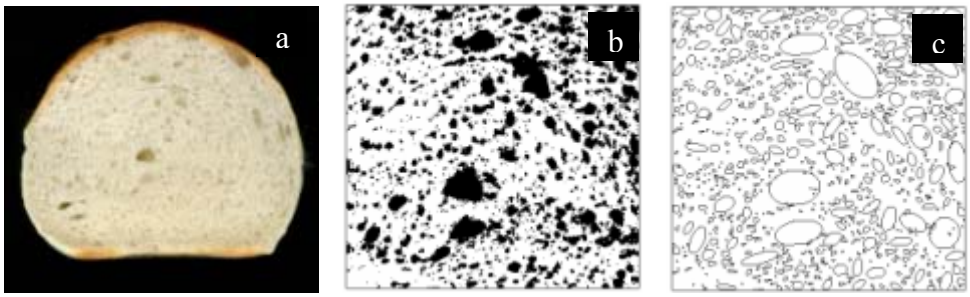

Figure 3.8 a) Scanned image of conventionally baked control bread used in image analysis, b-c) Illustration of how the software ImageJ uses contrast in the scanned image to find the edges of pores and defines the regions representing voids before measuring their areas.

The pore area fractions of breads formulated with different gums baked in conventional oven can be seen in Figure 3.9. It can be seen from the figure that xanthan-guar blend addition to the formulation increased pore area fraction significantly (Table A.18).

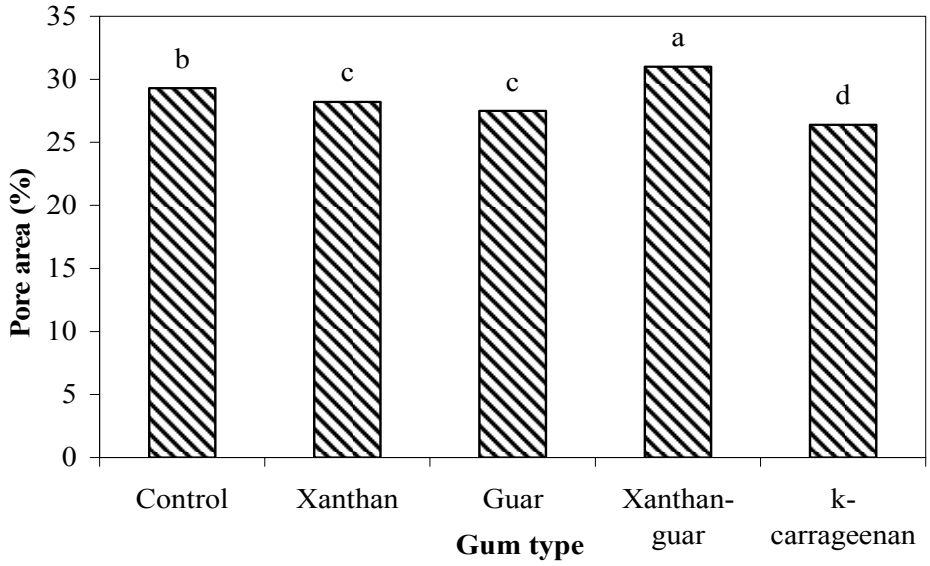

Figure 3.9 Variation in pore area fraction of bread samples formulated with different gums baked in conventional oven

In the case of IR-microwave combination oven, it was seen that xanthan-guar blend addition to the formulation resulted in significant increase in pore area fraction values, as compared to other gum formulations (Figure 3.10 and Table A.19).

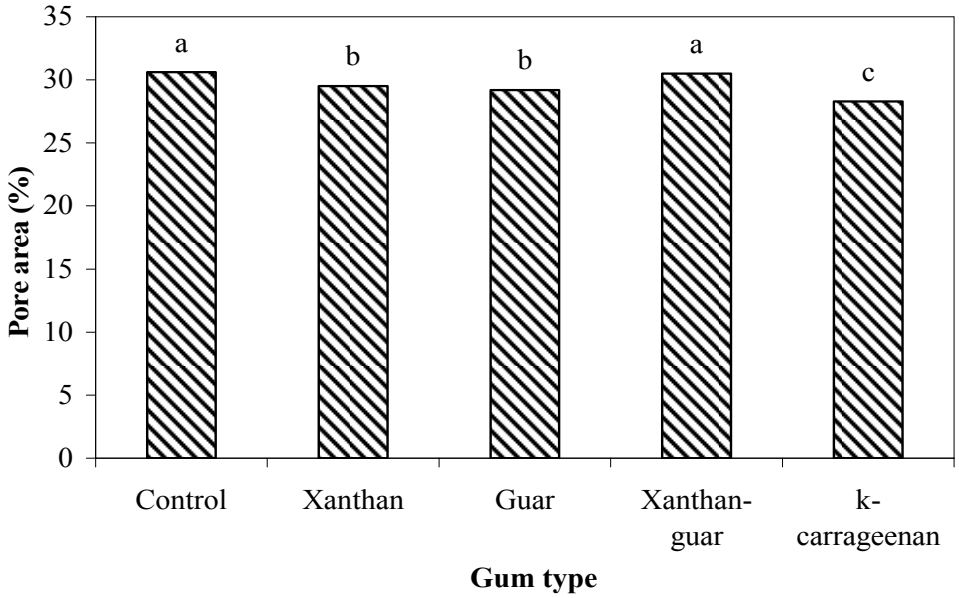

Figure 3.10 Variation in pore area fraction of bread samples formulated with different gums baked in IR-microwave combination oven

It was observed that κ-carrageenan added samples had the lowest pore area fraction and porosity values in conventional and IR-microwave combination ovens (Figures 3.7, 3.9 and 3.10). The interaction of κ-carrageenan with the ingredients in the formulation, such as gluten, may be the reason of low pore area fraction and porosity values. It was demonstrated in literature (Ribotta et al., 2005) that carrageenan isoforms (sulphated hydrocolloids) has selective interaction with medium molecular weight gluten proteins (30,000-42,000), which can form hydrophilic complexes, affecting its

solubility. The capacity of complexation appears to be related to the density of the anionic group in the polysaccharide. Moreover, it has been stated that hydrocolloids may interact with other gluten proteins (having different molecular weight) and the resulting complexes are not water-soluble (Ribotta et al., 2005, Leon et al., 2000). These complexes may affect formation of desirable starch-gluten matrix in terms of gluten strength for gas holding, at the end, affecting pore cell wall structure and porosity of the final product.

Pore area fractions of samples baked in IR-microwave combination oven were found to be significantly higher than that of the conventionally baked ones (Table A.20, Figures 3.9 and 3.10). The high pressure formed inside the bread because of microwave heating mechanism may have yielded a loose, void porous structure in microwave-assisted baking.

Cumulative pore area fraction versus pore diameter plot of breads baked in conventional oven can be seen in Figure 3.11. It was found that in breads formulated with xanthan-guar blend, the amount of pores higher than 1000μm were the highest with the percentage of 67%. The cumulative pore area fractions of breads formulated with different gums were not found to be different (Figure 3.11).

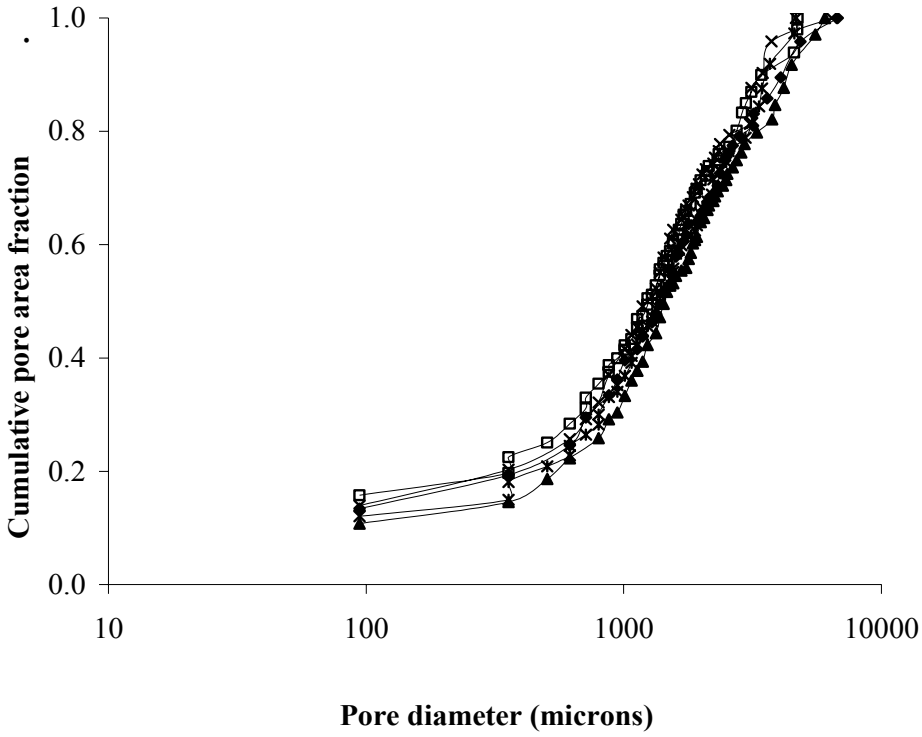

Figure 3.11 Variation in cumulative pore area fraction of bread samples formulated with different gums baked in conventional oven

xanthan guar xanthan-guar carrageenan control

When the cumulative pore area fraction of samples baked in IR-microwave combination oven was considered, in breads formulated with xanthan-guar blend, 71% of the pores had diameter above 1000µm, which was the highest amount among the samples formulated with other gum types (Figure 3.12).

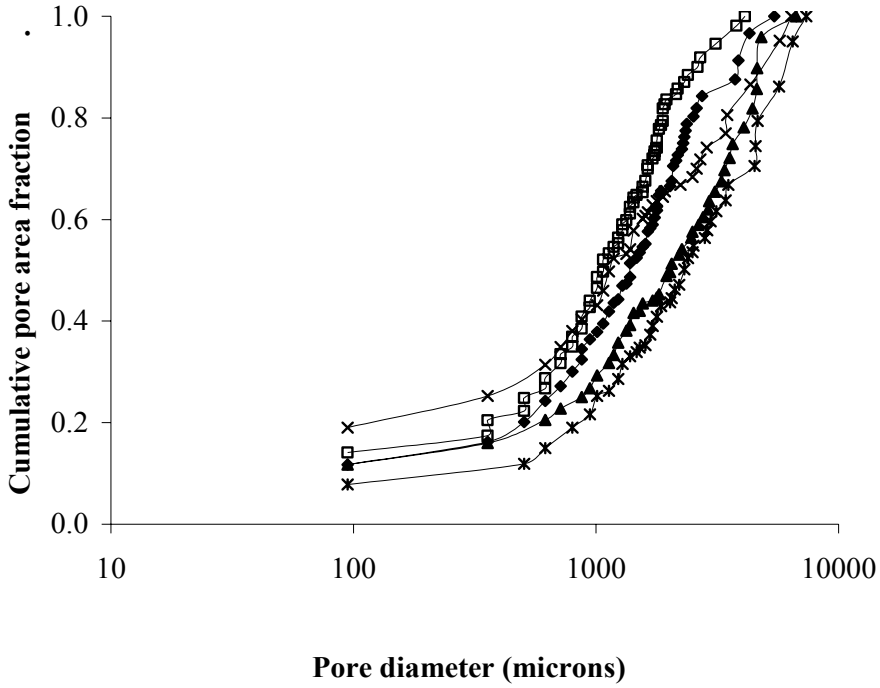

Figure 3.12 Variation in cumulative pore area fraction of bread samples formulated with different gums baked in IR-microwave combination oven

—◆— xanthan —□— guar —▲— xanthan-guar —✳— carrageenan —✱— control

When the cumulative pore data of samples baked in conventional and IR-microwave combination ovens was accounted, it was seen that about 75% of the pores of control breads baked in IR-microwave combination and about 63% of the pores of control breads baked in conventional oven had diameter of above 1000µm (Figures 3.11 and 3.12). Moreover, gum addition had more significant effect on the pore size distribution of breads baked in IR-microwave combination oven than that of conventionally baked ones (Figures 3.11 and

3.12). The heating mechanisms in conventional and IR-microwave combination baking differ. The high pressure formed during IR-microwave combination heating, resulting in high moisture removal may be the reason of observing such kind of difference in the effects of gum types on pore size distribution of breads. Since gums have ability to redistribute water inside the matrix and they have different water binding capacities, these abilities may be more distinguishable in IR-microwave combination heating. The difference in dielectric properties of different gum containing breads may affect the heating rate and pore formation during IR-microwave combination baking.

3.2.2 Micro-structure of samples baked in IR-microwave combination and conventional ovens

Figure 3.13 (a-b) show the microstructure at (70 x) magnification of control breads baked in IR-microwave combination and conventional ovens. From the general view it can be said that the gas cells present large cavities and some smaller holes in samples baked in both conventional and IR-microwave combination ovens.

When microstructure of control breads baked in IR-microwave combination and conventional ovens was considered, the pores in conventionally baked breads were found to be smaller (Figures 3.13a and 3.13b), as in the case of image analysis results (Figures 3.11 and 3.12). Mean pore diameter for conventionally baked control breads were smaller than that of samples baked in IR-microwave combination oven, which were about 1700 and 2500 microns, respectively. Pores of conventionally baked breads had spherical, oval-like shapes (Figure 3.13b). Moreover, more homogeneous closed-cell structure was observed for conventionally baked control breads. The pores of breads baked in IR-microwave combination oven are so close to each other which results in coalescence of the gas cells to form channels, therefore, the pores were no longer spherical (Figure 3.13a). This may be

because of the pressure driven moisture removal in combination baking which resulted in a different pore structure. Besides these findings, the presence of microwave heating mechanism in IR-microwave combination heating may result in coarser air cells in the microstructure of samples baked. Similar findings were obtained in some studies for microwave-baked cakes (Martin and Tsen, 1981; Demirkol, 2007).

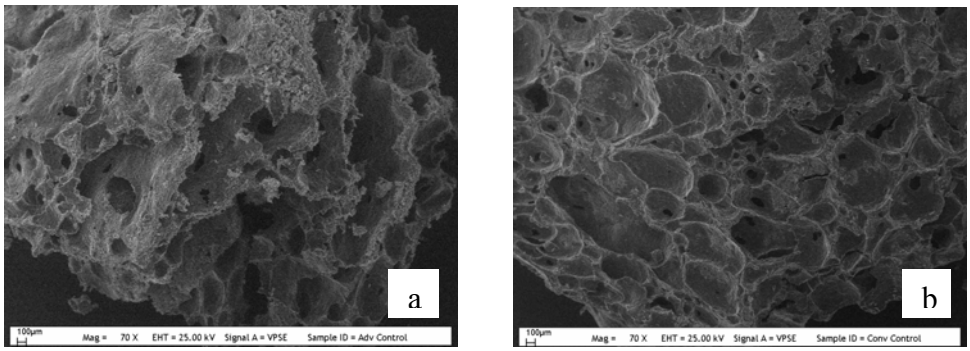

Figure 3.13 Microstructure at (70 x) magnification of control bread crumbs baked in a) IR-microwave combination and b) conventional ovens

Moreover, it can be seen that control breads baked in IR-microwave combination oven was more porous than the conventionally baked ones (Figure 3.13a and 3.13b).

When microstructure of breads baked in conventional oven was considered, the microstructure of control breads baked in conventional oven seemed to have more smooth structure than that of gum added ones (Figures 3.14 (a-e)).

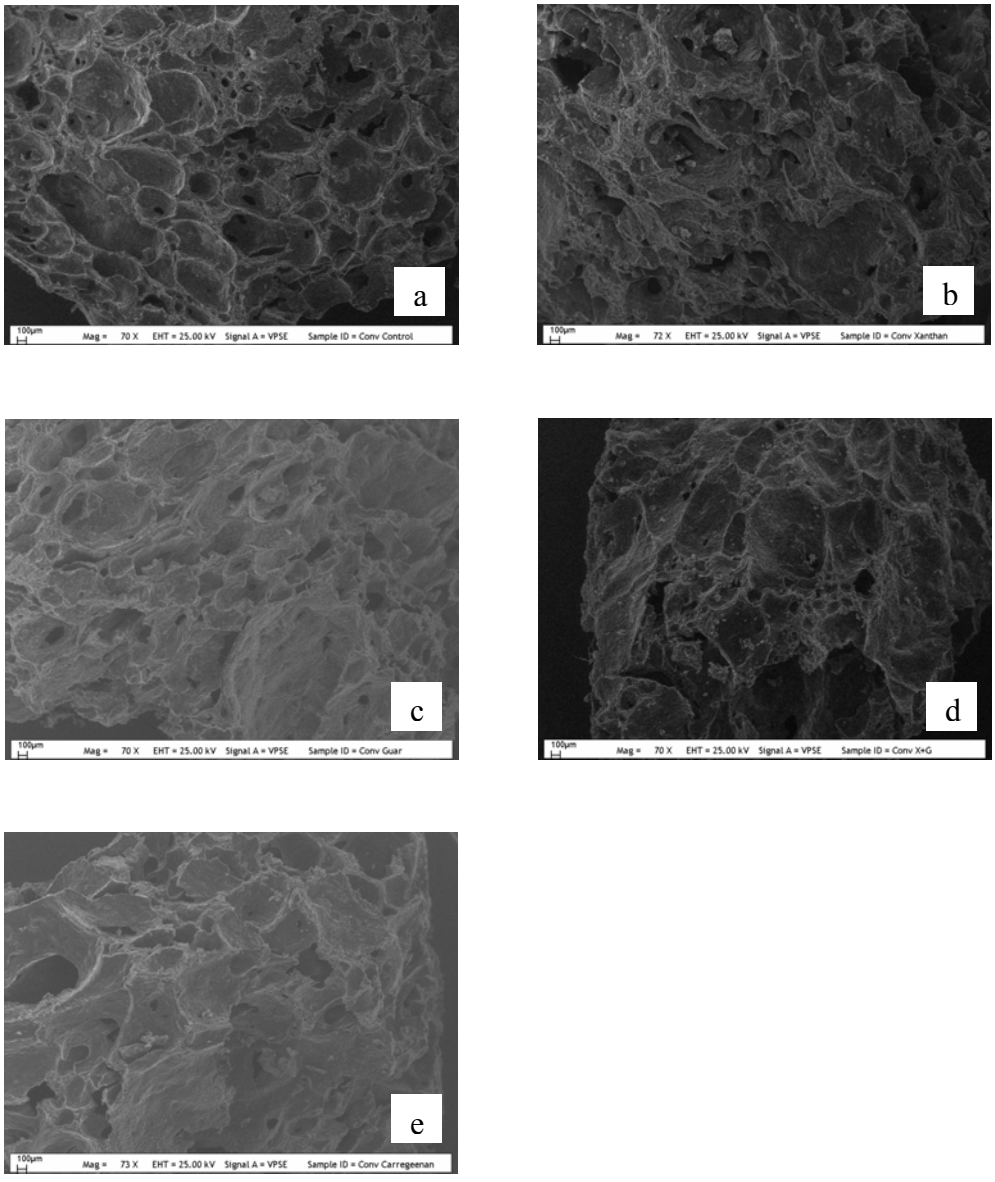

Figure 3.14 Microstructure at (70 x) magnification of a) no gum b) xanthan c) guar d) xanthan-guar blend e) κ-carrageenan added bread crumbs baked in conventional oven

When the microstructure of breads formulated with different gums baked in IR-microwave combination oven was taken into consideration, pores were mostly in spherical and/or oval-like shapes in the case of gum containing formulations, resulting in formation of stable morphology (Figures 3.15 (a-e)).

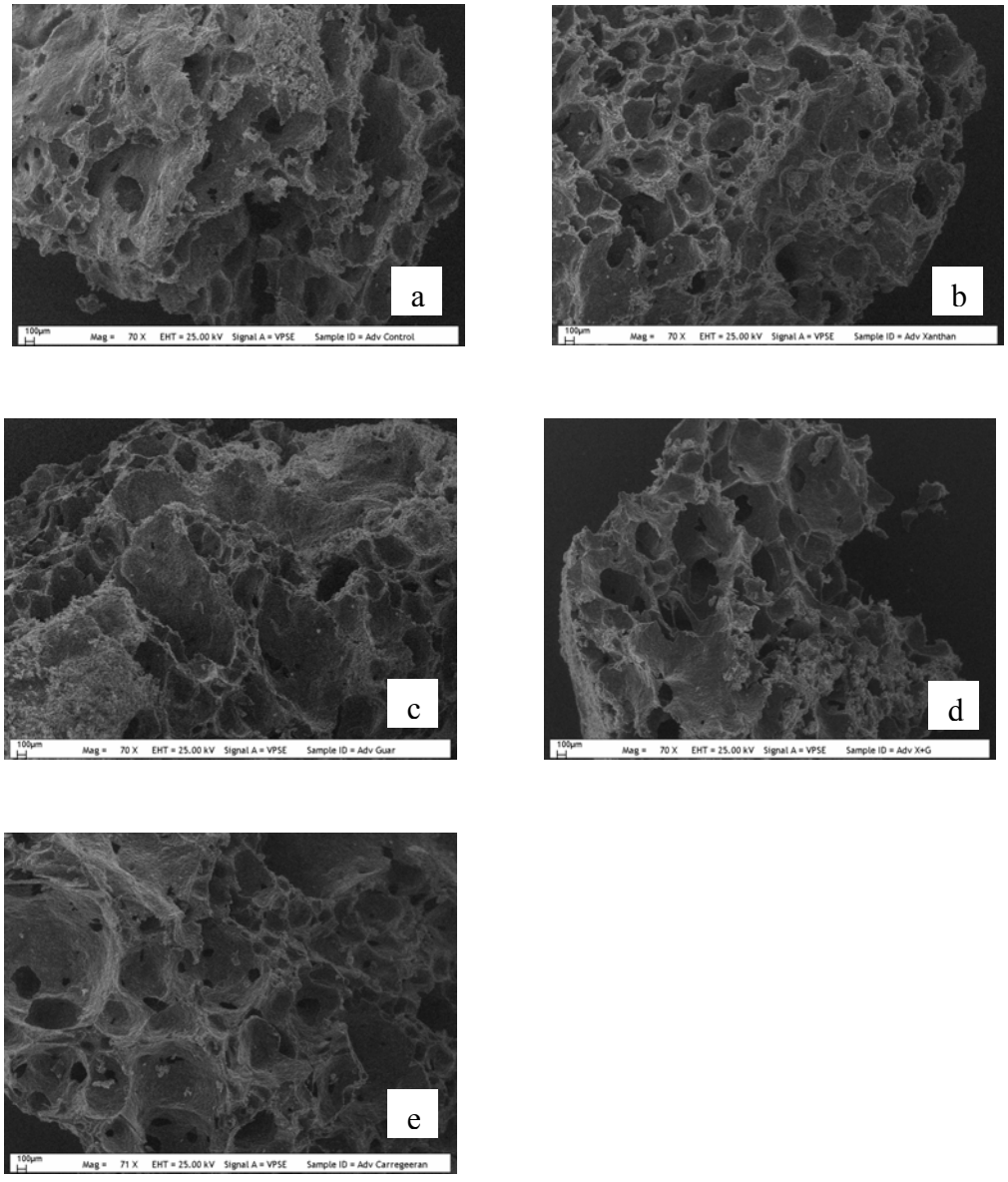

Figure 3.15 Microstructure at (70 x) magnification of a) no gum b) xanthan c) guar d) xanthan-guar blend e) κ-carrageenan added bread crumbs baked in IR-microwave combination oven

Additionally, more uniform microstructure was observed for the samples formulated with xanthan baked in IR-microwave combination oven (Figures 3.15b). The uniformity in microstructure of samples formulated with xanthan can also be seen in cumulative pore area fractions of those samples (Figures 3.11 and 3.12). Since xanthan may thicken the gas cell walls, the samples formulated with this gum can compensate microwave induced high pressure formed during IR-microwave combination baking, resulting in uniform morphology. The samples formulated with carrageenan were found to have larger pores (Figure 3.15e). This may be because of the high dielectric properties of gum carrageenan that the breads formulated with this gum were heated more efficiently and higher internal pressure resulted in larger pores in bread samples.

Figures 3.16 (a-b) show the microstructure at (1000 x) magnification of control breads baked in IR-microwave combination and conventional ovens.

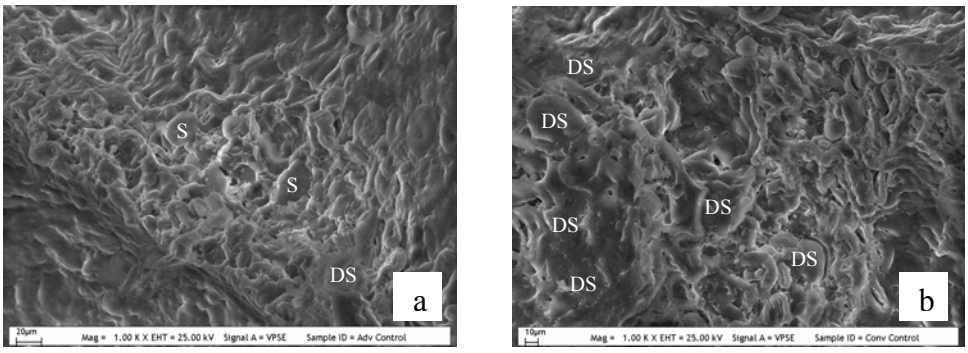

Figure 3.16 Microstructure at (1000 x) magnification of control bread crumbs baked in a) IR-microwave combination and b) conventional ovens (DS: Deformed structure; S: Starch granule residues)

The starch granules in conventionally baked control breads were more distorted and they lost their identity and formed a more continuous sheet of gelatinized starch. The starch granules in breads baked in IR-microwave

combination oven were deformed but not completely lost their identity and did not disintegrate completely. Granular residues and deformed starch structure were observed together in IR-microwave combination heating.

The results obtained for control breads are also valid for the samples formulated with gums. The starch granules in conventionally baked samples containing gums were more distorted compared to the ones baked in IR-microwave combination oven (Figures 3.17 (a-h)). The granular boundaries of starch molecules can be easily observed in xanthan-guar and guar gum added samples baked in IR-microwave combination oven (Figures 3.17c and 3.17e).

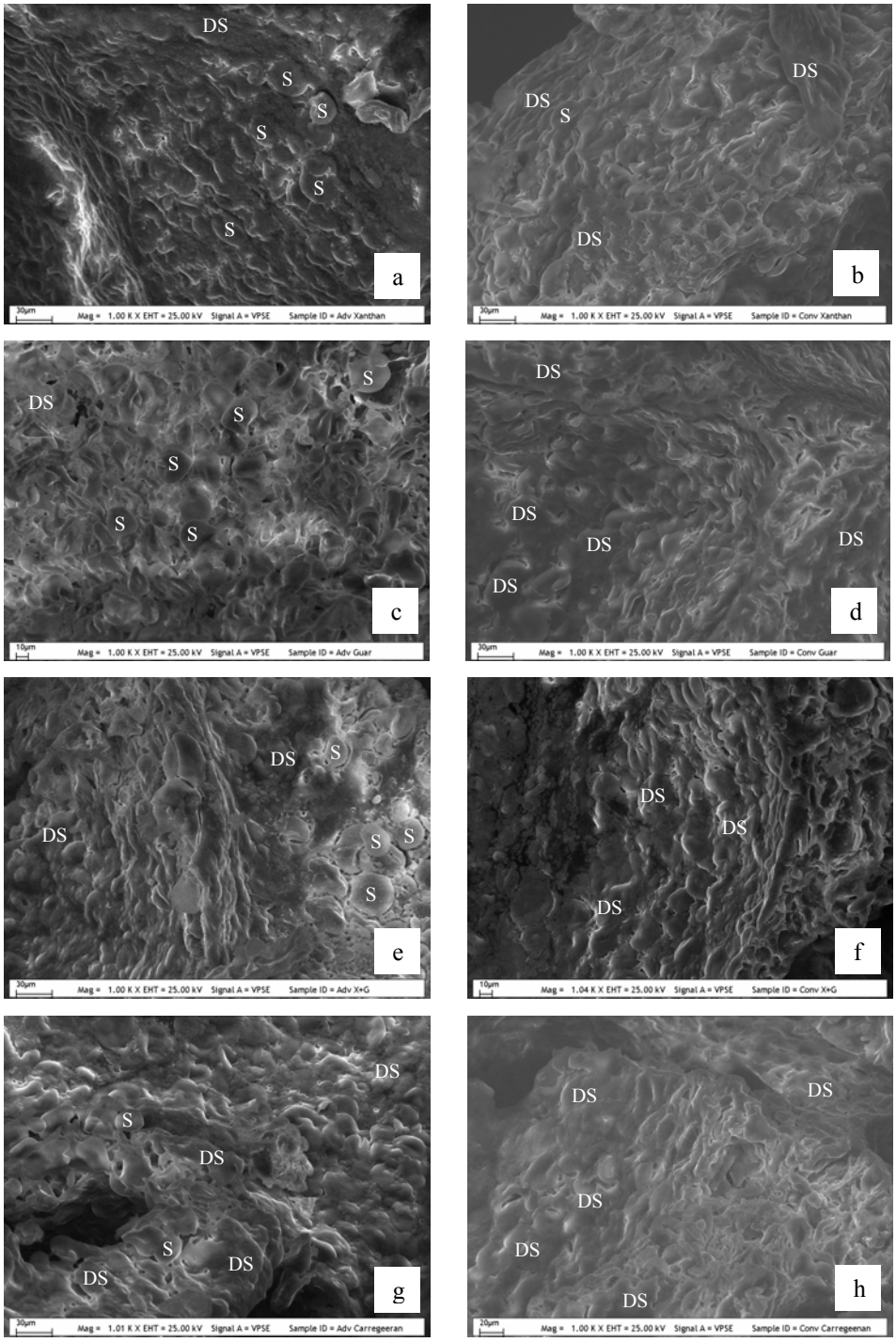

Figure 3.17 Microstructure at (1000 x) magnification of a,b) xanthan c,d) guar e,f) xanthan-guar blend g,h) κ-carrageenan added bread crumbs baked in IR-microwave combination (a, c, e and g) and conventional ovens (b, d, f and h) (DS: Deformed structure; S: Starch granule residues)

It was observed that gums coated the surface of starch granules and formed veil-like structure (Figures 3.17b, d, f, h). This was also seen in other studies (Brennan et al., 1996; Barcenas and Rosell, 2005),

When the effects of gums on microstructure of breads baked in IR-microwave combination oven were compared, the starch granules in breads formulated with carrageenan were found to be more distorted. This may be because of the high dielectric properties of gum carrageenan. Breads formulated with this gum were heated more efficiently which resulted in more starch gelatinization (Figure 3.17g).

