USE OF POLYDEXTROSE AS A SUGAR- AND FAT- REPLACER IN HIGH-RATIO CAKES

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ABSTRACT

USE OF POLYDEXTROSE AS A SUGAR-AND FAT-REPLACER IN HIGH-RATIO CAKES

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The main objective of this study was to investigate the functionality of polydextrose on the physical properties of a high-ratio cake system as a sugar- and fat-replacer. Specifically, it was aimed to investigate the effect of polydextrose on the foaming characteristics of a high-ratio cake batter and on the expansion properties and color of a high-ratio cake. It was also aimed to investigate an optimum for simultaneous sugar-and fat-replacement.

Sugar-replacer characteristics of polydextrose were investigated on a set of samples containing both polydextrose and sugar corresponding to the total sugar amount in the original formulation. Fat-replacer characteristics of polydextrose were investigated on a set of samples containing both polydextrose and fat corresponding to the total fat amount in the original formulation. Simultaneous sugar- and fat-replacement was studied by the application of a second order two-variable, five-level Central Composite Design.

Polydextrose substitution led to a change in relative foam viscosity measurement; foam drainage and stability of the cake batter with an increase in bubble size variation and bubble sizes because of the inability of polydextrose to integrate air bubbles into the batter. Change in the expansion properties of polydextrose-substituted cakes was attributed mainly to the functionality of fat in batter stage to incorporate air bubbles and that of sugar in baking to regulate simultaneous starch gelatinization and protein denaturation. Polydextrose-substitution led to a loss in the desired lightness and yellowness of the high-ratio cake.

Simultaneous sugar- and fat replacement results showed that 15.03 % fat-replacement and 33.87% sugar-replacement was possible for the manufacture of a diet cake formulation.

Key Words: High-ratio-cake, Cake, Cake Batter, Food Foams, Foam Stability, Foam Drainage, Litesse, Polydextrose, Image Analysis, Baking

ÖZ

POLİDEKSTROZUN YÜKSEK ŞEKER ORANI İÇEREN KEKLERDE ŞEKER VE YAĞ YERİNE KULLANIMI

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Bu çalışmanın ana amacı yüksek şeker oranı içeren kek sistemlerinde polidekstrozun şeker ve yağ yerine kullanımındaki işlevselliğinin ürünün fiziksel özellikleri üzerine etkilerinin araştırılmasıdır. Bu amaca yönelik olarak polidekstrozun yüksek şeker içerikli kek hamurunun köpüklenme özellikleri ile kekin kabarma ve renk özellikleri üzerine etkileri araştırılmıştır. Ayrıca, polidekstrozun aynı zamanda hangi oranda hem şeker, hem de yağ yerine kullanılabileceği en uygun değerlerinin de araştırılması amaçlanmıştır.

Polidekstrozun şeker yerine kullanım özyapılarının araştırılması için özgün reçetedeki toplam şeker oranını sağlayacak biçimde farklı miktarlarda şeker ve polidekstroz içeren örnekler kullanılmıştır. Yağ yerine kullanım özyapılarının araştırılması içinse bu kez özgün reçetedeki toplam yağ oranını sağlayacak biçimde farklı miktarlarda yağ ve polidekstroz içeren örnekler kullanılmıştır. Polidekstrozun aynı zamanda hem şeker, hem de yağ yerine kullanım özelliklerinin araştırılması içinse iki-değişkenli, beş-düzeyli Merkezi Kompozit Deneysel Tasarım sonucu bulunan ikinci derece bir görgül modelden yararlanılmıştır.

Polidekstroz kullanımı, kek hamuruna yeterince hava katılamaması sonucu hava kabarcıklarının boyutlarının büyümesine, boyut dağılımının genişlemesine, dolayısıyla göreli hamur akışkanlığı ölçümü; köpük drenajının ve kalıcılığının değişmesine neden olmuştur. Polidekstroz içeren kekin kabarma özelliklerindeki değişimlerin nedeni ise, yağın hamur aşamasında hava kabarcıklarını birleştirme işlevselliğinin tam olarak karşılanamamasına, şekerin ise pişme aşamasında nişasta jelatinizasyonu ve protein denaturasyonunu birlikte kılma işlevselliğinin de tam olarak karşılanamamasına bağlanabilir. Ayrıca yüksek şeker oranı içeren keklerde polidekstroz kullanımı renkteki sarılığın koyulmasına yol açmıştır.

Polidekstrozun hem şeker, hem de yağ yerine kullanımı üzerine elde edilen sonuçlar polidekstrozun özgün reçetedeki yağın %15,03'ü, şekerin ise %33,78'i yerine kullanılarak diyet özellikli bir kek ürünü elde edilebileceğini göstermiştir.

Anahtar Kelimeler: Şeker oranı yüksek kek, Kek, Kek hamuru, Gıda Köpükleri, Köpük Drenajı, Köpük kararlılığı, Polydextrose, Polidekstroz, Görüntü analizi, Pişirme

To Huriye, Dursun Ali and Mehmet Koçer

To my parents and grandfather

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INTRODUCTION

1.1 The Scope

Cake is a complex fat and water emulsion system containing flour, starch, sugar, fat, eggs, and baking powder. A proper combination of the ingredients can give a high-quality product with desirable flavor and texture.

The most important ingredients of the cake are fat and sugar. Sugar affects the physical structure of the cake by regulating the gelatinization of starch such that the air bubbles can be properly expanded by carbon dioxide and water vapor before the cake sets (Kim, et. al., 1992). In addition, sugar contributes to color development related with caramelization and Maillard browning. Fat has an important function is entrapping air during mixing. Also it tenderizes the crumb and contributes to flavor (Matz, 1972).

Today, there is a consumer demand for replacing fat and sugar in their diet. Diet foods that contain low calorie sugar- and fat-replacers have recently been popular due to the health considerations. The most important point in the usage is the consideration of the functionality of these fat and sugar replacers in the products.

Polydextrose is a prenium-quality bulking and fat-sparing agent. It is a randomly bonded condensation polymer of dextrose, containing minor amounts of bound sorbitol and citric acid. It contributes only 1 kcal/g, in

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comparison with 4 kcal/g provided by sugar and 9 kcal/g by fat (Xyrofin, 1997).

From the functional point of view polydextrose elevates the starch gelatinization temperature (Pateras et. al., 1994; Rosenthal, 1995). High polydextrose concentration in the cake batters is known to reduce the air-holding capacity of batters with a consequent increase in bubble size variation and average bubble size (Pateras et. al., 1994). The numbers of bubbles in the cake batter were found to increase remarkably with increasing polydextrose concentration which can be attributed to the fact that polydextrose can also be used as a fat-replacer (Yazgan, 1997).

In the light of the previous researches, the present study focused on the investigation of the functionality of polydextrose as a sugar- and fat-replacer in high-ratio cakes and the investigation of an optimum for the fat- and sugar-replacement characteristic of polydextrose using response surface methodology. The high-ratio cake formulation was chosen because such systems contain more sugar and fat when compared to other cakes and are extensively used in the baking industry due to high eating quality.

1.2 Objectives

The main objective of this study was to investigate the functionality of polydextrose on the physical properties of a high-ratio cake system as a sugar- and fat-replacer.

Specifically, it was aimed to investigate of the effect of polydextrose on the foaming characteristics of the cake batter and the physical properties of the high-ratio cake. The cake batter characteristics were evaluated on the basis of foam drainage and foam stability, while the high-ratio characteristics were evaluated on the basis of the expansion properties (bulk and true density, porosity, cake height, pores size and shape distributions) and color. It was also aimed to describe model equations giving the dependence of these parameters on polydextrose replacement and to investigate an optimum for simultaneous sugar-and fat-replacement that would mimic the high-ratio cake the best.

CHAPTER 2

USE OF POLYDEXTROSE IN HIGH-RATIO CAKES

2.1 Cake and Cake Setting

Cake batters are complex fat-in-water emulsions with four bulk phases (aqueous, fat, gas and solid starch granules) (Ngo et. al., 1986; Shelke et. al., 1990). Cake batter is a foam composed of bubbles as the discontinuous phase and of egg-sugar-water-fat mixture as the continuous phase in which flour particles are dispersed (Mizukoshi et. al., 1983). The physical properties of these batters play an important role in determining the characteristics of the resulting cakes (Shelke et. al., 1990). The complexity of cake batters containing many ingredients, such as wheat flour, sugar, egg, fat, leavening agents, salt, nonfat dry milk solids and water has made it difficult to clarify the mechanism of the heat setting process during baking (Mizukoshi et. al., 1979).

Cakes can be classified into five types depending upon the mixing (two-stage mixing, single-stage mixing, creaming, blending, sugar-and-water method) (Matz, 1972). Cake quality is determined by the suitability of the individual ingredients (Lin et. al., 1994), the proportions or balance in which the ingredients are combined in the cake formula, and the procedures followed in mixing and baking (Matz, 1972; Mizukoshi, 1985). There are numbers of different cake formulas; yellow layer cakes, white layer cakes, chocolate cakes, high-ratio cakes, angel and sponge cakes (Matz, 1972).

High-ratio cakes contain more sugar than flour (Table 2.1) and are used extensively in the baking industry because of their high eating quality and long shelf-life (Rosenthal, 1995). In addition, the fat content of the high-ratio cake is very high as compared to other cake formulations (Table 2.1). Thus, a high-ratio cake is the most suitable formulation towards the manufacture of diet cake products.

Kim et. al. (1992) studied the interactions between starches, sugars and emulsifiers in the high-ratio cake model systems and found that the sugar in the high-ratio cake formulation plays an important role in delaying starch gelatinization during baking such that the resulting crumb structure is highly aerated and has a higher volume. Replacement might be beneficial in the high-ratio cake if proper combinations of starch, sugar, water, and emulsifier are used to achieve the appropriate batter viscosity and air incorporation, an

Table 2.1 High-ratio cake formulation

	Weight (Grams)	Weight (%)
Flour	100	24.42
Sugar	115	28.08
Fat	65	15.87
Whole egg	85	20.76
Skim Milk Powder (SMP)	5	1.22
Salt	1	0.24
Water	35	8.55
Baking Powder (BP)	3.5	0.86

optimum cake setting point by gelatinization temperature control, better cake batter stability and a sufficiently rigid starch gel formation during baking such that the cake does not collapse during cooling (Kim et. al., 1992).

2.1.1 Functions of Ingredients

In general, cake ingredients may be classified as tougheners, tenderizers, moisturizers, and driers. In order to make a satisfactory cake, tougheners and tenderizers must be properly balanced with adequate leavening. Flour, egg white, milk solids, and salt toughen cakes, whereas sugar, fat, and egg yolk tenderize them (Mizukoshi, 1985).

Flour consists of starch and proteins and serves as a basic structural element in cakes. Gelatinization of starch and coagulation of flour protein have been shown to contribute to the structural development of cakes during baking (Mizukoshi, 1985).

The functions of milk solids in cakes include; contribution of greater moisture retention therefore longer apparent freshness and keeping quality, improved appearance and crust color as a result of its lactose content and improved flavor (Matz, 1972).

Eggs contribute to leavening, binding and emulsifying actions and development of flavor and color. Egg proteins in combination with gluten form the bubble nuclei wall and permit the entrapment of air during mixing (Matz, 1972). Thus, egg acts as a toughener or a tenderizer depending upon its concentration (Paton et. al., 1981; Mizukoshi, 1985).

Baking powder causes vapor pressure build-up due to entrapped carbondioxide as batter expands and leads to the formation of pore structure as starch gelatinizes (Ngo et. al., 1986; Hicsasmaz et. al., 1992).

Water supplies a reaction and phase change medium thus contributes to cake structure as a tenderizer (Mizukoshi, 1985).

2.1.1.1 Sugar

Sugar affects the physical structure of baked products by regulating gelatinization of starch. The effects of different sugars on gelatinization of starch vary (Spies et. al., 1982; Horton et. al., 1990; White et. al., 1990). Solutions of monosaccharide glucose and fructose raise the initial gelatinization temperature of wheat starch, but to a lesser extent than sucrose (Bean et. al., 1978; White et. al., 1990).

Differences in starch gelatinization temperature due to sugar type must be taken into account in formula adjustment. Successful cakes are obtained if the sugar/water ratio in the batter would permit a starch gelatinization temperature of approximately 90°C (Bean et. al.; 1978). At the concentration used in cakes (55-60%), sugar delays gelatinization of starch from 57 to 92°C (Spies, et. al., 1982), an important phenomenon in the formation of layer cake structure (Bean et. al.; 1978). Delay in starch gelatinization during baking allows air bubbles to expand properly due to vapor pressure build up by carbon dioxide and water vapor before the cake sets (Kim, et. al., 1992).

In a starch-water system, sugars retard gelatinization by lowering a_w (Spies et. al., 1982; Koepsel et. al., 1980) and by interacting with the amorphous regions of the starch granules thus inhibiting swelling leading to an increase in the onset temperature (Derby et. al., 1975; Bean et. al., 1978; Spies et. al., 1982; Hansen et. al., 1989). Moreover, chemical bonding of sugar molecules with the chain of the amorphous regions of the starch granule restricts flexibility of the chains thus energy requirement to pull crystallites apart also increases. This results in an even higher gelatinization temperature (Spies et. al., 1982). Microscopic observations on cooked slurries and on starches extracted from baked products have suggested limited swelling of the granules in the presence of high levels of sugar (Bean et. al.; 1978). Determination of gelatinization temperature by counting swollen granules, measuring loss of birefringence and performing differential scanning calorimetry has shown that initial gelatinization occurs at progressively higher temperatures as sugar level increases (Bean et. al.; 1978).

Batter viscosity at ambient temperature increases as sugar concentration increases (Shelke et. al., 1990). Good air incorporation is obtained at all levels of added sugar leading to a more viscous and stable foam (Paton et. al., 1981). The batter contains a high ratio of solids at ambient temperature than during heating because not all the sugar dissolves prior to heating. As batter temperature increases, its volume increases since carbondioxide and water vapor diffuses into occluded air bubbles and the gas phase expands. Moreover, increase in temperature causes residual sugar crystals to dissolve resulting in a decrease in batter viscosity (Shelke et. al., 1990). On a molecular level, the secondary and tertiary structures of proteins also (milk, egg and gluten) change. The magnitude of elastic and viscous properties of the batter declines continuously (Ngo et. al. 1986).

Sugar also contributes to color development related with caramelization and Maillard browning. It retains moisture in the crumb and thereby retards staling (Matz, 1972). The amount of sugar present greatly affect the flavor, volume, texture and color of the cake (Coleman et. al., 1983)

2.1.1.2 Fat

The major function of fat is to entrap air to the batter during mixing. It tenderizes the crumb and contributes flavor to the product (Matz, 1972). In baked goods attributes of fat includes; flavor, viscosity, body, richness, texture/grain, aeration, shortening, tenderness, leavening, lubricity, dough handling and batter stability (Giese et. al., 1996).

In the cake batter largest part of the fat crystals remain in the aqueous phase and they not only adsorb to the bubble surface but they also penetrate to the air-water interface (Figure 2.1). When air starts expanding, fat crystals adsorbed to the air-water interface approach their melting point. Eventually, all the fat crystals melt and the resulting oil runs over the inside surface of the bubble, forming a uniform layer. In this process, the original fat-water interface at the bubble surface is no longer associated with crystalline fat and is therefore available for bubble expansion. Large numbers of adsorbed crystals release sufficient interface to allow the bubbles to expand without rupturing (Figure 2.2). The air-water interface in the cooked batter is therefore a hybrid interface composed of the original air-water and fat-water interfaces.

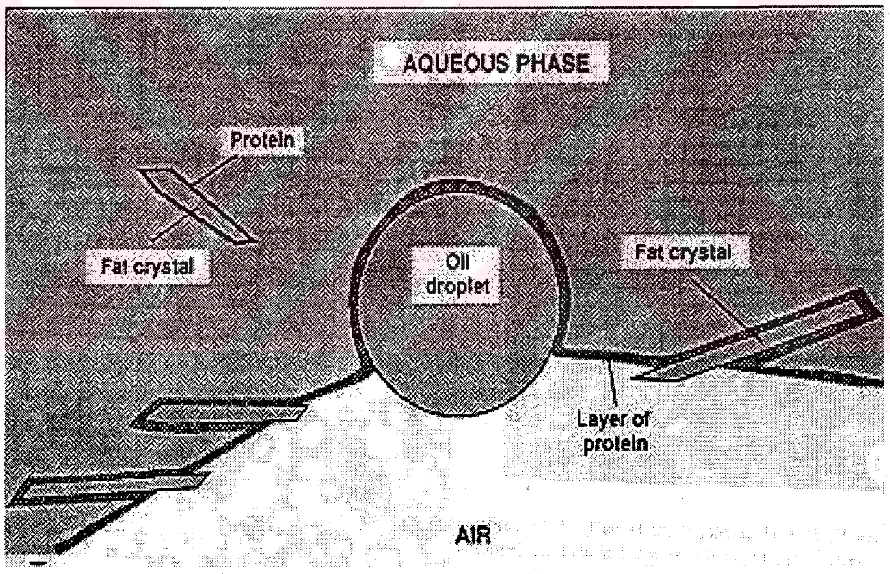


Figure 2.1 Representation of fat crystals and adsorbed protein at the air/water interface (Brooker, 1993)

