EVALUATION OF THE EFFECTS OF MALTODEXTRIN AND MICROFLUIDIZATION ON THE RHEOLOGICAL AND TEXTURAL PROPERTIES OF COOKIE AND COOKIE DOUGH

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EVALUATION OF THE EFFECTS OF MALTODEXTRIN AND MICROFLUIDIZATION ON THE RHEOLOGICAL AND TEXTURAL PROPERTIES OF COOKIE AND COOKIE DOUGH

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ABSTRACT

EVALUATION OF THE EFFECTS OF MALTODEXTRIN AND MICROFLUIDIZATION ON THE RHEOLOGICAL AND TEXTURAL PROPERTIES OF COOKIE AND COOKIE DOUGH

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Several health problems like diabetes and obesity are associated with consumption of highly fatty food, leading consumers to be more conscious about what they eat. This concern has been a driving factor for manufacturers to research and develop low- or reduced-fat products. Therefore, the baking industry finds new ways to respond to the demands. For this reason, fat replacement in bakery products has gained a popularity. Maltodextrin is commonly used to trim fat from bakery products because it gives some properties to products similar to those of fat.

The main objective of this study was to investigate the effects of microfluidization (MF) and maltodextrin (MD) (DE18) (0%, 3.75%, and 7.5%) on the rheological and textural properties of cookie and cookie dough. Also, the effects of type of fat - palm olein (PON) and palm stearin (PS) - on the rheological and textural properties of both cookie and cookie dough were investigated.

In the first part of the study, the rheological (elastic and viscous moduli) and hardness and cohesiveness of cookie doughs containing different percentages (0%, 3.75%, and 7.5%) of MD were observed. The cookie doughs showed a solid-like behavior. The elastic and viscous moduli were low in the control dough, containing 100% PON or PS without no fat replacement, compared to those of dough with fat replacement. It was observed that the use of MD at 0%, 3.75%, and 7.5% increases both storage and loss moduli in all samples. Also, the G' and G" of doughs containing MD at 0%, 3.75%, and 7.5% were affected by the application of MF at 1000 Bar. The cookie dough containing 3.75% MD, PON2, had the closest G' and G" values to the control cookie dough. Dough hardness increased as the percentage of MD increased whereas increase in the amount of MD led to reduction in the moisture content of doughs both with MF and without MF. However, MF did not have a significant effect on the moisture contents of doughs. Control dough had the highest cohesiveness value. However, replacement of fat with MD at different percentages decreased cohesiveness of doughs.

In the second part of this study, the effects of replacement of fat by MD at 0%, 3.75%, and 7.5% on quality of cookies (hardness, moisture content, size, and color) were determined. There was an increase in the hardness of cookies with the increasing percentages of MD. Consequently, it could be concluded that there was a correlated relation between cookie and its dough in terms of hardness because increase in hardness of both cookie and dough was observed with increasing MD level. Also, MD increased the moisture content of the cookies, compared to control cookie. There were no significant changes in the heights of all types of cookies after 7 day storage. In diameter measurement, there was no significant difference between the cookies without MF at 0%, 3.75%, and 7.5% MD. However, there was a significant difference in diameter between cookies with MF at different MD percentages. On the other hand, the increase of MD levels in the cookie and the use of MF process did not any significant effect on the change of the cookie color. The significant effect of MF on color was only observed with the cookie prepared from 0-day dough including PS.

In the study, it was found that the use of MF at 0%, 3.75%, and 7.5% MD was

not required for the cookie making because no significant effect on hardness and size of cookie was observed. On the contrary, using MD18 was a good option for fat replacement in cookie making in terms of textural and rheological properties. Also, when 3.75% MD was used, the cookie (PON2) with 20% less calorie was obtained if the control cookie was considered as a baseline.

Keywords: maltodextrin, cookie, rheology, texture, microfluidization

ÖZ

MALTODEKSTRİNİN VE MİKROFLUDİZASYONUN KURABİYENİN REOLOJİK VE YAPISAL ÖZELLİKLERİ ÜZERİNDEKİ ETKİLERİ

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Diabet ve obezite gibi pek çok sağlık problemi yüksek yağlı gıdalardan kaynaklanmaktadır. Bu durum insanları ne yedikleri konusunda daha bilinçli olmaya yönlendirmektedir. Bu kaygı üreticileri, az ya da azaltılmış yağlı ürünlerin geliştirilmesi konusundaki talepleri karşılamak üzere yeni yolların bulunması için teşvik etmektedir. Unlu mamuller endüstrisi bu taleplere cevap vermek için yeni yollar bulmaktadır. Bu yüzden unlu mamullerde yağ yerine geçen madde kullanımı popülarite kazanmıştır. Genellikle maltodextrin unlu mamullerde yağı azaltmak için kullanılmaktadır çünkü MD ürüne, yağın verdiği özelliklere benzer özellikler vermektedir.