3.3 Effects of Different Gums on Thermal Properties of Dough and Bread Samples Baked in IR-Microwave Combination Oven

When thermal properties of dough and bread samples baked in IR-microwave combination oven were considered, it was seen that the thermal conductivity values of dough were higher than that of breads (Table 3.4). This is explained by the loss of moisture and increase in specific volume of breads. Such decrease has been noted in the literature (Bakshi and Yoon 1984; Sumnu et al., 2007). Sumnu et al. (2007) showed that thermal conductivity of breads were related with the changes in moisture content and porosity.

Table 3.4 The effect of gum type on thermal conductivity of dough and breads baked in IR-microwave combination oven

	Thermal conductivity ($W/m^2{}^\circ C$)	
GUM TYPE	**DOUGH**	**BREADS**
Control	0.34^{a*}	0.12^{a}
Xanthan	0.35^{a}	0.12^{a}
Guar	0.35^{a}	0.12^{a}
Xanthan-guar	0.34^{a}	0.12^{a}
κ-carrageenan	0.36^{a}	0.12^{a}

* means gums having different letters in a column are significantly different ($p \leq 0.05$)

The addition of gums to the formulation did not affect the thermal conductivity values of doughs significantly (Table 3.4). Thermal conductivity of bread samples were also found to be independent of gum type (Table 3.4). This may be due to the similarity in moisture retention ability of gums.

3.4 Effects of Different Gums on Dielectric Properties of Dough and Bread Samples Baked in IR-Microwave Combination Oven

When dielectric properties of dough were considered, dielectric constant of dough formulated with xanthan-guar blend was found to be significantly lower than control dough (Figure 3.18, Table A.21). However, the magnitude of this change may not be of practical importance. Dielectric properties of dough prepared with xanthan-guar blend are not within the range of the dielectric properties of dough containing xanthan and guar gum alone. This can be explained by the synergistic effects of gums. There was no

significant difference between xanthan and xanthan-guar blend containing dough in affecting dielectric constant. The significantly low dielectric constant of dough formulated with xanthan gum and xanthan-guar blend might be due to their significantly higher water binding capacity (Tables 3.5 and A.22).

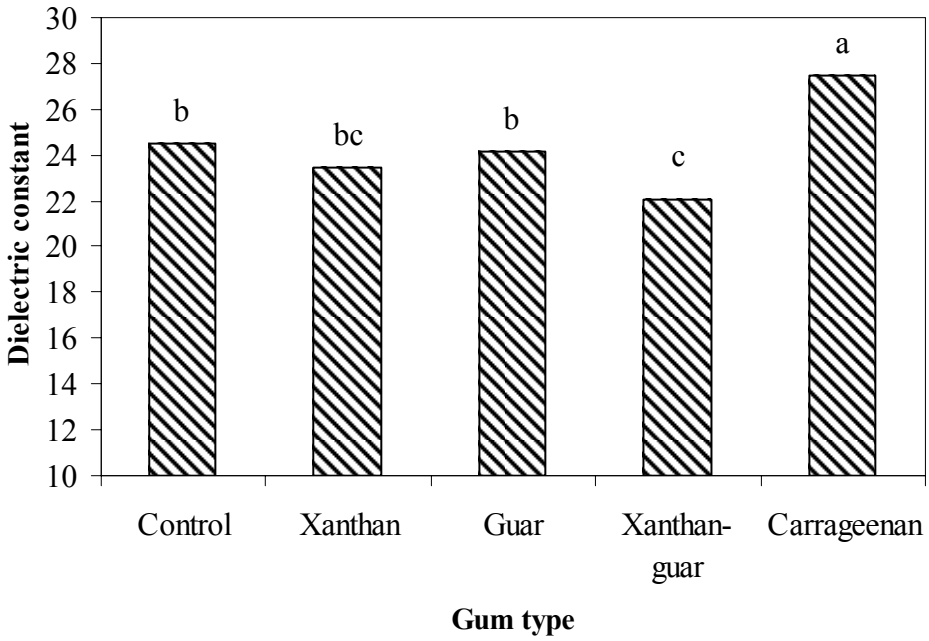

Figure 3.18. The effects of different gums on dielectric constant of dough

Since gums have ability to bind high amount of free water in the system and dielectric properties depend on free moisture content, interaction of bread with microwaves is expected to change in the presence of gums.

Table 3.5 Water binding capacity values for dough samples formulated with different gums

DOUGH TYPE	WBC (w\w)
Control	0.551[b]
xanthan	0.910[a]
guar	0.621[b]
xanthan-guar	0.887[a]
κ- carrageenan	0.571[b]

When dielectric loss factors of dough were taken into account, doughs formulated with κ- carrageenan was found to have the highest value (Figure 3.19 and Table A.23).

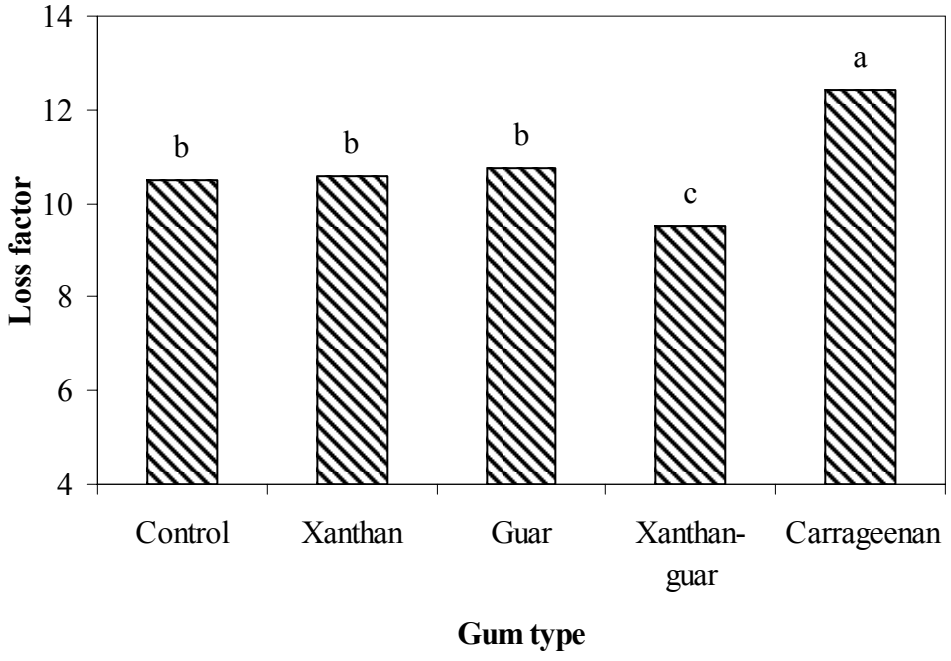

Figure 3.19 The effects of different gums on loss factor of dough

The highest dielectric constant and loss factor was also observed in the case of breads formulated with κ- carrageenan (Figure 3.20 and 3.21, Tables A.24 and A.25). Since dielectric properties of dough formulated with κ-carrageenan were found to be higher, it was not surprising to obtain breads, formulated with κ- carrageenan, with high dielectric properties. This result may be due to the ionic nature of gum κ- carrageenan, which increases the dielectric loss factor due to the effect of the ionic property in increasing the free charge density in the system (Ryynänen, 1995). The loss factor affects the microwave heatability of a food product. Since the loss factor of κ- carrageenan containing formulation is significantly higher; the temperature increase of this sample is significantly higher than that of the other formulations (Table A.26) at the initial stages of heating which can be seen in Figure 3.22. The high dielectric loss factor may increase the heating rate resulting in slightly higher temperatures.

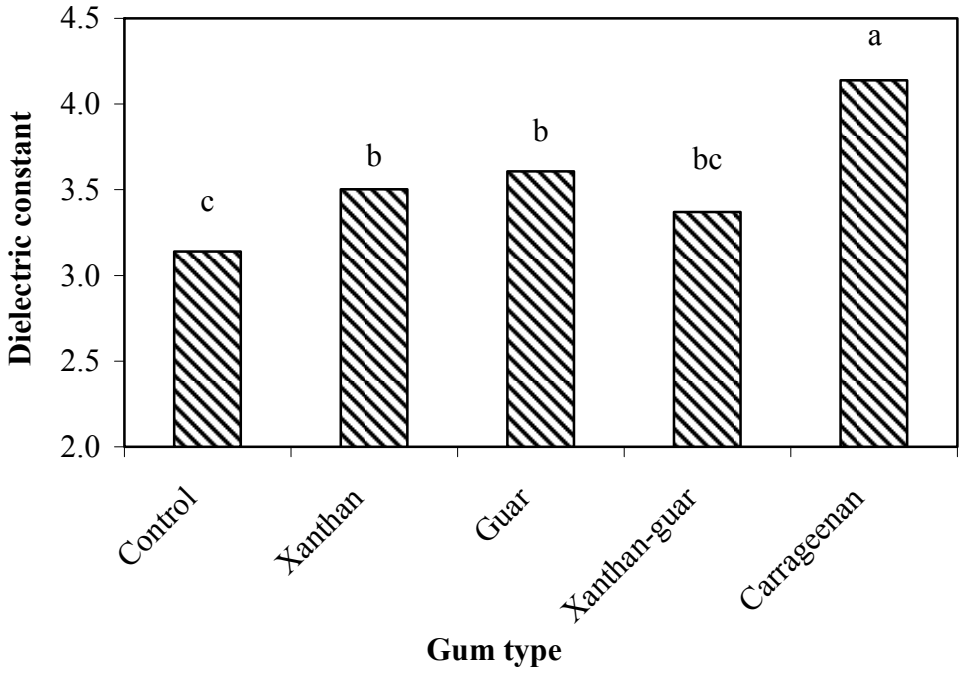

Figure 3.20 The effects of different gums on dielectric constant of breads baked in IR-microwave combination oven

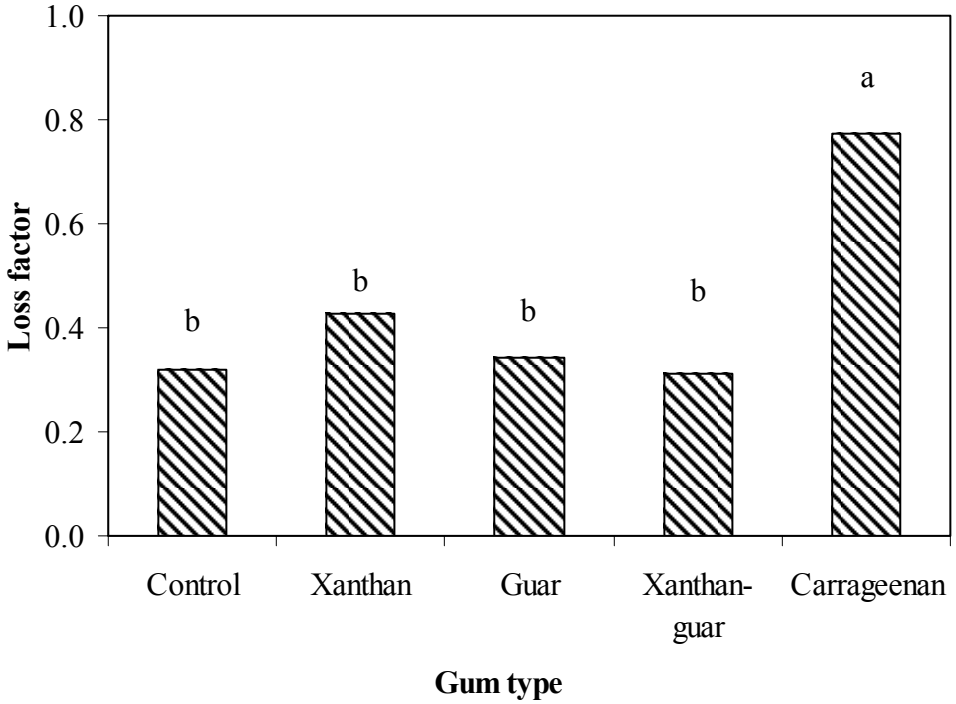

Figure 3.21 The effects of different gums on loss factor of breads baked in IR-microwave combination oven

The high dielectric properties of carrageenan containing bread may also be related to its low porosity (Figure 3.7). The increase in dielectric properties with increasing bulk density is well known in the literature (Calay et al., 1995; Nelson, 1983).

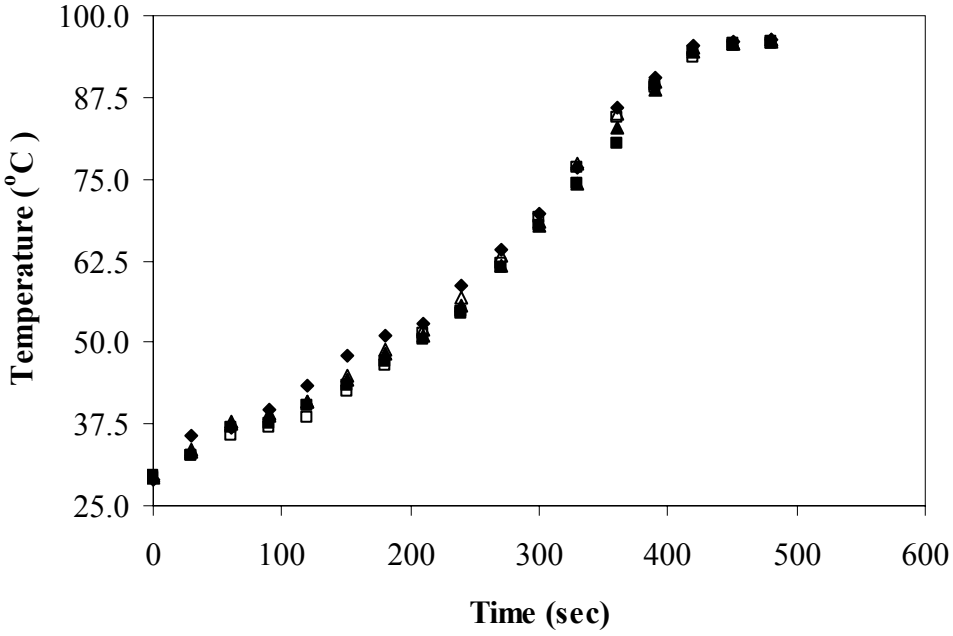

Figure 3.22 Transient temperature near the center of breads formulated with different gums during IR-microwave combination baking (♦:κ-carrageenan, Δ: guar, ▲: xanthan ■: xanthan-guar, □: control)

The dielectric properties of breads were lower than those of doughs which may be explained by the low moisture content and high porosity of breads. It is known that higher moisture content (Bengtsson and Risman, 1971; Roebuck et al., 1972; Nelson, 1978; Ndife et al., 1998) and lower porosity (Calay et al., 1995; Nelson, 1983) causes higher dielectric properties.

3.5 Determination of Acrylamide Content of Breads Baked in Different Ovens

Acrylamide analyses were performed by taking the samples from the crust portion of breads baked in different ovens. Figure 3.23 demonstrates the acrylamide content of breads during baking in different ovens.

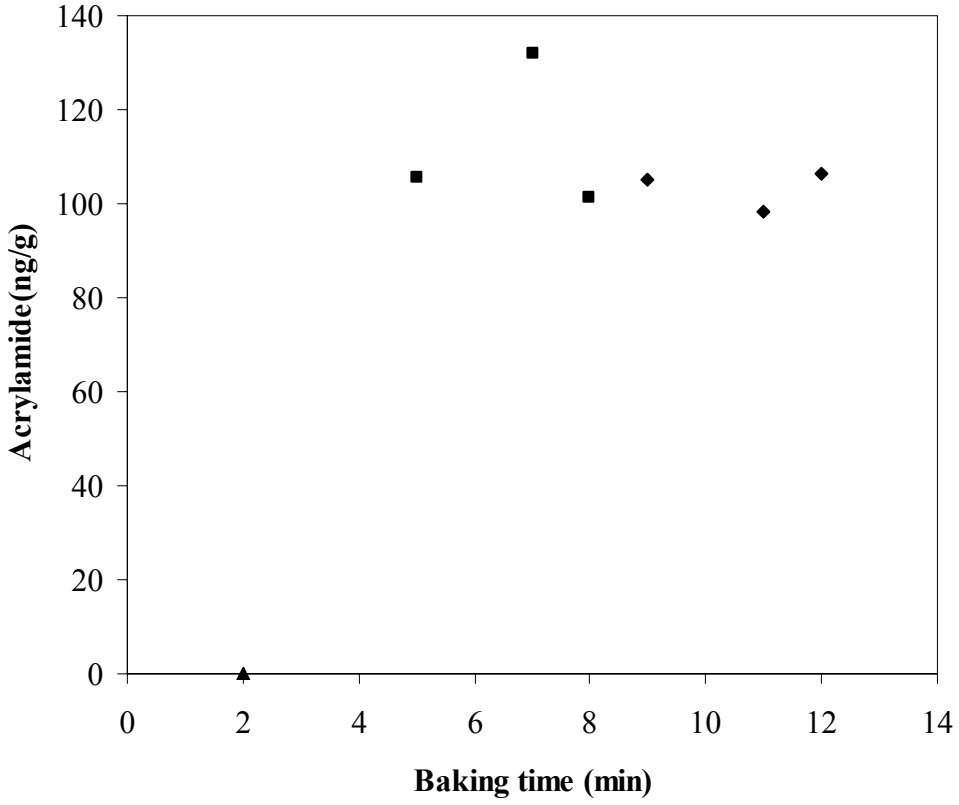

Figure 3.23 Variation in acrylamide content of bread crusts during baking in different ovens (♦: conventional oven; ■: IR-microwave combination oven; ▲: microwave oven)

No acrylamide was detected in the samples baked in microwave oven. The major mechanistic pathway for the formation of acrylamide in foods is via the Maillard reaction. Since the cool ambient temperature inside a microwave oven causes surface cooling of microwave-baked products and low surface temperature prevents Maillard browning reactions to occur, acrylamide could not be formed in microwave baked breads. Acrylamide content of bread samples baked in conventional oven was almost constant with respect to baking time within the studied period.

On the other hand, the acrylamide content of the samples first increased and then decreased during baking in IR-microwave combination oven. The increase of acrylamide content as baking time increases was demonstrated in early studies (Surdyk et al., 2004; Bråthen and Knutsen, 2005; Ahrné et al., 2007). The decrease in acrylamide content of samples baked in IR-microwave combination oven for 8 minutes may be due to the destruction of acrylamide at extended baking conditions. Since infrared heating focuses energy on the surface of the samples, the heat generated at that baking condition may cause polymerization reactions (Claus et al., 2006), which results in acrylamide reduction. Similar results related to coffee beans (Bagdonaite & Murkovic, 2004) and bread crusts (Ahrné et al., 2007) are available in the literature.

Many factors, including moisture content, pH, reducing sugars, amino acids, baking temperature and time, relative humidity and heat transfer modes during baking influence the surface color of breads. The total color change in samples during baking in different ovens can be seen in Figure 3.24. As baking time increased color of samples baked in different ovens increased. It was not surprising that the color of samples baked in microwave oven was closer to the color of reference (dough), since low surface temperature of product during baking prevents Maillard browning reactions to occur.

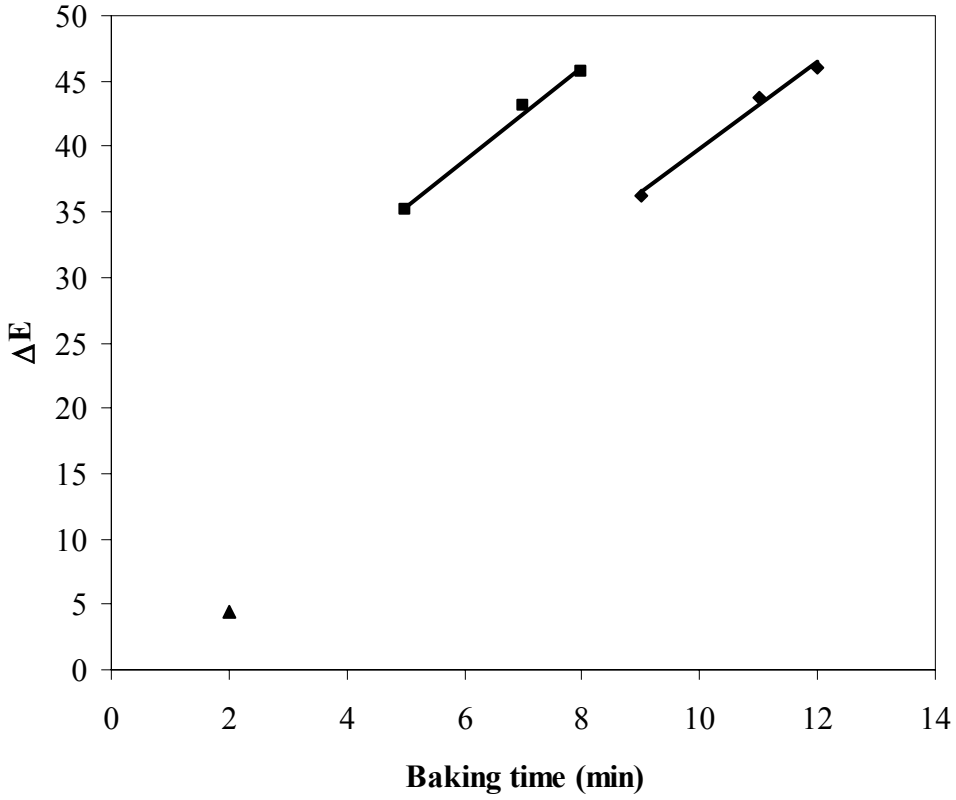

Figure 3.24 Variation in total color difference (ΔE) of bread crusts during baking in different ovens (♦: conventional oven; ■: IR-microwave combination oven; ▲: microwave oven)

When the relation between color and acrylamide values were considered, although total color change increased during baking, acrylamide content of breads baked in conventional oven were almost constant (Figures 3.23 and 3.24). It may be concluded that color alone cannot be used as an indicator of acrylamide content. Similar results can be found from the literature in the studies related to potatoes, potato chips (Taubert et al., 2004; Granda et al., 2005). Moreover, in model studies it was found that the levels of Maillard products (browning) do not necessarily align with acrylamide levels (Sadd and Hamlet 2005; Hamlet et al. 2005).

The pictures of ground bread crusts obtained from samples baked in different ovens can be seen in Figure 3.25.

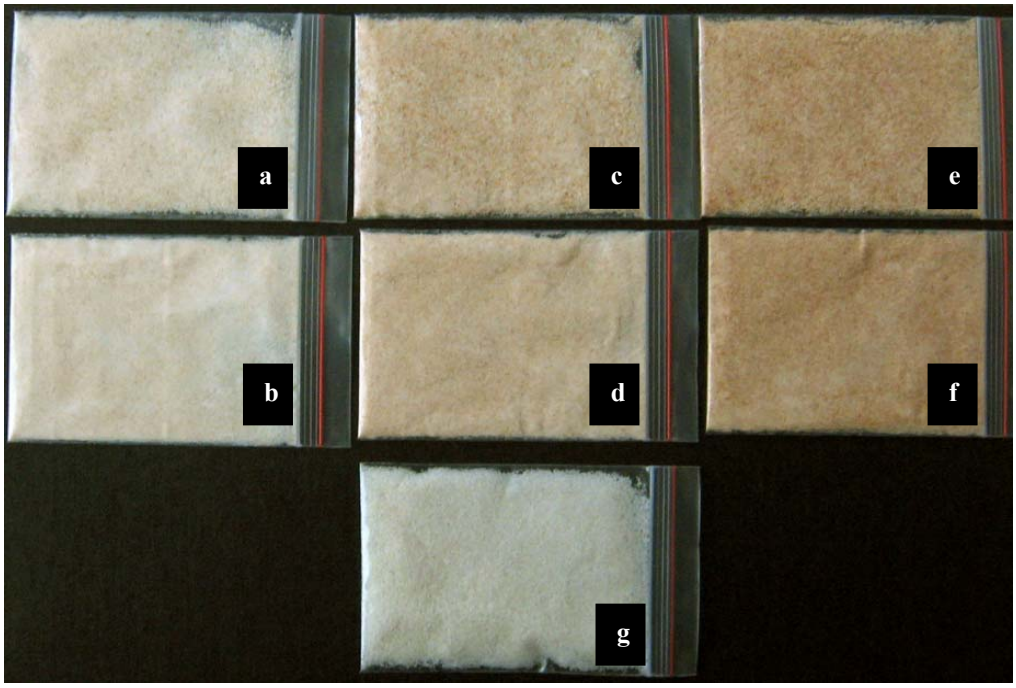

Figure 3.25 The pictures of ground bread crusts obtained from samples baked in different ovens at different baking conditions. The letters represent the samples baked in: **a**) IR-microwave combination oven for 5 min., **b**) conventional oven for 9 min., **c**) IR-microwave combination oven for 7 min., **d**) conventional oven for 11 min., **e**) IR-microwave combination oven for 8 min., **f**) conventional oven for 12 min., **g**) microwave oven for 2 min.

On the other hand, the a* value of samples may be correlated with the acrylamide content, which was confirmed by different researchers in different studies (Granda et al., 2005; Pedrechi et al., 2005; Gokmen and Senyuva, 2006). Figure 3.26 demonstrates the variation in a* value of the samples during baking in different ovens. Slight change in a* value of samples was seen. This trend was similar to that observed in the variation of acrylamide content during baking.

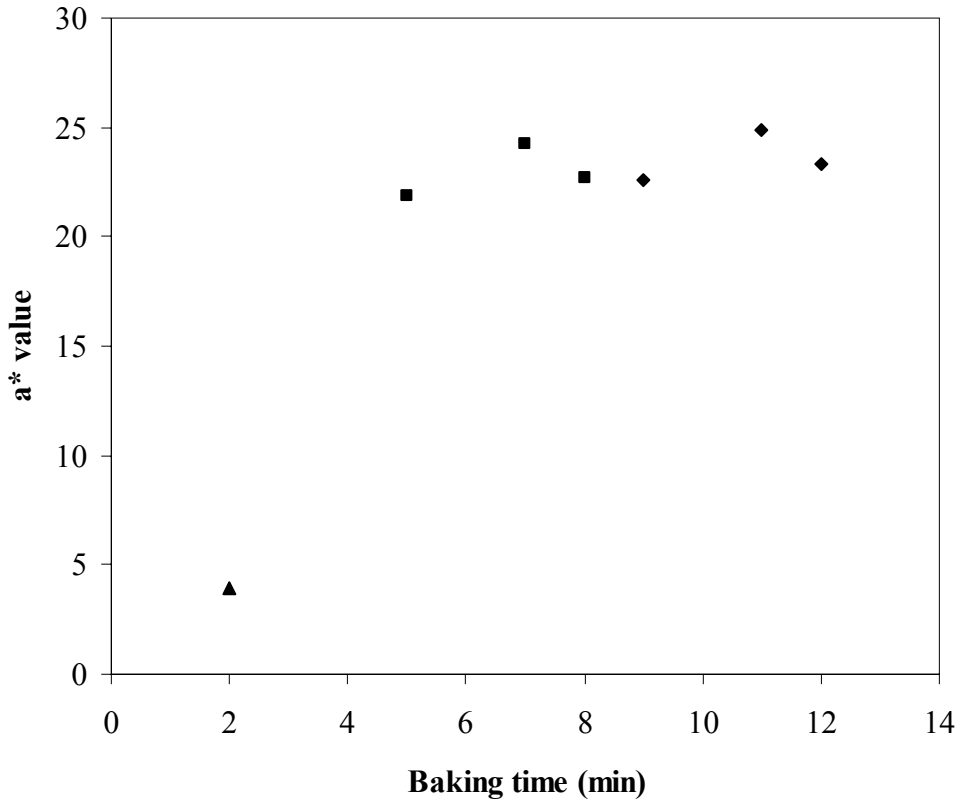

Figure 3.26 Variation in a* values of bread crusts during baking in different ovens (♦: conventional oven; ■: IR-microwave combination oven; ▲: microwave oven)

The moisture content of bread crusts can be seen in Figure 3.27. Although moisture content of samples decreased during baking, the acrylamide content of the samples were not affected. It has been declared that low moisture content is a more important promoter of acrylamide than temperature, and so crust moisture is a key factor for controlling acrylamide levels (Konings et al., 2007). However, this is not the case in our study. This may be because samples do not have the critical low moisture content to affect formation of different acrylamide contents. It was reported in literature that high amount of acrylamide did not occur until the moisture content of the cakes fell below 5 % (Elmore et al. 2005).