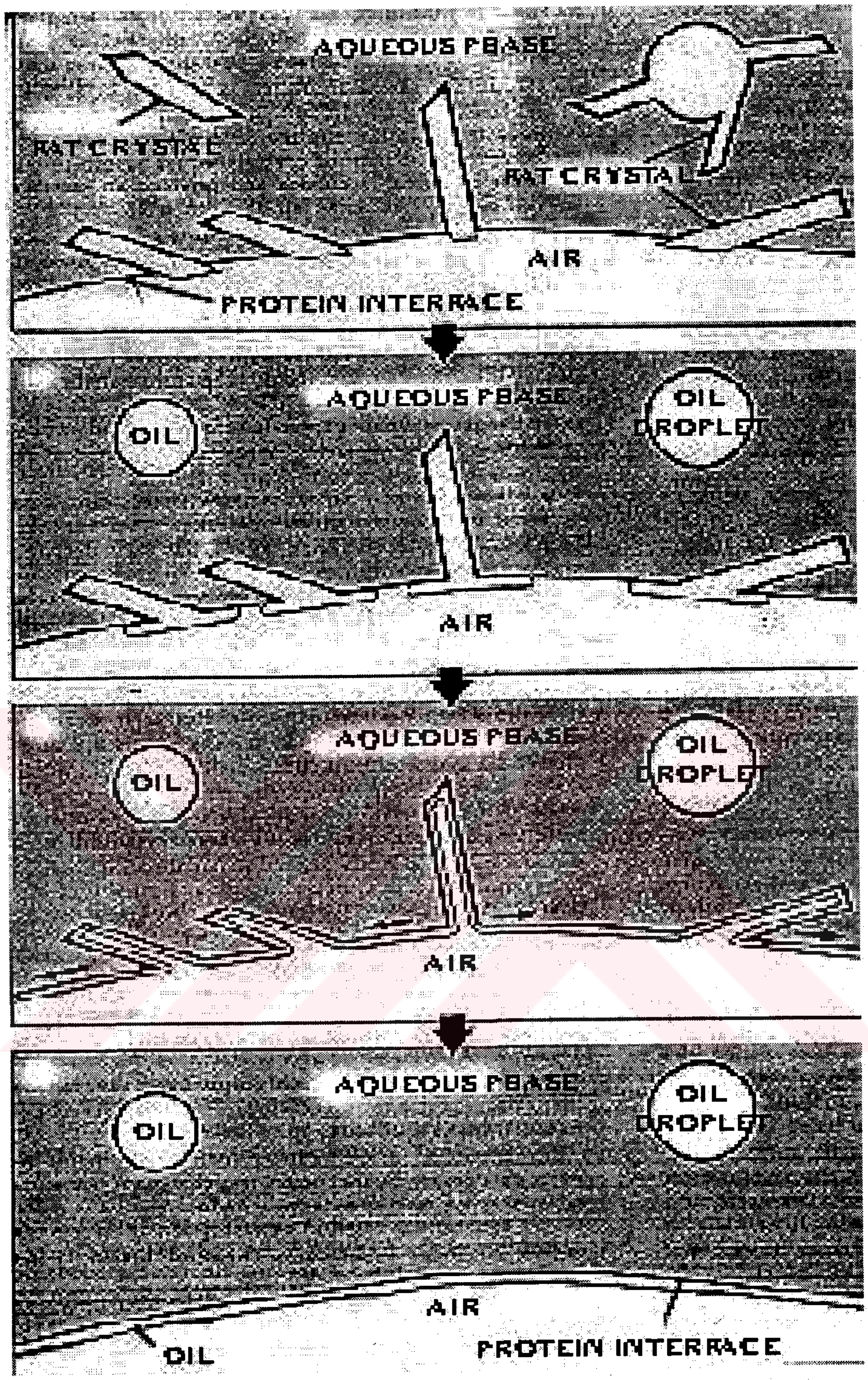


Figure 2.2 Representation of the interfacial behavior of fat during cake setting (Brooker, 1993)

The melting point of fat is important because it determines the temperature at which adsorbed fat crystals melt and thereby release the fat-water interface for bubble expansion. If the melting point is too high, considerable bubble expansion may occur before the fat-water interface is released, thus running the risk of premature bubble rupture. On the other hand, for low melting point fats there is a danger of melted crystals before they are adsorbed to the bubbles (Brooker, 1993).

When the solid fat phase consists of crystals of the β' polymorph many small bubbles can be stabilized whereas much larger β crystals incorporate relatively little air in the form of fewer large bubbles. β' polymorphs are more efficient at contributing interface to the bubbles during baking and melt faster than the larger β polymorph (Brooker, 1993).

Final grain size and cake volume are a function of air bubbles incorporated during mixing and expanded during baking since no new cells are formed after mixing (Ebeler et. al., 1986). In the finished batter most of the air bubbles are held in the fat phase at room temperature. During heating, many of the bubbles move from the fat into the aqueous phase where the bubbles are partly stabilized by egg proteins (Brooker, 1993). Cake batters lose volume if bubbles are too large because during baking their buoyancy carries them to the surface from which they escape. Furthermore, the presence of too many large bubbles leads to early cake rise prior to egg protein coagulation and starch gelatinization. A finer texture for the final baked product can be obtained with a narrow bubble size distribution in the batter (Ebeler et. al., 1986; Pateras et. al., 1994).

Viscosity of a batter controls the rate at which air bubbles rise to the surface. During baking, the degree of bulk flow of the batter by convective currents at any given time depends on its viscosity, with low batter viscosity resulting in more convective flow (Frye et. al., 1991). A sufficiently high batter viscosity might keep the air bubbles from rising out of the batter, providing increased batter stability at room temperature. High batter viscosity is caused by more air bubbles being incorporated to the batter (Kim et. al., 1992).

Batter viscosity at ambient temperature increases with increased levels of shortening in the batter because of the functionality of the fat to integrate air bubbles to the dough. The rapid increase in batter viscosity could be attributed to starch gelatinization. The onset of starch gelatinization due to heating that causes a rapid viscosity increase is not affected significantly by the shortening level. However, the rate of the viscosity increase decreases with increased shortening levels because shortening is reported to limit starch swelling (Shelke et. al., 1990).

2.1.2 Cake Setting

Thermal setting stage is defined as the time at which the batter changes from a fluid, aerated emulsion to a solid, porous structure that will not shrink or collapse when the cake is removed from the oven (Ngo et. al., 1986). Transformation from a foam-like structure to a sponge-like structure with interconnected gas cells occurs due to starch gelatinization (He et. al., 1991). For this physical transformation to occur, free water in the system must be absorbed by starch (Ngo et. al., 1986). Starch gelatinization together with protein denaturation is accompanied with changes in light transmission, viscosity and microscopic structure (Mizukoshi et. al., 1979).

Vapor induced puffing is the process which governs the formation of pore structure (Hicsasmaz et. al., 1992). Thermal expansion of air is a minor factor during the leavening process. In the oven, as temperature increases the vapor pressure of water and the rate of formation of carbondioxide gas increases which further diffuse into air bubbles resulting in the expansion of the batter (Mizukoshi et. al., 1980; Mizukoshi et. al., 1983). Further increase in temperature causes starch gelatinization and protein coagulation. Thus, the sol of the cake batter begins to change into a gel-like structure. Formation of a continuous gel phase depresses the expansion of bubbles, and further increase in pressure causes the gas in the bubble to release. At this point, expansion of the cake batter stops. Continued heating causes further coagulation of egg and flour proteins, and strengthening of the cake structure continues until the end of baking (Mizukoshi et. al., 1980).

In a batter containing sugar and fats or lipids in addition to the flour, vapor induced puffing does not only depend on the interactions of proteins and starch to form a gel network, but also on the physicochemical interactions between all these components going through phase transitions. Moreover, although the batter may be homogenous on a macroscopic level, it is not expected to be uniform on the microscopic level with respect to the interactions between proteins, starch granules, fat globules and sugar. Part of the globular fat and lipid material remains as globular material blocking the pore network formed during vapor induced puffing (Hicsasmaz et. al., 1992). In baked cakes starch and fat are embedded in or at the surface of the protein matrix. Starch granules distort their shapes due to gelatinization. A bricks-and-mortar structure for cake is proposed in which starch granules are building blocks held together by strands of egg protein (Ngo et. al., 1986).

2.2 Functionality of Litesse (Polydextrose)

Today, there is a consumer demand for replacing fat and sugar in their diet. Diet foods that contain low calorie sugar- and fat-replacers have recently been popular due to health considerations. There are numbers of fat and sugar replacers in the market, however the important point is the consideration of the functionality of these fat-and sugar-replacers in a variety of high sugar and/or fat containing products to obtain products with similar quality parameters (Kamel et. al., 1988).

During formulation of many food products simple replacement of sugar with an alternative sweetener is inadequate because of the functionality of sugar as well as its sweetness. Bulking agents such as cellulose, maltodextrin, polydextrose and polyols are known to infer functionality to the system as well as sweetness (Giesse J. H., 1996).

Litesse® is a premium quality, water-soluble bulking agent marketed by the Xyrofin Division of Cultor Food Science and it is one of the bulking agents of the Litesse® family. Litesse (improved polydextrose FCC) is a unique ingredient because it is partially metabolized (75%), resulting in a calorie utilization of 1 Kcal. When used to replace sugars and reduce fats, polydextrose contributes only 25% of the sugar-calories (approximately 4 Kcal) and 11% of the fat-calories (approximately 9 Kcal) (Xyrofin, 1997). USA Food and Drug Administration approved polydextrose for use in frozen dairy desserts, sweet baked goods and mixes, confections and frostings, salad dressings, gelatins, puddings and fillings, hard and soft candy, chewing gum, fruit spreads, peanut spread, sweet sauces, toppings and syrups. Polydextrose was also approved by the European Union and a number of other European countries including Switzerland, Norway and Poland (Xyrofin, 1997).

Polydextrose is a randomly bonded polymer of dextrose containing minute amounts of bound sorbitol and citric acid (Figure 2.3) (Carroll, 1990, Bullock et. al., 1992, Xyrofin, 1997). It is a water-soluble (approximately 80% at 25°C), white-to-cream colored amorphous powder that has a minimal titratable acidity (0.1 to 0.002 mequiv) and it forms a clear melt above 130°C. It has been found to have an effect similar to that of sugar on starch thermal transitions, thus can provide alternatives to sugar for sweetening bakery products (Neville et. al., 1986; Kim et. al., 1992). Polydextrose based cakes have a yellower cake crumb than conventional all-sugar cakes (Rosenthal, 1995).

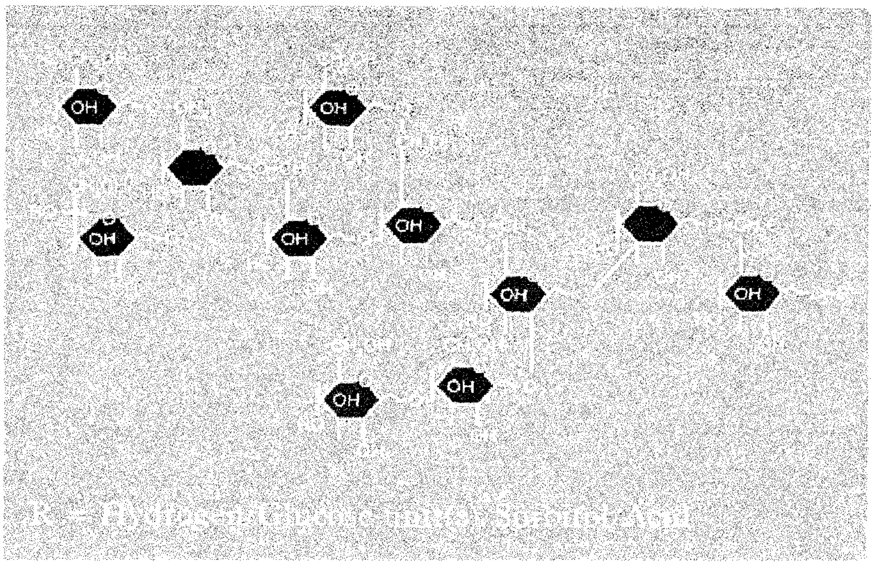


Figure 2.3 Chemical structure of polydextrose

Important qualities–such as texture, mouthfeel and body–are often adversely affected when foods are modified to achieve a lower caloric value. Polydextrose enables the formulation of healthy food products by replacing the bulk and functionality of sugar. In addition, polydextrose improves the mouthfeel of reduced calorie products and can be used to successfully replace fat in many food formulations. Although polydextrose possesses many of the functional properties of sugar, it is not sweet. However, when polydextrose is used in combination with an intense sweetener, one can usually achieve a 50% caloric reduction without sacrificing eating quality (Xyrofin, 1997). At high levels of substitution of polydextrose additional sweetness need to be added often in the form of heat stable intense sweeteners such as Acesulfame-K (Rosenthal, 1995).

Polydextrose is an amorphous powder, unlike sugar that is crystalline. It lacks the ability to promote fat crystal aggregates to break down to a more favorable size during mixing. Mixing of high polydextrose concentration cake batters resulted in a reduction in the air-holding capacity of the batters with a consequent increase in bubble size variation and average bubble size. This causes a destabilizing affect on the batter foam. Bubble expansion rate is slower in polydextrose batters during baking (Pateras, et. al., 1994). Polydextrose elevates starch gelatinization temperature while leaving the egg protein denaturation temperature essentially unchanged (Rosenthal, 1995).

For high-ratio cake samples containing polydextrose only, bulk density decreases, cake height and porosity increases until 100% polydextrose replacement. This is due to the increase in the setting temperature of the cake batter which owes itself to the increase in the gelatinization temperature (Yazgan, 1997). It is known that sugar causes the temperature of setting to increase to 84-91°C while 50% replacement with polydextrose causes a further increase to 87-95°C and 100% replacement leads to an increase to 90-97°C (Pateras et. al., 1994). Therefore, at 100% replacement by polydextrose part of the water will evaporate before setting of the cake batter, since the gelatinization temperature is higher than the boiling point of water at the experimental conditions (Yazgan, 1997).

Increase in polydextrose content results in a decrease in the number and size of crack-like pores. The decrease in the number of crack-like pores hinders interconnectivity of the pore structure (Yazgan, 1997). Decrease in bulk density and increase in porosity observed at 75% level sugar replacement by polydextrose suggests an optimum polydextrose replacement (Yazgan, 1997). The numbers of bubbles in the cake batter increased remarkably by increasing polydextrose concentration. This can be attributed to the fact that Litesse can also be used as a fat replacer (Yazgan, 1997).

T.C. YÜKS

The present study focuses on the investigation of the functionality of polydextrose as a fat- and sugar- replacer in high-ratio cakes, in the light of these considerations.

2.3 Physical Properties of the Cake and the Cake Batter

To assess the effect of ingredient changes on the quality of the final product, a number of analysis are performed for the identification of the physical properties of the cake batter and the cake. Analysis of the cake batter includes foam drainage and foam stability measurements, whereas analysis of the cake samples include measurement of the cake height, bulk density, solid density, porosity, pore size and pore shape distribution, and color.

2.3.1 Physical Properties of Cake

2.3.1.1 Bulk Density

Bulk density expressed as kg/m^3, is a measure of expansion. Density is one of the important physical constants that are required to evaluate the baking process applied to food products (Hwang et. al., 1980). Density and porosity characterize the texture and the quality of food products (Marousis et. al., 1990; Rosenthal, 1995). It is measured by the volumetric displacement method using of several media such as glass beads, sand and rapeseeds. In the present study solid displacement technique using rapeseeds (Seguchi et. al., 1977; Clements et. al., 1982; Lee et. al., 1982; Donelson et. al., 1986; Ngo et. al., 1986; Mizukoshi 1983; Pierce et. el., 1987, Kamel et. al., 1988; Delcour et. al., 1991; Hiçşaşmaz and Clayton, 1992, Lin et. al., 1994; Takeda et. al., 1994; Yazgan, 1997) was used.

2.3.1.2 True (Solid) Density

Solid density is defined as the ratio of the sample weight to the volume of the solid portion of the sample and is usually carried out by pycnometry. Bulk density and true density are used to calculate the porosity of a food product. Porosity is an important physical property characterizing the texture of food products (Marousis et. al., 1990).

2.3.1.3 Pore Size and Shape Distribution

Pore structure is a measure of the crumb characteristics of the cake. The crumb structure is an important quality parameter for cakes. Therefore, pore size and shape distributions can be used to identify the crumb structure.

By computerized image analysis techniques, analysis of the cell size distributions has become considerably simplified (Lange et. al., 1994). Cakes have pore sizes larger then 200 μm that is beyond the range of mercury porosimetry and have pore shapes which are not cylindrical. Thus, the use of computerized image processing techniques are more suitable than mercury porosimetry for the analysis of the pore structure of cakes (Yazgan, 1997).

2.3.1.4 Color

Color is an important quality aspect together with flavor and texture in food acceptability. In addition, it is an indication of chemical changes occurring in the cake such as browning and caramelization (Johnson et. al., 1989).

There are several systems of color classification systems as the CIE system and the Hunter system. The CIE system is a trichromatic system that is based on the fact that any color can be matched by a suitable mixture of three primary colors red, green and blue. These colors are indicated by X, Y and Z. One of the problems with this system is that X, Y and Z values have no relationship to color as perceived, even though a color is completely defined. Because of the limitations of the CIE system, Hunter L, a, b system is used for the determination of the crumb color in the present study (Coleman et. al., 1983; McCullough et. al., 1986; Johnson et.al., 1989; Marx et. al., 1990). In the Hunter L, a, b system it is assumed that there is an intermediate signal switching stage between the light receptors in the retina and the optic nerve that transmits color signals to the brain. In this switching mechanism, red responses are compared with green and the result is a red-to-green color dimension. The green response is compared with blue to give a yellow-to-blue color dimension. These two color dimensions are associated with the symbols a and b.

2.3.2 Physical Properties of the Cake Batter

Foam is a two-phase system in which distinct gas phase bubbles are surrounded by a continuous lamellar liquid phase. The quality of food foams are dependent on the surface activity and film forming properties of the specific protein components which may be present at relatively low concentrations (Philips et. al., 1990).

The rheological properties of the cake batter during baking affect the final cake quality (cake volume, texture, mouthfeel, contour, grain and flavor) (Mizukoshi, 1985; Pateras et.al., 1994). It is emphasized that the colloidal and interfacial properties during baking of the cake batter play an important role in the formation of the cake structure (Mizukoshi et. al., 1983; Pateras et. al., 1994).

Pateras et. al. (1994) studied the foam characteristics of cake batters before and during baking in the case of sugar replacement by polydextrose by means of hot stage microscopy combined with image analysis. They found that polydextrose substitution increased the mean size of air bubbles in the cake batter and introduced a larger variation in bubble size distribution that effect the expansion rates of bubbles during heating.

2.3.2.1 Foam Stability

Foams are thermodynamically unstable, and bubbles in the foam tend to escape. At least three processes occur during the life of typical liquid foam. The films rearrange their positions such that the numbers and the linear dimensions of bubbles change with time. The liquid in the lamellae and plateau borders flow downward and finally the lamellae burst (Mizukoshi et. al., 1983) (Figure 2.4). The main destabilizing mechanism of the cake batter foam is that of gas diffusion from small to large bubbles. The inter-bubble gas diffusion that is caused by difference in the gas pressure between bubbles, promotes the phenomenon of disproportionation on the batter foam (Pateras et.al., 1994). Therefore, foam stability plays an important role during baking and the formation of the desired crumb structure.