Bu çalışmanın amacı, microfludizasyon (MF) ve farklı yüzdelerdeki maltodextrinin (MD) (DE18) (0%, 3.75%, ve 7.5%) bisküvi ve bisküvi hamurunun reolojik ve tekstürel özelliklerine etkisinin araştırılmasıdır. Ayrıca, farklı yağ çeşitlerinin - palm olein (PON) ve palm stearin (PS) - bisküvi ve bisküvi hamurunun reolojik

ve tekstürel özellikleri üzerindeki etkisine de bakılacaktır.

Çalışmanın ilk bölümünde, farklı yüzdelerde maltodextrin (0%, 3.75%, and 7.5%) içeren bisküvi hamurlarının reolojik (elastik ve viskoz modülleri), sertlik ve yapışkanlık özellikleri gözlenecektir. Bisküvi hamurları katı benzeri bir davranış göstermektedir. 100% PON ya da PS içeren ve yağ yerine geçen madde kullanılmamış olan kontrol hamurlarındaki elastik ve viskoz modülleri yağ yerine geçen madde içeren hamurlara kıyasla daha düşüktür. 0%, 3.75%, ve 7.5% MD kullanımının tüm örneklerde elastik ve viskoz modüllerini artırdığı gözlemlenmiştir. Ayrıca, 0%, 3.75%, ve.5% MD içeren hamurların G' ve G" değerleri 500 Bar'da MF uygulanmasından etkilenmektedir. Elastik ve viskoz değerleri kontrol hamur değerlerine en yakın olan hamur 3.75% maltodextrin içeren bisküvi hamurudur (PON2). Maltodextrin yüzdesinin artışı hamurların sertliğini artırırken, hamurların nem miktarının azalmasına sebep olmaktadır. Ancak nem miktarındaki azalış MF prosesinden bağımsız olarak gerçekleşmektedir, diğer bir deyişle MF prosesinin hamurların nem miktarında dikkate değer bir etkisi yoktur. Kontrol hamurları en yüksek yapışkanlık değerine sahiptir ve yağın farklı maltodextrin yüzdeleriyle yer değiştirmesi de hamurların yapışkanlığının azalmasına neden olmaktadır.

Çalışmanın ikinci bölümünde ise yağın farklı yüzdelerde maltodextrin ile değiştirilmesinin bisküvinin kalitesini (sertlik, nem miktarı, boyut ve renk) nasıl etkilediği araştırılmaktadır. Maltodextrin yüzdelerindeki artış bisküvinin sertliğinde de artışa sebep olmaktadır. Bunun sonucu olarak da sertlik açısından bisküvi ve bisküvi hamuru arasında ilişki olduğu söylenebilir çünkü MD seviyesinin artırılmasıyla bisküvi ve bisküvi hamurunun ikisinin de sertliğinde artış görülmektedir. Ayrıca MD kullanımı bisküvilerin nem miktarını kontrol bisküviye kıyasla artırmaktadır. 7 günlük muhafaza sonrasında tüm bisküvilerin yüksekliğinde önemli bir değişiklik gözlenmemektedir. MF işlemine maruz kalmamış ve maltodekstrin (0%, 3.75%, ve 7.5%) içeren bisküvilerin çaplarında bir değişiklik görülmüyor. Ancak MF işlemi uygulanan farklı maltodextrin yüzdesine sahip örneklerin çaplarında farklılıklar mevcuttur. Diğer taraftan, bisküvi içinde bulunan MD seviyesindeki artış ve MF kullanımı bisküvi renginin değişimi üstünde dikkate değer bir etkiye sahip değildir. MF'nin renk üzerindeki dikkate değer etkisi sadece PS içeren 0-günlük hamurundan hazırlanan bisküvide gözlemlenmektedir.

Sonuç olarak, çalışmada, bisküvi yapımı için 0%, 3.75% ve 7.5% MD seviyelerinde MF kullanımının gerekli olmadığı bulunmuştur çünkü bisküvilerin sertliği ve boyutu üzerinde dikkate değer bir etki gözlemlenmemektedir. Tam tersine, tekstürel ve reolojik açılardan bakıldığında yağ yerine geçen madde olarak maltodekstrin kullanılması iyi bir seçenektir. Ayrıca, kontrol bisküvisi baz alınırsa, 3.75% MD kulanıldığında, %20 daha az kalorili bisküvi elde edilmektedir.