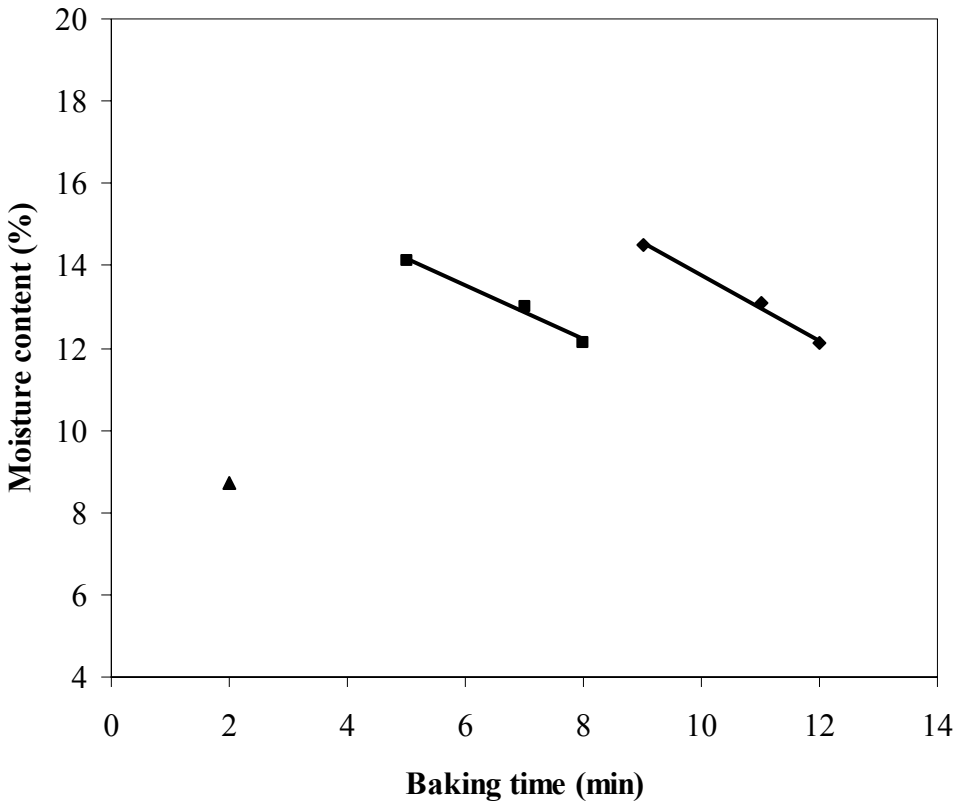

Figure 3.27 Variation in moisture content of bread crusts during baking in different ovens (♦: conventional oven; ■: IR-microwave combination oven; ▲: microwave oven)

When reducing sugar contents of the samples were considered, glucose contents of samples baked in conventional and IR-microwave combination ovens were found to be similar, as in the case of acrylamide content results (Figures 3.23 and 3.28). Samples baked in microwave oven had the highest glucose content which may be due to the fact that glucose was not used in Maillard reactions and also in acrylamide formation.

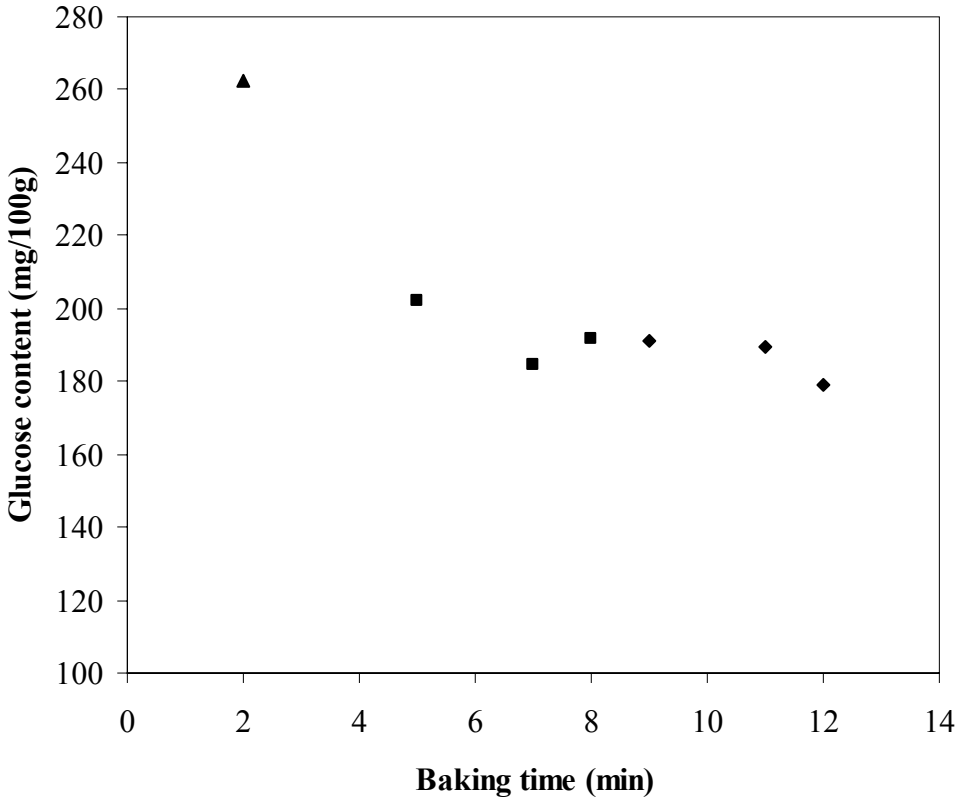

Figure 3.28 Variation in glucose content of bread crusts during baking in different ovens (♦: conventional oven; ■: IR-microwave combination oven; ▲: microwave oven)

It can be seen from Figure 3.29 that as baking time increased, fructose content of samples decreased. However, the acrylamide content of samples baked in different ovens was found to be almost constant. Acrylamide may be formed and destructed at the same time at longer baking times so an increase in acrylamide content during baking may not be observed.

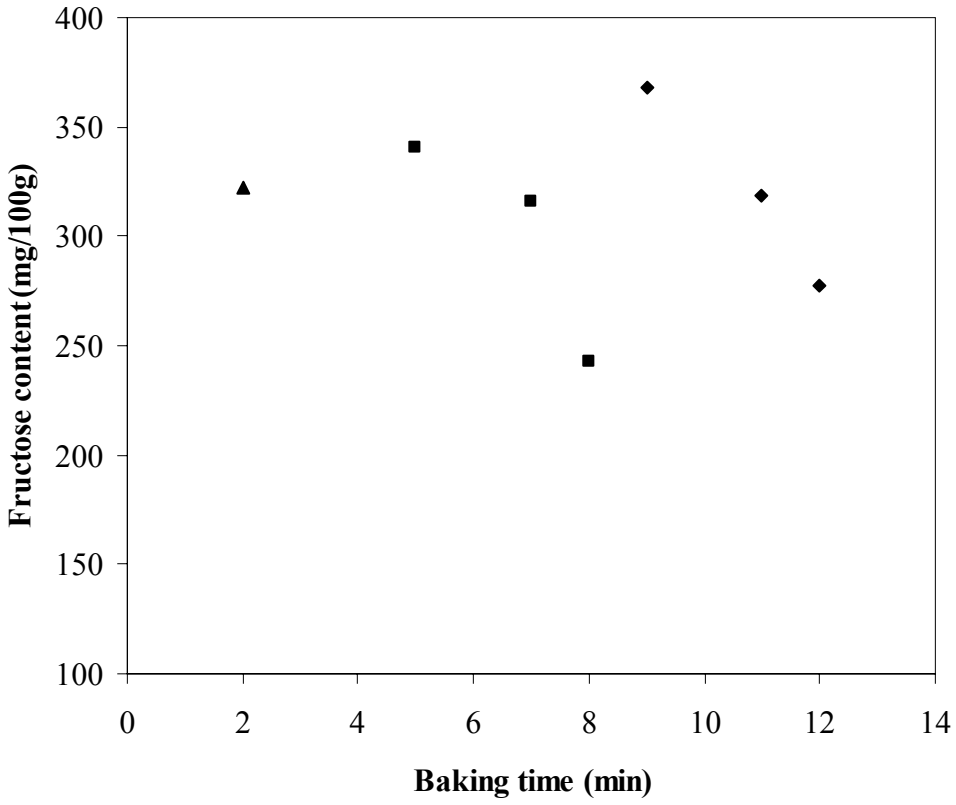

Figure 3.29 Variation in fructose content of bread crusts during baking in different ovens (♦: conventional oven; ■: IR-microwave combination oven; ▲: microwave oven)

The variation in amino acid composition of bread crusts during baking in different ovens can be seen in Table 3.6. Asparagine content of breads baked in conventional and IR-microwave combination ovens decreased as baking time increased. Since asparagine is the main component used in Maillard reaction, and also in acrylamide formation, it was not surprising to obtain this result. But this decrease was not found to be very effective in increasing acrylamide content of samples.

Aspartic acid is one of the amino acids, which can go through acrylic acid upon pyrolysis to produce acrylamide (Eriksson, 2005) (Figure 1.4). Free amino acid content analysis demonstrated that the aspartic acid content of breads baked in IR-microwave combination oven decreased as baking time increased (Table 3.6), which may be due to consumption of aspartic acid in acrylamide formation. Moreoever, it was found that serine, cysteine and alanine content of breads baked in conventional oven decreased as baking time increased (Table 3.6). Those amino acids may be consumed in Maillard reactions or acrylamide formation, since serine and cysteine amino acids can go through pyruvic and then acrylic acid (Figure 1.4), and alanine can go through acrylic acid upon pyrolysis to produce acrylamide (Figure 3.30) (Eriksson, 2005). It was demonstrated that β-alanine can generate acrylic acid during its thermal decomposition which can subsequently react with free ammonia to form acrylamide (Yaylayan et al., 2004; Amrein, 2005).

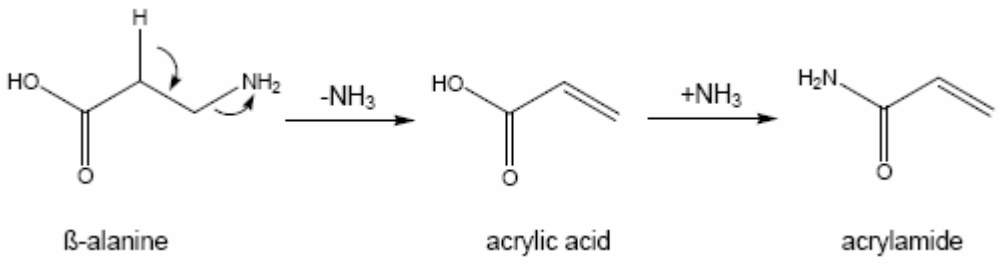

Figure 3.30 Formation of acrylamide starting from β-alanine (Yaylayan et al., 2004)

Table 3.6 Free amino acid composition of bread crusts during baking in different ovens (M[a], microwave power; H[b], halogen lamp power)

	Aminoacid content (mg/100g)																				
Baking method	Asn	Asp	Ser	Gly	Lys	Cys	Glu	Thr	Ala	Pro	Val	Met	Tyr	Trp	His	Arg	Phe	Hpr	Leu-lie	Gln	C-C
MW (100 M[a]/2 min)	0.952	1.369	0.454	0.855	2.393	1.014	0.764	0.260	4.492	2.584	2.183	1.287	0.546	0.649	1.185	2.525	0.240	0.315	0.311	1.898	19.230
IR-microwave (70 H[b]/20 M/5 min)	2.148	1.265	0.345	0.832	2.570	0.888	0.653	0.164	2.925	1.682	1.300	0.919	0.483	0.482	0.984	2.167	0.176	0.274	0.282	2.081	17.049
IR-microwave (70 H/20 M/8 min)	1.328	1.003	0.408	0.670	2.589	1.051	0.735	0.139	3.486	1.515	1.922	0.904	0.471	0.376	1.141	2.375	0.141	0.287	0.253	3.293	18.897
Conv (200°C/9 min)	1.423	0.972	0.351	0.720	2.979	1.144	0.719	0.354	4.707	2.771	2.224	0.884	0.614	0.784	1.877	2.524	0.282	0.302	0.364	2.381	21.006
Conv (200°C/12 min)	1.031	1.160	0.172	0.601	1.476	0.913	0.523	0.131	3.192	1.329	1.343	0.991	0.391	0.443	1.240	2.511	0.135	0.257	0.221	3.687	19.794

Total free amino acid content of bread crusts baked in different ovens at the final baking time can be seen in Figure 3.31. It was not surprising to obtain high total free amino acid content for the samples baked in microwave oven. The ambient temperature inside the microwave oven results in surface cooling of microwave-baked products, which prevents Maillard browning reactions to occur at the surface. The total amino acid content of conventionally and IR-microwave combination baked breads were similar to each other. The reduction in total free aminoacid content of bread crusts during heating in IR-microwave and conventional ovens may be due to formation of complexes between free amino acids and other components in the medium.

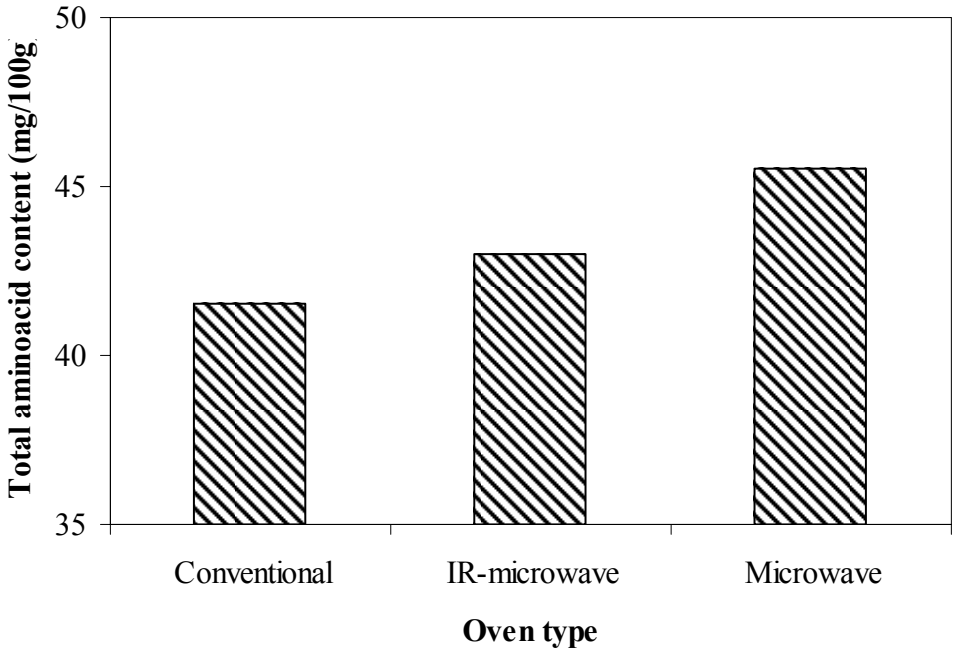

Figure 3.31 Variation in total amino acid content of bread crusts in different ovens at final baking time

3.6 Effect of Gum Addition on Staling of Breads Baked in Different Ovens

In the second part of the study, staling of breads formulated with no gum and with 0.5% xanthan-guar gum blend baked in different ovens

(conventional, microwave, IR-microwave combination ovens) were studied. Since it was found from the previous study that xanthan-guar addition to the formulation resulted in a decrease in hardness values; it was thought that addition of xanthan-guar gum to the formulation could retard staling of breads.

In order to investigate the effects of storage time on hardness of breads, breads baked in different ovens were stored 1h, 21h, 24h, 29h, 48h, 72h, 96h, 120h, 144h and 168h at 22±2 °C. It was seen that the hardness value became constant after 120h storage (Figure 3.32). For this reason, the staling experiments were decided to be performed until 120h of storage.

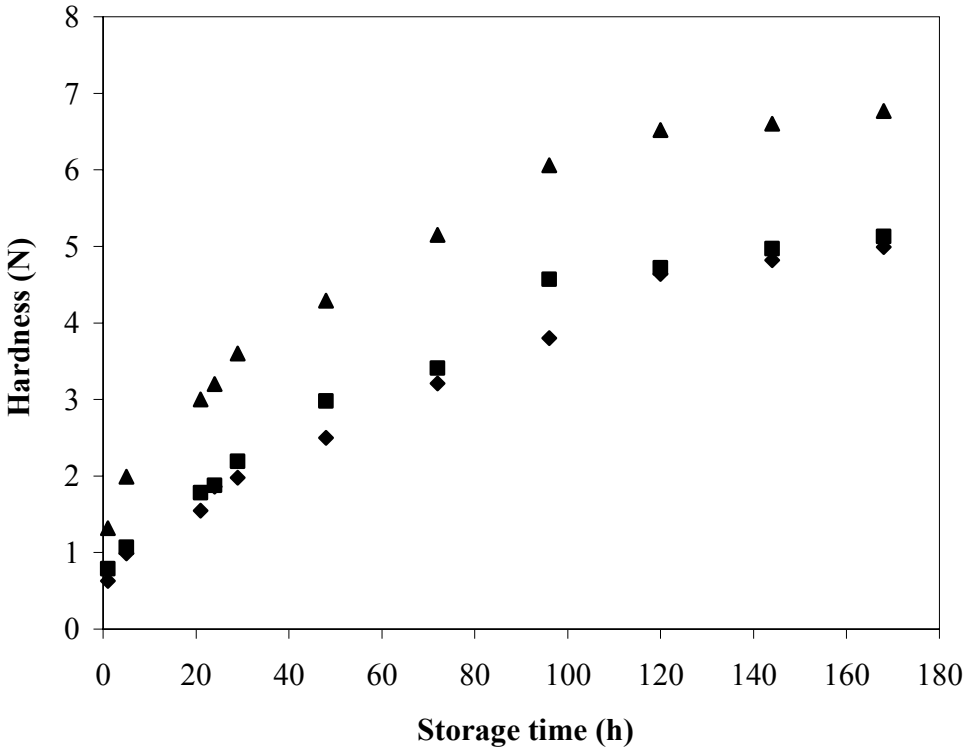

Figure 3.32. Variation in hardness of control breads baked in different ovens during 168h storage (♦: conventional oven; ■: IR-microwave combination oven; ▲: microwave oven)

The staling rate of breads baked in different ovens at the initial stage of storage (1h-24h) was found to be the highest. After 24h of storage, the staling rate decreased as compared to initial stage of storage (Figure 3.32). In general, there is a rapid and significant increase in hardness of breads within the first day. This early hardness development is attributed to solubilized amylose in the gel phase forming double helices (Zobel and Kulp, 1996). Amylose gelation covers a rapid network development, occurring in less than one day, via chain entanglement; while amylopectin is responsible for slow development of the crystallinity in the polymer-rich regions, which may continue for weeks (Leon et al., 2006).

3.6.1 Effect of gum addition on moisture content of bread samples baked in different ovens

ANOVA results demonstrated that moisture content of samples were dependent on storage time and oven type (Table A.27). The rapid decrease in moisture content of samples was seen during the first 1h cooling period (Figure 3.33). During storage, the variation of moisture content with storage time decreased more slowly. This may be because of the decrease in the difference between moisture content of crust and crumb as time passes, which means lower water migration within the bread during storage. Similar findings were obtained in early studies (He and Hoseney, 1990).

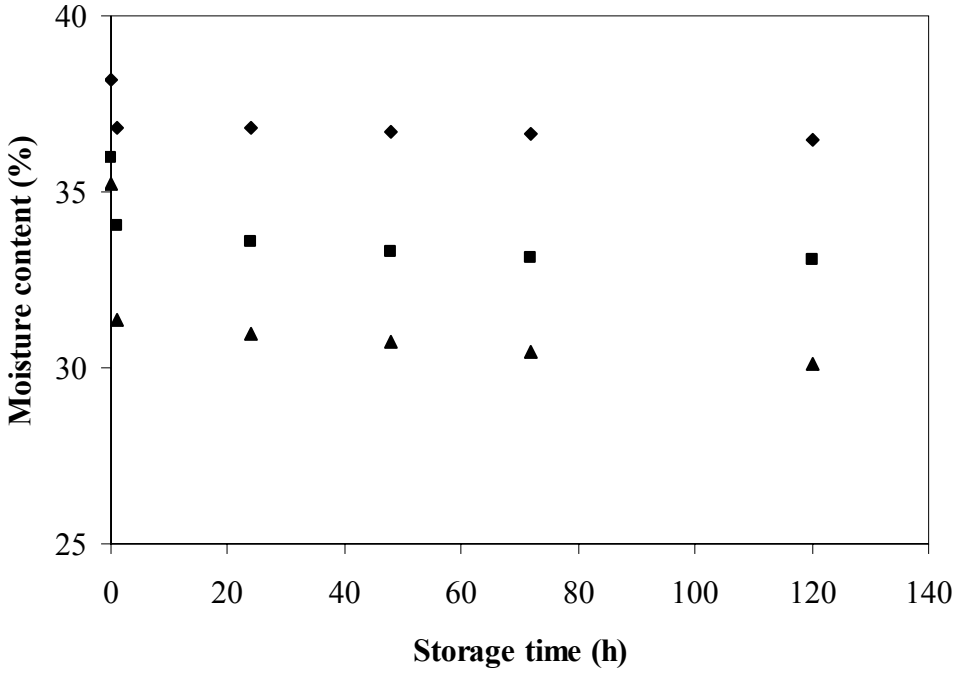

Figure 3.33 Variation in moisture content of control breads baked in different ovens during staling (♦: conventional oven; ■: IR-microwave combination oven; ▲: microwave oven)

The moisture content of microwave-baked breads were found to be the lowest among other heating modes (Figures 3.33 and 3.34). During microwave heating, relative to conventional baking, larger amounts of interior heating result 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, creating an outward flux of rapidly escaping vapor (Datta, 1990). In early studies, it was shown that breads and cakes baked in microwave oven lost more moisture as compared to conventionally baked ones (Sumnu et al., 1999; Zincirkiran et al., 2002; Demirekler et al., 2004; Keskin et al., 2004a).

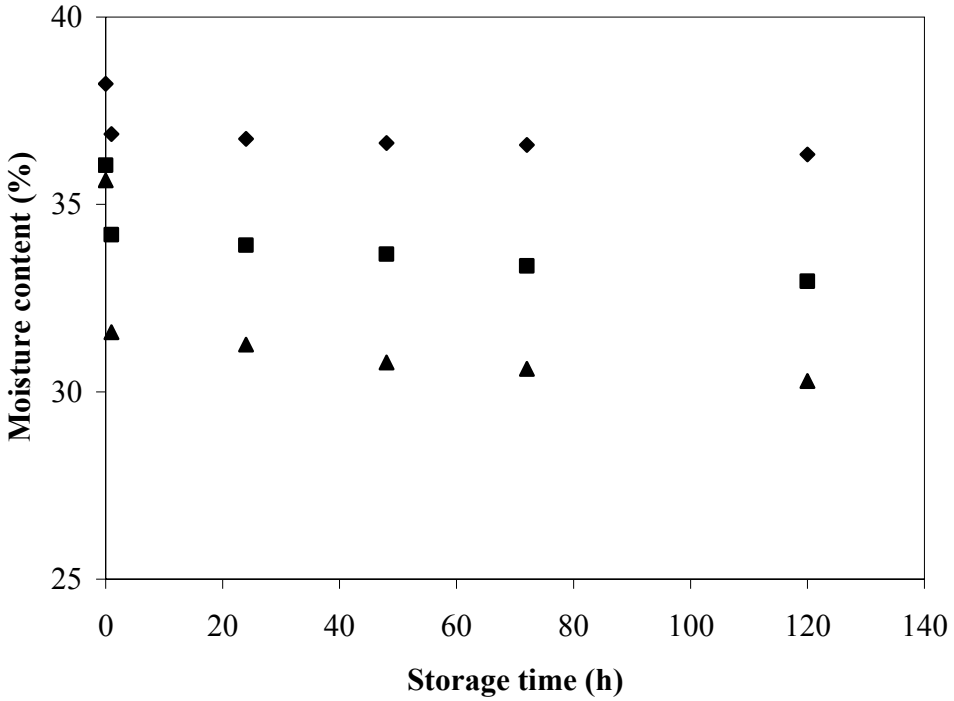

Figure 3.34 Variation in moisture content of breads formulated with xanthan-guar blend baked in different ovens during staling (♦: conventional oven; ■: IR-microwave combination oven; ▲: microwave oven)

When Figures 3.33 and 3.34 were compared, it was seen that the addition of xanthan-guar blend to the formulation did not significantly affect the moisture content of samples during storage (Table A.27). It is stated that the overall increase in dough water absorption due to the addition of a gum can be relatively small since it is used at low amounts (typically from 0.01 % to 0.5 % total formula basis), the additional water may be insignificant, but the viscous, slippery mouth feel that the gums retain even after baking can be perceived as a beneficial increase in product moistness (Heflich, 1996).

3.6.2 Effect of gum addition on hardness of bread samples baked in different ovens

The hardness values of microwave baked samples were found to be the highest among other heating modes (Figures 3.35 and 3.36), which was also observed in early studies (Demirekler et al., 2004; Keskin et al., 2004). According to ANOVA results, it was found that hardness values were dependent on storage time, oven and gum types (Table A.28). During 5 days of storage, hardness of bread samples increased significantly with time (Figure 3.35). The increase in firmness can be related to the decrease in moisture content. Moisture content has been shown to be inversely proportional to the rate of firming (Rogers et al., 1988). Bread firmness is caused mainly by the formation of interactions between partially solubilized starch and gluten protein (Martin, 1989). In bread, water acts as a plasticizer. When moisture decreases, it accelerates the formation of interactions between starch and protein, thus the bread firms faster (He and Hoseney, 1990). Therefore, crumb moisture and firmness are closely related. Since the moisture content of microwave-baked samples was the lowest among other heating modes, it was not surprising that the hardness values of microwave-baked samples was the highest (Figure 3.35). Moreover, the hardness of IR-microwave combination baked bread samples were in between that of conventionally and microwave-baked ones, showing that IR-microwave combination heating partially solved the rapid staling problem of microwave baking.

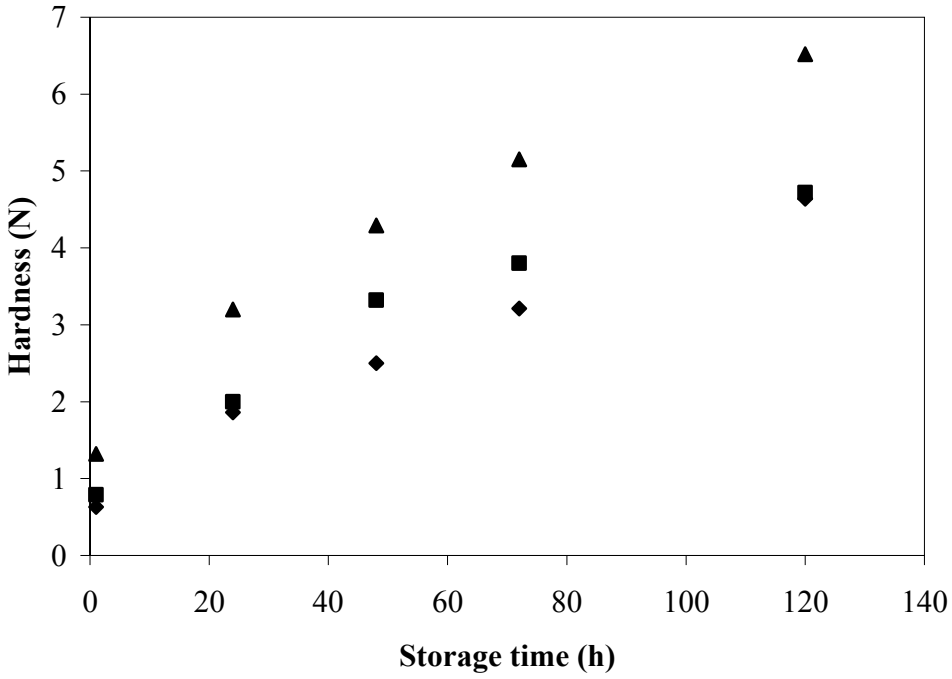

Figure 3.35. Variation in hardness of control breads baked in different ovens during staling (♦: conventional oven; ■: IR-microwave combination oven; ▲: microwave oven)

It was found that the addition of xanthan-guar blend to the formulation resulted in a significant decrease in the hardness values of samples baked in all types of ovens (Figure 3.35 and 3.36, Table A.28). This showed that gum addition retarded staling in terms of hardness values. Gums are able to modify starch gelatinization and to retard starch retrogradation by interacting with starch components; amylose and amylopectin, or gluten (Rosell et al., 2001). It was previously shown that gums reduced the firmness of bread crumb (Rosell et al., 2001).

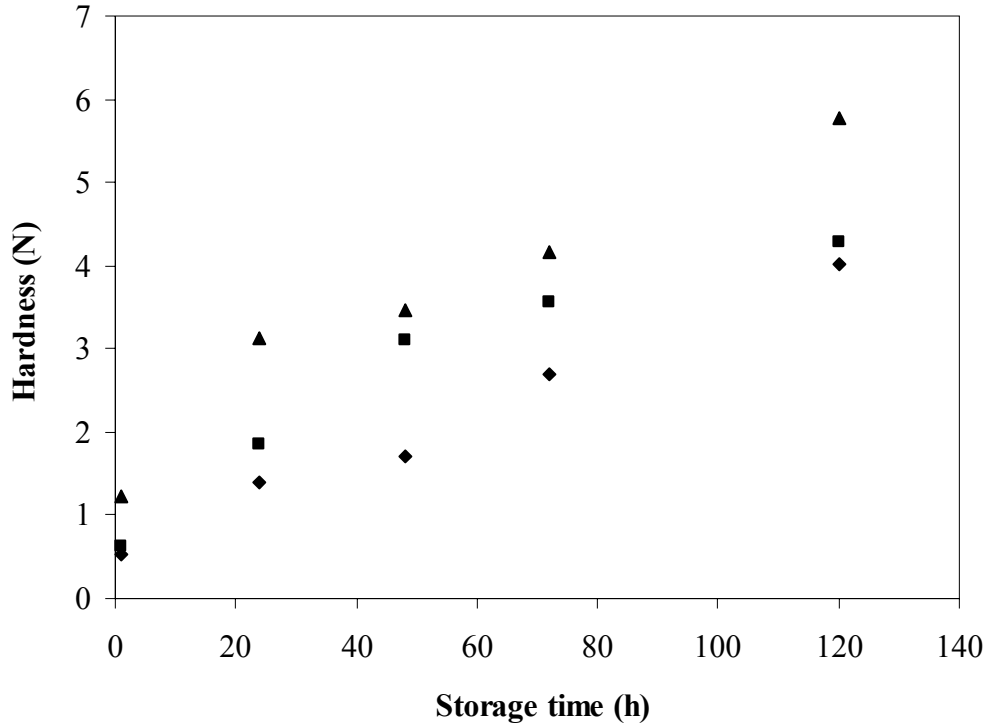

Figure 3.36. Variation in hardness of breads formulated with xanthan-guar blend baked in different ovens during staling (♦: conventional oven; ■: IR-microwave combination oven; ▲: microwave oven)

3.6.3 Effect of gum addition on soluble starch content of bread samples baked in different ovens

It can be seen from Figure 3.37 that soluble starch content of samples decreased as storage time increased. Similar results were also obtained previously (Morad and D' Appolonia, 1980; Lent and Grant, 2001). Decrease in soluble starch contents of samples during storage may be due to retrogradation/crystallization, which would reduce starch solubility (Sidhu et al., 1997).