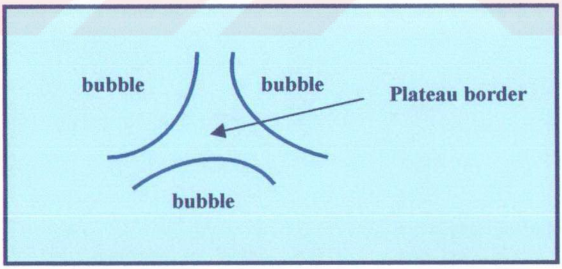


Figure 2.4 Simple representation of liquid in a foam system

Batter specific gravity can be used as an indication of foam stability such that the amount of air incorporated to the batter gives information about stability (Coleman et. al., 1983; Ebeler et. al., 1986; Mccullough et. al., 1986; Pierce et. al., 1987, Vaisey-Genser et. al., 1987 Marx et. al., 1990; Shelke et. al., 1990, Frye et. al., 1992; Kim et. al., 1992).

In the present study foam stability was determined by image analysis as proposed by Yazgan (1997).

2.3.2.2 Foam Drainage

Foam drainage measurements are indications of batter viscosity. Viscosity of a batter controls the rate at which air bubbles rise to the surface during baking (Frye et. al., 1992) and affects the final grain size and cake volume (Ebeler et. al., 1986). Viscosity of the cake batter can also be measured by viscometry (Lee et. al., 1982; Berglund et.al., 1986; Ebeler et. al., 1986; Ngo et. al., 1986; Shelke et. al., 1990; Frye et. al., 1992; Kim et. al., 1992)

In the present study foam drainage measurements of the batter samples were made by a method similar to the method used by Philips et. al., (1987).

2.5 Response Surface Methodology

The term response surface is associated with experiments intended to identify or evaluate one or more response variables as a function of the independent variables. After data are collected in a response surface experiment, the next step is to estimate the model parameters. The model fit to experimental data is carried out. The equations are graphed as response surfaces and used to describe how the test variables affect the responses and the relationships among the test variables are determined. The individual and the general optima for the responses are evaluated.

Lee et. al. (1982) studied the optimization of the fat-emulsifier system and the gum-egg white-water system for a cake mix by response surface methodology. They used a three-variable (the amount of shortening, propylene glycol monostearate, and mono-and diglycerides), five-level Central Composite Design in which batter viscosity and specific gravity, cake volume contour and shrinkage were measured.

Neville et. al. (1986) studied the textural optimization of reduced-calorie layer cakes for ingredients using response surface methodology. They used a five-variable (the amount of polydextrose, water, leaving, N-Flate and fructose), five-level Central Composite Design.

Vaisey-Genser et. al. (1987) studied the selection of levels of canola, oil, water and an emulsifier system in cake formulations by response surface methodology. They found that canola oil successfully replaced hydrogenated shortening in layer cakes when used with appropriate levels of water and an emulsifier system. Three-variables (the amount of oil, water and emulsifier), five-level Central Composite Design was applied in which the batter specific gravity, baked volume index, firmness, sensory features of crumb quality, crumb color and flavor were selected as the dependent variables.

In the present study, response surface methodology was used to find an optimum for simultaneous sugar- and fat-replacement by polydextrose that mimics the high-ratio cake the best.

CHAPTER 3

EXPERIMENTAL

3.1 Materials

A standard high-ratio cake formulation (Table 2.1) was provided from the **Flour, Milling and Research Association** (Chorleywood, UK).

All purpose flour (Söke Un), crystal sugar, skim milk powder (Pınar Süt), and baking powder (Bağdat; composed of sodium pyrophosphate, sodium bicarbonate and starch) were used. Eggs were purchased fresh daily (Johnson et. al., 1989). Improved polydextrose FCC (Litesse) was provided by Cultor Food Science.

3.2 Methods

3.2.1 Batter Preparation

All ingredients were tempered to room temperature. First all dry ingredients, then fat, water and eggs were added. The single-stage mixing procedure (Krups 3-mix 3000 mixer) was used in which all of the ingredients were dumped and beaten until they become homogeneous (Rosenthal et.al., 1995). Initially, the mixer was run at slow speed for 1 min. Then, the mixture was scraped and beaten at top speed for 3 min. The temperature of the batter at the end of mixing was 21-25°C.

3.2.2 Baking

At the end of batter mixing, 50 grams of batter was placed into conical shaped Teflon coated cake pans (height = 51.75 mm, top diameter = 74.55 mm, bottom diameter = 49.35 mm). Five samples of each batter were prepared and duplicate cakes were made. The samples so prepared were then placed in the oven (Arçelik, ARMF 4), preheated to 170°C and baked for 25 min. After baking, the cake samples were cooled at room temperature for one hour before being wrapped by a plastic film (Takeda, 1994; Paraskevopoulou et. al., 1997). The samples were kept in frozen storage at -15°C for further testing (Berglund et. al., 1986; Vaisey-Genser et. al., 1987).

3.2.3 Determination of the Physical Properties of the Cake Samples

3.2.3.1 Cake Height

The height of the cake samples was measured before wrapping in plastic film as an indicator of relative expansion. The measurements were made between the highest point of the cake samples and the bottom of the container.

3.2.3.2 Bulk Density

Bulk density of the cake samples was determined by the solid displacement technique using rapeseeds (Hiçşaşmaz and Clayton, 1993). A 79.40-ml glass beaker was used. First, the tapped bulk density of rapeseed was determined by filling the glass container uniformly with rapeseeds through four tappings and smoothing the surface using a sharp razor blade.

$$W_{rapeseeds} = W_{total} - W_{beaker}$$

$$D_{rapeseeds} = W_{rapeseeds} / V_{beaker}$$

The arithmetic mean of ten measurements yielded a bulk density of 679.8 kg/m^3 for rapeseeds. The bulk density of cake samples with measured weights was determined as follows;

$$W_{rapeseeds} = W_{total} - W_{cake\ sample} - W_{beaker}$$

$$V_{rapeseeds} = W_{rapeseeds} / D_{rapeseeds}$$

$$V_{cake\ sample} = V_{beaker} - V_{rapeseeds}$$

$$D_{cake\ sample} = W_{cake\ sample} / V_{cake\ sample}$$

where W (kg) is weight, V (m^3) is volume and D (kg/m^3) is density.

Two cake samples and three rectangular pieces from each cake sample were analyzed. The size of the cake pieces was adjusted such that the weight was around 1-1.5 gram. The cake pieces were dried in an oven (Dedeoğlu) at 45°C for 48 hours before bulk density measurement.

3.2.3.3 True Density

True densities of cake samples were determined by the gas expansion method using a pycnometer (Quantachrome, model SPY-3, stereopycnometer). The volume of solids was calculated from the ideal gas law as;

$$V_s (P_1 - P_2) = V_1 (P_1 - P_2) - P_2V_2$$

where, V_1 is the volume of the sample chamber (m^3), V_2 is the volume of the expansion chamber (m^3), P_1 is the initial pressure (Pa), P_2 is the pressure after expansion (Pa) and V_s is the volume of solids (m^3).

The instrument was equipped with two sample cells, 1.56×10^{-4} and 3.42×10^{-5} m^3. The expansion chamber of the pycnometer had a volume of 8.71×10^{-5} m^3 as supplied by the manufacturer. The maximum pressure allowed in the sample chamber was 1.4×10^5 Pa and pressurization was achieved by using nitrogen gas. Tests were carried out between 1.10×10^5 – 1.24×10^5 Pa. Solid volume measurements for each porous sample of measured weight were carried out in three replicates and the arithmetic mean was reported as the solid volume of the sample. Samples were prepared as described in Section 3.2.3.2.

3.2.3.4 Porosity

Porosity of the cake samples were calculated using the solid (true) density (SD) and bulk density (BD) measurements as

$$\textbf{Porosity} = \mathbf{1 - (BD) / (SD)}$$

3.2.3.5 Pore Structure Evaluation

Image analysis of the cake samples was carried out by a method similar to that of Smolarz et. al. (1989), Barret et. al. (1990, 1992), Lange et. al. (1994), Kaptan (1996) and Yazgan (1997).

Cake crust and crumb were analyzed by cutting samples from the cakes in which the cut cell wall surfaces were blackened using ink delineating cells and allowing a clear projection of the structure onto the dual image processing monitor.

The image analysis equipment consists of three main parts that are connected by several interfaces; a camera (COHU Inc.), a dual monitor image processing computer equipped with an image grabber (TARGA, Truevision) and an image processing software (MOCHA Image Analysis Software for Windows, Jandel Inc.). The images were taken by the camera coupled to a microscope (Olympus, SZ40) and directly by the camera. For lighting LSGA-Epi-Illuminator (Olympus, TL-3) employing a 6V, 15W high-intensity halogen bulb was used.

The pore structure and pore size parameters were calculated for the images taken by the microscope coupled to the camera. The analysis procedure consists of a number of steps. The first step was image acquisition and calibration in which the image was captured and grabbed on 256 gray levels and then stored. This stored image has a standard format of 719x511 pixels in which each pixel may have a color or monochrome value. After storing the image, a scale value that is a function of magnification is entered in order to convert the spatial measurement value in pixels to centimeters.

The next step was the calculation of the pore structure parameters (pore area and pore shape). The grabbed image was subjected to a process called tresholding in order to identify the pores. Tresholding is simply detecting only those areas whose color value falls within a specified range.

The pore structure parameters of the cake samples were measured by image measurement software (SigmaScanPro 4.0 Jandel Inc). After tresholding, the computer mouse was used to trace over any slightly broken sections in the structure to ensure that cell walls were continuous, so that the program could measure discrete, separated cells. The image was then inverted-making black pixels white and white pixels black. After that, black pixels were converted to red, because the analyzer only measures objects with this color. Three sections of sample were analyzed and the pore area and shape data were combined such that 100 cells were measured. Finally, the distributions were presented in the form of histograms (Microsoft Excel 1997) for pore area and pore shape.

The results of such determinations are usually expressed in the form of a histogram depicting the number of cells in ranges of area intervals.

However, these histograms are very difficult to compare meaningfully unless the samples of which they are representative have very different structural properties. Therefore, to quantify such distributions number of cells were represented in ranges of log area intervals (Barret et. al., 1992).

3.2.3.6 Crumb Color

Crumb color was measured using a spectrophotometer (Shimadzu UV-Visible Recording UV-2100). The crust of the cake samples was eliminated by cutting. Then fine powders of cake samples were obtained and pressed into the sample cell holder. Samples were covered with a stretch film before being placed in the spectrophotometer. Blank measurements were made using the stretch film.

3.2.4 Physical Properties of the Cake Batter

3.2.4.1 Foam Stability by Image Analysis

A teaspoonful of sample was placed on a 5x2.5 cm^2 glass piece. Four samples were prepared. Two of the samples were used for the analysis of the fresh batter. The other two samples were analyzed after 24 h. Another glass piece was placed over the glass piece on which the sample batter was placed such that the gap between the two glass pieces was about 2.5 mm. The images were taken under the camera coupled to the microscope (Olympus CH40).

The analysis procedure consists of a number of steps. The first was image acquisition and calibration in which the image was captured and stored. The air bubbles under the light microscope looked as two-dimensional bright circles with a dark boundary depending on its position with respect to the focal plane of the microscope. The image was captured at the position of all the bubble circles could be detected.

The next step was the measurement of the bubble area. The bubble area of the cake batters was measured by image measurement software (SigmaScanPro 4.0 Jandel Inc) as described in Section 3.2.3.5. Three sections of each sample were analyzed and the bubble area data were combined such that 100 bubbles of each sample were measured. The measurements made in a such a way that all bubbles were set in the same level for bubble size analysis. Finally, the distributions were presented in the form of histograms (Microsoft Excel 1997) as described in Section 3.2.3.5.

3.2.4.2 Foam Drainage

Foam drainage measurement of the batter samples was made by a method similar to the method used by Philips et al. (1987).

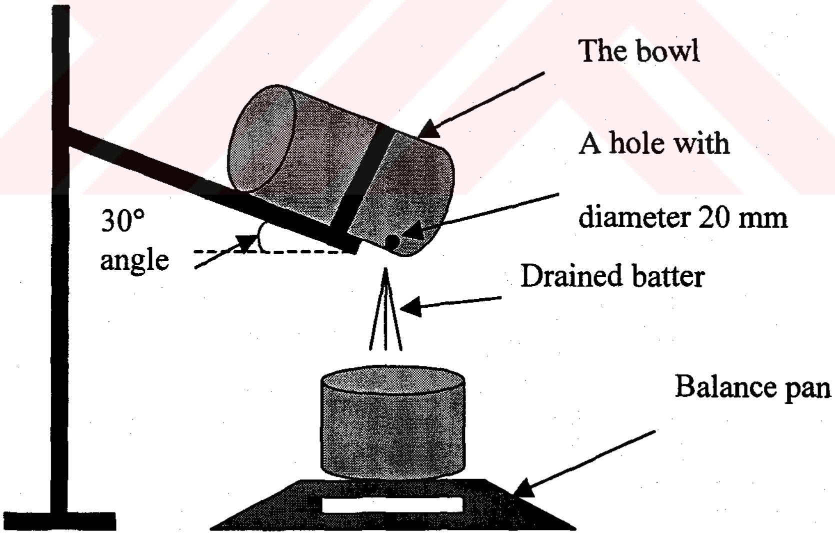


Figure 3.1 Set-up used for foam drainage measurement

According to this method (Figure 3.1), a hole with a diameter of 20 mm was drilled at the bottom of a bowl. A piece of tape was placed over the hole on the outside of the bowl. The prepared batter was poured into the bowl. The bowl was weighed and placed in the ring stand 30° angle above the balance pan. The tape was quickly removed. The drained batter was collected in a container on the balance pan and the weight of drained batter was continuously recorded using a balance pan (Gec, Avery).

3.3 Experimental Design and Optimization Procedure

In order to determine the working range for response surface methodology studies preliminary experiments were carried out to investigate the sugar- and fat-replacer characteristics of polydextrose separately.

Sugar-replacer characteristics of polydextrose were investigated on a set of samples containing both polydextrose (0, 20, 25, 40, 50, 60, 75, 80, 100% levels) and sugar (100, 80, 75, 60, 50, 40, 25, 20, 0% levels) corresponding to the total sugar amount in the original formulation as shown in Table 3.1.

Fat-replacer characteristics of polydextrose were investigated on a set of samples containing both polydextrose (0, 20, 25, 40, 50, 60, 75, 80, 100% levels) and fat (100, 80, 75, 60, 50, 40, 25, 20, 0% levels) corresponding to the total fat amount in the original formulation as shown in Table 3.2.

Table 3.1 Sugar-replacement samples

	Weight	1	2	3	4	5	6	7	8	9
Sugar	%	0	20	25	40	50	60	75	80	100
	Grams	0	23	29	46	57.5	69	86	92	115
Polydextrose	%	100	80	75	60	50	40	25	20	0
	Grams	115	92	86	69	57.5	46	29	23	0

Table 3.2 Fat-replacement samples

	Weight	1	2	3	4	5	6	7	8	9
Sugar	%	0	20	25	40	50	60	75	80	100
	grams	0	13	16	26	32.5	39	49	52	65
Polydextrose	%	100	80	75	60	50	40	25	20	0
	grams	65	52	49	39	32.5	26	16	13	0

Then, a second order two-variable, five-level Central Composite Design in which fat and sugar content were independent variables was designed in the light of the results obtained from preliminary experiments. Table 3.3 shows the original and coded variables, while Table 3.4. shows the levels of independent variables indicated by the selected experimental design. The total fat and sugar amount in the high-ratio cake formulation was kept constant (180 grams) by the addition of polydextrose.

Each cake sample was analyzed with respect to the selected physical properties (dependent variables - cake height, bulk and true densities, porosity, color). The coefficients, R^2 and significant F values (SPSS for Windows 6,0) were obtained for the following second order model;

$$Y = b_0 + b_1X_1 + b_2X_2 + b_{11}X_1^2 + b_{22}X_2^2 + b_{12}X_1X_2$$

by enter method applied to all dependent variables. The response surfaces for each dependent variable (SigmaPlot 4.0 for Windows) were sketched. The two responses were selected and the individual optima for each of these selected responses was found (Mathematica Version 2.0 for Windows). The general process optimum was calculated using these individual optima (Mathematica Version 2.0 for Windows).

Table 3.3 Original- and coded-levels for independent variables

		Coded-level of the symbol				
		-1,414	**-1**	**0**	**1**	**1,414**
Independent variable	**Symbol**	**Un-coded-level of the symbol**				
Sugar	X_1	23	36,5	69	101,5	115
Fat	X_2	26	31,7	45,5	59,3	65

Table 3.4 Experimental Design

Exp. No.	Independent Variables	
	Codes	
	X_1	X_2
1	1	1
2	1	-1
3	-1	1
4	-1	-1
5	1.414	0
6	-1.414	0
7	0	1.414
8	0	-1.414
9	0	0
10	0	0
11	0	0
12	0	0
13	0	0
14	0	0
15	0	0
16	0	0

CHAPTER 4

RESULTS AND DISCUSSION

The main objective of the present study was to investigate the functionality of polydextrose on the physical properties of the high-ratio cake system as a fat- and sugar-replacer. Also, an optimum for the sugar- and fat-replacement properties of polydextrose was searched. For these purposes, macroscopic (i.e., cake height, bulk and true densities, porosity) and microscopic (pore area and shape distributions) expansion properties and color measurements were carried out. Foaming characteristics of the batter were also investigated.

First, the characteristics of polydextrose as either a sugar- or fat-replacer were investigated (Tables 3.1 and 3.2) to identify the replacement extremes with respect to sugar and fat. Then, a two-variable, five-level Central Composite Design was applied between the original high-ratio cake and the replacement extremes to find an optimum for simultaneous sugar-and fat-replacement (Tables 3.3 and 3.4).

It is well understood that colloidal and interfacial properties of the cake batter during baking play an important role in the formation of the cake structure. Therefore cake batter characteristics are first discussed before assessing the effect of polydextrose on the macroscopic and microscopic expansion properties of the cake.