Anahtar Kelimeler: maltodekstrin, kurabiye, reoloji, tekstür, mikrofludizasyon

To my grandfather, Refik BALCI for his endless love and faith in me...

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DE	Dextrose Equivalent
MD	Maltodextrin
MF	Microfluidization
PON	Palm Olein/Cookie or Cookie dough containing 100% palm olein
PS	Palm Stearin/Cookie or Cookie dough containing 100% palm stearin
Melted PON	Cookie/Cookie dough containing 100% melted palm olein
Melted PS	Cookie/Cookie dough containing 100% melted palm stearin
PON1	Cookie/Cookie dough containing PON and 0% MD without MF process
PON2	Cookie/Cookie dough containing PON and 3.75% MD without MF process
PON3	Cookie/Cookie dough containing PON and 7.5% MD without MF process
PS1	Cookie/Cookie dough containing PS and 0% MD without MF process
PS2	Cookie/Cookie dough containing PS and 3.75% MD without MF process
PS3	Cookie/Cookie dough containing PS and 7.5% MD without MF process
MFPON1	Cookie/Cookie dough containing PON and 0% MD with MF process
MFPON2	Cookie/Cookie dough containing PON and 3.75% MD with MF process
MFPON3	Cookie/Cookie dough containing PON and 7.5% MD with MF process
MFPS1	Cookie/Cookie dough containing PS and 0% MD with MF process
MFPS2	Cookie/Cookie dough containing PS and 3.75% MD with MF process
MFPS3	Cookie/Cookie dough containing PS and 7.5% MD with MF process

G'	Elastic Modulus
G"	Viscous Modulus

CHAPTER 1

INTRODUCTION

1.1 Cookie Dough

The biscuit term includes broad range of baking products such as crackers, cookies, even pet foods and biscuits are one of the most popular bakery products consumed because of ready to eat nature, good nutritional quality, and availability in different varieties and affordable cost (Sudha, Vetrimani, & Leelavathi, 2007). Biscuits are classified in terms of dough types as shown in Table 1.1.

Certain kinds of cookies are made of soft dough. For the doughs which are of soft category, gluten development is not desirable (Zoulias et al., 2000). In these cookies, gluten development is prevented by the use of high level of sugar and fat in cookie formulation as shown in Table 1.1. Also, all sugar cannot dissolve in the water so that the level of sugar is high in these products whereas most of the dry ingredients are dissolved in water. Additionally, dispersion of fat and aqueous phase while obtaining dough without hydration of gluten may result in problem. Therefore, these doughs are obtained by mixing in a two stage process to firstly form an emulsion of the fat in the water and then to add flour. Applied energy in the first stage mixing can be high and take a longer time than in second stage because it contributes to good dispersion and provides interaction of ingredients by promoting water absorption. The second mixing stage, where flour is added, is very short to preclude developing the gluten. According to investigation conducted by Edwards (2007), the results are like obtaining a satisfactory emulsion in the first stage but avoiding gluten

Table 1.1: Comparison of Types of Biscuits (Cauvain & Young, 2008)

	Crackers	**Semi-Sweet**	**Short Dough (High Fat)**	**Short Dough (High Sugar)**	**Soft**	**Wafer**
Added water in dough	33%	21%	2-3%	2-3%	15%	140%
Moisture in biscuit	3-4%	1-2%	2-3%	2-3%	3+%	1-2%
Critical ingredients	Flour	Flour	Fat	Fat and sugar particle size	Fat and sugar particle size	Flour and batter
Dough piece forming	A	A	B,C,D,A	B,C,D,A	C,B,D,A	E
Baking Time (minutes)	3	5-6	15-25	6	12+	1.5-3

development in the second stage.

Baking process causes certain chemical and physical changes in cookie. At first, any gases including air and carbon dioxide due to the effect of leavening agent will expand which results in the expansion of cookie. Water will be converted into steam, also causing cookie to expand. Moreover, with the effect of high temperature, proteins will denature and starch will start to gelatinize which causes setting structure of cookie. Furthermore, Maillard reaction occurs because of the interaction between proteins and reducing sugars on the surface and will spread to the interior of cookie as the interior of it is heated (Edwards, 2007). Also, baking process continues with the physical changes in cookie appearance such as discoloration of product. During baking process, water loss in the cookies will be observed and the moisture content of cookies will have a significant effect on obtaining crispy cookie structure and having longer shelf life. All the cookies have water content of 4% at the end as Bourne (2002) stated in his book. Because they have low final water content, cookies can be stored for very long times. Additionally, according to Cauvain and Young (2008), fat rancidity can occur in cookies as a result of long storage time and low moisture content of cookies.