When the effect of oven types on soluble starch content of samples were considered, it was seen that soluble starch contents of breads baked in microwave and IR-microwave combination ovens were found to be higher than that of conventionally baked ones (Figure 3.37). It is known that high temperatures can cause larger starch granule modification and disruption and as a result, larger amount of starch can be expelled from the granule (Faridi and Rubenthaler, 1984; Martin et al., 1991) Since microwave heated samples may reach to higher temperatures than conventionally heated ones in a shorter time, the leached starch amount of breads baked in microwave oven might be higher than that of conventionally baked ones. It was found in early studies that more amylose leached out during microwave baking of breads (Higo and Noguchi, 1987) and cakes (Seyhun, 2002) as compared to conventionally baked ones.

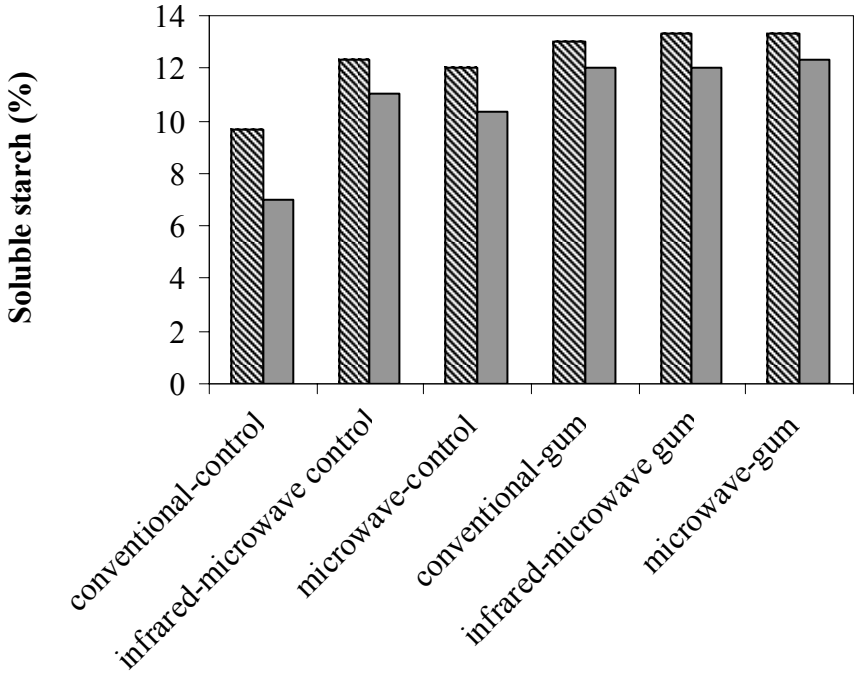

Figure 3.37 Variation in soluble starch content of control and gum added breads baked in different ovens during staling

24h 48h

The soluble starch content of gum added samples were found to be higher than that of control breads. Lent and Grant (2001) demonstrated in their studies that xanthan gum addition to bagel formulation resulted in an increase in soluble starch content of bagel crumb samples, which was related to resistance to starch retrogradation. Gum addition to the formulation decreased the difference in soluble starch content of samples baked in different heating modes (Figure 3.37).

3.6.4 Effect of gum addition on retrogradation enthalpies of bread samples baked in different ovens

When stored bread samples are heated in a DSC pan, an endotherm is observed as reordered amylopectin reaches to its glass transition and/or melting

temperature, and the enthalpy change associated with this transition can be measured. Therefore, DSC can be used to measure the rate of bread staling quantitatively (Jagannath et al., 1999).

DSC thermograms of control and gum added breads baked in different ovens during storage were shown in Appendix B (Figures B.1-B.18).

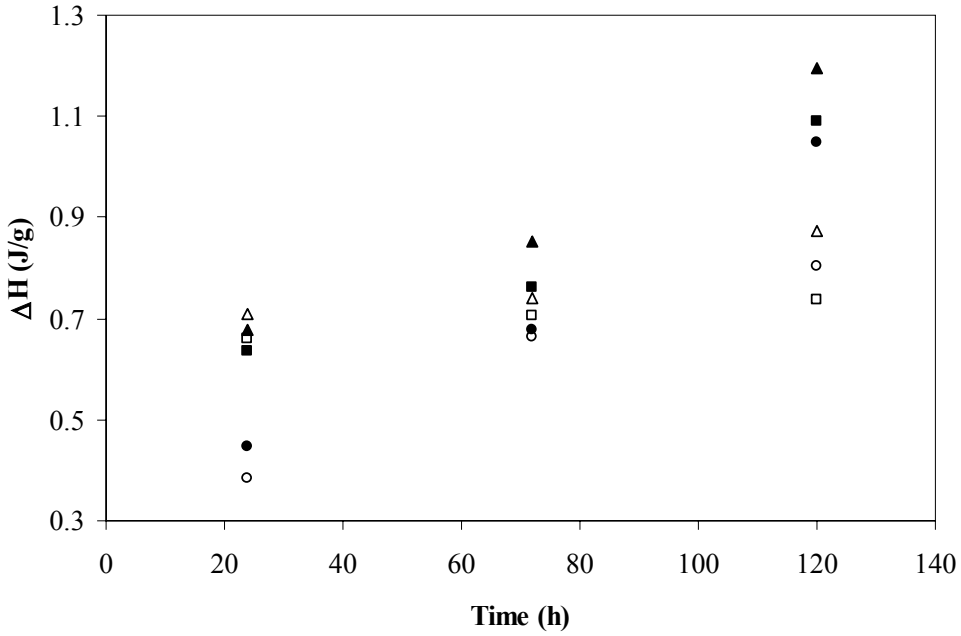

Figure 3.38 Variation in retrogradation enthalpy of control and gum added breads baked in different ovens during storage (▲:control breads baked in microwave oven; ■: control breads baked in IR-microwave combination oven, ●: control breads baked in conventional oven; Δ: gum added breads baked in microwave oven; □: gum added breads baked in IR-microwave combination oven; ○: gum added breads baked in conventional oven)

The ANOVA results demonstrated that retrogradation enthalpies of samples were dependent on storage time, gum and oven types (Table A.29). It can be seen from Figure 3.38 that retrogradation enthalpy of samples increased significantly as storage time increased which is in accordance with the studies

in literature (Leon et al., 2006). The significant increase in retrogradation enthalpies can be clearly seen for 120h stored of control breads baked in all types of ovens.

Moreover, it was not surprising that the retrogradation enthalpies of microwave-baked breads were the highest, due to the rapid staling problem of microwave heating. On the other hand, the retrogradation enthalpies of samples baked in IR-microwave combination oven were in between the values of conventionally and microwave-baked breads, which means combination heating partially solved the rapid staling problem of microwave heating.

It can be easily seen from Figure 3.38 that gum addition reduced retrogradation enthalpy significantly after 72h storage time, meaning that staling was retarded. Chaisawang and Suphantharika, (2006), found that the retrogradation enthalpy values of gum added starch samples were significantly ($P \leq 0.05$) lower than those of the starch alone. They associated their results with a reduction in water availability causing partial gelatinization of crystalline regions in the starch granules and starch-gum interactions (Chaisawang and Suphantharika, 2006). The interaction of gums with starch fractions may prevent reordering of amylopectin chains.

Table 3.7 demonstrates the onset, peak and final temperatures related to DSC analysis. 3-way ANOVA results showed that peak temperature was dependent on gum and oven types. Xanthan-guar blend addition caused significant shifting/delaying in peak temperatures of samples baked in different ovens. Similar findings were obtained in different studies (Gujral et al., 2004; Chaisawang and Suphantharika, 2006). Gujral et al. (2004), demonstrated that addition of hydrocolloids (HPMC, guar, locust bean gum) brought a slight delay in peak temperature. Moreover, in a study that starch was modified by guar and xanthan gums, Chaisawang and Suphantharika (2006) found that peak temperature of starches with gum additions significantly shifted to higher

temperatures. Less perfect crystals result in lower peak temperatures (Karim et al., 2000). Since crystal formation is linked to distribution of water within the crumb, and gums have ability to redistribute water, there may be a shift in peak temperatures resulting in perfect crystals, which can not be related to the amount of crystals. This suggests that anti-staling properties of gum addition rely on reducing the degree of re-crystallization of amylopectin. In our study, the peak temperatures of samples baked in microwave oven were found to be significantly lower than that of samples baked in IR-microwave combination and conventional ovens (Table 3.7). Microwave heating may cause occurrence of imperfect crystals, which can melt at lower temperatures.

Table 3.7 Onset, peak, and final temperature of retrogradation peak of control and xanthan-guar blend added breads baked in different ovens

Sample	T_{onset}	T_{peak}	T_{final}
conventional control 24h	40.00	58.22	73.00
conventional x+g 24h	40.00	59.01	73.00
microwave control 24h	39.00	52.86	70.00
microwave x+g 24h	39.00	53.98	72.00
IR-microwave combination control 24h	42.00	54.69	70.00
IR-microwave combination x+g 24h	42.00	55.12	71.00
conventional control 72h	43.00	55.22	69.00
conventional x+g 72h	43.00	56.83	71.00
microwave control 72h	39.00	52.86	72.00
microwave x+g 72h	39.00	54.63	70.00
IR-microwave combination control 72h	40.00	54.99	70.00
IR-microwave combination x+g 72h	43.00	56.61	71.00
conventional control 120h	39.00	54.65	70.00
conventional x+g 120h	42.00	56.95	70.00
microwave control 120h	38.00	53.35	73.00
microwave x+g 120h	38.00	53.85	72.00
IR-microwave combination control 120h	40.00	54.79	71.00
IR-microwave combination x+g 120h	40.00	57.15	71.00

x: xanthan, g:guar

3.6.5 Effect of gum addition on RVA profiles of bread samples baked in different ovens

The RVA profiles (peak, final, setback, breakdown viscosities) of bread samples baked in different ovens can be seen in Table 3.8. The *peak viscosity* occurs at the equilibrium point between swelling and polymer leaching. Swelling and polymer leaching increase peak viscosity, while rupture and polymer alignment decrease it. It indicates also the water-binding capacity of the starch or mixture. As a result of granule rupture during exposure to high temperature and shear, the viscosity decreased to a minimum (*hot paste viscosity*). When the gelatinized starch cools, reordering of amylose results in an increase in viscosity until a gel is formed at the end of the test (*Final* or *cool paste viscosity*). That increase of viscosity is named *setback* and it is related with the retrogradation of the amylose chains. The *breakdown* in viscosity is related to the ability of the starches to withstand heating at high temperature and shear stress (Sopade et al., 2006).

Among RVA data, set back viscosity values have been related with staling in literature (Lent and Grant, 2001; Collar, 2003). When gelatinized starch cools down, an increase in viscosity is observed until the formation of gel due to the ordering of amylose molecule. The increase in viscosity is known as set back viscosity in RVA profile (Leon et al., 2006).

As can be seen in Table 3.8, the setback viscosity of samples baked in microwave and IR-microwave combination oven increased significantly during storage. It was found that the set back viscosities of the samples baked in IR-microwave combination oven were in between the values for conventionally and microwave-baked ones (Table 3.8). Since set back viscosity was related with starch retrogradation, it was not surprising that the samples baked in microwave oven had higher set back viscosities. Similar results were obtained in DSC analysis.

The RVA profiles of control and gum added breads can be seen in Appendix C (Figures C.1 and C.2, respectively).

Table 3.8. RVA profile of control and xanthan-guar blend added breads baked in different ovens during 120h storage

Oven type	Presence of gum	Storage time (h)	Peak viscosity (cP)	Break down viscosity (cP)	Setback viscosity (cP)	Final viscosity (cP)
microwave	No	1	663	91	1023	1023
microwave	No	120	1248	157	2160	2160
IR-microwave combination	No	1	290	9	644	644
IR-microwave combination	No	120	919	52	1645	1645
conventional	No	1	286	11	664	664
conventional	No	120	344	8	673	673
microwave	Yes	1	1493	214	2195	2195
microwave	Yes	120	1595	259	2275	2275
IR-microwave combination	Yes	1	1219	172	1683	1683
IR-microwave combination	Yes	120	1520	493	1883	1883
conventional	Yes	1	968	40	1675	1675
conventional	Yes	120	1103	75	1839	1839

The results showed that gum addition to the formulation resulted in an increase in viscosity values of most of the samples baked in different ovens during storage (Table 3.8). It was stated by some researchers (Bahnassey and Breene, 1994; Collar, 2003; Chaisawang and Suphantharika, 2006) that viscosity of starch/hydrocolloid systems after heating and cooling was greater

than in systems containing only starch. Thus, the increase in viscosity in the presence of gum can not be related to staling.

Table 3.8 also demonstrates the peak, break down and final viscosities of breads baked in different ovens. It was observed that all of the viscosity values increased as storage time increased. The peak viscosity values of fresh samples (stored for 1h) baked in microwave oven were higher than that of the ones baked in other ovens. The higher peak viscosity values means that less starch is gelatinized. There was no difference between peak viscosity values of control fresh breads (stored for 1h) baked in conventional and IR-microwave combination ovens. Therefore, it can be concluded that combination baking partially solved the insufficient gelatinization problem of microwave baking.

3.6.6 Effect of gum addition on X-ray pattern and total crystallinity of bread samples baked in different ovens

The diffraction pattern analysis showed that fresh bread stored for only 1h contained only a peak around 20.7° corresponding to a V-type structure (Figure 3.39 (a, c, e)). This is indicative of amylose complexing with fatty acids, which remains virtually unchanged with aging (Zobel et al., 1988). Peaks at 15.8° and 17.7-18°, 22.8° indicating B-type structure appeared during storage (Figure 3.39 (b, d, f). In the case of microwave-baked samples, the physical orientation of the branched amylopectin molecules of starch within the swollen granule may be different than that of the other samples baked in conventional and IR-microwave combination ovens. This results in appearence of an additional peak at 15.8°, indicating more crystalline structure since the swelling, hydration and gelatinization degree of starch in the samples baked in microwave oven is different from the ones baked in conventional and IR-microwave combination ovens.

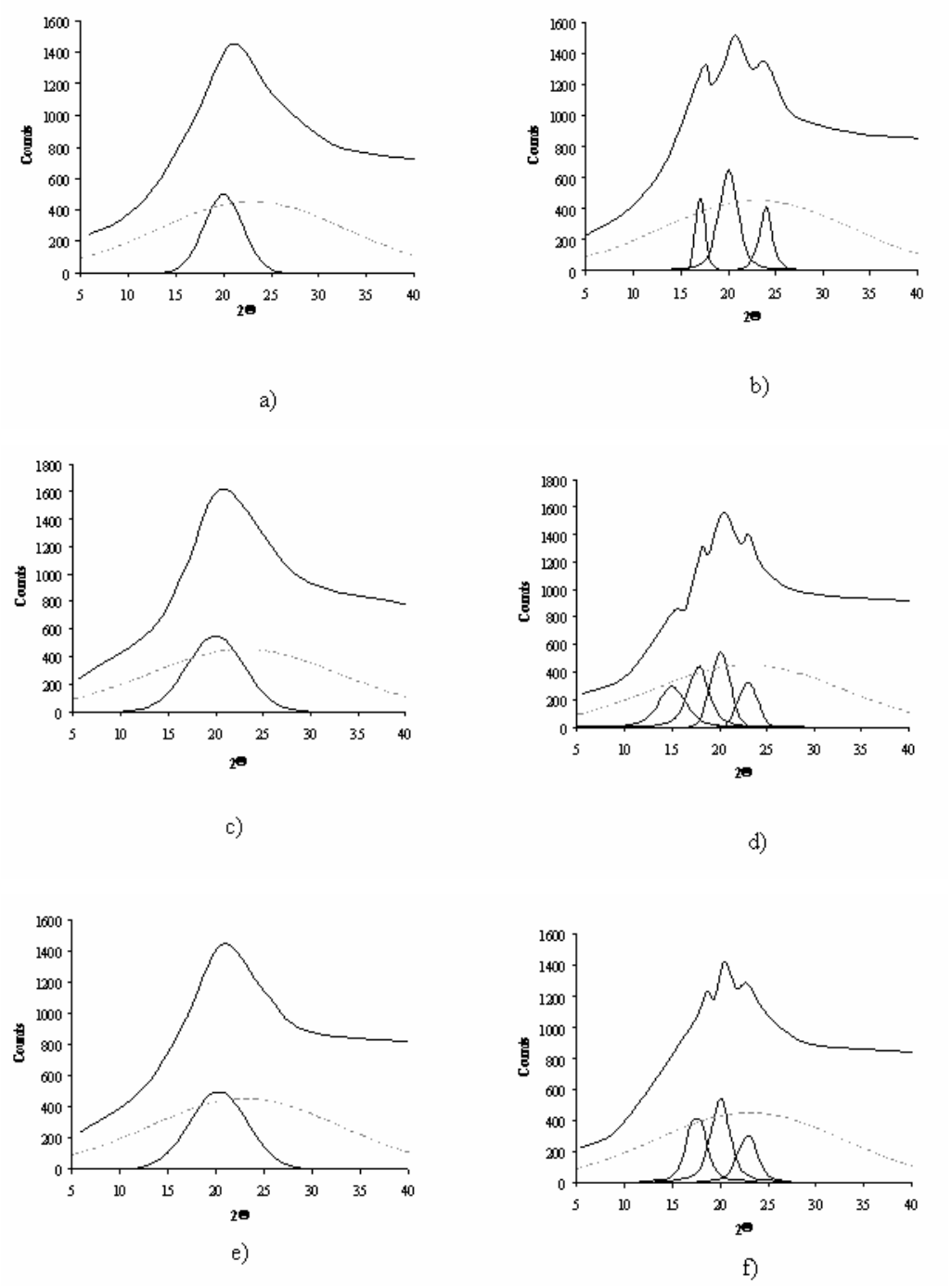

Figure 3.39 (a-f) X-ray pattern change after 1h and 120h storage for control breads baked in different ovens (**a**: conventional 1h; **b**: conventional 120h; **c**: microwave 1h; **d**: microwave 120h; **e**: IR-microwave combination 1h; **f**: IR-microwave combination 120h)

The different types of crystals influence the distribution of water within the crumb differently. The A-type crystal contains eight water molecules, whereas the B-type crystal contains 36 water molecules. As a result, in breads recrystallization of amylopectin develops B-type crystalline regions and the crumb becomes firmer because more water has migrated into the crystalline region. This water which participates in the formation of the crystal is no longer available as a plasticizer of the starch-gluten. Macroscopically, the lack of the plasticizing effect from water results in firmer bread and drier mouth feel (Slade and Levine, 1987). This result is supported by the firm texture of microwave-baked breads (Figure 3.35). B-type crystalline structure is larger for microwave-baked ones.

When the X-ray pattern of gum added samples was considered, it was found that there was no change in number of peaks appeared in X-ray pattern of gum added samples baked in different ovens (Figure 3.39 (a-f) and 3.40 (a-f)).

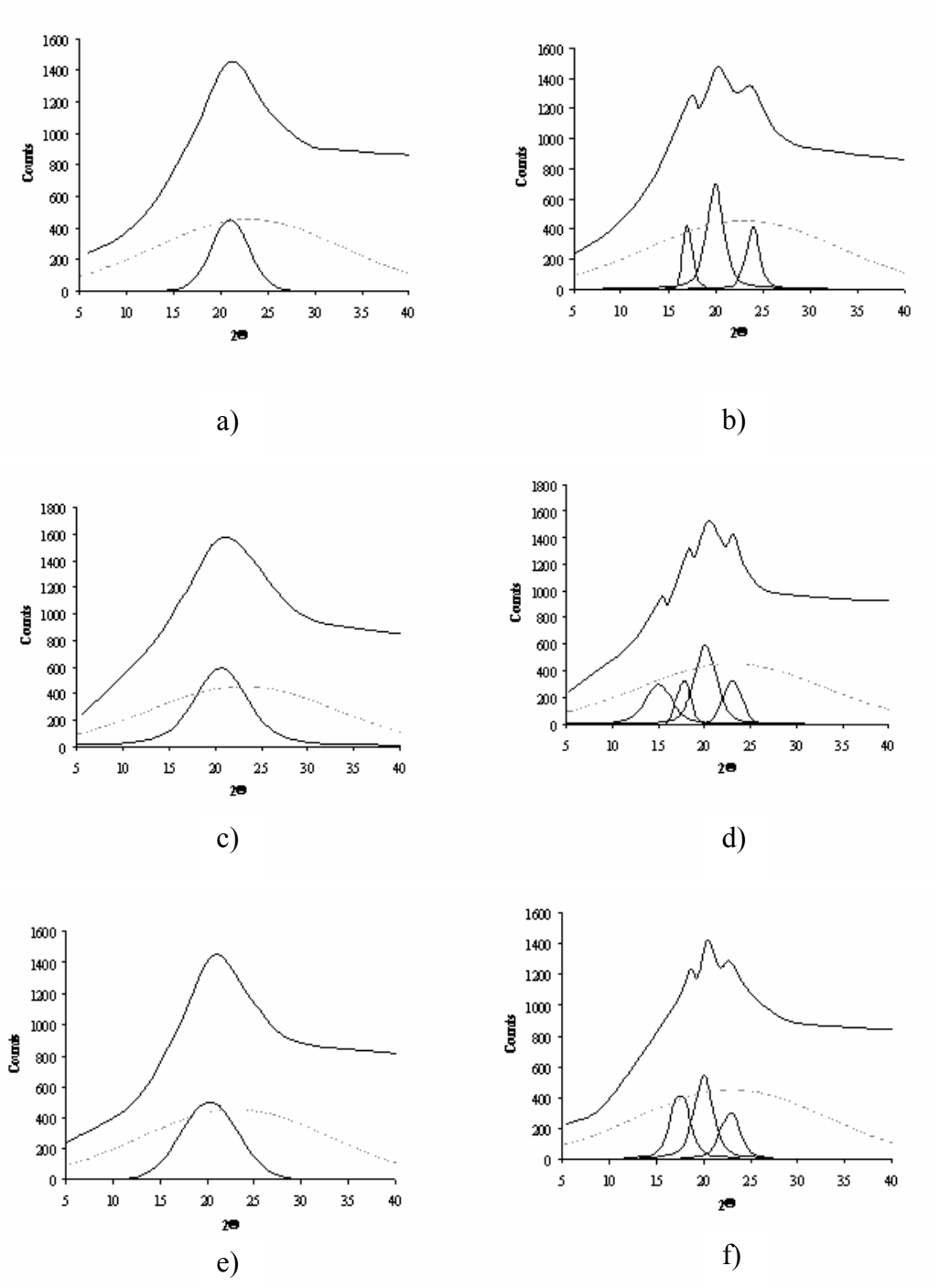

Figure 3.40 (a-f) X-ray pattern change after 1h and 120h storage for gum added breads baked in different ovens (**a**: conventional 1h; **b**: conventional 120h; **c**: microwave 1h; **d**: microwave 120h; **e**: IR-microwave combination 1h; **f**: IR-microwave combination 120h)

In determining the total crystallinity of samples, software, PeakFit V4.12 was used in curve fitting analysis, the details of which was given in Appendix D (Figures D.1-D4).

The total mass crystallinity grades of samples baked in different ovens can be seen in Figure 3.41. According to ANOVA, total mass crystallinity grades of samples were dependent on storage time, gum and oven types (Table A.30). As storage time increased crystallinity value of all samples increased significantly (Figure 3.41). The formation of gel structure due to the starch retrogradation during storage is linked to the development of crystallites, which is considered to be the interchain association of the amylose and amylopectin fraction (Jagannath et al., 1998).

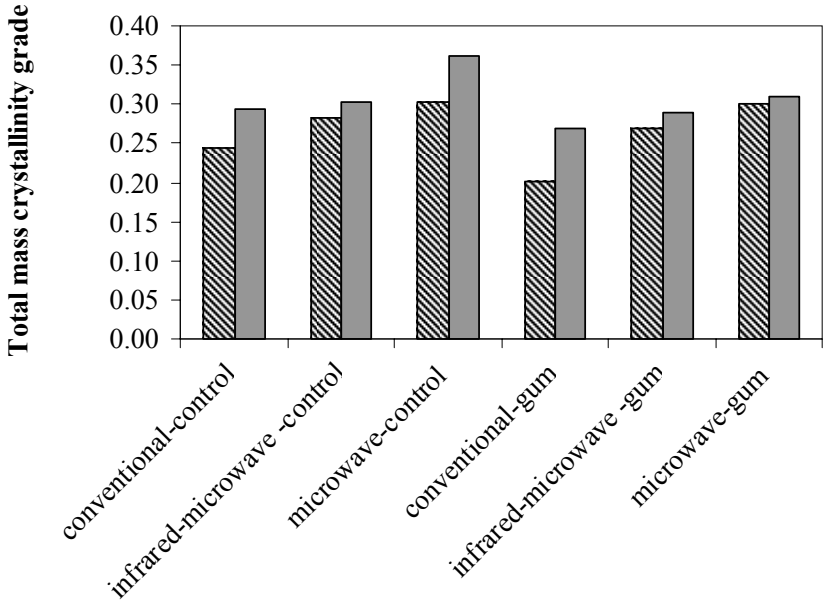

Figure 3.41 Variation in total mass crystallinity of control and gum added breads baked in different ovens during storage

1h 120h

When the crystallinity values of samples baked in different ovens were considered, it was found that the samples baked in microwave oven had

significantly higher crystallinity values than the other ones baked in conventional and IR-microwave combination ovens (Figure 3.41). It is known that high temperatures can cause larger starch granule modification and disruption and as a result, a larger amount of starch can be expelled from the granule (Faridi and Rubenthaler, 1984; Martin et al., 1991) Since microwave heated samples may reach to higher temperatures than conventionally heated ones in a shorter time, amount of leached starch in breads baked in microwave oven might be higher than that of conventionally baked ones which might explain the high crystallinity values.

When the effect of gum addition on total mass crystallinity values of samples were considered, it was found that gum addition decreased crystallinity values of all samples (Figure 3.41). Thus, staling was retarded.

3.6.7 Effect of gum addition on FTIR spectra of bread samples baked in different ovens

Water-related variations such as drying and water redistribution, have an influence on the measured spectra. In Figures 3.42 (a-f) the water-related variations, lying in the 3000-3600 cm^{-1} wavenumber interval, which corresponds to the O-H bond stretching vibration, can be easily seen. This fact is due to the lower water content of breads in the storage period and probably due to the subsequent reorganisation of the water molecules into the protein-polisaccharide network (Schiraldi and Fessas, 2001). Progressive intensity reduction in that region of the spectra with staling was suggested by Cocchi et al. (2005).

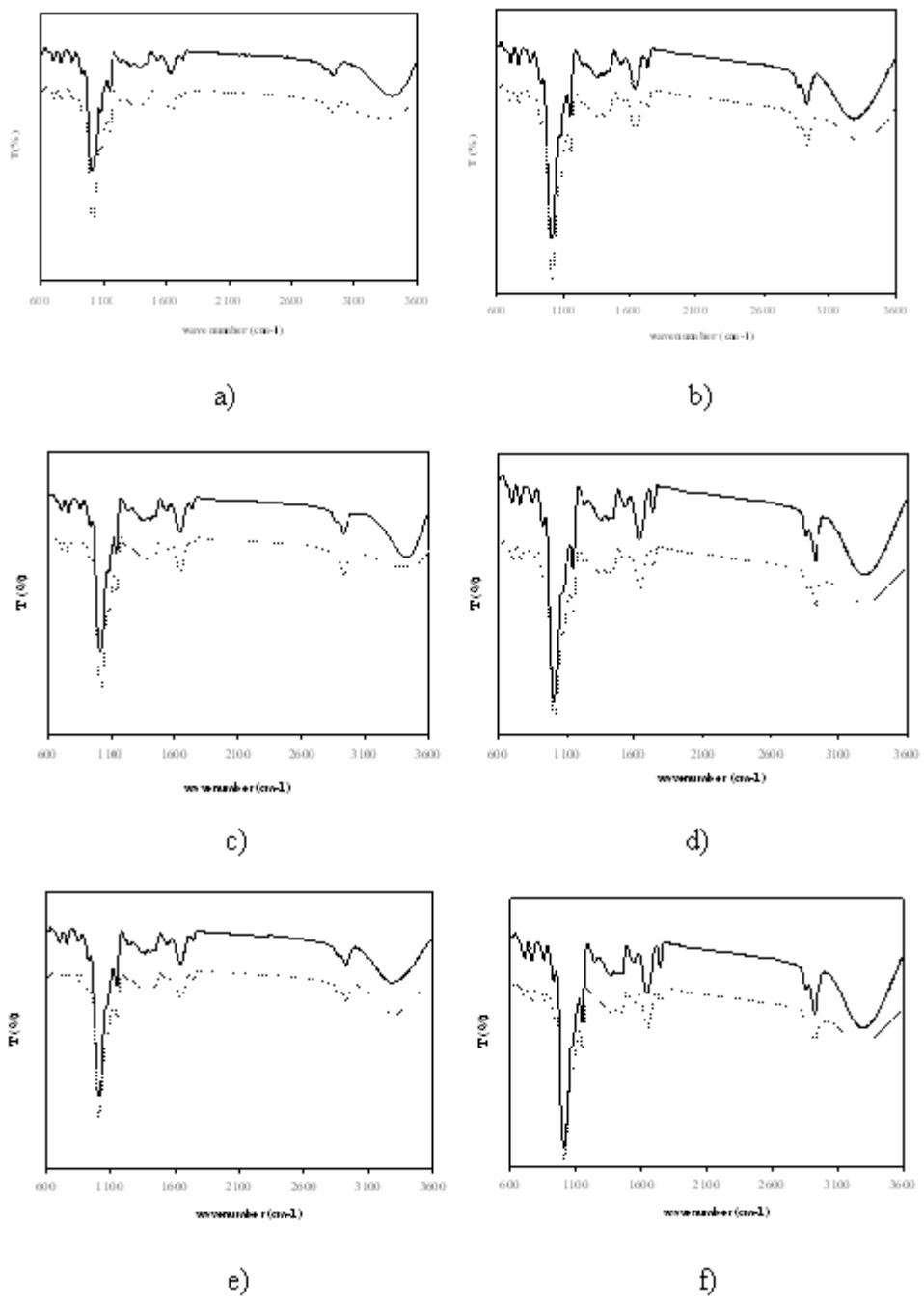

Figure 3.42 (a-f) FTIR spectra of control and gum added breads baked in different ovens after 1h (————) and 120h (---------) storage (**a**: conventional, control; **b**: conventional, gum; **c**: microwave, control; **d**: microwave, gum; **e**: IR-microwave combination, control; **f**: IR-microwave combination, gum)

The integral area of peaks appeared at 2980-3600 cm^{-1}, which represents water-related variations and changes during storage, was proportionated to the 2810-2970 cm^{-1} loadings region, which is almost exactly related to the "C-H strech in saturated lipids" (2806-2840 cm^{-1}) (Cocchi et al., 2005), to make the measurements independent of uncontrollable factors. The variation in contact surface between the ATR crystal and sample at every measurement can be regarded as an uncontrollable factor in FTIR analysis (Cocchi et al., 2005; Ottenhof et al., 2005).