4.1 Effect of Polydextrose on the Cake Batter Characteristics

4.1.1 Foam Drainage

Foam drainage measurements are indications of relative foam viscosity. Both sugar- and fat-replacement by polydextrose caused a decrease in batter viscosity (Figure 4.1). The reason for this decrease is insufficient air incorporation into the cake batter in the absence of sugar and fat. However, the effect of fat-replacement on foam drainage was more significant than sugar-replacement (Figure 4.1). This is because the major function of the fat phase is to entrap air within the cake batter in order to obtain a viscous foam (Matz, 1972). In the finished batter most of the air bubbles are held by the fat phase and stabilized by the fat globules (Brooker, 1993).

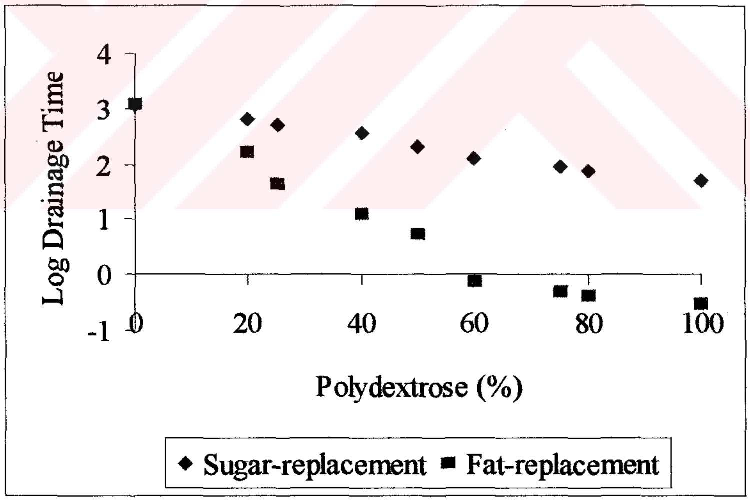
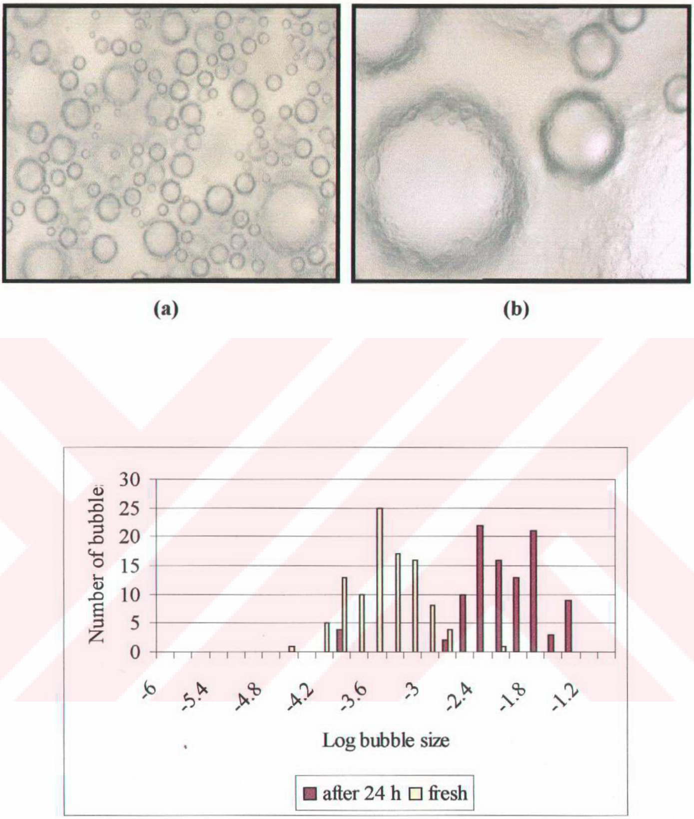


Figure 4.1 Effect of polydextrose substitution on drainage time

4.1.2 Foam Stability

The image of the cake batter with 100% fat-replacement (Figure 4.2.a, Figure 4.2.c) showed that replacing all the fat in the formulation by polydextrose resulted in a dramatic reduction in the air holding capacity with a consequent increase in bubble size as expected. This further caused a destabilizing effect on the cake batter (Figure 4.2.b, Figure 4.2.c) due to a dramatic decrease in the batter viscosity as supported by the foam drainage results (Figure 4.1). Batter viscosity increases with increasing fat level in the batter. Viscosity of the batter controls the rate at which air bubbles rise to the surface. A sufficiently high batter viscosity might keep the air bubbles from rising out of the batter, providing increased stability. The images of 60% fat-replacement (Figure 4.3) revealed that bubble size decreased and stability of the cake batter increased with a decrease in polydextrose substitution. Although the cake batter with 60% fat-replacement was more stable than the batter at 100% fat-replacement, extreme variation in bubble size caused a destabilizing effect leading to a difference in gas pressure between the bubbles. This, in turn causes gas diffusion from small to large bubbles (Pateras et. al., 1994). At 25% fat-replacement (Figure 4.4) a similar bubble size distribution and stability to the high-ratio cake batter was obtained (Figure 4.5). A narrower bubble size distribution resulted in the formation of a stable batter. The images of the high-ratio cake batter revealed that the formation of a large number of small bubbles and decrease in the bubble size variation result in a stable cake batter.

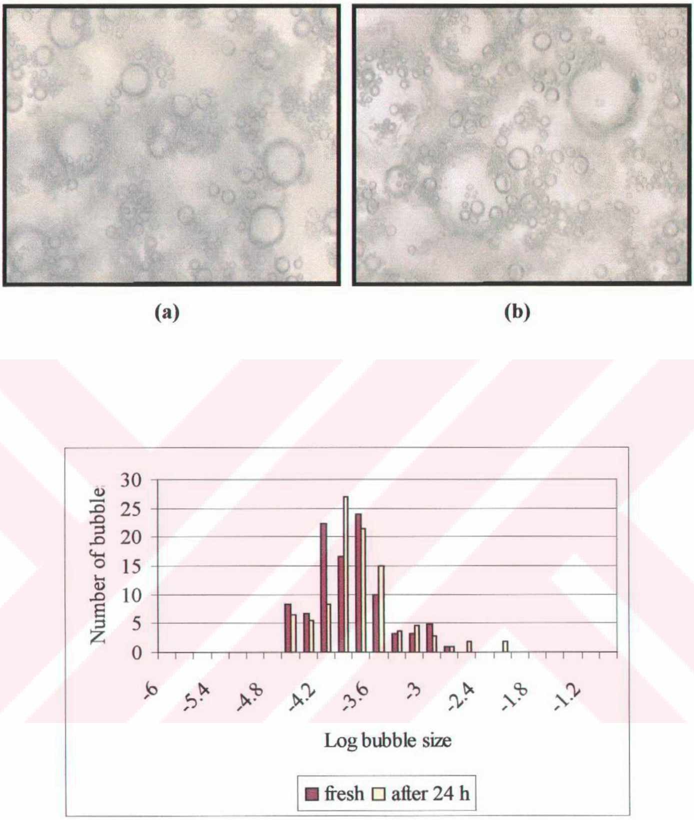
Figure 4.6 revealed that replacement of all the sugar in the formulation by polydextrose has a destabilizing effect on the batter. On the other hand, 50% sugar-replacement (Figure 4.7) resulted in a similar bubble size distribution and stability to high ratio cake batter (Figure 4.5). The decrease in bubble size and a narrower bubble size distribution resulted in an increase in stability.



(a) (b)

(c)

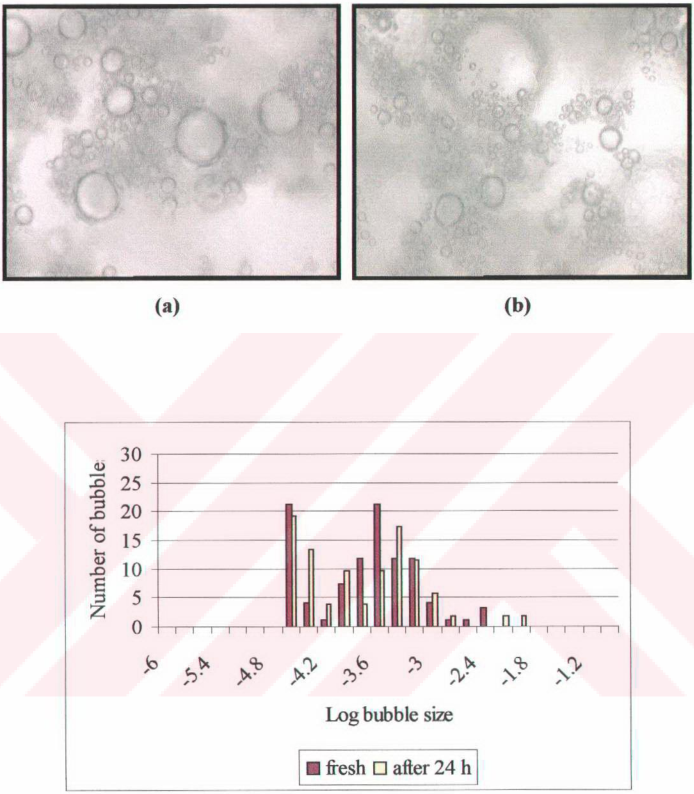
Figure 4.2 The cake batter with 100% fat-replacement (a) The image of the fresh batter; (b) The image of the batter after 24 h (c) Bubble size distribution histogram



(a) (b)

(c)

Figure 4.3 The cake batter with 60% fat-replacement (a) The image of the fresh batter; (b) The image of the batter after 24 h (c) Bubble size distribution histogram

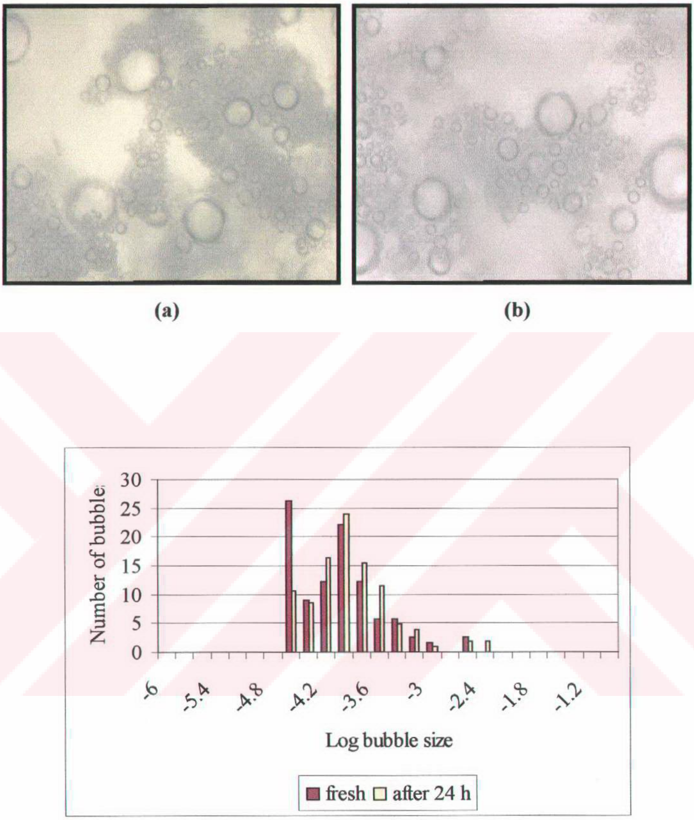


(a)

(b)

(c)

Figure 4.4 The cake batter with 25% fat-replacement (a) The image of the fresh batter; (b) The image of the batter after 24 h (c) Bubble size distribution histogram

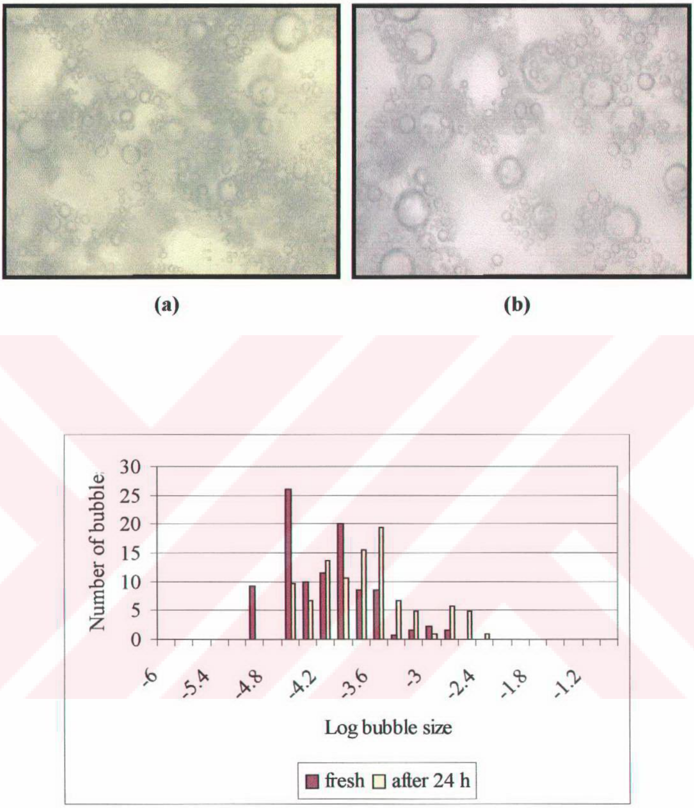


(a)

(b)

(c)

Figure 4.5 The high-ratio cake (a) The image of the fresh batter; (b) The image of the batter after 24 h (c) Bubble size distribution histogram



(a) (b)

(c)

Figure 4.6 The cake batter with 100% sugar-replacement (a) The image of the fresh batter; (b) The image of the batter after 24 h (c) Bubble size distribution histogram

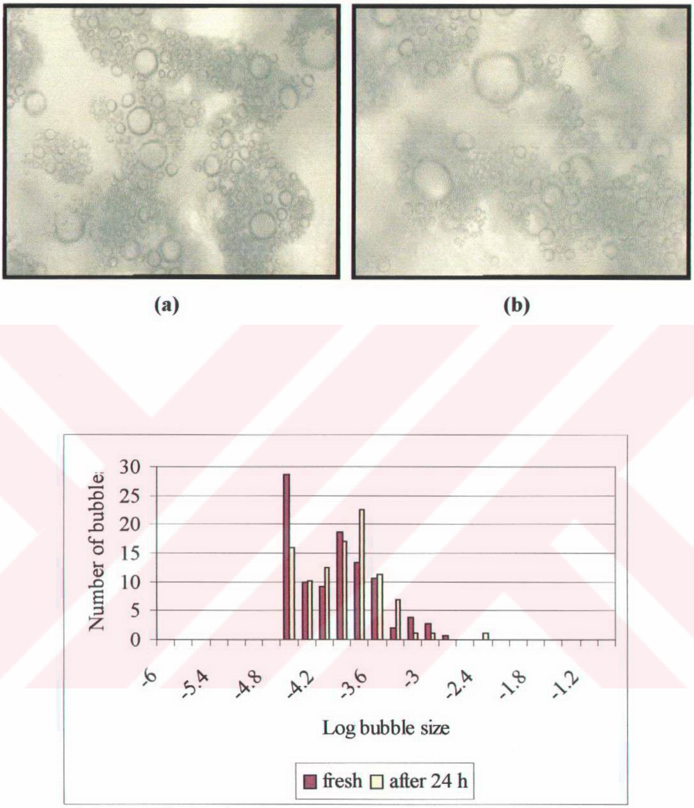

(a)
(b)
(c)

Figure 4.7 The cake batter with 50% sugar-replacement (a) The image of the fresh batter; (b) The image of the batter after 24 h (c) Bubble size distribution histogram

T.C. YÜKSEKÖĞRETİM KURULU
DOKÜMANTASYON MERKEZİ

4.2 Effect of Polydextrose on Macroscopic Expansion Properties

Sugar-replacement by polydextrose caused an increase in bulk density (Figure 4.9) followed by a decrease in cake height (Figure 4.8) and porosity (Figure 4.10).

Cake height measurements indicated that 50% sugar-replacement can be tolerated in comparison with the original high-ratio cake (Figure 4.8). Bulk density measurements showed that even up to 60% sugar-replacement was possible, after which a dramatic increase in bulk density was observed indicating a dense crumb (Figure 4.9). Porosity results are also in accordance with the bulk density results (Figure 4.10). These findings indicate that replacement of sugar by polydextrose is limited up to a certain level due to an increase in gelatinization temperature by polydextrose addition to levels, which are not suitable for the desired cake structure after setting. It is known that the desired cake crumb structure was obtained if the sugar/water ratio in the batter would permit a starch gelatinization temperature of approximately 90°C (Bean et. al., 1978). Sugar causes the onset gelatinization temperature to increase to 84-91°C, while 50% replacement with polydextrose causes a further increase to 87-95°C and 100% replacement leads to an increase to 90-97°C (Pateras et. all., 1994). Our results showed that increases in gelatinization temperature cause a denser crumb after 50% replacement of sugar by polydextrose due to unsuitable setting conditions. The formation of a dense crumb can be explained by the evaporation of water, which has the important leavening functionality in cake setting. At high replacement levels of sugar with polydextrose, part of the water will evaporate before setting of the cake batter, since the gelatinization temperature is higher than the boiling point of water at the experimental conditions.