1.1.1 Cookie Ingredients

Cookie formulation is generally composed of flour, sugar, fat, milk powder, leavening agent, salt and water while some formulations may also include eggs, flavor ingredients and nuts, fruits.

However, cookie formulation includes three major components, i.e. flour, sugar, and fat. Sugar-snap cookie typically consists of 47.5–54% flour, 33.3–42% sugar and 9.4–18% fat (Bram et al., 2008). Since each component has functions on the quality of cookie and its dough, any slight change in the amounts and ratios of all ingredients, especially these principal ones, affects significantly final cookie quality and its dough quality. Consequently, it is an important point to provide a balance in cookie formulation; thus, there are many cookie formulations and procedures in cookie production. Therefore, it is necessary to know the functions of cookie ingredients and to provide a proper balance in formulation to be able to obtain cookie with desirable quality.

1.1.1.1 Flour

Flour is a significant component in cookie production; consequently, types and treatments of flour gain huge importance on obtaining good quality cookie at the end.

Table 1.2: Comparison of Flours in Bread and Biscuits (Edwards, 2007)

Property	Bread Flour	Biscuit Flour
Protein	High	Low
Starch damage	High	Low
Dough extensibility	Low	High
Dough resistance	High	Low
Wheat	Hard	Soft
Flour treatment	Oxidizing agent	Reducing agent

As shown in Table 1.2, flours used in bread and cookies are compared and flour used in the cookie production has low protein and starch damage by contrast with bread flour. Also, soft wheat flour is preferred in the production of cookie. For cookie, high dough extensibility is preferred while dough resistance in cookie is not desirable (Edwards, 2007).

Flour consists of proteins, carbohydrates, lipid and fiber. Mostly, proteins and carbohydrates among its compositions play distinctive role on the flour quality, rheological property of dough and textural quality of final baked product. Major ones of flour proteins are gliadins and glutenins, responsible for development of gluten network that forms the structure of dough; consequently affects the rheology of dough. In addition to function of proteins, the study conducted by Bram et al. (2008) concluded that higher gluten levels decreased dough piece weight, its density, stickiness and hardness.

Also, starch among carbohydrates in the flour mostly comes into prominence because of the its water absorption ability that enables damaged starch to gelatinize. However, starch gelatinization may occur depending on the availability of water in dough because there is a water competition among sugar, proteins and starch.

Furthermore, water binding property of flour is an important issue for the production of cookie having low moisture content. Thus, flour type which is soft white wheat flour, consisting of low protein content and low damaged starch due to their hydrophilic property is mainly preferred in cookie production (Edwards, 2007).

Furthermore, flour does not provide flavor to cookie; but affects texture, hardness and shape of cookies (Manley, 2000). According to Bram et al. (2008), quality of soft white wheat flour affects the diameter of cookie. Also, cookies in which soft wheat flour is used both show large spread and uniform surface cracking pattern (R. A. Miller & Hoseney, 1997).

1.1.1.2 Sugar

Sugar is one of the most important ingredients in cookie because it not only provides sweetness to the product but also gives nutritional value, improves texture, volume, appearance, color and affects moisture retention and viscosity. In addition to the effects of the structural and textural properties of cookies, sugar contributes to incorporation of air into the fat during cookie dough preparation (Wehrle et al., 1999).

According to Hoseney et al. (1994), throughout baking, the undissolved sugar progressively dissolves, and helps cookie spread. Moreover, Hoseney et al. (1994) states that during baking, sugar recrystallizes at the surface of cookie and that leads to typical surface cracking pattern. Furthermore, according to the study of Bram et al. (2008), level of sugar in the cookie dough is important issue because cookie diameter increases and its height decreases with increasing level sugar.

Apart from these properties of sugar, it has an important function on delaying the starch gelatinization temperature. It shifts the starch gelatinization point to a higher temperature thus allowing the dough more time to rise in the oven due to providing more time to gluten for its stretching (Manley, 2000) In addition, in the medium where water is limited, sucrose competes with the starch and gluten for water; thus, so little or no starch gelatinization is observed during baking (Sanchez et al., 1995). As stated in the thesis of Çıkrıkçı (2013), sugar has so many roles on the surface appearance, browning and spreading during cookie production.