It can be seen from Tables 3.9 and 3.10, that as storage time increased the ratio of peaks appeared at 2980-3600 cm^{-1} (A_1) and 2810-2970 cm^{-1} (A_2) significantly decreased, which was because of the decrease in moisture content of the samples during storage. The ratio of the peak intensities of samples baked in microwave and IR-microwave combination ovens were found to be significantly lower than that of conventionally baked ones (Table A.31). Additionally, the effect of gum addition in decreasing moisture loss during storage was especially seen for breads baked in microwave oven (Table 3.10).

Table 3.9. The integral area ratios of peaks appeared at 2980-3600 cm^{-1} (A_1) and 2810-2970 cm^{-1} (A_2); appeared around 1060-1070 cm^{-1} (A_3) and ~1151 cm^{-1} (A_4) related to control breads

	Oven Type					
	Conventional		Microwave		IR-microwave	
Storage time	Peak ratios					
	A1 / A2	A3 / A4	A1 / A2	A3 / A4	A1 / A2	A3 / A4
1 h	5.1	0.89	1.8	1.25	3.5	0.96
120 h	3.5	1.07	1.4	1.27	2.1	1.03

Table 3.10 The integral area ratios of peaks appeared at 2980-3600 cm^{-1} (A_1) and 2810-2970 cm^{-1} (A_2); appeared around 1060-1070 cm^{-1} (A_3) and ~1151 cm^{-1} (A_4) related to gum added breads

	Oven Type					
	Conventional		Microwave		IR-microwave	
Storage time	Peak ratios					
	A1 / A2	A3 / A4	A1 / A2	A3 / A4	A1 / A2	A3 / A4
1 h	5.0	0.91	3.3	1.22	3.6	0.97
120 h	3.8	1.09	2.1	1.30	2.4	1.09

The spectral region 1200-800 cm^{-1}, which has been shown to be sensitive to the degree of molecular order in starch, was used in analyzing starch related variations (Ottenhof et al, 2005). The modification with ageing of the absorption values in this spectral region, consisting in the variation of the relative intensities of overlapped bands at ~ 1000 cm^{-1}, has been observed by other researchers (Cocchi et al., 2005), relating it to the progressive ordering of the amylopectin polymer present in bread. Peaks at 1047 cm^{-1} are related to crystalline regions of starch (Karim et al., 2000; van Soest et al., 1994). The band at ~ 1151 cm^{-1} is often used as an "internal correction standard peak" to make the measurements independent of uncontrollable factors (van Soest et al., 1994; Ottenhof et al., 2005). The ratio of peak intensities at 1047 cm^{-1} and 1151 cm^{-1}, which was assigned in literature, was used to monitor starch retrogradation (Ottenhof et al., 2005).

In determining the peak intensity ratios of samples around 1060-1070 cm^{-1} (A_3) and 1151 cm^{-1} (A_4), software, PeakFit V4.12 was used in curve fitting analysis, the details of which was given in Appendix D (Figures D.1-D.4).

The peak intensity ratios of samples around 1060-1070 cm^{-1} (A_3) and 1151 cm^{-1} (A_4) can be seen in Tables 3.9 and 3.10. ANOVA results demonstrated that A3/A4 was dependent on oven type and storage time (Table A.32). Since increase in the ratio of peak intensities around 1060-1070 cm^{-1} (A_3) and 1151 cm^{-1} (A_4) is related to starch retrogradation, A3/A4 of samples baked in microwave oven was found to be the highest among other heating modes (Tables 3.9 and 3.10). Similarly, the results of hardness, DSC, setback viscosity,and X-ray analysis of microwave-baked samples were the highest (Figures 3.35, 3.38, 3.41 and Table 3.8). Additionally, it was found that A3/A4 of samples increased as storage time increased (Tables 3.9 and 3.10). However, FTIR analysis was not found to be as capable as the other methods (i.e. DSC, hardness and X-ray), in demonstrating the effect of gum addition in decreasing starch retrogradation.

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS

Specific volume, hardness, porosity, and dielectric properties of breads baked in IR-microwave combination oven were found to be dependent on gum type. Among the gums studied, the addition of xanthan-guar gum blend to the formulation resulted in an increase in specific volume and porosity and a decrease in hardness of breads.

SEM analysis showed that the starch granules in conventionally baked control breads were more distorted and they formed a more continuous sheet of gelatinized starch. Granular and deformed starch structure was observed together in combination heating. The results of the SEM analysis also demonstrated that the heating mechanism was more effective than formulation in microstructure development. Control breads baked in IR-microwave combination oven had larger pores than those baked in conventional oven.

When xanthan-guar gum blend was added to the formulation, the dielectric constant and dielectric loss factor of dough decreased as compared to control dough. Dielectric properties of the bread samples formulated with κ-carrageenan were found to be higher than that of control breads and breads formulated with other gums. Dielectric constant and loss factor data will be helpful for modeling of microwave and IR-microwave combination baking of foods and for developing new microwaveable products.

No acrylamide was formed in microwave baked breads. Breads baked in IR-microwave combination oven had similar acrylamide content with the conventionally baked ones. Moreover, the results confirm that color alone can not be used as an indication of acrylamide content.

Breads baked in microwave oven staled rapidly as compared to the ones baked in conventional and IR-microwave combination ovens. This result was confirmed by their low moisture content, high hardness, soluble starch, retrogradation enthalpy, setback viscosity, FTIR peak intensity and total mass crystallinity values. In addition, microwave heating resulted in appearence of an additional peak at 15.8° in X-ray analysis indicating more crystalline structure. The hardness, setback viscosity and total mass crystallinity values of IR-microwave combination baked bread samples were lower than those of microwave-baked ones, meaning that combination heating partially solved the rapid staling problem of microwave baking. The retrogradation enthalpy values and FTIR outputs of breads baked in IR-microwave combination oven was not found to be statistically different than that of conventionally baked ones. The number of peaks appeared in X-ray pattern of IR-microwave combination baked samples was found to be similar to that of conventionally baked ones. These results show that it is possible to produce breads by combination heating with similar staling degrees as conventionally baked ones.IR-microwave combination oven can be an alternative to conventional oven for bread baking.

The addition of xanthan-guar blend to the formulation retarded staling of breads. Xanthan-guar blend can be recommended to be used in bread formulations for baking in IR-microwave combination oven to improve bread quality and to retard staling.

As future work, the effects of other ingredients (emulsifiers, gum-emulsifier blends, starches, etc.) with varying blend ratios may be studied to obtain the best formulation in terms of improving product quality and retarding

staling. The effect of different storage temperatures on staling of breads baked in IR-microwave combination baking may be also studied. In addition, as further research, par-baking of breads in IR-microwave combination oven can be studied since there is no information about this topic in literature. Moreover, the effect of reheating of breads in IR-microwave combination oven on staling may be studied.

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APPENDIX A

ANOVA and TUKEY TEST TABLES

Table A.1 ANOVA and Tukey Single Range Test Table for specific volume of breads formulated with different gums baked in IR-microwave combination oven

Factor Levels Values

Gum types 11 control, xanthan, guar, xanthan-guar, carrageenan, xanthan-carrageenan, guar-carrageenan, HPMC, LBG, LBG-xanthan, LBG-carrageenan

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Gum Type	10	0.508133	0.050813	155.26	0.000
Error	22	0.007200	0.000327		
Total	32	0.515333			

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Gum Type

Gum Type = carrageenan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Control	0.0800	0.01477	0.0008
Guar-carrageenan	0.0467	0.01477	0.1153
Guar	0.1000	0.01477	0.0001
HPMC	-0.0767	0.01477	0.0014
LBG	-0.2333	0.01477	0.0000
LBG-carrageenan	-0.1733	0.01477	0.0000
LBG-xanthan	-0.2000	0.01477	0.0000
Xanthan-carrageenan	0.0000	0.01477	1.0000
Xanthan-guar	0.1567	0.01477	0.0000
Xanthan	0.0433	0.01477	0.1752

Gum Type = control subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Guar-carrageenan	-0.0333	0.01477	0.4926
Guar	0.0200	0.01477	0.9474
HPMC	-0.1567	0.01477	0.0000
LBG	-0.3133	0.01477	0.0000
LBG-carrageenan	-0.2533	0.01477	0.0000
LBG-xanthan	-0.2800	0.01477	0.0000
Xanthan-carrageenan	-0.0800	0.01477	0.0008
Xanthan-guar	0.0767	0.01477	0.0014
Xanthan	-0.0367	0.01477	0.3645

Gum Type = guar-carrageenan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Guar	0.0533	0.01477	0.0464
HPMC	-0.1233	0.01477	0.0000
LBG	-0.2800	0.01477	0.0000
LBG-carrageenan	-0.2200	0.01477	0.0000
LBG-xanthan	-0.2467	0.01477	0.0000
Xanthan-carrageenan	-0.0467	0.01477	0.1153
Xanthan-guar	0.1100	0.01477	0.0000
Xanthan	-0.0033	0.01477	1.0000

Gum Type = guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
HPMC	-0.1767	0.01477	0.0000
LBG	-0.3333	0.01477	0.0000
LBG-carrageenan	-0.2733	0.01477	0.0000
LBG-xanthan	-0.3000	0.01477	0.0000
Xanthan-carrageenan	-0.1000	0.01477	0.0001
Xanthan-guar	0.0567	0.01477	0.0286
Xanthan	-0.0567	0.01477	0.0286

Gum Type = HPMC subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
LBG	-0.1567	0.01477	0.0000
LBG-carrageenan	-0.0967	0.01477	0.0001
LBG-xanthan	-0.1233	0.01477	0.0000
Xanthan-carrageenan	0.0767	0.01477	0.0014
Xanthan-guar	0.2333	0.01477	0.0000
Xanthan	0.1200	0.01477	0.0000

Gum Type = LBG subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
LBG-carrageenan	0.06000	0.01477	0.0175
LBG-xanthan	0.03333	0.01477	0.4926
Xanthan-carrageenan	0.23333	0.01477	0.0000
Xanthan-guar	0.39000	0.01477	0.0000
Xanthan	0.27667	0.01477	0.0000

Gum Type = LBG-carrageenan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
LBG-xanthan	-0.02667	0.01477	0.7654
Xanthan-carrageenan	0.17333	0.01477	0.0000
Xanthan-guar	0.33000	0.01477	0.0000
Xanthan	0.21667	0.01477	0.0000

Gum Type = LBG-xanthan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-carrageenan	0.2000	0.01477	0.0000
Xanthan-guar	0.3567	0.01477	0.0000
Xanthan	0.2433	0.01477	0.0000

Gum Type = Xanthan-carrageenan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-guar	0.15667	0.01477	0.0000
Xanthan	0.04333	0.01477	0.1752

Gum Type = xanthan-guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan	-0.1133	0.01477	0.0000

Table A.2 ANOVA and Tukey Single Range Test Table for hardness of breads formulated with different gums baked in IR-microwave combination oven

Factor	Levels	Values
Gum types	11	control, xanthan, guar, xanthan-guar, carrageenan, xanthan-carrageenan, guar-carrageenan, HPMC, LBG, LBG-xanthan, LBG-carrageenan

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Gum Type	10	6.12967	0.61297	142.71	0.000
Error	24	0.10308	0.00430		
Total	34	6.23275			

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Gum Type

Gum Type = carrageenan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Control	-0.1500	0.05983	0.3479
Guar-carrageenan	0.0133	0.05983	1.0000
Guar	-0.2200	0.05676	0.0240
HPMC	0.0900	0.05983	0.9044
LBG	0.9167	0.05983	0.0000
LBG-carrageenan	0.3433	0.05983	0.0003
LBG-xanthan	0.9667	0.05983	0.0000
Xanthan-carrageenan	0.0267	0.05983	1.0000
Xanthan-guar	-0.3150	0.05351	0.0002
Xanthan	0.0200	0.06554	1.0000

Gum Type = control subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Guar-carrageenan	0.1633	0.05351	0.1365
Guar	-0.0700	0.05005	0.9371
HPMC	0.2400	0.05351	0.0058
LBG	1.0667	0.05351	0.0000
LBG-carrageenan	0.4933	0.05351	0.0000
LBG-xanthan	1.1167	0.05351	0.0000
Xanthan-carrageenan	0.1767	0.05351	0.0833
Xanthan-guar	-0.1650	0.04634	0.0483
Xanthan	0.1700	0.05983	0.2013

Gum Type = guar-carrageenan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Guar	-0.2333	0.05005	0.0038
HPMC	0.0767	0.05351	0.9275
LBG	0.9033	0.05351	0.0000
LBG-carrageenan	0.3300	0.05351	0.0001
LBG-xanthan	0.9533	0.05351	0.0000
Xanthan-carrageenan	0.0133	0.05351	1.0000
Xanthan-guar	-0.3283	0.04634	0.0000
Xanthan	0.0067	0.05983	1.0000

Gum Type = guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
HPMC	0.31000	0.05005	0.0001
LBG	1.13667	0.05005	0.0000
LBG-carrageenan	0.56333	0.05005	0.0000
LBG-xanthan	1.18667	0.05005	0.0000
Xanthan-carrageenan	0.24667	0.05005	0.0020
Xanthan-guar	-0.09500	0.04230	0.4973
Xanthan	0.24000	0.05676	0.0107

Gum Type = HPMC subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
LBG	0.8267	0.05351	0.0000
LBG-carrageenan	0.2533	0.05351	0.0032
LBG-xanthan	0.8767	0.05351	0.0000
Xanthan-carrageenan	-0.0633	0.05351	0.9785
Xanthan-guar	-0.4050	0.04634	0.0000
Xanthan	-0.0700	0.05983	0.9801

Gum Type = LBG subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
LBG-carrageenan	-0.573	0.05351	0.0000
LBG-xanthan	0.050	0.05351	0.9963
Xanthan-carrageenan	-0.890	0.05351	0.0000
Xanthan-guar	-1.232	0.04634	0.0000
Xanthan	-0.897	0.05983	0.0000

Gum Type = LBG-carrageenan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
LBG-xanthan	0.6233	0.05351	0.0000
Xanthan-carrageenan	-0.3167	0.05351	0.0002
Xanthan-guar	-0.6583	0.04634	0.0000
Xanthan	-0.3233	0.05983	0.0007

Gum Type = LBG-xanthan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-carrageenan	-0.940	0.05351	0.0000
Xanthan-guar	-1.282	0.04634	0.0000
Xanthan	-0.947	0.05983	0.0000

Gum Type = Xanthan-carrageenan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-guar	-0.3417	0.04634	0.0000
Xanthan	0.0067	0.05983	1.0000

Gum Type = xanthan-guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan	0.3350	0.05351	0.0001

Table A.3 ANOVA and Tukey Single Range Test Table for cohesiveness value of breads formulated with different gums baked in IR-microwave combination oven

Factor	Levels	Values
Gum types	5	control, xanthan, guar, xanthan-guar, κ-carrageenan

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Gum Type	4	0.0037017	0.0009254	5.17	0.016
Error	10	0.0017917	0.0001792		
Total	14	0.0054933			

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Gum Type

Gum Type = carrageenan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Control	0.038333	0.01222	0.0635
Guar	-0.002500	0.01159	0.9994
Xanthan-guar	0.005000	0.01159	0.9916
Xanthan	-0.005000	0.01339	0.9952

Gum Type = control subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Guar	-0.04083	0.01022	0.0169
Xanthan-guar	-0.03333	0.01022	0.0524
Xanthan	-0.04333	0.01022	0.0336

Gum Type = guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-guar	0.007500	0.009465	0.9271
Xanthan	-0.002500	0.011592	0.9994

Gum Type = Xanthan-guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan	-0.01000	0.01159	0.9041

Table A.4 ANOVA and Tukey Single Range Test Table for springiness value of breads formulated with different gums baked in IR-microwave combination oven

Factor	Levels	Values
Gum types	5	control, xanthan, guar, xanthan-guar, κ-carrageenan

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Gum Type	4	0.056667	0.014167	3.47	0.056
Error	11	0.044933	0.004085		
Total	15	0.101600			

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Gum Type

Gum Type = carrageenan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Control	-0.08167	0.05834	0.6401
Guar	0.05833	0.05834	0.8502
Xanthan-guar	-0.08000	0.05218	0.5640
Xanthan	0.03500	0.06391	0.9800

Gum Type = control subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Guar	0.140000	0.05218	0.1209
Xanthan-guar	0.001667	0.04519	1.0000
Xanthan	0.116667	0.05834	0.3267

Gum Type = guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-guar	-0.1383	0.04519	0.0662
Xanthan	-0.0233	0.05834	0.9938

Gum Type = Xanthan-guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan	0.1150	0.05218	0.2473

Table A.5 ANOVA and Tukey Single Range Test Table for chewiness value of breads formulated with different gums baked in IR-microwave combination oven

Factor	Levels	Values
Gum types	5	control, xanthan, guar, xanthan-guar, κ-carrageenan

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Gum Type	4	1.01691	0.25423	100.35	0.000
Error	12	0.03040	0.00253		
Total	16	1.04731			

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Gum Type

Gum Type = carrageenan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Control	-0.2200	0.04595	0.0033
Guar	-0.4300	0.04359	0.0000
Xanthan-guar	-0.6200	0.04110	0.0000
Xanthan	0.0100	0.05033	0.9996

Gum Type = control subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Guar	-0.2100	0.03844	0.0011
Xanthan-guar	-0.4000	0.03559	0.0000
Xanthan	0.2300	0.04595	0.0023

Gum Type = guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-guar	-0.1900	0.03249	0.0006
Xanthan	0.4400	0.04359	0.0000

Gum Type = Xanthan-guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan	0.6300	0.04110	0.0000

Table A.6 ANOVA and Tukey Single Range Test Table for total color change (ΔE) of breads formulated with different gums baked in IR-microwave combination oven

Factor	Levels	Values
Gum types	5	control, xanthan, guar, xanthan-guar, κ-carrageenan

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Gum Type	4	0.037333	0.009333	2.00	0.171
Error	10	0.046667	0.004667		
Total	14	0.084000			

Table A.7 ANOVA and Tukey Single Range Test Table for specific volume of breads formulated with different gums baked in conventional oven

Factor	Levels	Values
Gum types	5	control, xanthan, guar, xanthan-guar, κ-carrageenan

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Gum Type	4	0.07276	0.01819	60.63	0.000
Error	10	0.003	0.0003		
Total	14	0.07576			

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Gum Type

Gum Type = carrageenan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Control	0.030000	0.01414	0.2830
Guar	0.030000	0.01414	0.2830
Xanthan-guar	0.183333	0.01414	0.0000
Xanthan	-0.006667	0.01414	0.9884

Gum Type = control subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Guar	0.00000	0.01414	1.0000
Xanthan-guar	0.15333	0.01414	0.0000
Xanthan	-0.03667	0.01414	0.1452

Gum Type = guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-guar	0.15333	0.01414	0.0000
Xanthan	-0.03667	0.01414	0.1452

Gum Type = Xanthan-guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan	-0.1900	0.01414	0.0000

Table A.8 ANOVA and Tukey Single Range Test Table for hardness of breads formulated with different gums baked in conventional oven

Factor	Levels	Values
Gum types	5	control, xanthan, guar, xanthan-guar, κ-carrageenan

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Gum Type	4	0.140480	0.035120	11.40	0.000
Error	15	0.046200	0.003080		
Total	19	0.186680			

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Gum Type

Gum Type = carrageenan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Control	-0.0250	0.03924	0.9665
Guar	-0.0525	0.03924	0.6733
Xanthan-guar	-0.2100	0.03924	0.0007
Xanthan	0.0300	0.03924	0.9369

Gum Type = control subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Guar	-0.0275	0.03924	0.9532
Xanthan-guar	-0.1850	0.03924	0.0022
Xanthan	0.0550	0.03924	0.6360

Gum Type = guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-guar	-0.1575	0.03924	0.0085
Xanthan	0.0825	0.03924	0.2691

Gum Type = Xanthan-guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan	0.2400	0.03924	0.0002

Table A.9 ANOVA and Tukey Single Range Test Table for cohesiveness value of breads formulated with different gums baked in conventional oven

Factor	Levels	Values
Gum types	5	control, xanthan, guar, xanthan-guar, κ-carrageenan

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Gum Type	4	0.0007768	0.0001942	1.37	0.296
Error	14	0.0019917	0.0001423		
Total	18	0.0027684			

Table A.10 ANOVA and Tukey Single Range Test Table for springiness value of breads formulated with different gums baked in conventional oven

Factor	Levels	Values
Gum types	5	control, xanthan, guar, xanthan-guar, κ-carrageenan

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Gum Type	4	0.238150	0.059538	20.99	0.000
Error	15	0.042550	0.002837		
Total	19	0.280700			

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Gum Type

Gum Type = carrageenan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Control	-0.1275	0.03766	0.0285
Guar	0.0125	0.03766	0.9971
Xanthan-guar	-0.1775	0.03766	0.0022
Xanthan	0.1300	0.03766	0.0251

Gum Type = control subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Guar	0.14000	0.03766	0.0151
Xanthan-guar	-0.05000	0.03766	0.6793
Xanthan	0.25750	0.03766	0.0001

Gum Type = guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-guar	-0.1900	0.03766	0.0012
Xanthan	0.1175	0.03766	0.0471

Gum Type = Xanthan-guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan	0.3075	0.03766	0.0000

Table A.11 ANOVA and Tukey Single Range Test Table for chewiness value of breads formulated with different gums baked in conventional oven

Factor	Levels	Values
Gum types	5	control, xanthan, guar, xanthan-guar, κ-carrageenan

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Gum Type	4	0.68963	0.17241	91.79	0.000
Error	13	0.02442	0.00188		
Total	17	0.71404			

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Gum Type

Gum Type = carrageenan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Control	-0.0200	0.03064	0.9631
Guar	-0.0708	0.03310	0.2612
Xanthan-guar	-0.3775	0.03310	0.0000
Xanthan	0.2525	0.03064	0.0000

Gum Type = control subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Guar	-0.0508	0.03310	0.5592
Xanthan-guar	-0.3575	0.03310	0.0000
Xanthan	0.2725	0.03064	0.0000

Gum Type = guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-guar	-0.3067	0.03539	0.0000
Xanthan	0.3233	0.03310	0.0000

Gum Type = Xanthan-guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan	0.6300	0.03310	0.0000

Table A.12 Two way ANOVA and Tukey Single Range Test Table for hardness of breads formulated with different gums baked in IR-microwave combination and conventional ovens

Factor	Levels	Values
Oven types	2	conventional, IR-microwave combination
Gum types	5	control, xanthan, guar, xanthan-guar, κ-carrageenan

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Oven Type	1	0.25296	0.25296	59.65	0.000
Gum Type	4	0.26408	0.09224	21.75	0.000
Error	31	0.13147	0.00424		
Total	36	0.64851			

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Oven Type

Oven Type = IR-microwave combination subtracted from:

Oven Type	Difference of Means	SE of Difference	Adjusted P-Value
Conventional	-0.1697	0.02198	0.0000

All Pairwise Comparisons among Levels of Gum Type

Gum Type = carrageenan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Control	-0.0697	0.03629	0.3276
Guar	-0.1208	0.03536	0.0144
Xanthan-guar	-0.2483	0.03414	0.0000
Xanthan	0.0267	0.03760	0.9528

Gum Type = control subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Guar	-0.0511	0.03374	0.5621
Xanthan-guar	-0.1785	0.03231	0.0001
Xanthan	0.0964	0.03629	0.0844

Gum Type = guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-guar	-0.1275	0.03097	0.0023
Xanthan	0.1475	0.03536	0.0020

Gum Type = Xanthan-guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan	0.2749	0.03414	0.0000

Table A.13 Two way ANOVA and Tukey Single Range Test Table for cohesiveness value of breads formulated with different gums baked in IR-microwave combination and conventional ovens

Factor	Levels	Values
Oven types	2	conventional, IR-microwave combination
Gum types	5	control, xanthan, guar, xanthan-guar, κ-carrageenan

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Oven Type	1	0.0031488	0.0029823	17.41	0.000
Gum Type	4	0.0043794	0.0010948	6.39	0.001
Error	29	0.0049689	0.0001713		
Total	34	0.0124971			

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Oven Type

Oven Type = IR-microwave combination subtracted from:

Oven Type	Difference of Means	SE of Difference	Adjusted P-Value
Conventional	-0.01886	0.004522	0.0003

All Pairwise Comparisons among Levels of Gum Type

Gum Type = carrageenan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Control	0.029394	0.007295	0.0032
Guar	-0.001061	0.007109	0.9999
Xanthan-guar	0.008939	0.007109	0.7184
Xanthan	0.003333	0.007557	0.9917

Gum Type = control subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Guar	-0.03045	0.006782	0.0009
Xanthan-guar	-0.02045	0.006782	0.0391
Xanthan	-0.02606	0.007295	0.0102

Gum Type = guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-guar	0.010000	0.006545	0.5535
Xanthan	0.004394	0.007109	0.9710

Gum Type = Xanthan-guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan	-0.005606	0.007109	0.9319

Table A.14 Two way ANOVA and Tukey Single Range Test Table for springiness value of breads formulated with different gums baked in IR-microwave combination and conventional ovens

Factor	Levels	Values
Oven types	2	conventional, IR-microwave combination
Gum types	5	control, xanthan, guar, xanthan-guar, κ-carrageenan

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Oven Type	1	0.201120	0.259075	64.84	0.000
Gum Type	4	0.275586	0.068896	17.24	0.000
Error	31	0.123867	0.003996		
Total	36	0.600573			

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Oven Type

Oven Type = IR-microwave combination subtracted from:

Oven Type	Difference of Means	SE of Difference	Adjusted P-Value
Conventional	-0.1718	0.02133	0.0000

All Pairwise Comparisons among Levels of Gum Type

Gum Type = carrageenan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Control	-0.1111	0.03523	0.0273
Guar	0.0355	0.03432	0.8370
Xanthan-guar	-0.1281	0.03313	0.0045
Xanthan	0.0983	0.03650	0.0778

Gum Type = control subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Guar	0.14666	0.03275	0.0009
Xanthan-guar	-0.01702	0.03136	0.9821
Xanthan	0.20945	0.03523	0.0000

Gum Type = guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-guar	-0.1637	0.03006	0.0001
Xanthan	0.0628	0.03432	0.3756

Gum Type = Xanthan-guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan	0.2265	0.03313	0.0000

Table A.15 Two way ANOVA and Tukey Single Range Test Table for chewiness value of breads formulated with different gums baked in IR-microwave combination and conventional ovens

Factor	Levels	Values
Oven types	2	conventional, IR-microwave combination
Gum types	5	control, xanthan, guar, xanthan-guar, κ-carrageenan

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Oven Type	1	1.19515	1.19515	223.75	0.000
Gum Type	4	1.03881	0.40161	75.19	0.000
Error	29	0.15490	0.00534		
Total	34	2.38887			

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Oven Type

Oven Type = IR-microwave combination subtracted from:

Oven Type	Difference of Means	SE of Difference	Adjusted P-Value
Conventional	-0.3842	0.02569	0.0000

All Pairwise Comparisons among Levels of Gum Type

Gum Type = carrageenan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Control	-0.0849	0.04073	0.2536
Guar	-0.2241	0.04112	0.0001
Xanthan-guar	-0.4664	0.03946	0.0000
Xanthan	0.1717	0.04220	0.0029

Gum Type = control subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Guar	-0.1392	0.03924	0.0109
Xanthan-guar	-0.3815	0.03734	0.0000
Xanthan	0.2566	0.04073	0.0000

Gum Type = guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-guar	-0.2423	0.03691	0.0000
Xanthan	0.3958	0.04112	0.0000

Gum Type = Xanthan-guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan	0.6381	0.03946	0.0000

Table A.16 ANOVA and Tukey Single Range Test Table for total color change (ΔE) of breads formulated with different gums baked in conventional oven

Factor	Levels	Values
Gum types	5	control, xanthan, guar, xanthan-guar, κ-carrageenan

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Gum Type	4	0.02933	0.00733	0.19	0.937
Error	10	0.38000	0.03800		
Total	14	0.40933			

Table A.17 Two way ANOVA and Tukey Single Range Test Table for porosity of breads formulated with different gums baked in IR-microwave combination and conventional ovens

Factor	Levels	Values
Oven types	2	conventional, IR-microwave combination
Gum types	5	control, xanthan, guar, xanthan-guar, κ-carrageenan

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Oven Type	1	0.0049178	0.0049178	210.49	0.000
Gum Type	4	0.0034961	0.0008740	37.41	0.000
Error	24	0.0005607	0.0000234		
Total	29	0.0089745			

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Oven Type

Oven Type = IR-microwave combination subtracted from:

Oven Type	Difference of Means	SE of Difference	Adjusted P-Value
Conventional	-0.02561	0.001765	0.0000

All Pairwise Comparisons among Levels of Gum Type

Gum Type = carrageenan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Control	0.01530	0.002791	0.0001
Guar	0.01585	0.002791	0.0001
Xanthan-guar	0.03325	0.002791	0.0000
Xanthan	0.01012	0.002791	0.0107

Gum Type = control subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Guar	0.000550	0.002791	0.9996
Xanthan-guar	0.017950	0.002791	0.0000
Xanthan	-0.005183	0.002791	0.3661

Gum Type = guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-guar	0.017400	0.002791	0.0000
Xanthan	-0.005733	0.002791	0.2718

Gum Type = Xanthan-guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan	-0.02313	0.002791	0.0000

Table A.18 ANOVA and Tukey Single Range Test Table for pore area fraction of breads formulated with different gums baked in conventional oven