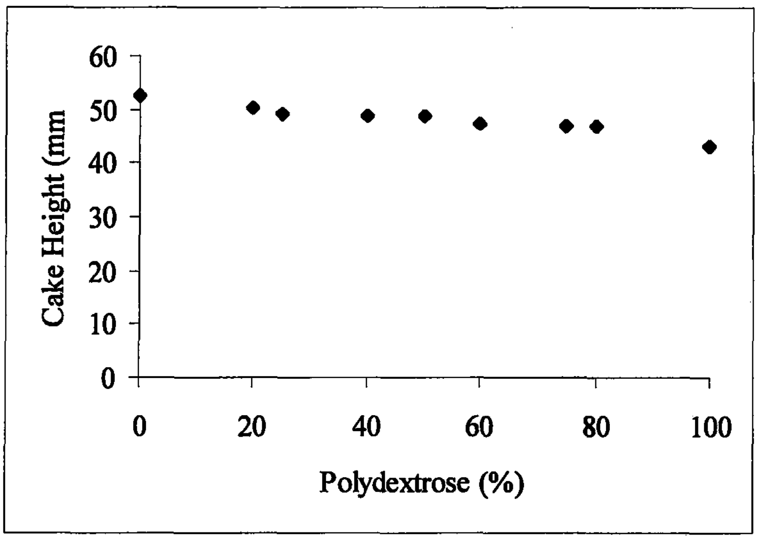


Figure 4.8 Effect of polydextrose-substitution as a sugar-replacement on cake height

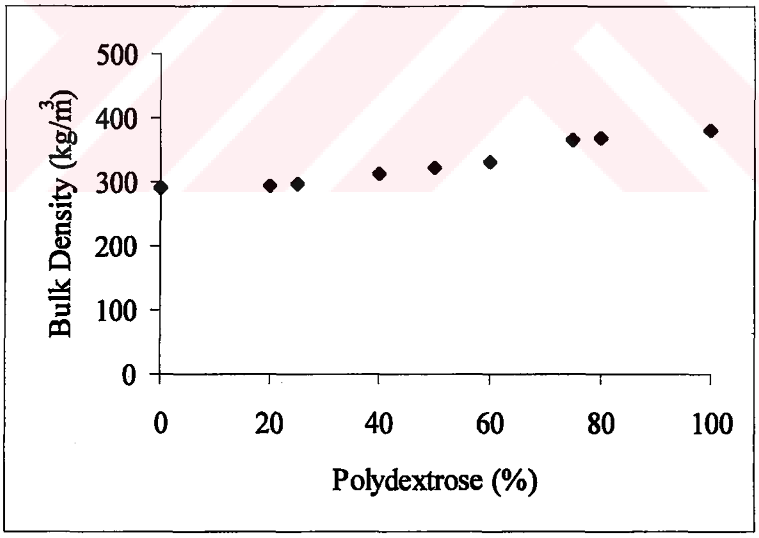


Figure 4.9 Effect of polydextrose-substitution as a sugar-replacer on bulk density

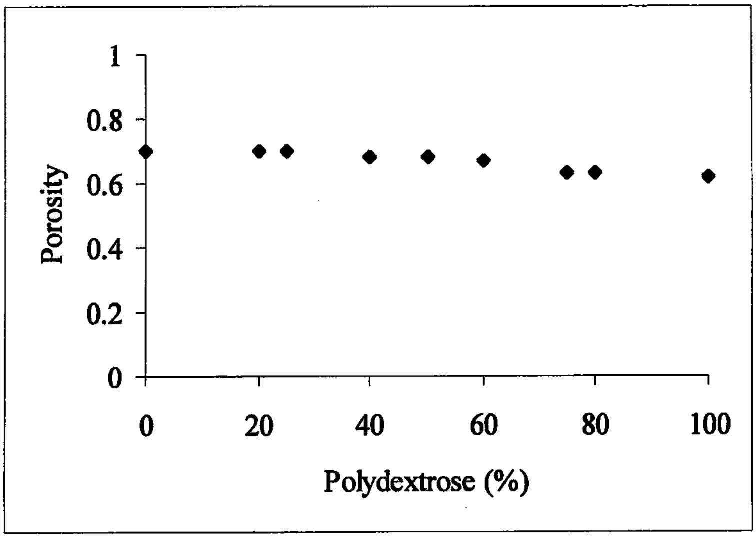


Figure 4.10 Effect of polydextrose-substitution as a sugar-replacer on porosity

Moreover, it is known that cake setting involves starch gelatinization and egg protein denaturation taking place in the same temperature range. Polydextrose elevates the starch gelatinization temperature while leaving the egg protein denaturation temperature essentially unchanged. Thus, high levels of polydextrose may have resulted in premature denaturation of the egg protein to form a gel with the embedded ungelatinized starch granules. The immobilization of the starch granules in the egg protein matrix and their subsequent gelatinization leads to a denser more friable cake (Rosenthal et. al., 1995).

In addition to the changes in setting conditions, change in the viscosity and stability of polydextrose-substituted cake batters is also expected to affect the cake structure formation. Polydextrose substitution as a sugar-replacer which caused a high variation in bubble sizes further affects the bubble expansion rate, which is slower in polydextrose batters (Pateras et. al., 1994). Slower expansion of bubbles in high polydextrose containing batters caused a denser crumb.

Fat-replacement by polydextrose also led to similar results in the macroscopic pore structure parameters (Figure 4.11, Figure 4.12, Figure 4.13) in comparison with sugar-replacement results. Sponge cake crumb structure was not observed at 100%, 80% and 75% fat-replacement. At 60% fat-replacement the desired sponge-like cake crumb structure could be obtained (Figure 4.14). The samples obtained by high levels of fat-replacement cannot be regarded as cakes, but rather as cooked foams due to the formation of a gummy-like structure compared to the desired sponge-like structure. The gummy structures at high levels of fat-replacement caused the destruction of the sample during preparation for bulk and true density analysis.

At high replacement levels decrease in batter viscosity and lack of stability accelerates drainage from foam lamella that flows downward causing the formation of an undesirable gummy structure (Mizukoshi et. al., 1983). Insufficient incorporation of air bubbles into the batter results in a decrease in cake height and increase in bulk density, since fat allows both air entrapment into the cake batter during mixing (Matz, 1972) and expansion of bubbles without rupturing (Brooker, 1993). Moreover, inadequate incorporation of air bubbles causing large bubble sizes led to a loss in volume expansion during baking. This is because buoyancy carries larger bubbles more easily to the surface through which they escape leading to early cake rise prior to protein coagulation and starch gelatinization (Pateras et. al., 1994).

The cake height measurements indicated that 40% replacement of fat by polydextrose was possible without losing the desired sponge-like cake structure. Although porosity and bulk density measurements indicated the possibility of fat replacement up to 60%, our observations showed that at such high levels of replacement sponge-like cake structure changes to a though, dense crumb structure (Figure 4.14). It is well known that fat functions as a tenderizer in cakes (Giese et. al., 1993). During baking, the surface of the air bubbles is coated with fat (Brooker, 1993) which is important in the formation of the desired sponge-like cake structure. It can be concluded that, although the bulk density and porosity results indicated that at 50 and 60% fat-replacement polydextrose gives the air entrapment functionality of fat to the cake, it can not function as a tenderizer.

True density measurements (Figure 4.15, Figure 4.16) showed that true density remains essentially unchanged due to polydextrose addition.

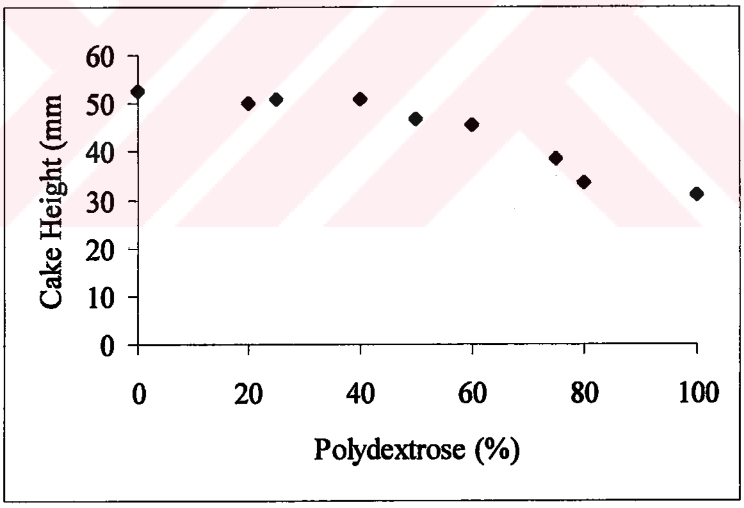


Figure 4.11 Effect of polydextrose-substitution as a fat-replacer on cake height

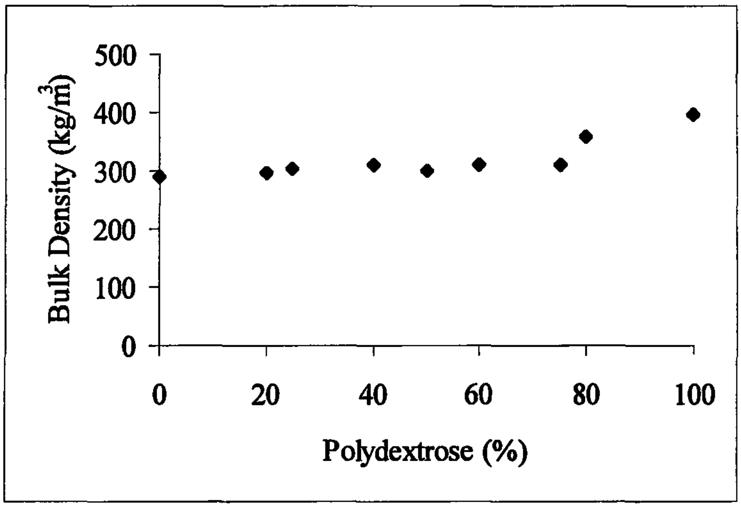


Figure 4.12 Effect of polydextrose-substitution as a fat-replacer on bulk density

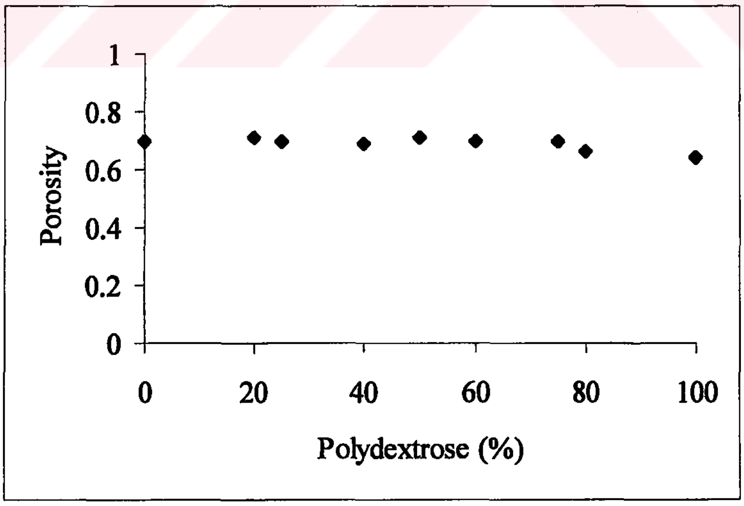


Figure 4.13 Effect of polydextrose-substitution as a fat-replacer on porosity

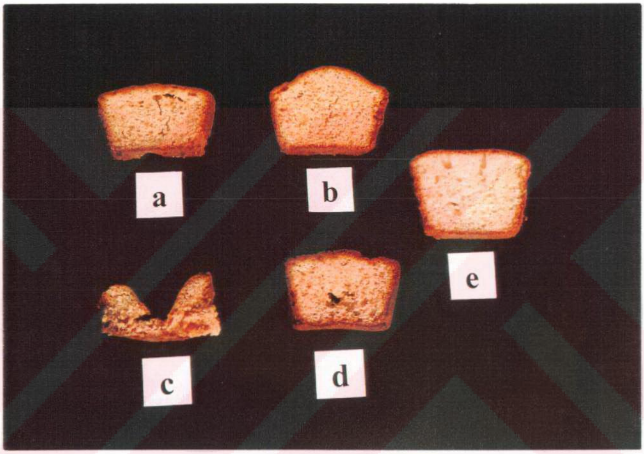


Figure 4.14 The photograph of the cake samples (a) 100% polydextrose (sugar replacement); (b) 20% sugar-80% polydextrose (sugar replacement); (c) 100% polydextrose (fat-replacement); (d) 40% fat-60% polydextrose (fat replacement); (e) high-ratio cake

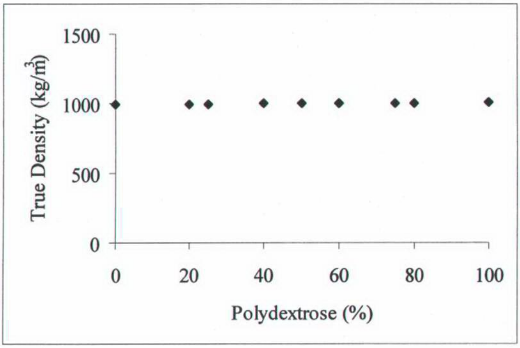


Figure 4.15 Effect of polydextrose-substitution as a sugar-replacer on true density

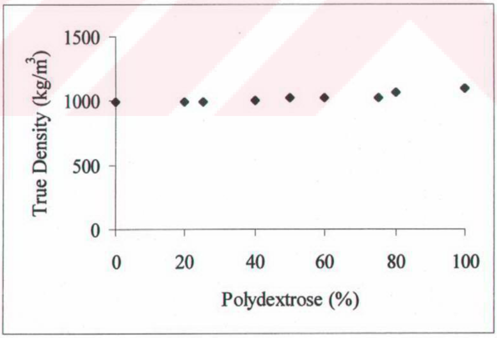


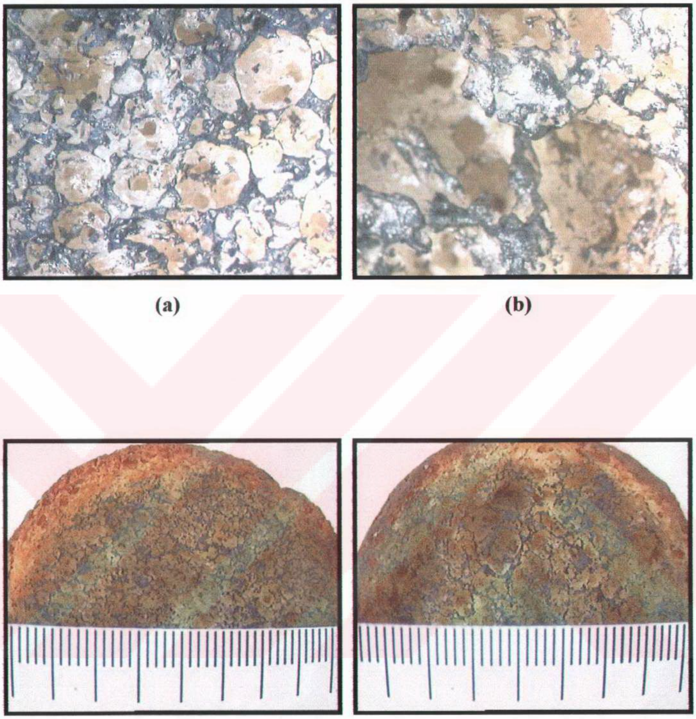
Figure 4.16 Effect of polydextrose-substitution as a fat-replacer on true density

4.3 Effect of Polydextrose on Microscopic Expansion Properties; Pore Size and Shape Distributions

The pore structure parameters taken into consideration were pore area and shape factor distributions. Images taken using the camera only were used for the global assessment of the microscopic pore structure, while the images taken under the microscope were used to reveal the details of the pore structure formation for the cake crumb and crust.

The images of the sample with 100% fat-replacement (Figure 4.17, Figure 4.18) revealed that large crack-like pores are located within the crumb, while there are small spherical pores towards the crust, thus exhibiting an isotropic pore structure. Lack of fat caused the formation of large bubbles within the cake batter due to inadequate air incorporation, which also caused rupture before expansion leading to large crack-like pores within the crumb. This premature rupture before cake setting led to a gummy structure rather than a sponge-like one. This gummy structure is characterized by high interconnectivity between the pores. On the other hand, the-sphere-like pores towards the crust are due to low viscosity causing convective currents. Low viscosity and premature rupture causes the crust to set before the interior, thus bubbles that rise to the surface by convective currents cannot escape (Frye et. al., 1992) forming air pockets towards the crust.

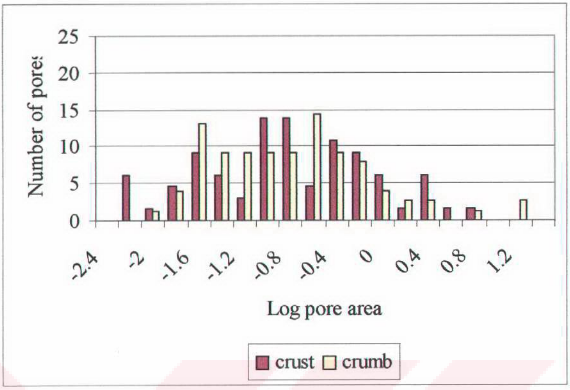
The desired crumb structure was obtained at 60% fat-replacement by polydextrose (Figure 4.19, Figure 4.20). Sponge-like structure is identified by sphere like pores within the crumb with decreasing pore size and pore size variation towards the crumb. Images of 25% fat-replacement (Figure 4.21, Figure 4.22) indicated a pore structure similar to that of the high-ratio cake (Figure 4.23, Figure 4.24) as spherical pores towards the crumb and crust with much less variation in pore size compared to the 60% fat-replacement level.



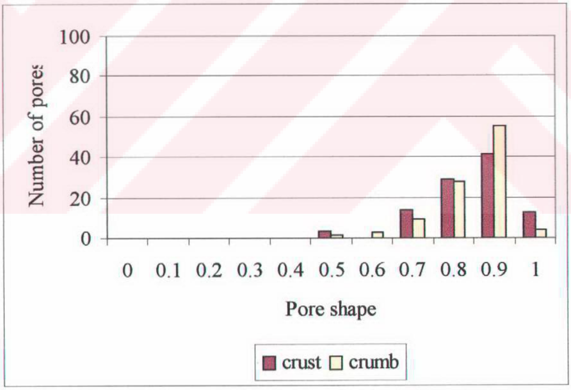
(a) (b)

(c) (d)

Figure 4.17 Image of the sample with 100% fat-replacement (a) cake crust taken by microscope; (b) cake crumb taken by microscope; (c) cake crust taken by camera; (d) cake crumb taken by camera

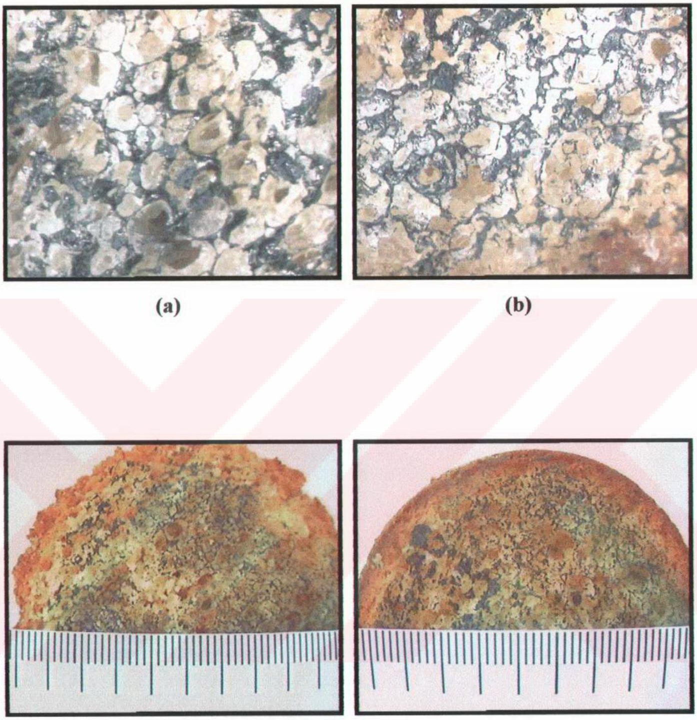


(a)



(b)

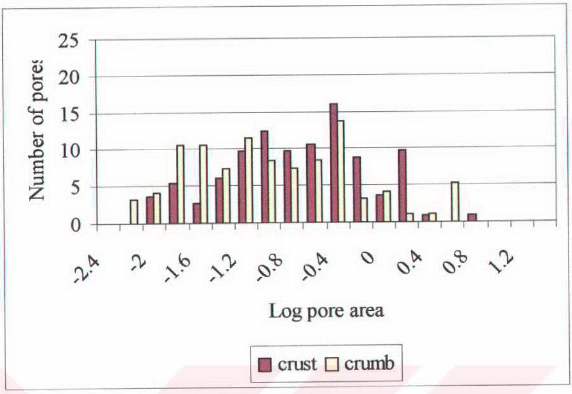
Figure 4.18 Pore structure distribution histograms for 100% fat-replacement (a) pore size, (b) pore shape



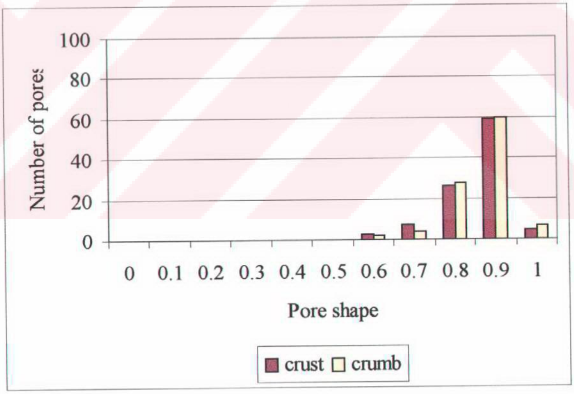
(a) (b)

(c) (d)

Figure 4.19 Image of the sample with 60% fat-replacement (a) cake crust taken by microscope; (b) cake crumb taken by microscope; (c) cake crust taken by camera; (d) cake crumb taken by camera

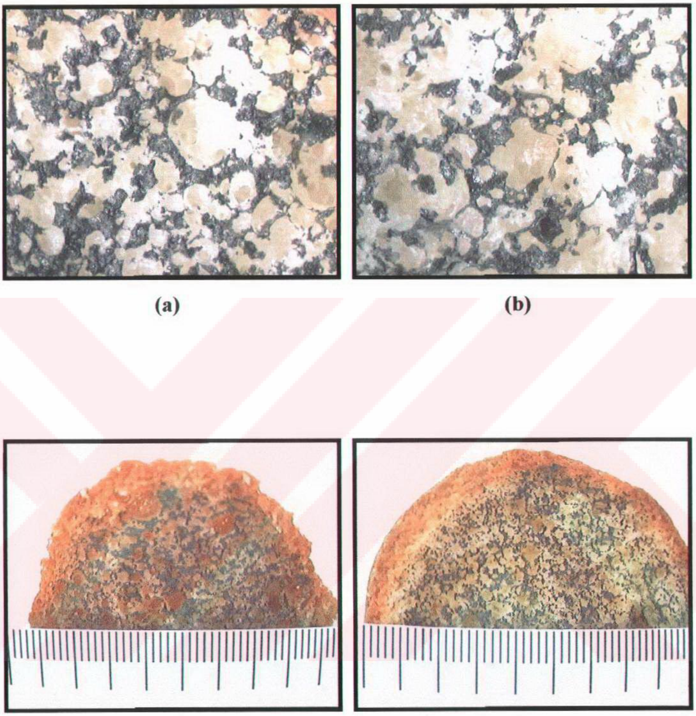


(a)



(b)

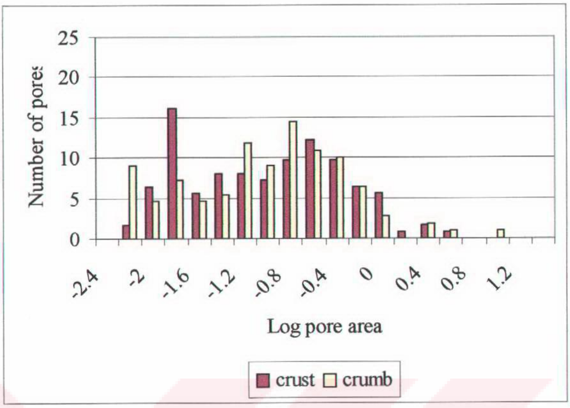
Figure 4.20 Pore structure distribution histograms for 60% fat-replacement (a) pore size, (b) pore shape



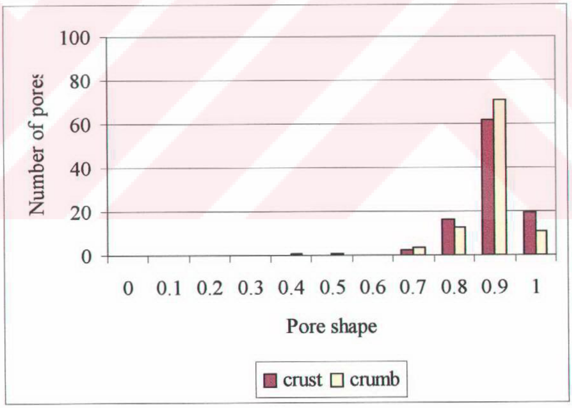
(a) (b)

(c) (d)

Figure 4.21 Image of the sample with 25% fat-replacement (a) cake crust taken by microscope; (b) cake crumb taken by microscope; (c) cake crust taken by camera; (d) cake crumb taken by camera

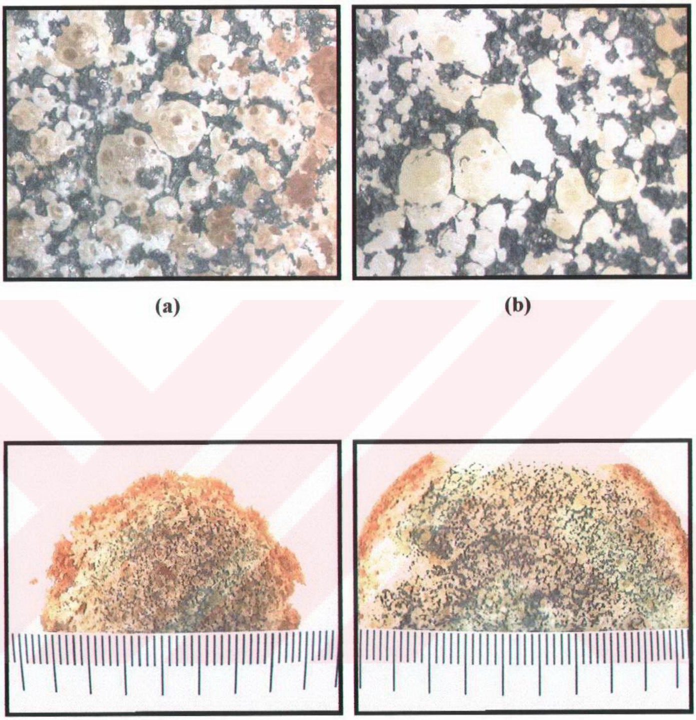


(a)



(b)

Figure 4.22 Pore structure distribution histograms for 25% fat-replacement (a) pore size, (b) pore shape



(a) (b)

(c) (d)

Figure 4.23 Image of the high-ratio cake (a) cake crust taken by microscope; (b) cake crumb taken by microscope; (c) cake crust taken by camera; (d) cake crumb taken by camera

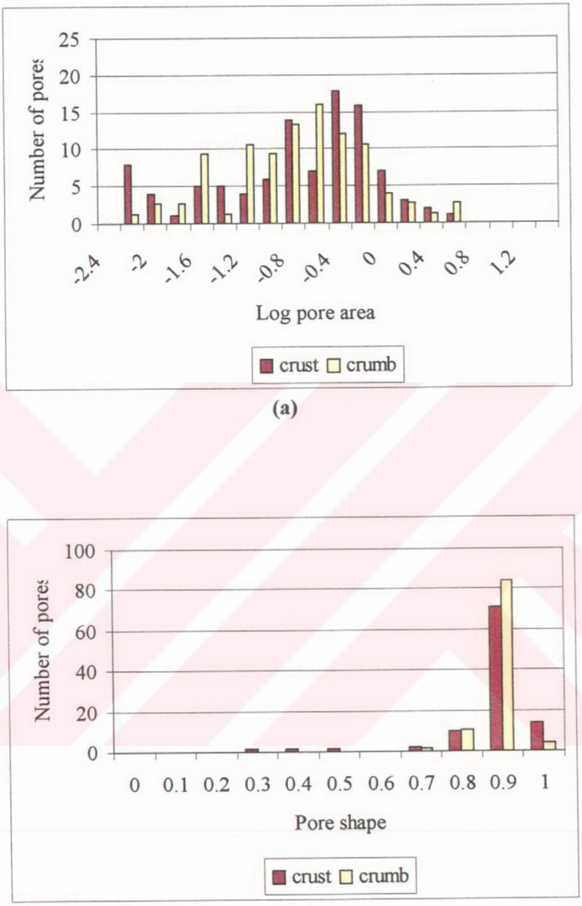
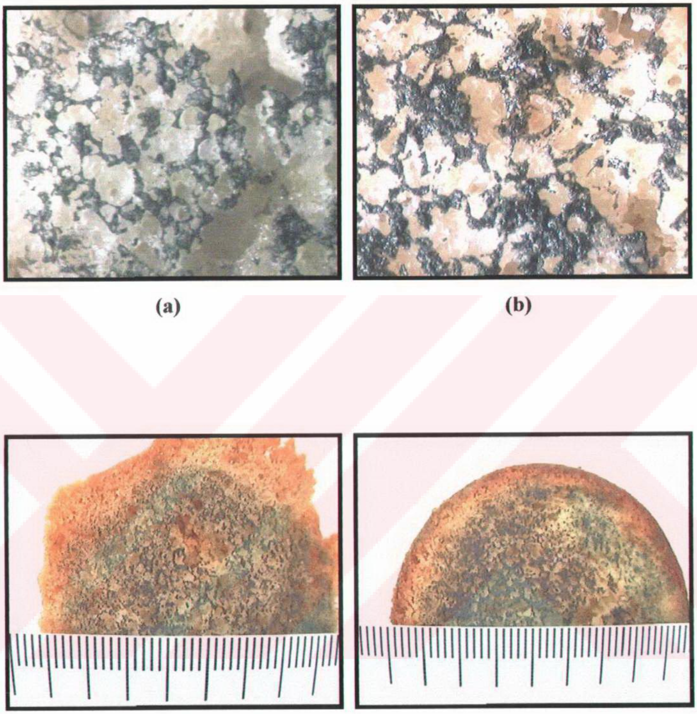


Figure 4.24 Pore structure distribution histograms for high-ratio cake (a) pore size, (b) pore shape

The images of the sample with 100% sugar-replacement (Figure 4.25, Figure 4.26) revealed that small spherical pores were located towards the crust and larger spherical pores were located towards the crumb. The comparison of the images of 100% sugar –replacement with that of high-ratio cake (Figure 4.23, Figure 4.24) showed that polydextrose substitution as a sugar-replacer caused a decrease in pore sizes. This behaviour was observed especially in the crust.

Decrease in pore sizes by sugar-replacement was the indication of the formation of a denser crumb. It is well known that sugar-replacement by polydextrose leads to a denser crumb because of the increase in gelatinization temperature (Pateras et. al., 1994) and insufficient incorporation of air bubbles (Paton et. al., 1981). In addition high levels of sugar-replacement by polydextrose causes slower bubble expansion rate (Pateras et.al., 1994). This causes the formation of smaller pore sizes in the cake crumb and the crust. As indicated previously high levels of sugar-replacement caused a decrease in viscosity of the cake batter. This led the setting of the cake crust before the crumb and resulted in the formation of small pores towards the crust.

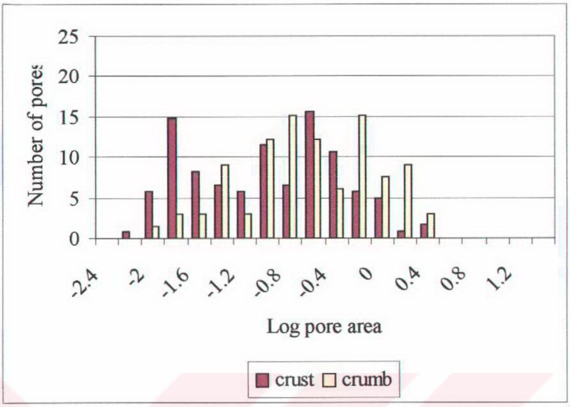
The images of 50% sugar-replacement (Figure 4.27, Figure 4.28) indicated a pore structure similar to that of high ratio cake (Figure 4.23, Figure 4.24).



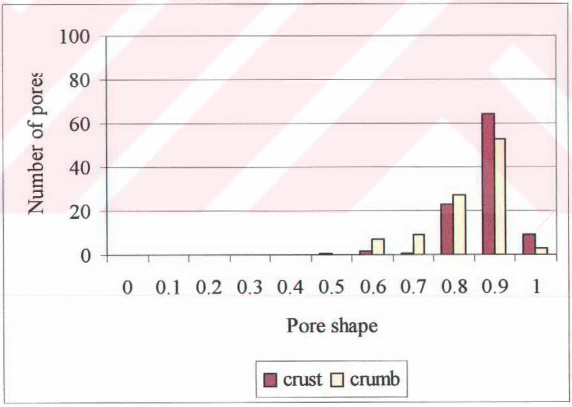
(a) (b)

(c) (d)

Figure 4.25 Image of the sample with 100% sugar-replacement (a) cake crust taken by microscope; (b) cake crumb taken by microscope; (c) cake crust taken by camera; (d) cake crumb taken by camera

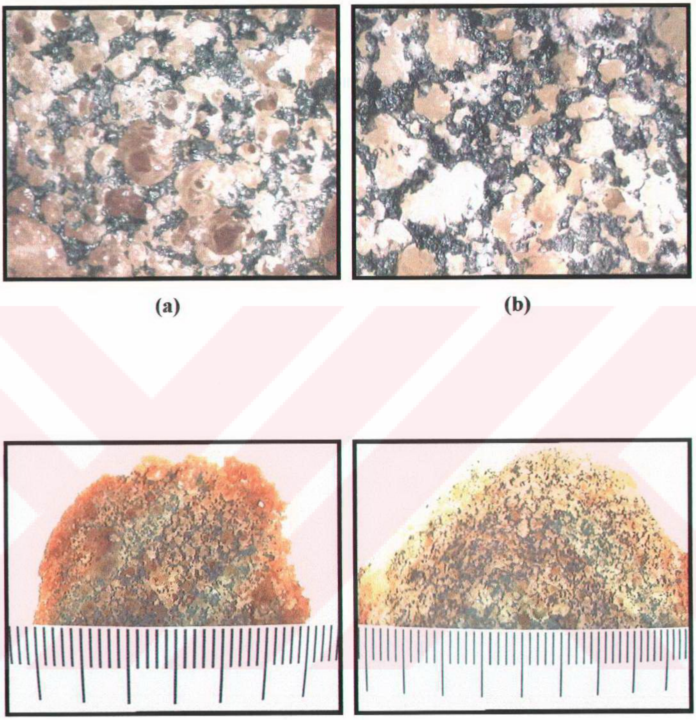


(a)



(b)

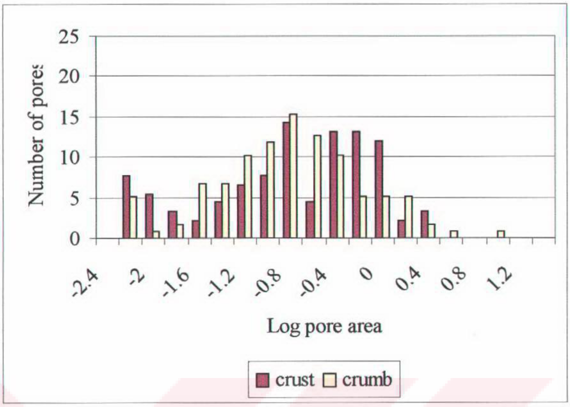
Figure 4.26 Pore structure distribution histograms for 100% sugar-replacement (a) pore size, (b) pore shape



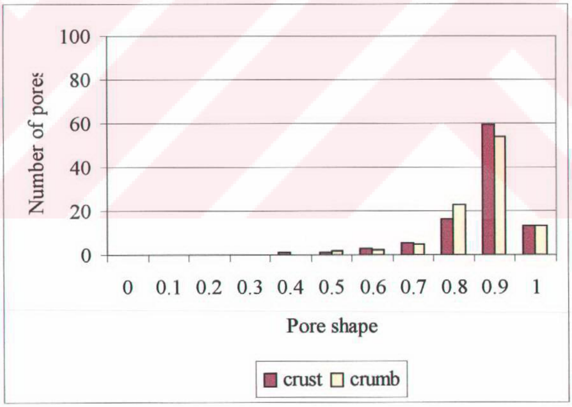
(a) (b)

(c) (d)

Figure 4.27 Image of the sample with 50% sugar-replacement (a) cake crust taken by microscope; (b) cake crumb taken by microscope; (c) cake crust taken by camera; (d) cake crumb taken by camera



(a)



(b)

Figure 4.28 Pore structure distribution histograms for 50% sugar-replacement (a) pore size, (b) pore shape

4.4 Effect of Polydextrose on Crumb Color

The lightness value, L and the yellowness value, b of the crumb on Hunter L, a, b scale, are related with Maillard browning. Maillard reactions are known to be minimized at pH=6 and the cake batter has a pH of 6.5 to 6.8 (Yazgan, 1997). Therefore, Maillard browning seems to be effective in color formation of the cake crumb. In Hunter L, a, b system a value indicates a red to blue scale therefore it was not taken into consideration in this study in the examination of the crumb color.