Factor	Levels	Values
Gum types	5	control, xanthan, guar, xanthan-guar, κ-carrageenan

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Gum Type	4	25.2540	6.3135	166.14	0.000
Error	5	0.1900	0.0380		
Total	9	25.4440			

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Gum Type

Gum Type = control subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Guar	-1.800	0.1949	0.0014
Carrageenan	-2.950	0.1949	0.0001
Xanthan-guar	1.700	0.1949	0.0018
Xanthan	-1.150	0.1949	0.0104

Gum Type = guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Carrageenan	-1.150	0.1949	0.0104
Xanthan-guar	3.500	0.1949	0.0001
Xanthan	0.650	0.1949	0.0964

Gum Type = carrageenan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-guar	4.650	0.1949	0.0000
Xanthan	1.800	0.1949	0.0014

Gum Type = Xanthan-guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan	-2.850	0.1949	0.0002

Table A.19 ANOVA and Tukey Single Range Test Table for pore area fraction of breads formulated with different gums baked in IR-microwave combination oven

Factor	Levels	Values
Gum types	5	control, xanthan, guar, xanthan-guar, κ-carrageenan

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Gum Type	4	7.9200	1.9800	55.00	0.000
Error	5	0.1800	0.0360		
Total	9	8.1000			

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Gum Type

Gum Type = control subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Guar	-1.500	0.1897	0.0028
Carrageenan	-2.400	0.1897	0.0003
Xanthan-guar	-0.150	0.1897	0.9230
Xanthan	-1.200	0.1897	0.0077

Gum Type = guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Carrageenan	-0.9000	0.1897	0.0260
Xanthan-guar	1.3500	0.1897	0.0045
Xanthan	0.3000	0.1897	0.5626

Gum Type = carrageenan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-guar	2.250	0.1897	0.0004
Xanthan	1.200	0.1897	0.0077

Gum Type = Xanthan-guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan	-1.050	0.1897	0.0137

Table A.20 Two way ANOVA and Tukey Single Range Test Table for pore area fraction of breads formulated with different gums baked in IR-microwave combination and conventional ovens

Factor	Levels	Values
Oven types	2	conventional, IR-microwave combination
Gum types	5	control, xanthan, guar, xanthan-guar, κ-carrageenan

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Oven Type	1	6.4980	6.4980	22.93	0.000
Gum Type	4	29.5770	7.3942	26.10	0.000
Error	14	3.9670	0.2834		
Total	19	40.0420			

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Oven Type

Oven Type = IR-microwave combination subtracted from:

Oven Type	Difference of Means	SE of Difference	Adjusted P-Value
Conventional	-1.140	0.2381	0.0003

All Pairwise Comparisons among Levels of Gum Type

Gum Type = control subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Guar	-1.650	0.3764	0.0048
Carrageenan	-2.675	0.3764	0.0001
Xanthan-guar	0.775	0.3764	0.2898
Xanthan	-1.175	0.3764	0.0495

Gum Type = guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Carrageenan	-1.025	0.3764	0.1004
Xanthan-guar	2.425	0.3764	0.0001
Xanthan	0.475	0.3764	0.7172

Gum Type = carrageenan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-guar	3.450	0.3764	0.0000
Xanthan	1.500	0.3764	0.0100

Gum Type = Xanthan-guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan	-1.950	0.3764	0.0011

Table A.21 ANOVA and Tukey Single Range Test Table for dielectric constant of doughs formulated with different gums

Factor	Levels	Values
Gum types	5	control, xanthan, guar, xanthan-guar, κ-carrageenan

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Gum Type	4	36.8079	9.2020	109.29	0.000
Error	7	0.5894	0.0842		
Total	11	37.3973			

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Gum Type

Gum Type = carrageenan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Control	-3.009	0.2369	0.0000
Guar	-3.385	0.2649	0.0000
Xanthan-guar	-4.956	0.2649	0.0000
Xanthan	-4.061	0.2649	0.0000

Gum Type = control subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Guar	-0.376	0.2649	0.6366
Xanthan-guar	-1.947	0.2649	0.0010
Xanthan	-1.052	0.2649	0.0309

Gum Type = guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-guar	-1.571	0.2902	0.0061
Xanthan	-0.676	0.2902	0.2395

Gum Type = Xanthan-guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan	0.8951	0.2902	0.0929

Table A.22 ANOVA and Tukey Single Range Test Table for WBC of dough formulated with different gums

Factor	Levels	Values
Gum types	5	control, xanthan, guar, xanthan-guar, κ-carrageenan

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Gum Type	4	0.247575	0.061894	111.36	0.000
Error	5	0.002779	0.000556		
Total	9	0.250354			

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Gum Type

Gum Type = carrageenan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Control	-0.02050	0.02358	0.8968
Guar	0.05000	0.02358	0.3366
Xanthan-guar	0.31600	0.02358	0.0002
Xanthan	0.33850	0.02358	0.0002

Gum Type = control subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Guar	0.07050	0.02358	0.1368
Xanthan-guar	0.33650	0.02358	0.0002
Xanthan	0.35900	0.02358	0.0001

Gum Type = guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-guar	0.2660	0.02358	0.0005
Xanthan	0.2885	0.02358	0.0004

Gum Type = Xanthan-guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan	0.02250	0.02358	0.8647

Table A.23 ANOVA and Tukey Single Range Test Table for loss factor of doughs formulated with different gums

Factor	Levels	Values
Gum types	5	control, xanthan, guar, xanthan-guar, κ-carrageenan

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Gum Type	4	11.3896	2.8474	102.60	0.000
Error	7	0.1943	0.0278		
Total	11	11.5839			

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Gum Type

Gum Type = carrageenan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Control	-1.904	0.1360	0.0000
Guar	-1.635	0.1521	0.0001
Xanthan-guar	-2.901	0.1521	0.0000
Xanthan	-1.818	0.1521	0.0001

Gum Type = control subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Guar	0.2690	0.1521	0.4559
Xanthan-guar	-0.9976	0.1521	0.0020
Xanthan	0.0860	0.1521	0.9762

Gum Type = guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-guar	-1.267	0.1666	0.0008
Xanthan	-0.183	0.1666	0.8029

Gum Type = Xanthan-guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan	1.084	0.1666	0.0021

Table A.24 ANOVA and Tukey Single Range Test Table for dielectric constant of breads formulated with different gums baked in IR-microwave combination oven

Factor	Levels	Values
Gum types	5	control, xanthan, guar, xanthan-guar, κ-carrageenan

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Gum Type	4	1.60979	0.40245	39.76	0.000
Error	8	0.08097	0.01012		
Total	12	1.69076			

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Gum Type

Gum Type = carrageenan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Control	-0.9954	0.08214	0.0000
Guar	-0.5315	0.08214	0.0013
Xanthan-guar	-0.7684	0.09184	0.0002
Xanthan	-0.6369	0.09184	0.0008

Gum Type = control subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Guar	0.4640	0.08214	0.0032
Xanthan-guar	0.2270	0.09184	0.1900
Xanthan	0.3586	0.09184	0.0273

Gum Type = guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-guar	-0.2370	0.09184	0.1645
Xanthan	-0.1054	0.09184	0.7788

Gum Type = Xanthan-guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan	0.1316	0.1006	0.6947

Table A.25 ANOVA and Tukey Single Range Test Table for loss factor of breads formulated with different gums baked in IR-microwave combination oven

Factor	Levels	Values
Gum types	5	control, xanthan, guar, xanthan-guar, κ-carrageenan

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Gum Type	4	0.43530	0.10883	27.19	0.000
Error	8	0.03202	0.00400		
Total	12	0.46732			

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Gum Type

Gum Type = carrageenan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Control	-0.4489	0.05166	0.0002
Guar	-0.4306	0.05166	0.0002
Xanthan-guar	-0.4631	0.05775	0.0003
Xanthan	-0.3458	0.05775	0.0022

Gum Type = control subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Guar	0.01837	0.05166	0.9959
Xanthan-guar	-0.01413	0.05775	0.9990
Xanthan	0.10312	0.05775	0.4412

Gum Type = guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-guar	-0.03250	0.05775	0.9771
Xanthan	0.08475	0.05775	0.6072

Gum Type = Xanthan-guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan	0.1173	0.06327	0.4091

Table A.26 Two-way ANOVA and Tukey Single Range Test Table for temperature profile of breads formulated with different gums during IR-microwave combination baking with respect to gum type and baking time

Factor	Levels	Values
Time	17	0, 30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330, 360, 390, 420, 450, 480,
Gum types	5	control, xanthan, guar, xanthan-guar, κ-carrageenan

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Time	16	89578.2	5598.6	7104.89	0.000
Gum Type	4	118.6	29.6	37.62	0.000
Error	149	117.4	0.8		
Total	169				

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Gum Type

Gum Type = carrageenan subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Control	-2.122	0.2153	0.0000
Guar	-0.959	0.2153	0.0002
Xanthan-guar	-2.251	0.2153	0.0000
Xanthan	-1.696	0.2153	0.0000

Gum Type = control subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Guar	1.1635	0.2153	0.0000
Xanthan-guar	-0.1282	0.2153	0.9756
Xanthan	0.4259	0.2153	0.2818

Gum Type = guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-guar	-1.292	0.2153	0.0000
Xanthan	-0.738	0.2153	0.0070

Gum Type = Xanthan-guar subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan	0.5541	0.2153	0.0805

All Pairwise Comparisons among Levels of Time

Time = 0 subtracted from:

Time	Difference of Means	SE of Difference	Adjusted P-Value
30	4.172	0.3970	0.0001
60	7.680	0.3970	0.0001
90	8.996	0.3970	0.0001
120	11.332	0.3970	0.0001
150	15.216	0.3970	0.0001
180	18.968	0.3970	0.0001
210	22.144	0.3970	0.0001
240	26.660	0.3970	0.0001
270	33.092	0.3970	0.0001
300	39.264	0.3970	0.0001
330	46.428	0.3970	0.0001
360	54.336	0.3970	0.0001
390	60.012	0.3970	0.0001
420	65.208	0.3970	0.0001
450	66.388	0.3970	0.0001
480	66.696	0.3970	0.0001

Time = 30 subtracted from:

Time	Difference of Means	SE of Difference	Adjusted P-Value
60	3.508	0.3970	0.0001
90	4.824	0.3970	0.0001
120	7.160	0.3970	0.0001
150	11.044	0.3970	0.0001
180	14.796	0.3970	0.0001
210	17.972	0.3970	0.0001
240	22.488	0.3970	0.0001
270	28.920	0.3970	0.0001
300	35.092	0.3970	0.0001
330	42.256	0.3970	0.0001
360	50.164	0.3970	0.0001
390	55.840	0.3970	0.0001
420	61.036	0.3970	0.0001
450	62.216	0.3970	0.0001
480	62.524	0.3970	0.0001

Time = 60 subtracted from:

Time	Difference of Means	SE of Difference	Adjusted P-Value
90	1.316	0.3970	0.0898
120	3.652	0.3970	0.0001
150	7.536	0.3970	0.0001
180	11.288	0.3970	0.0001
210	14.464	0.3970	0.0001
240	18.980	0.3970	0.0001
270	25.412	0.3970	0.0001
300	31.584	0.3970	0.0001
330	38.748	0.3970	0.0001
360	46.656	0.3970	0.0001
390	52.332	0.3970	0.0001
420	57.528	0.3970	0.0001
450	58.708	0.3970	0.0001
480	59.016	0.3970	0.0001

Time = 90 subtracted from:

Time	Difference of Means	SE of Difference	Adjusted P-Value
120	2.336	0.3970	0.0001
150	6.220	0.3970	0.0001
180	9.972	0.3970	0.0001
210	13.148	0.3970	0.0001
240	17.664	0.3970	0.0001
270	24.096	0.3970	0.0001
300	30.268	0.3970	0.0001
330	37.432	0.3970	0.0001
360	45.340	0.3970	0.0001
390	51.016	0.3970	0.0001
420	56.212	0.3970	0.0001
450	57.392	0.3970	0.0001
480	57.700	0.3970	0.0001

Time = 120 subtracted from:

Time	Difference of Means	SE of Difference	Adjusted P-Value
150	3.884	0.3970	0.0001
180	7.636	0.3970	0.0001
210	10.812	0.3970	0.0001
240	15.328	0.3970	0.0001
270	21.760	0.3970	0.0001
300	27.932	0.3970	0.0001
330	35.096	0.3970	0.0001
360	43.004	0.3970	0.0001
390	48.680	0.3970	0.0001
420	53.876	0.3970	0.0001
450	55.056	0.3970	0.0001
480	55.364	0.3970	0.0001

Time = 150 subtracted from:

Time	Difference of Means	SE of Difference	Adjusted P-Value
180	3.752	0.3970	0.0001
210	6.928	0.3970	0.0001
240	11.444	0.3970	0.0001
270	17.876	0.3970	0.0001
300	24.048	0.3970	0.0001
330	31.212	0.3970	0.0001
360	39.120	0.3970	0.0001
390	44.796	0.3970	0.0001
420	49.992	0.3970	0.0001
450	51.172	0.3970	0.0001
480	51.480	0.3970	0.0001

Time = 180 subtracted from:

Time	Difference of Means	SE of Difference	Adjusted P-Value
210	3.176	0.3970	0.0001
240	7.692	0.3970	0.0001
270	14.124	0.3970	0.0001
300	20.296	0.3970	0.0001
330	27.460	0.3970	0.0001
360	35.368	0.3970	0.0001
390	41.044	0.3970	0.0001
420	46.240	0.3970	0.0001
450	47.420	0.3970	0.0001
480	47.728	0.3970	0.0001

Time = 210 subtracted from:

Time	Difference of Means	SE of Difference	Adjusted P-Value
240	4.516	0.3970	0.0001
270	10.948	0.3970	0.0001
300	17.120	0.3970	0.0001
330	24.284	0.3970	0.0001
360	32.192	0.3970	0.0001
390	37.868	0.3970	0.0001
420	43.064	0.3970	0.0001
450	44.244	0.3970	0.0001
480	44.552	0.3970	0.0001

Time = 240 subtracted from:

Time	Difference of Means	SE of Difference	Adjusted P-Value
270	6.432	0.3970	0.0001
300	12.604	0.3970	0.0001
330	19.768	0.3970	0.0001
360	27.676	0.3970	0.0001
390	33.352	0.3970	0.0001
420	38.548	0.3970	0.0001
450	39.728	0.3970	0.0001
480	40.036	0.3970	0.0001

Time = 270 subtracted from:

Time	Difference of Means	SE of Difference	Adjusted P-Value
300	6.172	0.3970	0.0001
330	13.336	0.3970	0.0001
360	21.244	0.3970	0.0001
390	26.920	0.3970	0.0001
420	32.116	0.3970	0.0001
450	33.296	0.3970	0.0001
480	33.604	0.3970	0.0001

Time = 300 subtracted from:

Time	Difference of Means	SE of Difference	Adjusted P-Value
330	7.164	0.3970	0.0001
360	15.072	0.3970	0.0001
390	20.748	0.3970	0.0001
420	25.944	0.3970	0.0001
450	27.124	0.3970	0.0001
480	27.432	0.3970	0.0001

Time = 330 subtracted from:

Time	Difference of Means	SE of Difference	Adjusted P-Value
360	7.908	0.3970	0.0001
390	13.584	0.3970	0.0001
420	18.870	0.3970	0.0001
450	19.960	0.3970	0.0001
480	20.268	0.3970	0.0001

Time = 360 subtracted from:

Time	Difference of Means	SE of Difference	Adjusted P-Value
390	5.676	0.3970	0.0001
420	10.872	0.3970	0.0001
450	12.052	0.3970	0.0001
480	12.360	0.3970	0.0001

Time = 390 subtracted from:

Time	Difference of Means	SE of Difference	Adjusted P-Value
420	5.196	0.3970	0.0001
450	6.376	0.3970	0.0001
480	6.684	0.3970	0.0001

Time = 420 subtracted from:

Time	Difference of Means	SE of Difference	Adjusted P-Value
450	1.180	0.3970	0.2108
480	1.488	0.3970	0.0245

Time = 450 subtracted from:

Time	Difference of Means	SE of Difference	Adjusted P-Value
480	0.3080	0.3970	1.000

Table A.27 Three way ANOVA and Tukey Single Range Test Table for moisture content of control and gum added breads baked in different ovens

Factor	Levels	Values
Oven types	3	conventional, IR-microwave combination, and microwave
Storage time	6	0, 1, 24, 48, 72, 120
Gum types	2	control, xanthan-guar

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Oven Type	2	492.510	258.029	837.32	0.000
Storage time	5	159.594	31.919	103.58	0.000
Gum Type	1	0.452	0.452	1.47	0.229
Error	101	31.124	0.308		
Total	109	683.680			

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Oven Type

Oven Type = IR-microwave combination subtracted from:

Oven Type	Difference of Means	SE of Difference	Adjusted P-Value
Conventional	2.992	0.1308	0.0000
Microwave	-2.287	0.1293	0.0000

Oven Type = conventional subtracted from:

Oven Type	Difference of Means	SE of Difference	Adjusted P-Value
Microwave	-5.279	0.1293	0.0000

All Pairwise Comparisons among Levels of Storage time

Storage time = 0 subtracted from:

Storage time	Difference of Means	SE of Difference	Adjusted P-Value
1	-2.545	0.1805	0.0000
24	-2.826	0.1805	0.0000
48	-3.067	0.1805	0.0000
72	-3.232	0.1805	0.0000
120	-3.491	0.1805	0.0000

Storage time = 1 subtracted from:

Storage time	Difference of Means	SE of Difference	Adjusted P-Value
24	-0.2811	0.1850	0.6528
48	-0.5217	0.1850	0.0625
72	-0.6867	0.1850	0.0045
120	-0.9461	0.1850	0.0000

Storage time = 24 subtracted from:

Storage time	Difference of Means	SE of Difference	Adjusted P-Value
48	-0.2406	0.1850	0.7844
72	-0.4056	0.1850	0.2508
120	-0.6650	0.1850	0.0066

Storage time = 48 subtracted from:

Storage time	Difference of Means	SE of Difference	Adjusted P-Value
72	-0.1650	0.1850	0.9477
120	-0.4244	0.1850	0.2063

Storage time = 72 subtracted from:

Storage time	Difference of Means	SE of Difference	Adjusted P-Value
120	-0.2594	0.1850	0.7257

All Pairwise Comparisons among Levels of Gum Type

Gum Type = control subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-guar	0.1282	0.1059	0.2288

Table A.28 Three way ANOVA and Tukey Single Range Test Table for hardness of control and gum added breads baked in different ovens

Factor	Levels	Values
Oven types	3	conventional, IR-microwave combination, and microwave
Storage time	5	1, 24, 48, 72, 120
Gum types	2	control, xanthan-guar

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Oven Type	2	39.254	19.012	221.17	0.000
Storage time	4	202.299	49.568	576.65	0.000
Gum Type	1	4.328	4.328	50.35	0.000
Error	92	7.908	0.086		
Total	99	253.790			

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Oven Type

Oven Type = IR-microwave combination subtracted from:

Oven Type	Difference of Means	SE of Difference	Adjusted P-Value
Conventional	-0.4789	0.07184	0.0000
Microwave	1.0029	0.07239	0.0000

Oven Type = conventional subtracted from:

Oven Type	Difference of Means	SE of Difference	Adjusted P-Value
Microwave	1.482	0.07177	0.0000

All Pairwise Comparisons among Levels of Storage time

Storage time = 1 subtracted from:

Storage time	Difference of Means	SE of Difference	Adjusted P-Value
24	1.368	0.08806	0.0000
48	2.182	0.09160	0.0000
72	2.870	0.09033	0.0000
120	4.106	0.09160	0.0000

Storage time = 24 subtracted from:

Storage time	Difference of Means	SE of Difference	Adjusted P-Value
48	0.8142	0.09425	0.0000
72	1.5021	0.09292	0.0000
120	2.7381	0.09425	0.0000

Storage time = 48 subtracted from:

Storage time	Difference of Means	SE of Difference	Adjusted P-Value
72	0.6878	0.09647	0.0000
120	1.9239	0.09773	0.0000

Storage time = 72 subtracted from:

Storage time	Difference of Means	SE of Difference	Adjusted P-Value
120	1.236	0.09647	0.0000

All Pairwise Comparisons among Levels of Gum Type

Gum Type = control subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-guar	-0.4184	0.05897	0.0000

Table A.29 Three way ANOVA and Tukey Single Range Test Table for enthalpy of control and gum added breads baked in different ovens

Factor	Levels	Values
Oven types	3	conventional, IR-microwave combination, and microwave
Storage time	3	24, 72, 120
Gum types	2	control, xanthan-guar

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Oven Type	2	0.08776	0.04388	4.35	0.038
Storage time	2	0.41974	0.20987	20.81	0.000
Gum Type	1	0.06822	0.06822	6.77	0.023
Error	12	0.12100	0.01008		
Total	17	0.69671			

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Oven Type

Oven Type = IR-microwave combination subtracted from:

Oven Type	Difference of Means	SE of Difference	Adjusted P-Value
Conventional	-0.09363	0.05798	0.2771
Microwave	0.07713	0.05798	0.4061

Oven Type = conventional subtracted from:

Oven Type	Difference of Means	SE of Difference	Adjusted P-Value
Microwave	0.1708	0.05798	0.0306

All Pairwise Comparisons among Levels of Storage time

Storage time = 24 subtracted from:

Storage time	Difference of Means	SE of Difference	Adjusted P-Value
48	0.1481	0.05798	0.0609
72	0.3715	0.05798	0.0001

Storage time = 72 subtracted from:

Storage time	Difference of Means	SE of Difference	Adjusted P-Value
120	0.2234	0.05798	0.0060

All Pairwise Comparisons among Levels of Gum Type

Gum Type = control subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-guar	-0.1231	0.04734	0.0232

Table A.30 Three way ANOVA and Tukey Single Range Test Table for total crystallinity of control and gum added breads baked in different ovens

Factor	Levels	Values
Oven types	3	conventional, IR-microwave combination, and microwave
Storage time	2	1, 120
Gum types	2	control, xanthan-guar

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Oven Type	2	88.452	44.226	18.61	0.002
Storage time	1	40.333	40.333	16.97	0.004
Gum Type	1	17.763	17.763	7.47	0.029
Error	7	16.638	2.377		
Total	11	163.187			

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Oven Type

Oven Type = IR-microwave combination subtracted from:

Oven Type	Difference of Means	SE of Difference	Adjusted P-Value
Conventional	-3.375	1.090	0.0408
Microwave	3.275	1.090	0.0461

Oven Type = conventional subtracted from:

Oven Type	Difference of Means	SE of Difference	Adjusted P-Value
Microwave	6.650	1.090	0.0012

All Pairwise Comparisons among Levels of Storage time

Storage time = 1 subtracted from:

Storage time	Difference of Means	SE of Difference	Adjusted P-Value
120	3.667	0.8901	0.0045

All Pairwise Comparisons among Levels of Gum Type

Gum Type = control subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-guar	-2.433	0.8901	0.0292

Table A.31 Three way ANOVA and Tukey Single Range Test Table for FTIR data related to moisture content of control and gum added breads baked in different ovens

Factor	Levels	Values
Oven types	3	conventional, IR-microwave combination, and microwave
Storage time	2	1, 120
Gum types	2	control, xanthan-guar

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Oven Type	2	10.0067	5.0033	34.22	0.000
Storage time	1	4.0833	4.0833	27.93	0.001
Gum Type	1	0.6533	0.6533	4.47	0.072
Error	7	1.0233	0.1462		
Total	11	15.7667			

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Oven Type

Oven Type = IR-microwave combination subtracted from:

Oven Type	Difference of Means	SE of Difference	Adjusted P-Value
Conventional	1.4500	0.2704	0.0026
Microwave	-0.7500	0.2704	0.0632

Oven Type = conventional subtracted from:

Oven Type	Difference of Means	SE of Difference	Adjusted P-Value
Microwave	-2.200	0.2704	0.0002

All Pairwise Comparisons among Levels of Storage time

Storage time = 1 subtracted from:

Storage time	Difference of Means	SE of Difference	Adjusted P-Value
120	-1.167	0.2207	0.0011

All Pairwise Comparisons among Levels of Gum Type

Gum Type = control subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-guar	0.4667	0.2207	0.0724

Table A.32 Three way ANOVA and Tukey Single Range Test Table for FTIR data related to starch retrogradation of control and gum added breads baked in different ovens

Factor	Levels	Values
Oven types	3	conventional, IR-microwave combination, and microwave
Storage time	2	1, 120
Gum types	2	control, xanthan-guar

ANOVA Results

Source	DF	Sum of Squares	Mean Square	F Value	P
Oven Type	2	0.179550	0.089775	57.87	0.000
Storage time	1	0.035208	0.035208	22.70	0.002
Gum Type	1	0.001008	0.001008	0.65	0.447
Error	7	0.010858	0.001551		
Total	11	0.226625			

Tukey Simultaneous Tests

All Pairwise Comparisons among Levels of Oven Type

Oven Type = IR-microwave combination subtracted from:

Oven Type	Difference of Means	SE of Difference	Adjusted P-Value
Conventional	-0.02250	0.02785	0.7103
Microwave	0.24750	0.02785	0.0001

Oven Type = conventional subtracted from:

Oven Type	Difference of Means	SE of Difference	Adjusted P-Value
Microwave	0.2700	0.02785	0.0001

All Pairwise Comparisons among Levels of Storage time

Storage time = 1 subtracted from:

Storage time	Difference of Means	SE of Difference	Adjusted P-Value
120	0.1083	0.02274	0.0021

All Pairwise Comparisons among Levels of Gum Type

Gum Type = control subtracted from:

Gum Type	Difference of Means	SE of Difference	Adjusted P-Value
Xanthan-guar	0.01833	0.02274	0.4466

APPENDIX B

DSC THERMOGRAMS

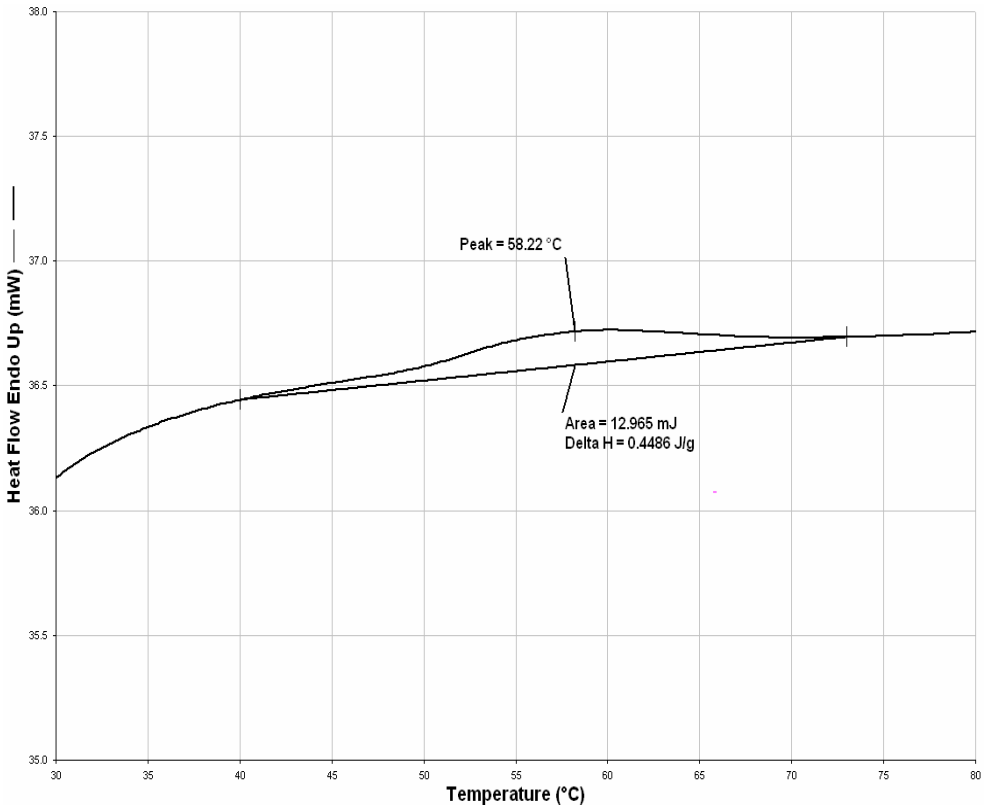

Figure B.1 DSC thermogram of control bread samples baked in conventional oven after 24h storage

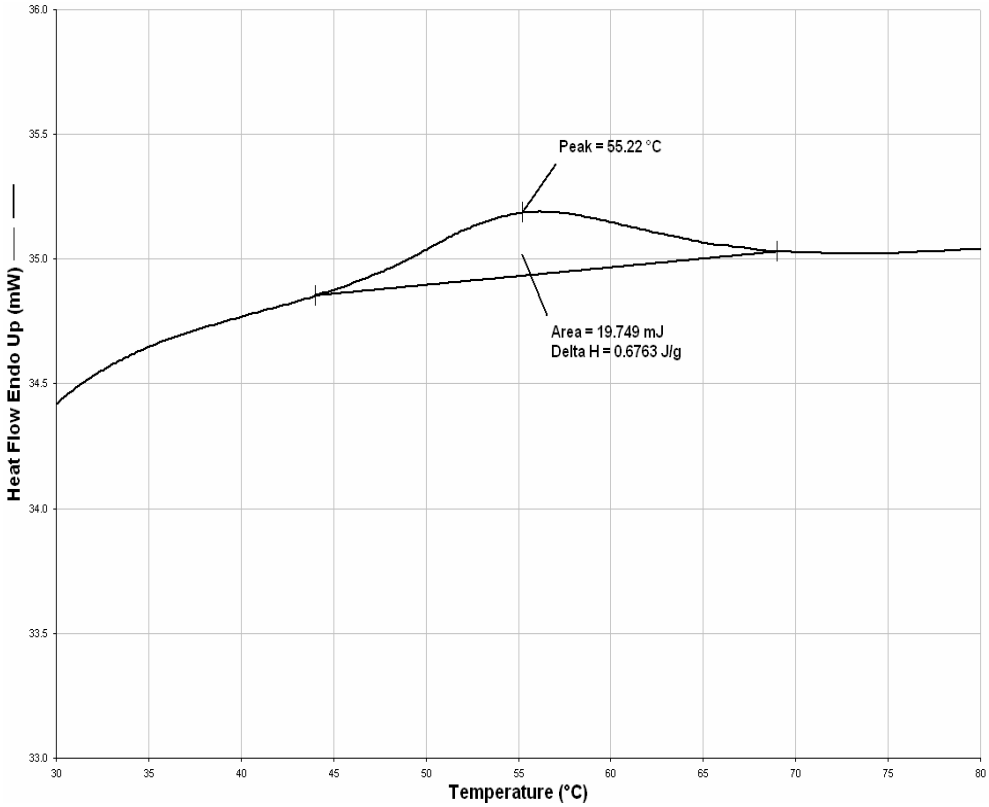

Figure B.2 DSC thermogram of control bread samples baked in conventional oven after 72h storage

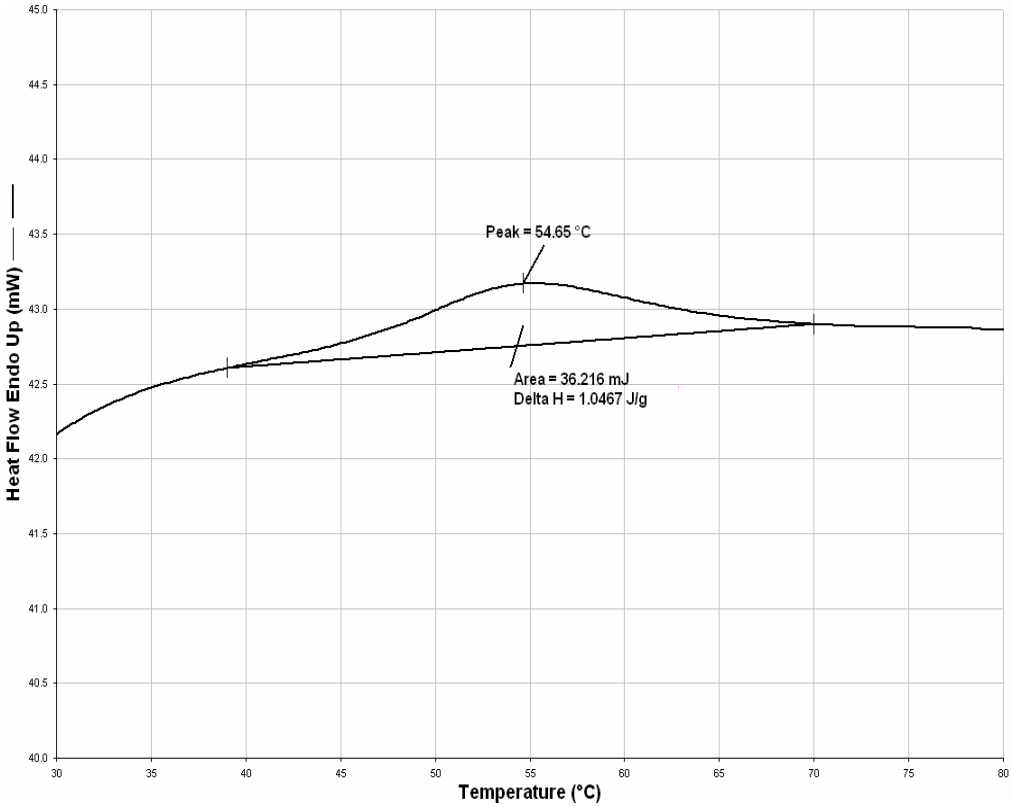

Figure B.3 DSC thermogram of control bread samples baked in conventional oven after 120h storage

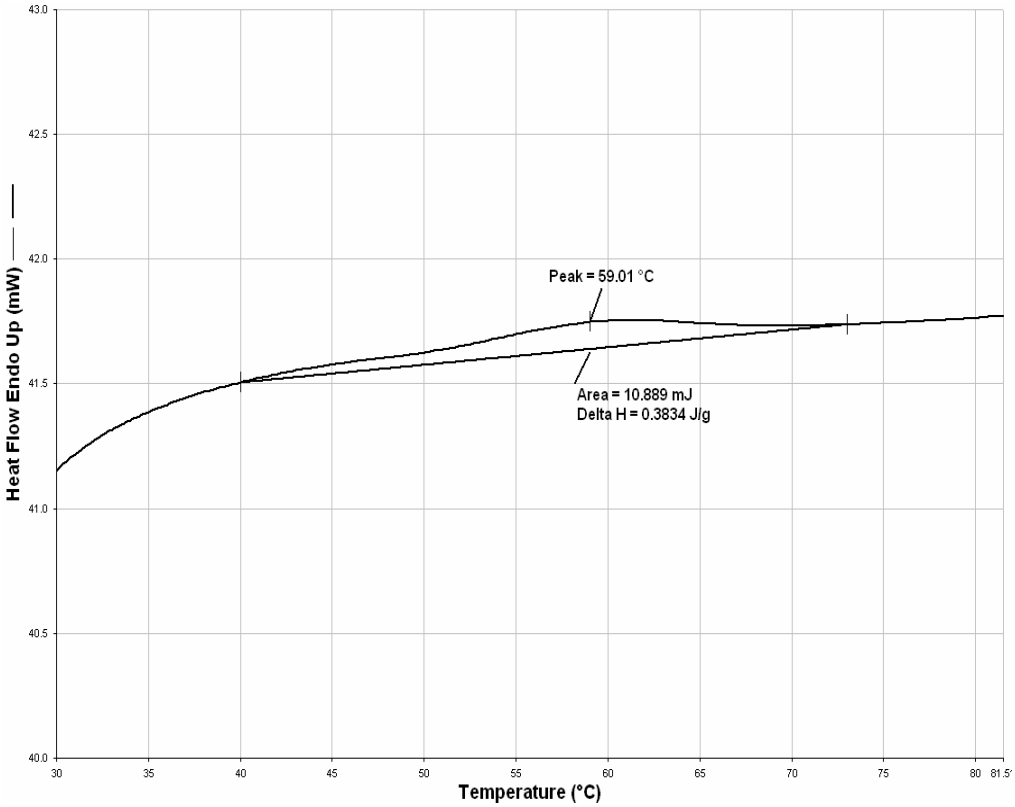

Figure B.4 DSC thermogram of gum added bread samples baked in conventional oven after 24h storage

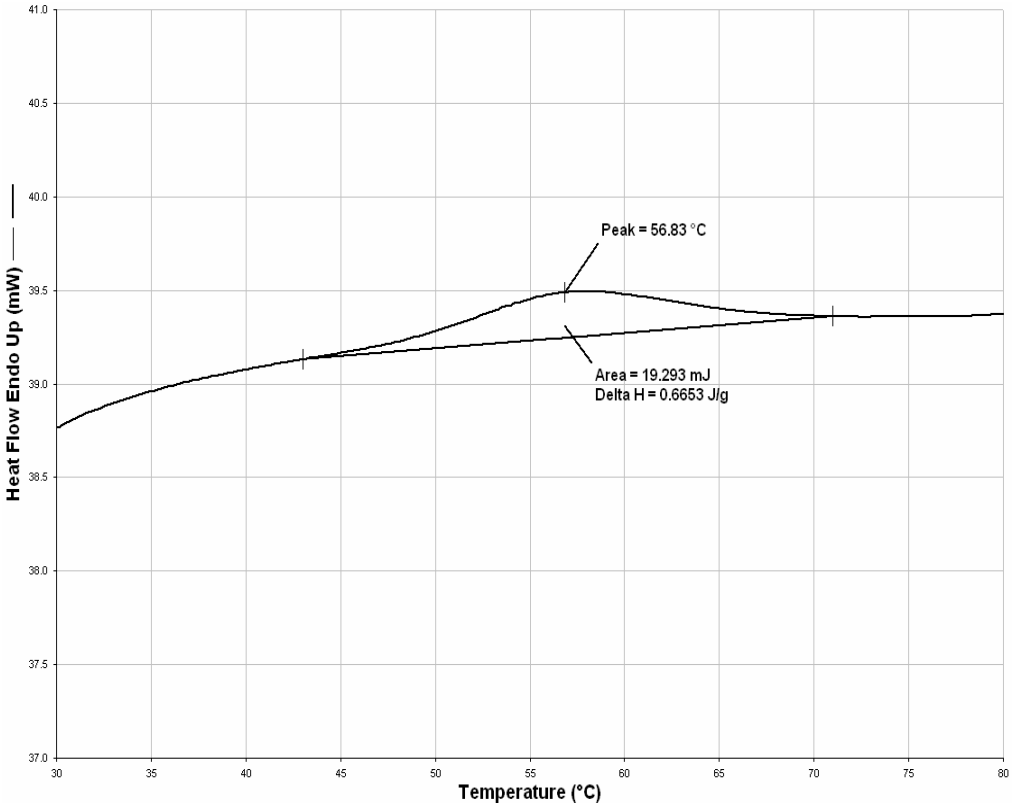

Figure B.5 DSC thermogram of gum added bread samples baked in conventional oven after 72h storage

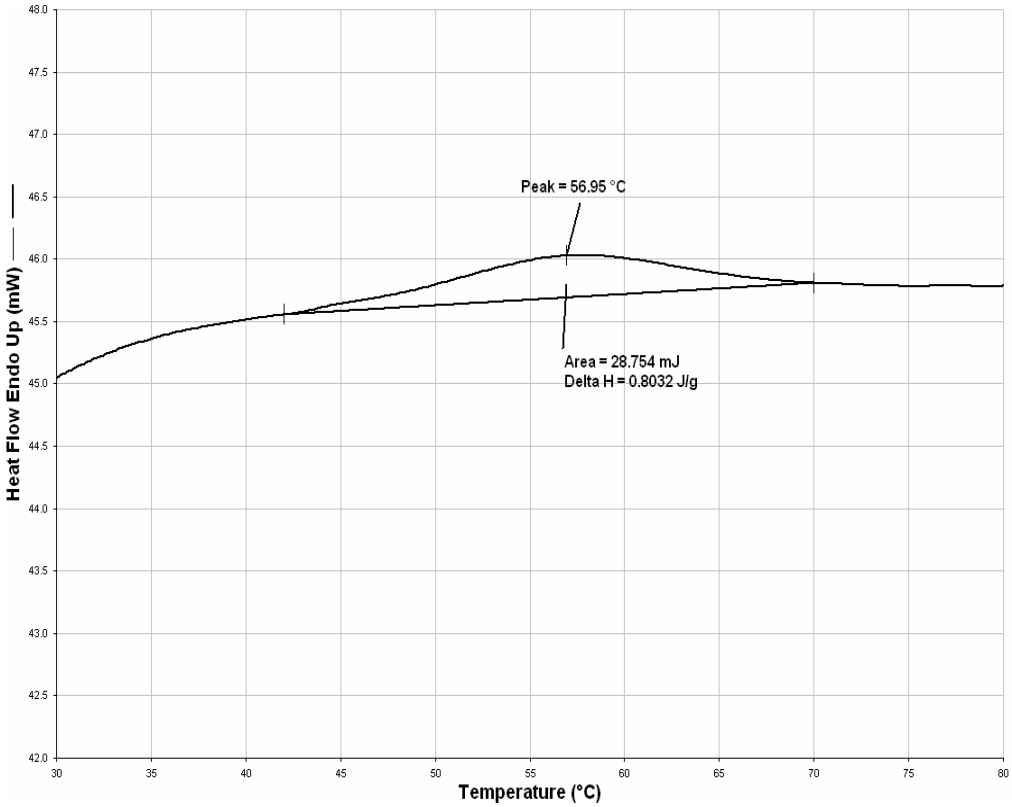

Figure B.6 DSC thermogram of gum added bread samples baked in conventional oven after 120h storage

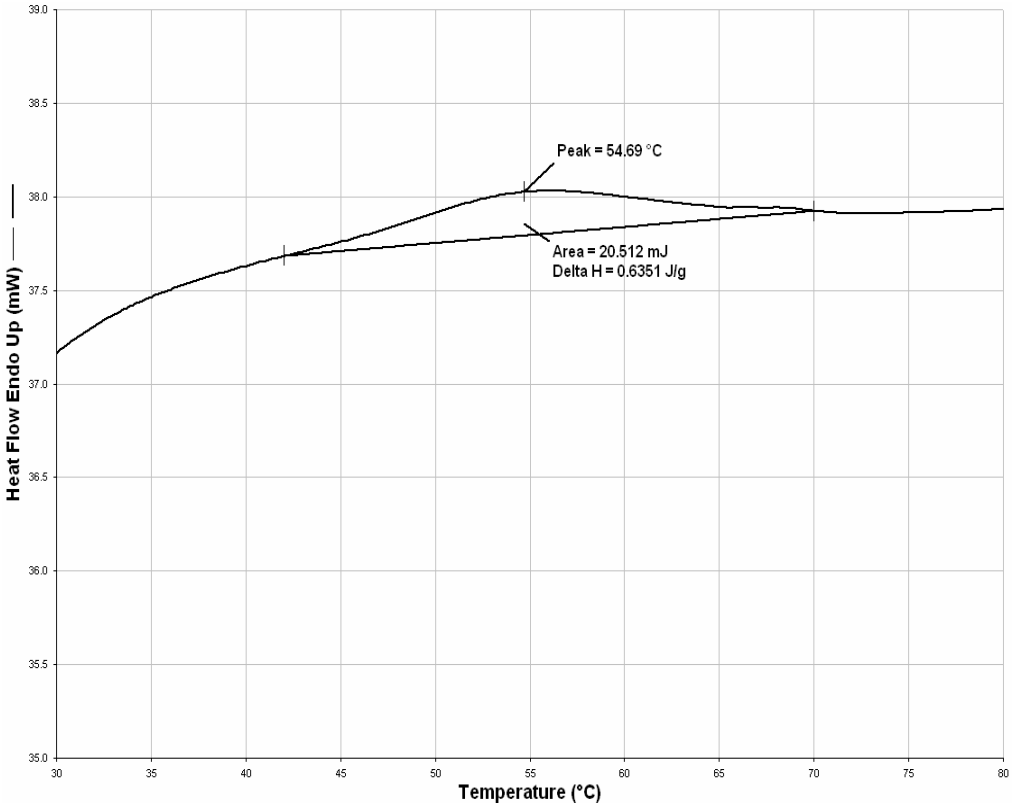

Figure B.7 DSC thermogram of control bread samples baked in IR-microwave combination oven after 24h storage

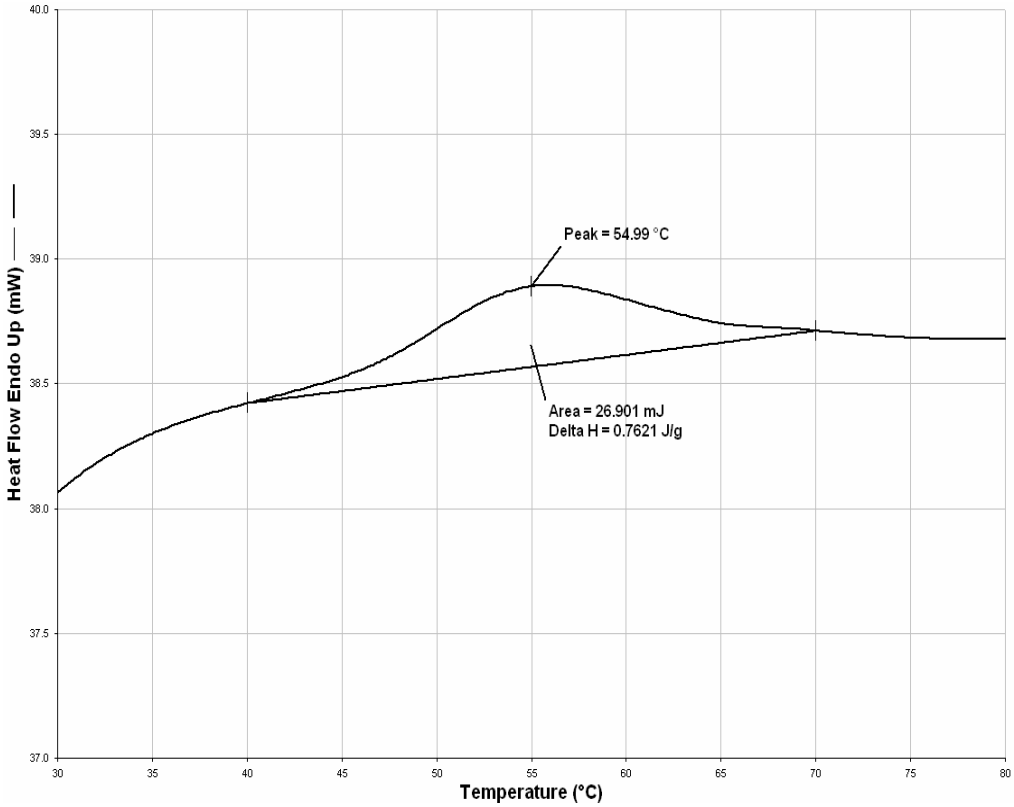

Figure B.8 DSC thermogram of control bread samples baked in IR-microwave combination oven after 72h storage

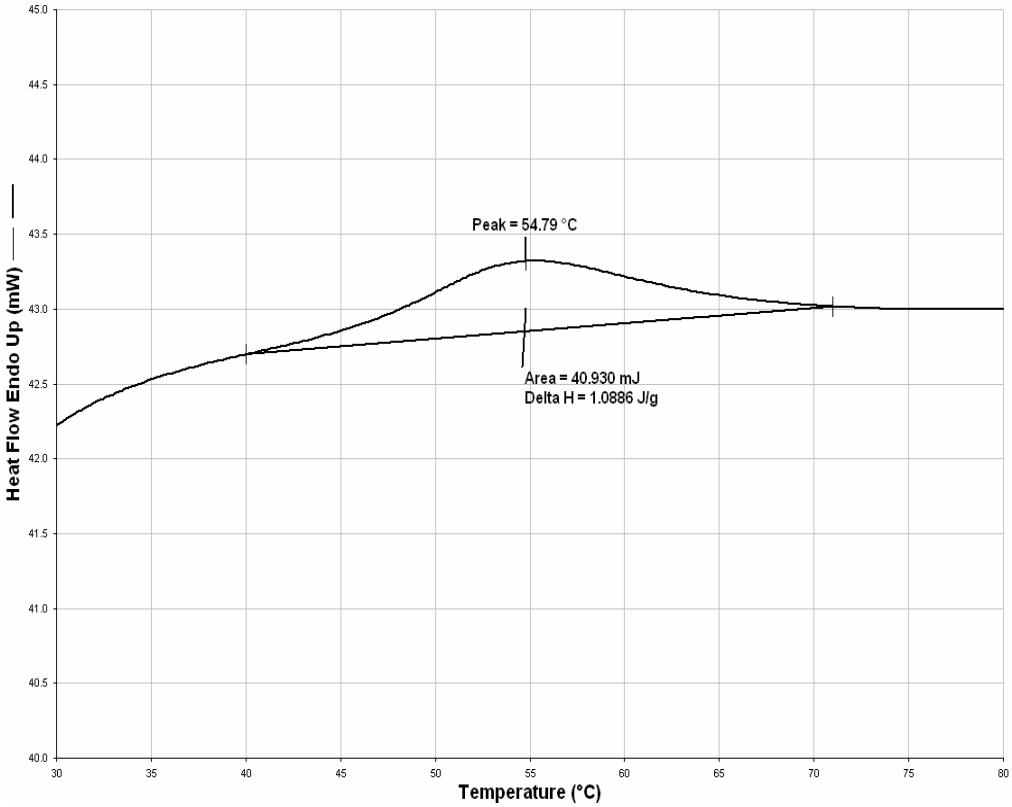

Figure B.9 DSC thermogram of control bread samples baked in IR-microwave combination oven after 120h storage

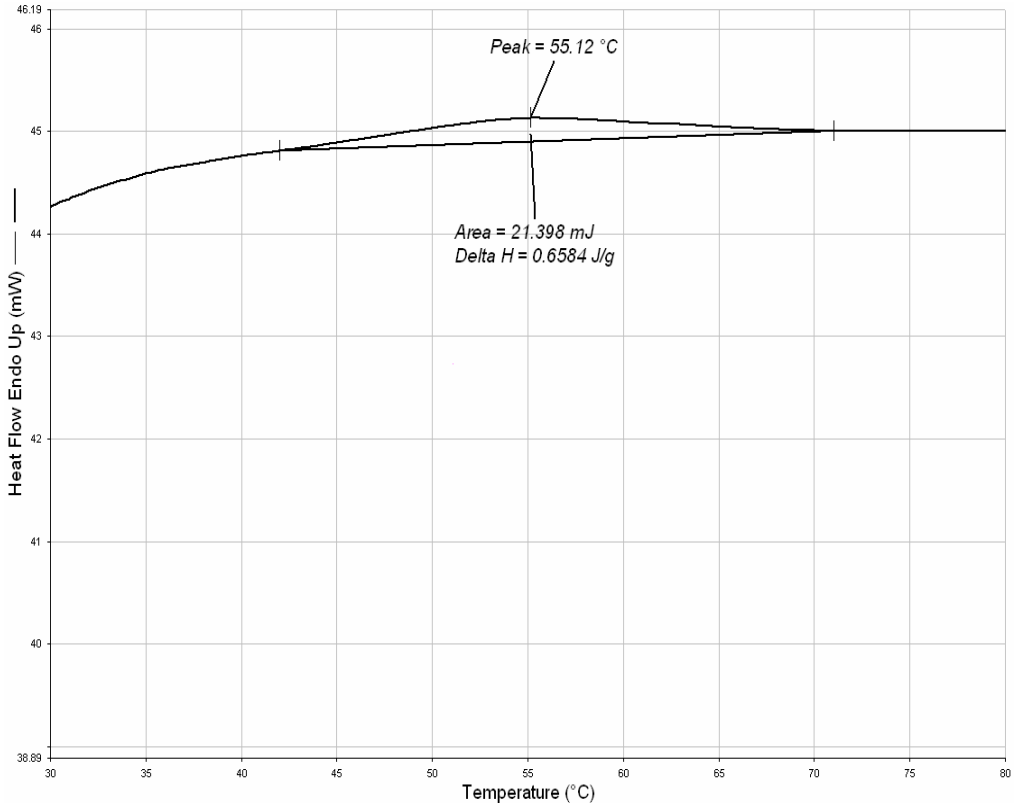

Figure B.10 DSC thermogram of gum added bread samples baked in IR-microwave combination oven after 24h storage

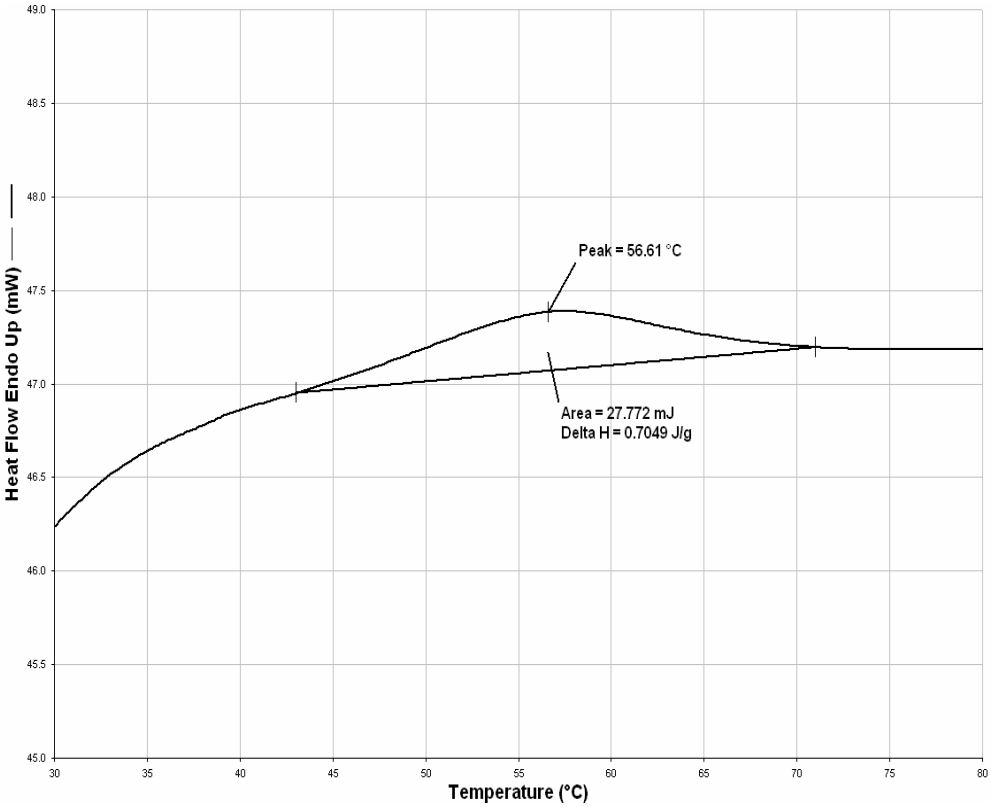

Figure B.11 DSC thermogram of gum added bread samples baked in IR-microwave combination oven after 72h storage

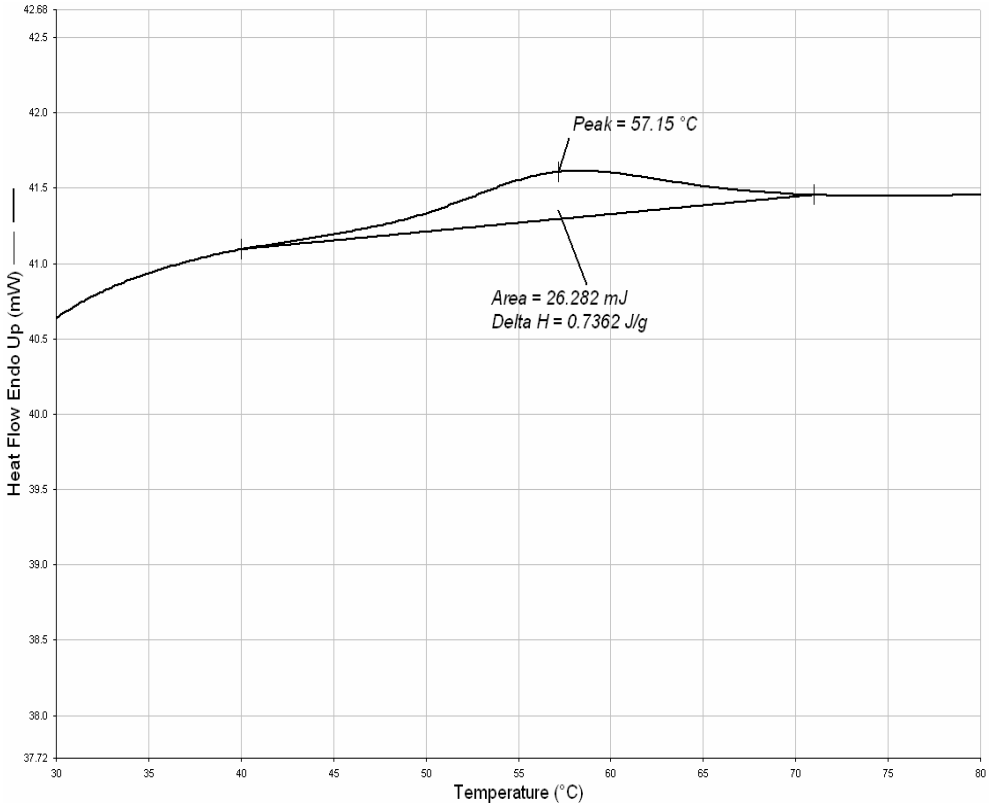

Figure B.12 DSC thermogram of gum added bread samples baked in IR-microwave combination oven after 120h storage

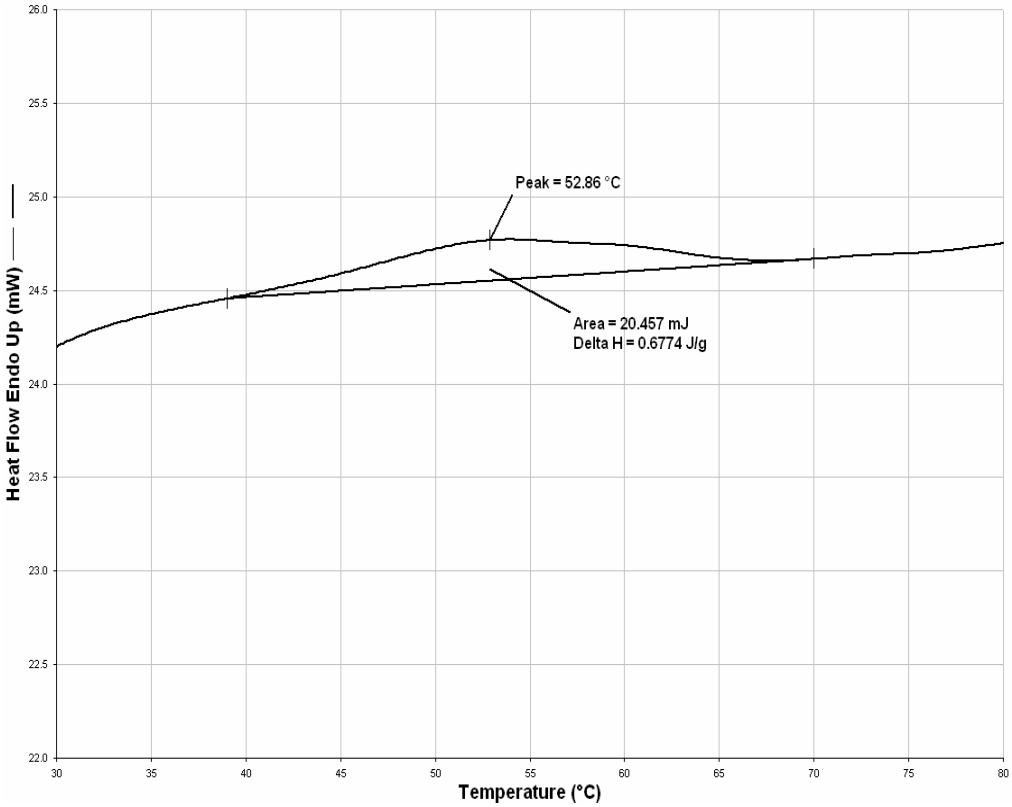

Figure B.13 DSC thermogram of control bread samples baked in microwave oven after 24h storage