Polydextrose substitution caused a decrease in Hunter L (Figure 4.17) and b values (Figure 4.18) due to the abundance of glucose units in polydextrose which undergo Maillard reactions resulting in the loss of the desired yellow crumb. The effect of fat-replacement by polydextrose was because fat that is not reactive in Maillard browning has been replaced by a high glucose-containing compound. In addition, the presence of fat prevents the formation of Maillard browning compounds by acting as a barrier between proteins and sugars.

Hunter L values suggested 25% sugar and 40% fat-replacement by polydextrose led to a reasonable lightness of the cake crumb in comparison with the high-ratio cake (Figure 4.17), while Hunter b values suggested 80% sugar and 60% fat-replacement led to a reasonable yellowness of the cake crumb (Figure 4.18).

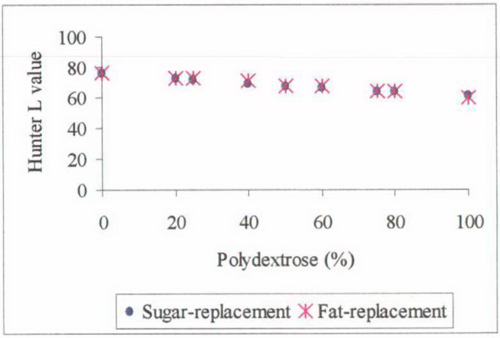


Figure 4.29 Effect of polydextrose substitution on Hunter L value

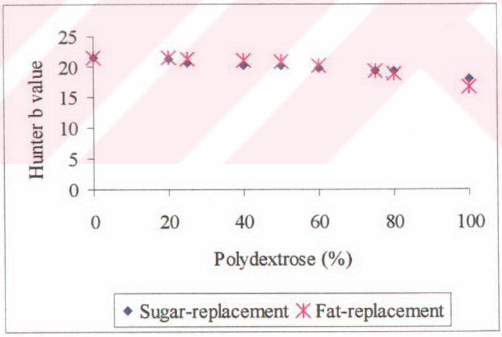


Figure 4.30 Effect of polydextrose substitution on Hunter b value

4.5 Simultaneous Sugar- and Fat-replacer Characteristics of Polydextrose

The results of the preliminary experiments showed that 80% sugar-replacement and 60% fat-replacement were possible to obtain a product with desired expansion properties, color and cake batter characteristics. In addition, the photograph of these samples (Figure 4.14) revealed that the sponge-like cake structure could be obtained at these levels and exceeding these values caused denser crumb for sugar-replacement (Figure 4.14.a) and a gummy structure for fat-replacement (Figure 4.14.b).

In the light of these findings, the working range of independent variables (sugar and fat) was determined (Table 3.3 and Table 3.4). The total fat and sugar amount in the high-ratio cake formulation was kept constant (180 grams) by addition of polydextrose (Table A.2). Two-variable, five-level Central Composite Design was applied. Foam drainage (LOGD), cake height (H) Bulk density (BD), porosity (P), Hunter L (L) and b (b) values were taken as dependent variables. In addition, pore size and shape distributions of the cake crust and crumb and the foam stability of the cake batter were used in the determination of the optimum fat- and sugar-replacement level.

The experimental results are shown in Table 4.1. The coefficients (Table 4.2), R^2 and significant F values (SPSS for Windows 6.0) were obtained for the following second order model;

$$Y = b_0 + b_1X_1 + b_2X_2 + b_{11}X_1^2 + b_{22}X_2^2 + b_{12}X_1X_2$$

by enter method applied to all the dependent variables. The response surfaces for each dependent variable (SigmaPlot 4.0 for Windows) were sketched. Correlation coefficients for each dependent variable were given in Table 4.3. R^2 values showed that the model equations account for about 95% variability except for bulk density and porosity.

Table 4.1 Experimental results

No	X1	X2	H	BD	P	L	b	Log D
1	1	1	51.50	299.85	0.70	72.77	22.04	3.95
2	1	-1	41.90	316.06	0.69	64.49	19.60	1.72
3	-1	1	44.40	323.34	0.67	61.56	18.30	3.48
4	-1	-1	33.50	335.75	0.67	56.46	16.10	1.30
5	1.414	0	50.10	303.07	0.70	71.57	21.90	3.35
6	-1.414	0	38.60	368.65	0.63	57.61	17.90	1.68
7	0	1.414	48.85	312.09	0.69	69.37	20.17	4.32
8	0	-1.414	31.54	371.22	0.64	60.37	18.10	1.67
9	0	0	46.68	313.90	0.69	66.95	19.38	2.75
10	0	0	46.32	313.47	0.69	66.83	19.32	2.75
11	0	0	46.43	315.40	0.68	66.75	19.36	2.75
12	0	0	46.78	313.17	0.69	66.95	19.32	2.75
13	0	0	46.51	312.90	0.69	66.88	19.38	2.75
14	0	0	47.30	312.60	0.69	66.80	19.33	2.75
15	0	0	46.78	314.93	0.68	66.99	19.40	2.75
16	0	0	46.57	315.03	0.68	67.00	19.35	2.75

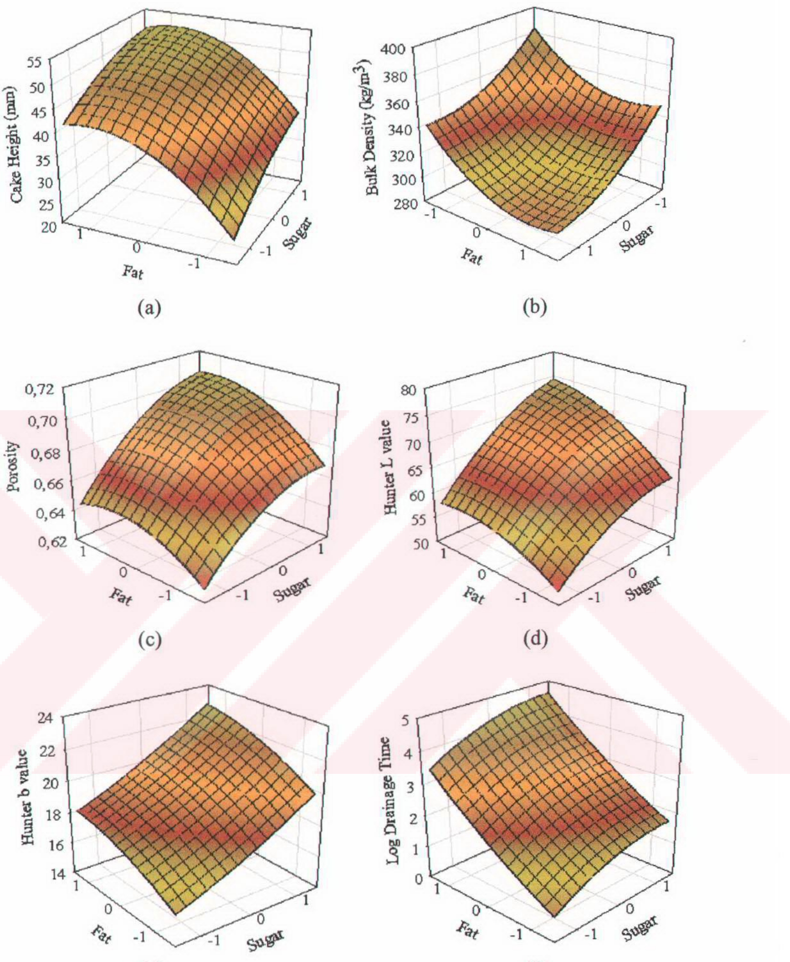
Table 4.2 Regression results

	H	BD	P	L	b	Log D
b_0	46.6712	313.9265	0.6862	66.8938	19.3550	2.7520
b_1	3.9707	-16.9913	0.1863	4.8732	1.6122	0.4083
b_2	5.6229	-14.0308	0.0101	3.2637	0.9460	1.0196
b_{11}	-1.0225	5.9648	-0.0063	-1.3797	0.1456	-0.1538
b_{22}	-3.1006	8.8632	-0.0063	-1.2396	-0.2370	0.0870
b_{12}	-0.3250	-0.9500	0.0025	0.7950	0.0600	0.0132
R^2	0.9929	0.7626	0.7308	0.9941	0.9597	0.9647
F	281.0303	6.4244	5.4298	339.3601	47.6091	54.6056
Signif. F	0.0000	0.0064	0.0113	0.0000	0.0000	0.0000

Table 4.3 Correlation Coefficients

	B	BD	H	L	LOGD	P	TD
B	1.00 16) P=.	-0.68 16) P=.004	0.82 16) P=.000	0.94 16) P=.000	0.72 16) P=.002	0.68 16) P=.004	-0.59 16) P=.016
BD	-0.68 16) P=.004	1.00 16) P=.	-0.87 16) P=.000	-0.83 16) P=.000	-0.67 16) P=.005	-0.97 16) P=.000	0.65 16) P=.006
H	0.82 16) P=.000	-0.87 16) P=.000	1.00 16) P=.	0.90 16) P=.000	0.83 16) P=.000	0.79 16) P=.000	-0.89 16) P=.000
L	0.94 16) P=.000	-0.83 16) P=.000	0.90 16) P=.000	1.00 16) P=.	0.78 16) P=.000	0.82 16) P=.000	-0.66 16) P=.006
LOGD	0.72 16) P=.002	-0.67 16) P=.005	0.83 16) P=.000	0.78 16) P=.000	1.00 16) P=.	0.60 16) P=.015	-0.80 16) P=.000
P	0.68 16) P=.004	-0.97 16) P=.000	0.79 16) P=.000	0.82 16) P=.000	0.60 16) P=.015	1.00 16) P=.	-0.52 16) P=.041
TD	-0.59 16) P=.016	0.65 16) P=.006	-0.89 16) P=.000	-0.66 16) P=.006	-0.80 16) P=.000	-0.52 16) P=.041	1.00 16) P=.

Regression analysis for foam drainage (Figure 4.31.and Table B.6) showed that there is a logarithmic relationship between the fat content and relative viscosity of the cake batter. The cake batter viscosity is expected to be affected more by the fat content, since polydextrose-substitution causes inadequate incorporation of air bubbles into the batter. However, the images (Figure 4.31, Figure 4.32) of the polydextrose-substituted cake batters in comparison with the high-ratio cake (Figure 4.5) showed that batter stability can tolerate between 11.7-40% sugar-replacement and 8.8-30% fat replacement.



(a) (b)

(c) (d)

(e) **(f)**

Figure 4.31 Sample response surfaces (a) cake height; (b) bulk density; (c) porosity, (d) Hunter L value; (e) Hunter b Value; (f) log drainage time

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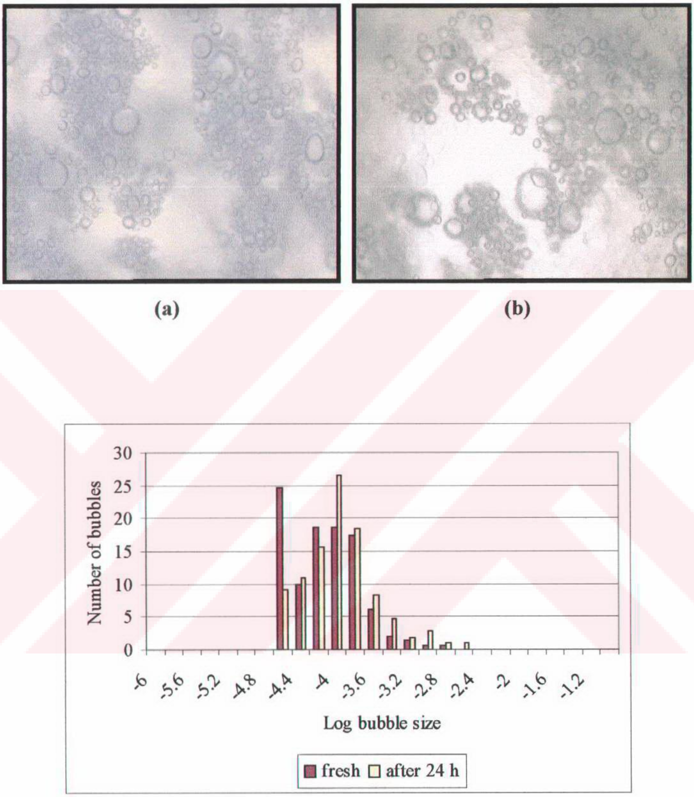
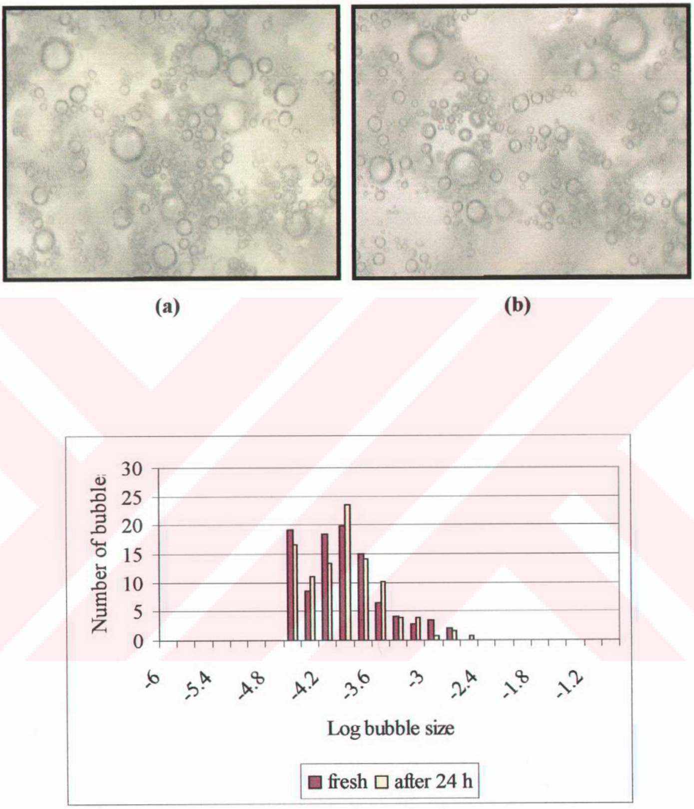


(a) (b)

(c)

Figure 4.32 The cake batter with sugar = 1, fat = 1 (11.7% sugar-replacement, 8.8% fat-replacement) (a) the image of the fresh batter; (b) the image of the batter after 24 h; (c) bubble size distribution histogram.


(a) (b)

(c)

Figure 4.33 The cake batter with sugar=0, fat=0 (40% sugar-replacement, 30% fat-replacement) (a) the image of the fresh batter; (b) the image of the batter after 24 h; (c) bubble size distribution histogram.

Regression analysis for the macroscopic pore structure parameters showed that the linear effect of fat content followed by the linear effect of sugar content and quadratic effect of fat content play the most significant role on cake height (Figure 4.31.a, Table B.1), while bulk density (Figure 4.31.b TableB.2) and porosity (Figure 4.31.c, TableB.3) were significantly influenced by both the linear and quadratic effects of fat and sugar contents. The cake height and porosity decreased, while bulk density increased with polydextrose substitution instead of both sugar and fat. Fat seems to play a more important role, since it starts affecting the final structure at the batter stage due to inadequate incorporation of air bubbles. On the other hand, the most important functions of sugar are during the baking stage at which polydextrose addition results in increased gelatinization temperatures with protein denaturation temperature unchanged. This causes premature cake setting prior to starch gelatinization causing a dense crumb.

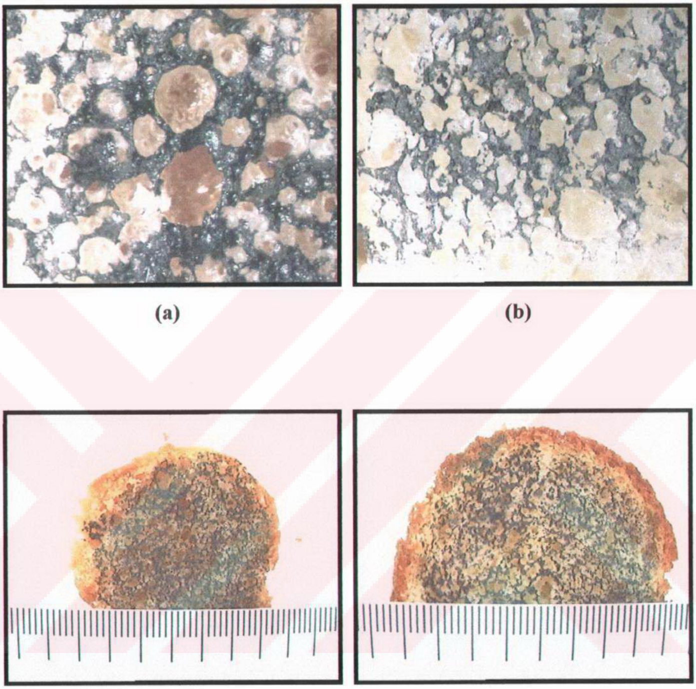
Although cake height, bulk density and porosity are all macroscopic indications of the cake crumb, the mechanisms that affect cake height seem to be different than those affecting bulk density and porosity. This is supported by the fact that there is almost a one–to-one correlation (Table 4.3) between bulk density and porosity, while the correlation (Table 4.3) is lower between porosity and cake height, and also between bulk density and cake height. This can be attributed to the fact that cake height is a one-dimensional measure of expansion, while bulk density and porosity are three-dimensional measures of expansion. Thus, porosity and bulk density are expected to be influenced more by the interaction of the batter mass with the container walls during baking.

Figure 4.31.a implies that cake height, the one-dimensional expansion property can tolerate up to 15% fat-replacement by polydextrose. On the other hand, porosity and bulk density measurements (Figure 4.31.b, Figure 4.31.c), which are more related with the macroscopic crumb structure indicate about 30% fat and 40% sugar-replacement can imitate the high-ratio cake quite well.

These findings are supported by the images of polydextrose-substituted cakes (Figure 4.34, Figure 4.35, Figure 4.36, Figure 4.37) in comparison with the high-ratio cake (Figure 4.23, Figure 4,24), which indicate that 11-40% sugar-replacement and 8.8-30% fat-replacement can imitate the high-ratio cake quite well.

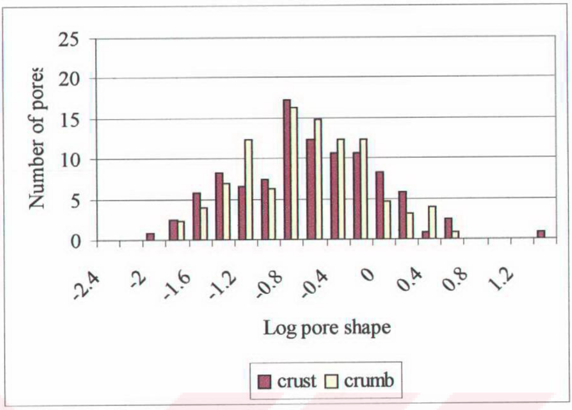
Regression analysis for Hunter L (Figure 4.31.d, Table B.4) and b values (Figure 4.31.e, Table B.5) showed that linear effect of sugar content followed by the linear effect of fat content play the most significant role on the color attributes of the cake samples. Increase in Hunter L and b values with polydextrose-substitution can be attributed to the abundance of glucose units in polydextrose, which undergo Maillard reactions resulting in a decrease in the desired yellow crumb. Fat content also had a significant effect on the color attributes, since fat-replacement means substituting an inert, fat, with respect to Maillard reactions by a glucose abundant material, polydextrose. Moreover, replacing the fat in the medium by polydextrose also means removing the barriers between the proteins and sugar in the original formulation.

The high correlation (Table 4.3) between Hunter L and b values indicate that lightness and yellowness of the crumb are affected by the same mechanism. Also the correlation coefficients (Table 4.3) between the color parameters and the macroscopic expansion properties are quite high indicating that the mechanism that cause inadequate expansion also lead to inadequate color attributes.

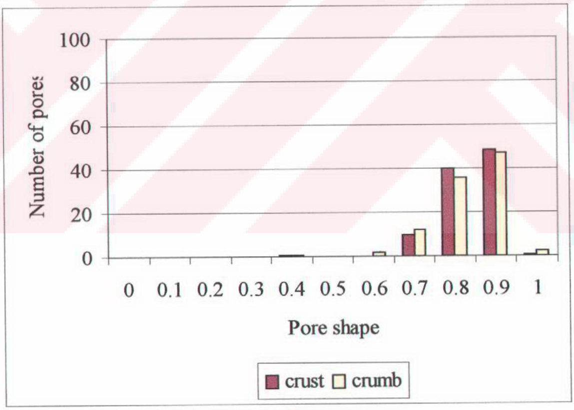

(a) (b)

(c) (d)

Figure 4.34 Image of the sample with sugar = 1, fat = 1 (11.7% sugar-replacement, 8.8% fat-replacement) (a) cake crust taken by microscope; (b) cake crumb taken by microscope; (c) cake crust taken by camera; (d) cake crumb taken by camera

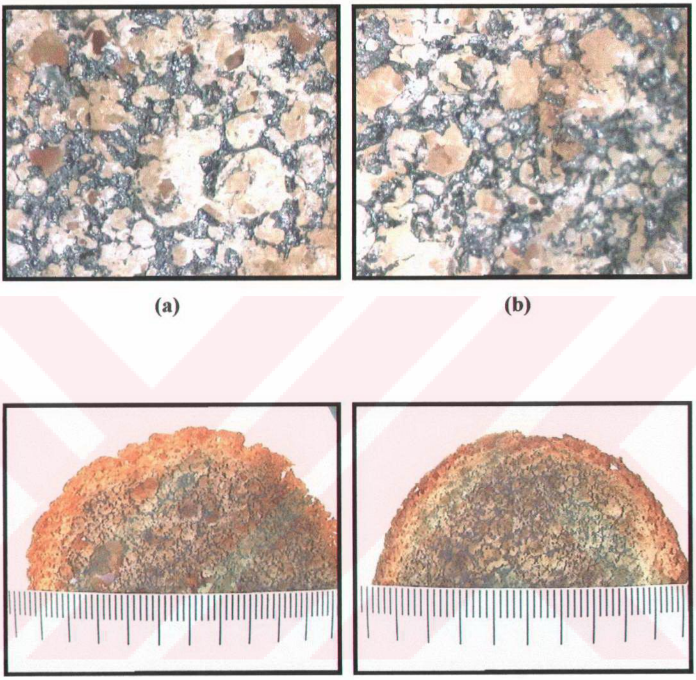


(a)



(b)

Figure 4.35 Pore structure distribution histograms for sugar = 1, fat = (11.7% sugar-replacement, 8.8% fat-replacement) (a) pore size, (b) pore shape



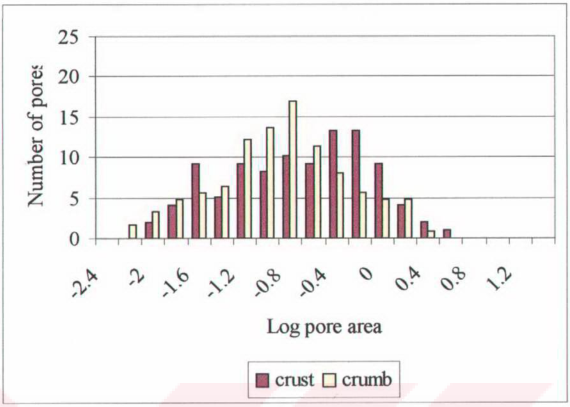
(a)

(b)

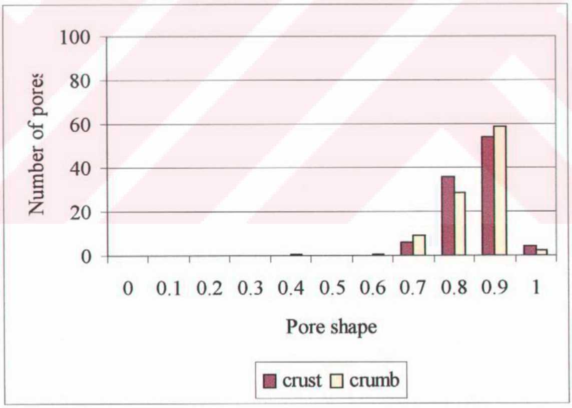
(c)

(d)

Figure 4.36 Image of the sample with sugar = 0, fat = 0 (40% sugar-replacement, 30% fat-replacement) (a) cake crust taken by microscope; (b) cake crumb taken by microscope; (c) cake crust taken by camera; (d) cake crumb taken by camera



(a)



(b)

Figure 4.37 Pore structure distribution histograms for sugar = 0, fat = 0 (40% sugar-replacement, 30% fat-replacement) (a) pore size, (b) pore shape

In the light of these findings optimization was carried out by maximizing the one-dimensional expansion measure, the cake height, and the measure of yellowness, Hunter b value.

The optimum product due to replacement was at 33.14% sugar, 24.06% fat and 42.80% polydextrose based on total fat and sugar content of the high-ratio cake formulation. This showed that 15.03 % fat-replacement and 33.87% sugar-replacement (Table 4.4) is possible for the manufacture of a diet cake formulation.

The superposition of contour plots also support this result, since the mathematically found optimum product falls within the optimum region in Figure 4.38.

Table 4.4 Process optimum

Independent variables	
Sugar	Fat
0.217	0.705
Dependent variables	
Cake Height (cm)	Hunter b value
49.86	20.27
High-ratio cake	
Cake Height (cm)	Hunter b value
52.57	21.56

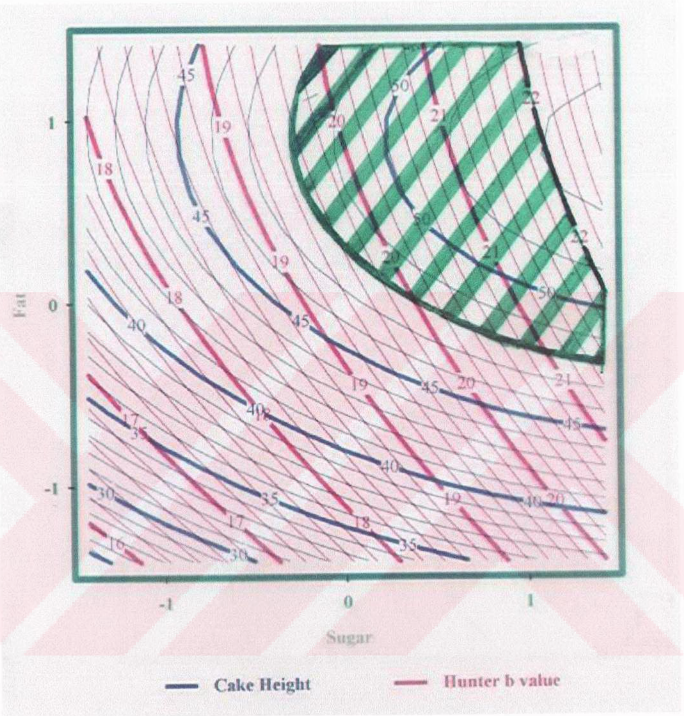


Figure 4.38. The superposition of contour plots for the cake height and Hunter b value

CHAPTER 5

CONCLUSIONS AND FUTURE WORK

5.1 Conclusions

Polydextrose is a potential sugar- and fat-replacer in the manufacture of a diet cake formulation. It can replace either 80% of the sugar or 60% of the fat in original formulation without affecting the expansion properties and color.

Foam drainage measurements showed that the relative measure of foam viscosity; foam drainage changes with polydextrose replacement. Polydextrose capability in integrating air bubbles to the batter is not enough all by itself. Polydextrose addition as a sugar-and fat-replacer resulted in a non-uniform distribution of bubble size in the batter leading to an unstable foam. Polydextrose addition as a fat-replacer resulted in an increase in the size of the bubbles and decrease in foam stability.

Change in the macroscopic and microscopic expansion properties of polydextrose-substituted cakes in comparison with the high-ratio cake is attributed mainly to the functionality of fat in batter stage to incorporate air bubbles and that of sugar in baking to regulate simultaneous starch gelatinization and protein denaturation. Generally it was observed that increase in polydextrose-substitution as a fat-replacer caused an increase in the pore size variation of the cake crumb and crust. Number of crack-like pores increased and a highly interconnected pore structure was obtained. On the other hand, high levels of sugar-replacement caused a decrease in pore sizes resulting in the formation of a dense crumb.

Hunter L and b values used to examine the crumb color of polydextrose-substituted cakes showed that polydextrose-substitution led to decrease in the desired lightness and yellowness of the cake crumb.

Simultaneous sugar- and fat-replacement by polydextrose showed that 15.03 % fat-replacement and 33.87% sugar-replacement is possible for the manufacture of a diet cake formulation.

5.2 Future Work

The functionality of polydextrose can be studied as a sugar- and fat-replacer in other food systems such as marshmallow, ice cream, whipped cream.

Thermodynamics and kinetics of the stability of polydextrose containing food foams can be investigated.

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APPENDIX A

Table A.1. Experimental design

Exp. No.	Codes				
	X1	X2			
	Sugar	Fat	Sugar (g)	Fat (g)	Polydextrose (g)
1	1	1	101.5	59.3	19.2
2	1	-1	101.5	31.7	46.8
3	-1	1	36. 5	59.3	84.2
4	-1	-1	36.5	31.7	111.8
5	1.414	0	115	45.5	19.5
6	-1.414	0	23	45.5	111.5
7	0	1.414	69	65	46
8	0	-1.414	69	26	85
9	0	0	69	45.5	65.5
10	0	0	69	45.5	65.5
11	0	0	69	45.5	65.5
12	0	0	69	45.5	65.5
13	0	0	69	45.5	65.5
14	0	0	69	45.5	65.5
15	0	0	69	45.5	65.5
16	0	0	69	45.5	65.5

APPENDIX B

Table B.1 Regression analysis for cake height

```
Listwise Deletion of Missing Data
Equation Number 1     Dependent Variable..    HEIGHT
Block Number  1.  Method:  Enter
   F        FF        S        SF        SS
Variable(s) Entered on Step Number
   1..     SS
   2..     SF
   3..     S
   4..     F
   5..     FF
Multiple R              .99646
R Square                .99293
Adjusted R Square       .98940
Standard Error          .57506
Analysis of Variance
                     DF       Sum of Squares        Mean Square
Regression            5            464.67506           92.93501
Residual             10              3.30694             .33069
F =       281.03031        Signif F =   .0000
------------------ Variables in the Equation ------------------
Variable                B         SE B         Beta          T  Sig T
F                5.622892      .203330      .735118     27.654  .0000
FF              -3.100583      .203360     -.405299    -15.247  .0000
S                3.970725      .203330      .519120     19.528  .0000
SF               -.325000      .287530     -.030047     -1.130  .2847
SS              -1.022456      .203360     -.133652     -5.028  .0005
(Constant)      46.671208      .203314                 229.552  .0000
End Block Number   1   All requested variables entered.
```

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Table B.2 Regression analysis for bulk density

```
Listwise Deletion of Missing Data
Equation Number 1    Dependent Variable..    BD
Block Number  1.  Method:   Enter
   F        FF        S         SF        SS
Variable(s) Entered on Step Number
   1..    SS
   2..    SF
   3..    S
   4..    F
   5..    FF
Multiple R            .87327
R Square              .76259
Adjusted R Square     .64389
Standard Error      12.22468
Analysis of Variance
                     DF       Sum of Squares       Mean Square
Regression            5           4800.37401         960.07480
Residual             10           1494.42689         149.44269
F =        6.42437        Signif F =  .0064
------------------ Variables in the Equation ------------------
Variable               B         SE B         Beta          T  Sig T
F             -14.030846     4.322402     -.500156     -3.246  .0088
FF              8.863171     4.323055      .315896      2.050  .0675
S             -16.991331     4.322402     -.605687     -3.931  .0028
SF              -.950000     6.112338     -.023948      -.155  .8796
SS              5.964796     4.323055      .212594      1.380  .1977
(Constant)    313.926511     4.322075                  72.633  .0000
End Block Number   1   All requested variables entered.
```

Table B.3 Regression analysis for porosity

```
Listwise Deletion of Missing Data
Equation Number 1    Dependent Variable..   P
Block Number  1.  Method:  Enter
   F        FF       S        SF       SS
Variable(s) Entered on Step Number
   1..    SS
   2..    SF
   3..    S
   4..    F
   5..    FF
Multiple R              .85488
R Square                .73081
Adjusted R Square       .59622
Standard Error          .01250
Analysis of Variance
                       DF      Sum of Squares      Mean Square
Regression              5              .00424           .00085
Residual               10              .00156           .00016
F =       5.42980       Signif F =  .0113
------------------ Variables in the Equation ------------------
Variable                  B        SE B        Beta          T  Sig T
F                   .010089     .004418     .374669      2.284  .0455
FF                 -.006250     .004419    -.232053     -1.414  .1876
S                   .018625     .004418     .691675      4.216  .0018
SF                  .002500     .006248     .065653       .400  .6975
SS                 -.006250     .004419    -.232053     -1.414  .1876
(Constant)          .686249     .004418                155.341  .0000
End Block Number   1   All requested variables entered.
```

Table B.4 Regression analysis for Hunter L value

```
Listwise Deletion of Missing Data
Equation Number 1    Dependent Variable..   L
Block Number  1.  Method:  Enter
   F        FF        S        SF       SS
Variable(s) Entered on Step Number
   1..    SS
   2..    SF
   3..    S
   4..    F
   5..    FF
Multiple R            .99707
R Square              .99414
Adjusted R Square     .99121
Standard Error        .42411
Analysis of Variance
                     DF       Sum of Squares      Mean Square
Regression            5           305.19733         61.03947
Residual             10             1.79866           .17987
F =      339.36012       Signif F =  .0000
------------------ Variables in the Equation ------------------
Variable                 B        SE B       Beta          T  Sig T
F                 3.263743     .149956    .526819     21.765  .0000
FF               -1.239620     .149978   -.200064     -8.265  .0000
S                 4.873166     .149956    .786606     32.497  .0000
SF                 .795000     .212053    .090747      3.749  .0038
SS               -1.379663     .149978   -.222666     -9.199  .0000
(Constant)       66.893819     .149944               446.124  .0000
End Block Number   1   All requested variables entered.
```

Table B.5 Regression analysis for Hunter b value

```
Listwise Deletion of Missing Data
Equation Number 1    Dependent Variable..   B
Block Number  1.  Method:  Enter
   F        FF        S        SF       SS
Variable(s) Entered on Step Number
   1..     SS
   2..     SF
   3..     S
   4..     F
   5..     FF
Multiple R            .97964
R Square              .95968
Adjusted R Square     .93953
Standard Error        .34652
Analysis of Variance
                    DF       Sum of Squares      Mean Square
Regression           5             28.58296          5.71659
Residual            10              1.20074           .12007
F =       47.60907        Signif F =  .0000
------------------ Variables in the Equation ------------------
Variable                 B          SE B          Beta          T  Sig T
F                  .946015       .122521       .490254      7.721  .0000
FF                -.236978       .122540      -.122791     -1.934  .0819
S                 1.612243       .122521       .835514     13.159  .0000
SF                 .060000       .173258       .021988       .346  .7363
SS                 .145638       .122540       .075462      1.188  .2621
(Constant)       19.355038       .122512                  157.985  .0000
End Block Number   1   All requested variables entered.
```

Table B.6 Regression analysis for log drainage time

```
Listwise Deletion of Missing Data
Equation Number 1    Dependent Variable..   LOGD
Block Number  1.  Method:  Enter
   F        FF       S        SF       SS
Variable(s) Entered on Step Number
   1..    SS
   2..    SF
   3..    S
   4..    F
   5..    FF
Multiple R           .98218
R Square             .96467
Adjusted R Square    .94700
Standard Error       .19040
Analysis of Variance
                   DF       Sum of Squares      Mean Square
Regression          5              9.89819          1.97964
Residual           10               .36253           .03625
F =      54.60563       Signif F =  .0000
------------------ Variables in the Equation ------------------
Variable              B        SE B       Beta          T  Sig T
F              1.019556     .067323    .900190     15.144  .0000
FF              .087039     .067333    .076837      1.293  .2252
S               .408250     .067323    .360454      6.064  .0001
SF              .013175     .095202    .008226       .138  .8927
SS             -.153783     .067333   -.135759     -2.284  .0455
(Constant)     2.752011     .067318                40.881  .0000
End Block Number   1   All requested variables entered.
```