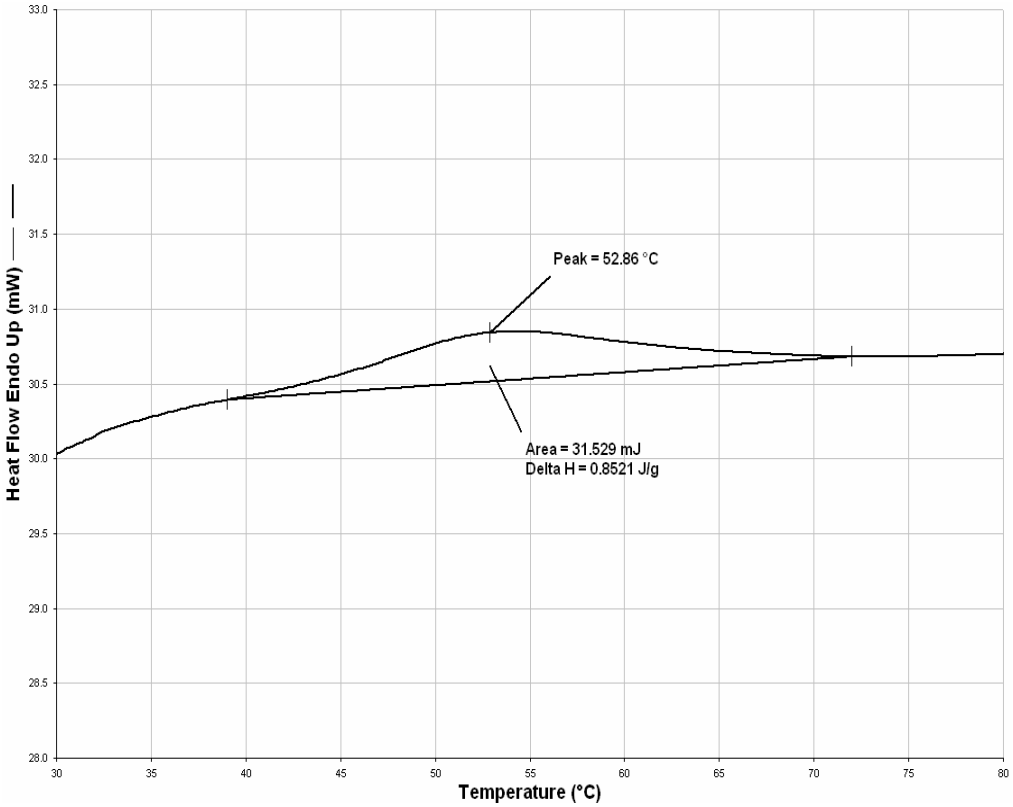

Figure B.14 DSC thermogram of control bread samples baked in microwave oven after 72h storage

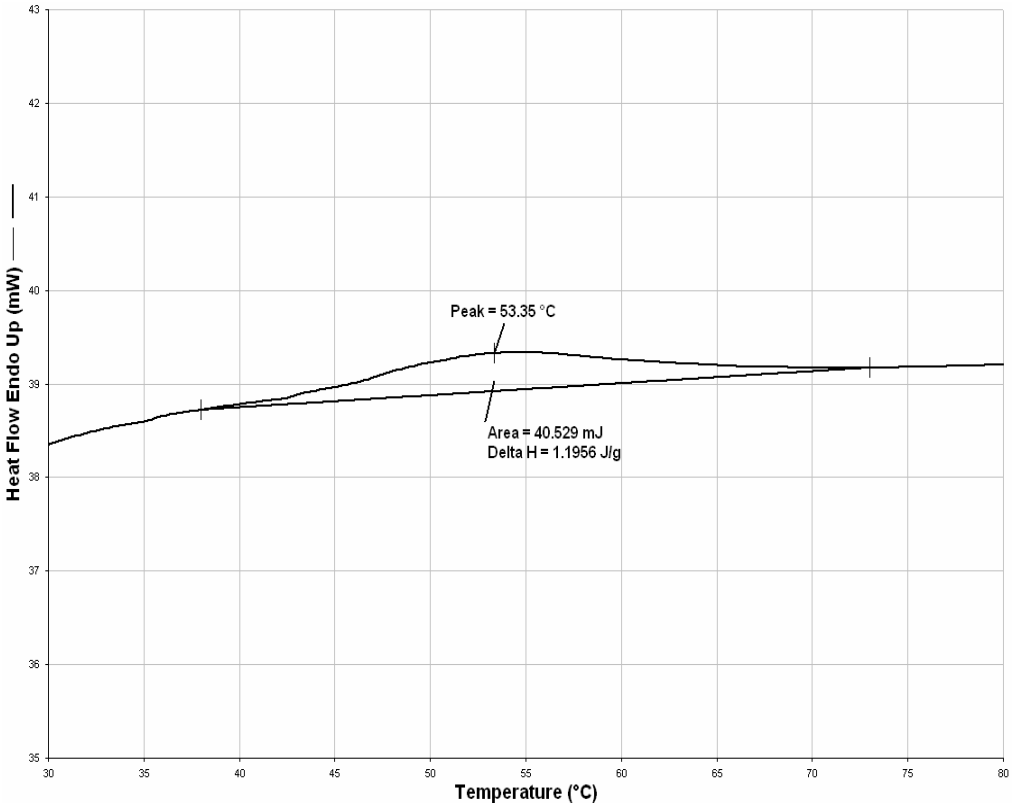

Figure B.15 DSC thermogram of control bread samples baked in microwave oven after 120h storage

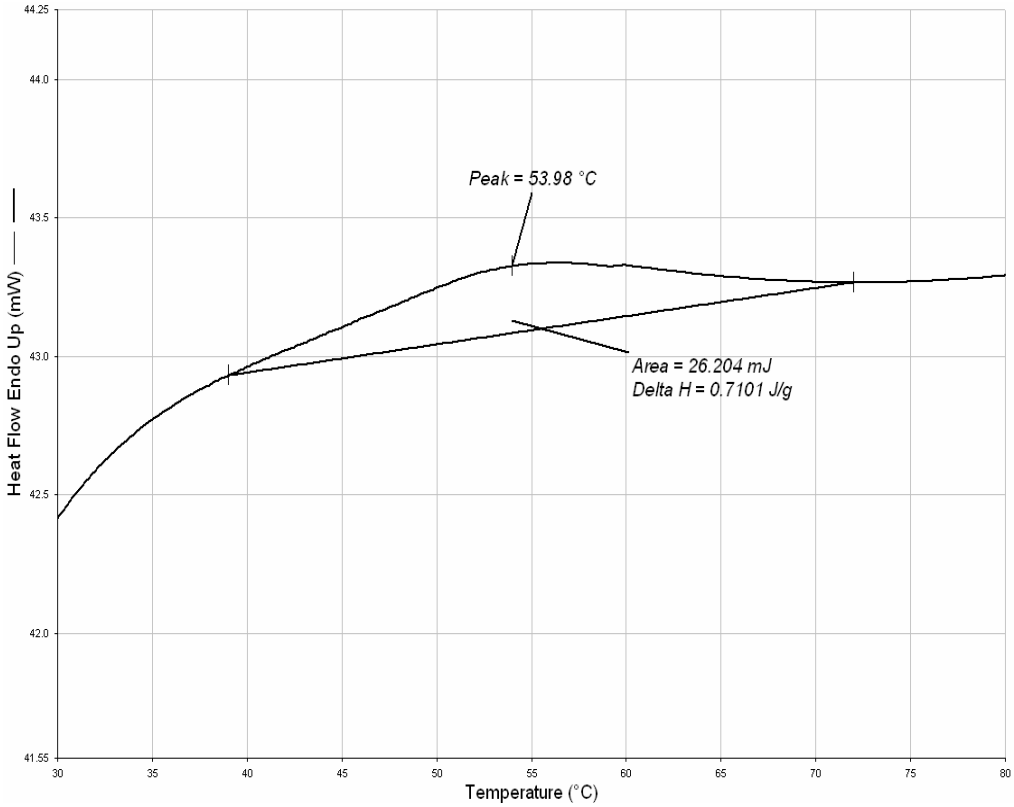

Figure B.16 DSC thermogram of gum added bread samples baked in microwave oven after 24h storage

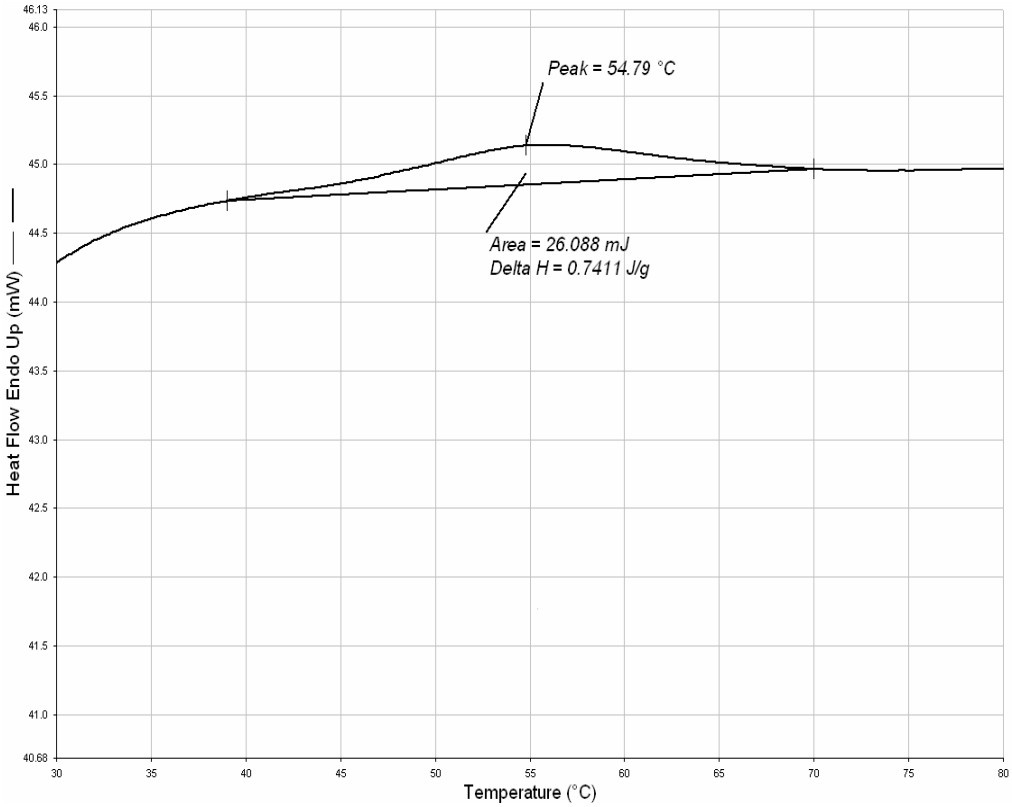

Figure B.17 DSC thermogram of gum added bread samples baked in microwave oven after 72h storage

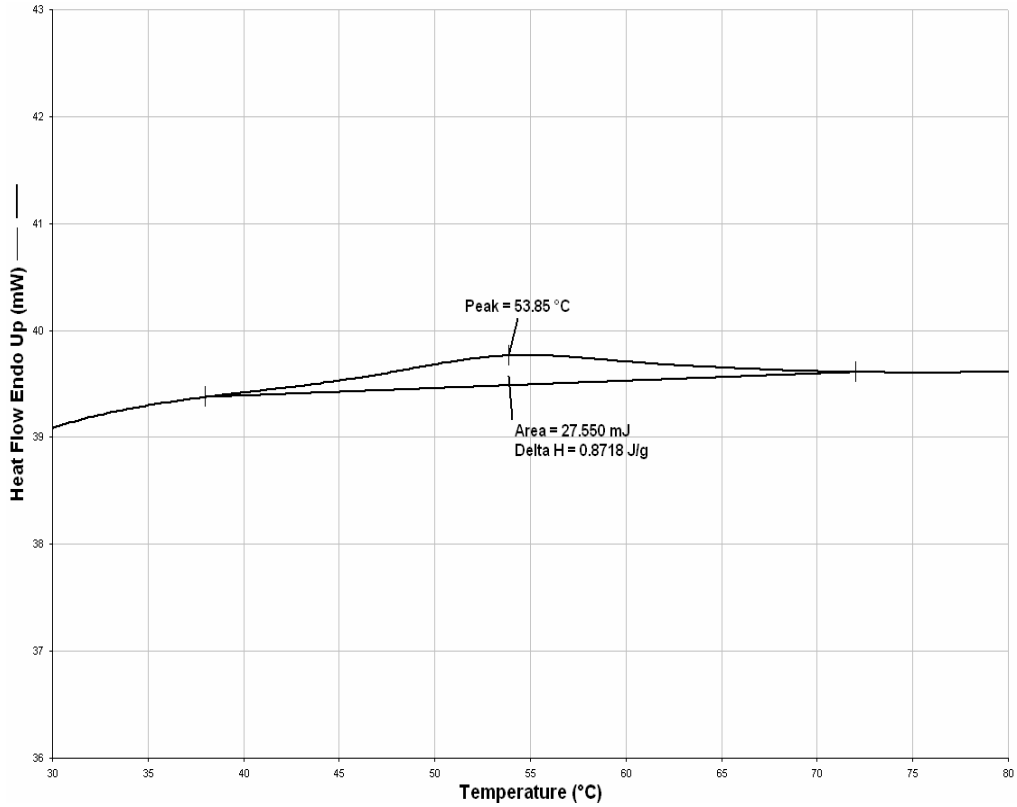

Figure B.18 DSC thermogram of gum added bread samples baked in microwave oven after 120h storage

APPENDIX C

RVA PROFILES

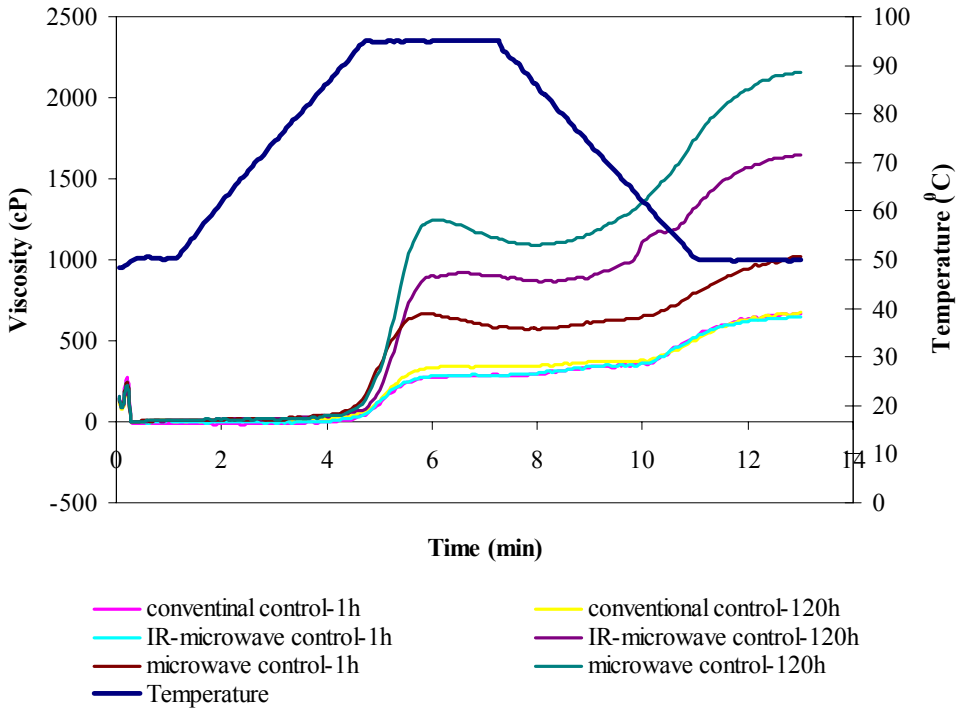

Figure C.1 RVA profile of control breads baked in different ovens during 1h and 120h storage

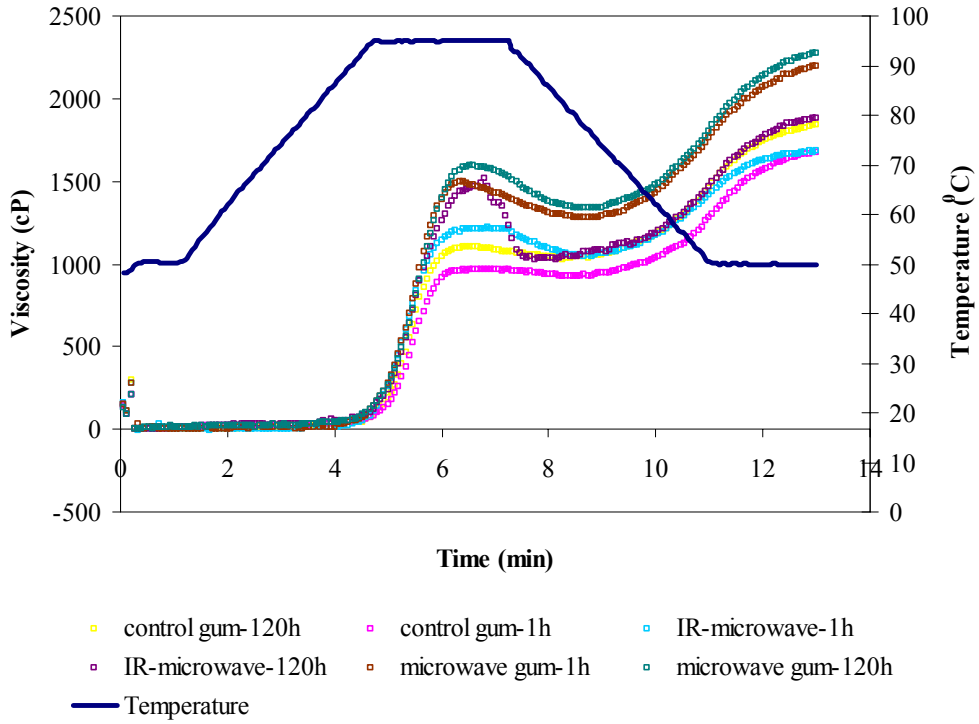

Figure C.2 RVA profile of gum added breads baked in different ovens during 1h and 120h storage

APPENDIX D

CURVE FITTING PROCEDURE

The XRD data were browsed with PeakFit V4.12 software, which was the first step of curve fitting procedure. The x-axis and the y-axis in the Figure D.1 represent 2θ and Counts, respectively.

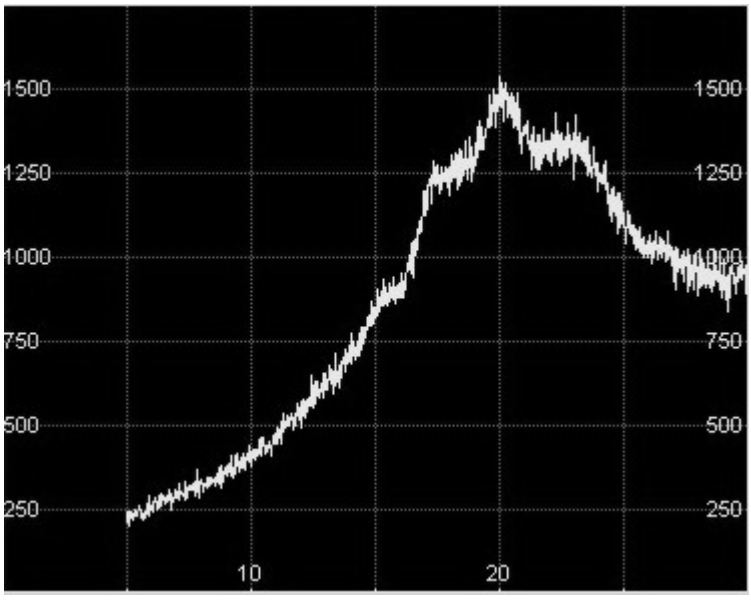

Figure D.1 The first step of curve fitting procedure for x-ray analysis

Then, the XRD pattern is smoothened as seen in Figure D.2. This curve will be utilized as the master curve in curve fitting.

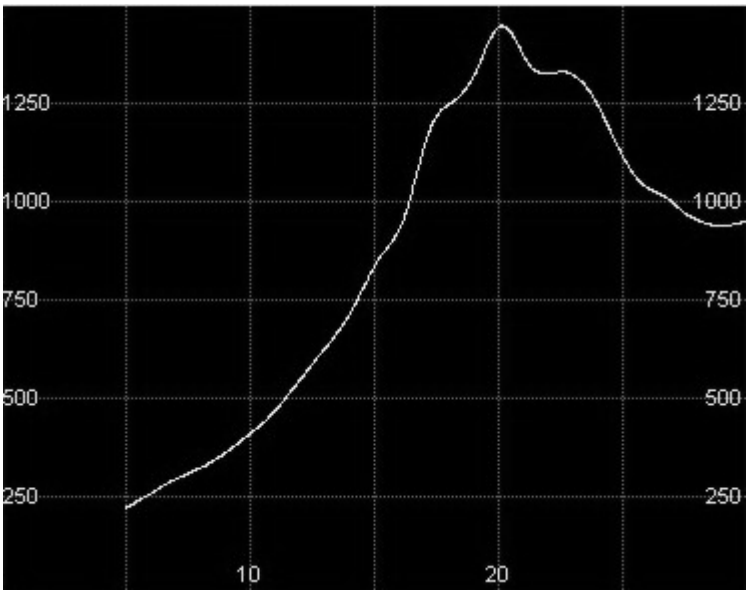

Figure D.2 The smoothening step of curve fitting procedure for x-ray analysis

The smoothened XRD pattern was deconvoluted into minor curves according to peak locations (Figure D.3).

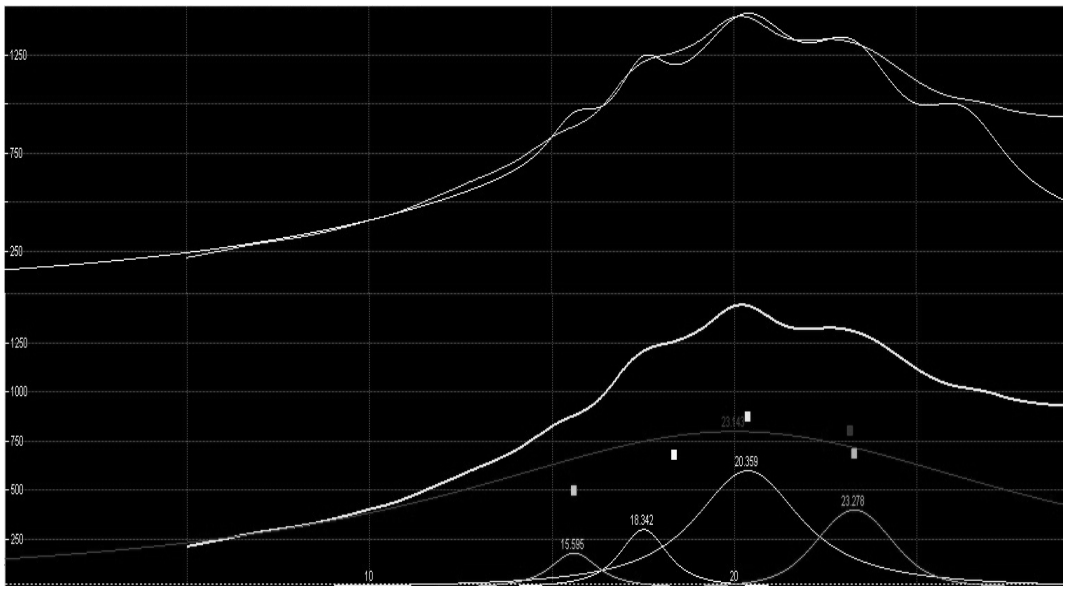

Figure D.3 The deconvolution step of curve fitting procedure for x-ray analysis

The minor curves were fitted to the master curve (smoothened XRD patterns) with the R-square value greater than 95% (Figure D.4). The area under the minor curves were determined.

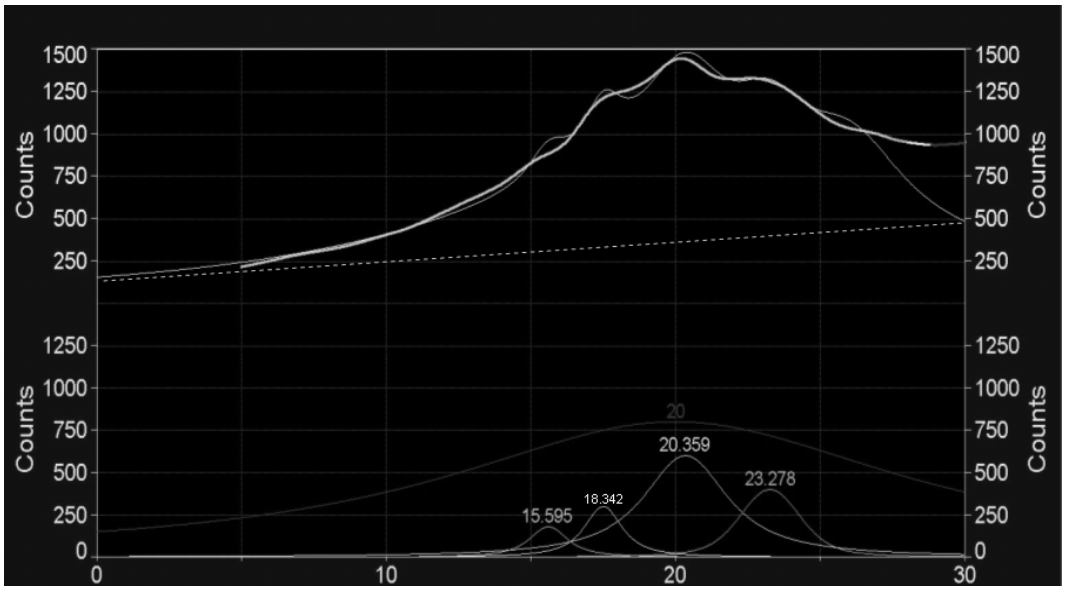

Figure D.4 The last step of curve fitting procedure for x-ray analysis

The curve fitting analysis of FTIR data related to starch retrogradation were also done by the help of PeakFit V4.12 software, with the procedure explained above (Figures D.1-D4). Since the FTIR data was given in terms of transmittance, before browsing the data with the software, the transmittance values were converted to absorbance. Rest of the curve fitting procedure for FTIR data was the same with that for X-ray data.

VITA

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Her publications are listed below:

1. Keskin, S. O., Sumnu, G., Sahin, S., "Bread baking in halogen lamp-microwave combination oven", *Food Research International* 37: 489-495 (2004).
2. Keskin, S. O., Sumnu, G., Sahin, S., "Usage of enzymes in novel baking process", *Nahrung-Food* 48: 156-160 (2004).
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1. Keskin, S. O., Sumnu, G and Şahin, S. "Effects of halogen lamp-microwave combination baking on bread quality," Microwave 2004 Proceedings, International Symposium on Microwave Science and its application to related fields, Takamatsu-Japan, pp: 556-559, 2004.
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5. Keskin, S. O., Şumnu, G. ve Şahin, S. "Farklı ekmek formülasyonlarının, mikrodalga ve halojen lamba-mikrodalga kombinasyonu ile pişirilen ekmeklerin kalitelerine olan etkileri", Gıda Kongresi 2005, pp: 518-521, İzmir, 2005.

6. Keskin, S. O., Şumnu G. ve Şahin, S. "The effects of different gums on dielectric properties of doughs and breads baked in infrared-microwave combination oven", 1st International Food and Nutrition Congress, pp: 166 , İstanbul, 2005.

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8. Keskin, S.O. Türkiye 9. Gıda Kongresi, Bolu, 24-26 Mayıs, 2006.

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14. Keskin, S. O., Sumnu G and Sahin, S. "Effects of gums on staling of breads baked in different ovens", 2nd International Food and Nutrition Congress, 24-26 October, İstanbul, 2007.

15. Keskin, S. O., Sumnu G., Sahin, S and Senyuva, H. "Acrylamide formation in breads during baking in different ovens", 2nd International Food and Nutrition Congress, 24-26 October, İstanbul, 2007.

16. Özkoç (Keskin), S. O., Sumnu, G and Sahin, S. "Effects of gums on micro- and macro- structure of breads baked in different ovens", ICC Bosphorus 2008, April 24-26, İstanbul, 2008.

17. Özkoç (Keskin), S. O., Sumnu, G., Sahin, S and Turabi, E. "Effects of gum addition on starch retrogradation of breads baked in different ovens", ICC Bosphorus 2008, 24-26 April, İstanbul, 2008.

PROJECT WORK:

- **TUBITAK Marmara Research Center,** Food Institute,
  Research topic: "EUROFIR (European Food Information Resource Network)", FP6-project (NoE), 2008-.
- **TUBITAK Marmara Research Center,** Food Institute,
  Research topic: "Ulusal Gıda Kompozisyonunun Belirlenmesi ve Yaygın-Sürekli Paylaşım Sisteminin Oluşturulması", Researcher, TARAL 1007, 2008-.
- **Middle East Technical University,** Department of Food Engineering,
  Research topic: "Investigation of acrylamide content of breads baked in different ovens", Researcher, BAP-2007-03-14-01, 2007.

- **Middle East Technical University,** Department of Food Engineering, Research topic: "Changes in physical properties of different bread formulations during microwave and halogen lamp-microwave combination baking", Researcher, BAP-2006-03-14-03, 2006-2007.
- **Cornell University and Middle East Technical University**
  Department of Biological and Environmental Engineering and Department of Food Engineering,
  Research topic: "Optimization of multiphase transport and deformation in novel baking process". TUBITAK-NSF Joint Project, TOGTAG-NSF-2004/3, Researcher, 2004-2006.
- **Middle East Technical University,** Department of Food Engineering, Research topic: "Changes in physical properties of different bread formulations during microwave and halogen lamp-microwave combination baking", Researcher, BAP-2004-03-14-01, 2004-2005.
- **Middle East Technical University,** Department of Food Engineering, Research topic: "The effects of different enzymes on the quality parameters of breads baked in advantium oven", Researcher, BAP-2003-07-02-00-69, 2003.

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