There are some investigations of the effect of sugar on the quality of cookie and cookie dough in the study conducted by Maache-Rezzoug et al. (1998a). One of them is that increase in the sugar concentration in a cookie dough reduces its consistency and cohesion. Another study reveals the effects of sugar quantity and its grain size on biscuit spreading. That is, contribution of a fine grain size and a high concentration of sugar to a significant spreading of the biscuit is observed. Next study is interested in when the sugar is sufficiently available, sugar makes the dough softer during storage due to water holding capability of sucrose;

however, sugar in excess acts as a hardening agent due to its crystallization.

1.1.1.3 Fat

Many cookies and especially soft type cookies include large amounts of fat and fat improves texture, provides desirable eating quality, and affects flavor perception. Also, fat enhances aeration for leavening and makes more breakable cookie. Thus, fat is a crucial component for the cookies.

Many types of fats are used in bakery industry but in particular shortenings, partially hydrogenated oil, are widely preferred due to some providing advantages such as ease handling, higher melting point and longer shelf life (Kweon et al., 2010). Liquid shortening is often used. The use of a hydrogenated vegetable shortening is mostly suggested for increase in effectiveness at creaming stage (Matz, 1968).

Not only the type but also the amount of fat added to dough have a significant effect on the viscoelastic properties of the dough (Jacob & Leelavathi, 2007). However, the type of fat does not affect the cookie spread; but, the amount of fat does it (Kweon et al., 2010). Cookie diameter increases when more fat is added to dough (Pareyt et al., 2009). According to the result of study conducted by Pareyt et al. (2009), higher fat levels results in higher spread rate (diameter/thickness). As fat melts and and sucrose dissolves during baking, mobility in the system increases and system mobility can probably be related to increased mobility.

Moreover, increase in fat amount added to dough raises air incorporation at creaming stage; thus, cookie dough with lower density is obtained. Furthermore, higher fat level lower dough hardness (Pareyt et al., 2009; Maache-Rezzoug et al., 1998a) and reduce elastic properties (Pareyt et al., 2010). The effect of fat on elastic properties of dough has been related to lubrication, which limits the formation of a gluten network (Maache-Rezzoug et al., 1998a).

1.1.1.4 Non-fat Dry Milk

Milk powder is used in baked products for the purpose of color improvement, water absorption, and spread-control properties, flavor and nutritional value (Matz, 1968). Dried milk products are mostly preferred due to the convenience of use, their longer shelf life and minimum storage space and good stability at ordinary temperature (Matz, 1968).

Non-fat dry milk includes lactose sugar and proteins, casein, lactalbumin and lactoglobulin. One of the major proteins of milk is casein. Casein is the structure-forming, and water-binding protein and it results in the formation of porous structure in cookie and crackers. Additionally, the interaction casein with lactose results in browning reactions (Matz, 1968).

1.1.1.5 Salt

Salt is used in baked products as preservative, which contributes to longer shelf life. Moreover, it advances flavor of other ingredients in the cookie. It also influences the solubility of proteins (Çıkrıkçı, 2013). Furthermore, gluten network formation is affected by the salt level in dough (Cauvain & Young, 2008).

1.1.1.6 Leavening agent

In baking industry, ammonium bicarbonate, sodium bicarbonate and baking powder are mostly used as chemically leavening agent. During decomposition of sodium bicarbonate, carbon dioxide is produced during mixing process since it reacts with an acid and then, during baking, heat contributes to release carbon dioxide (Çıkrıkçı, 2013). The thermal decomposition mechanism is the following reaction:

$$2\,NaHCO_3 + \text{Heat} \longrightarrow Na_2CO_3 + CO_2 + H_2O$$

Leavening agents are mainly inorganic salts and when added to dough, they produce carbon dioxide which contributes to development of texture of cookie during baking (Manley, 2000). Sodium bicarbonate has popularity as a gas source because it has some favorable properties such as low cost, lack of toxicity, ease of handling, relatively tasteless end products, and high purity of commercial product (Matz, 1968).

Moreover, using sodium bicarbonate in cookie dough is because of adjusting pH of dough. In addition to its advantages, its solutions are prone to be less alkaline. If too much sodium bicarbonate is used, the cookie is excessively alkaline, cookie will appear in a yellow color and have unpleasant taste (Edwards, 2007).

1.1.1.7 Water

Water is a solvent for sugar, salt, leavening agent, non-fat dry milk and other dry ingredients and regulates moisture content in the final product (Çıkrıkçı, 2013). It hydrates the flour proteins and gelatinizes starch that contributes to form structure of cookie. Adding water to dough affects flavor, color, physical assets of baked products (Matz, 1968). Water used in formulation of cookie is removed during baking; however, according to Manley, the effects of water continue on cookie quality because it provides steam that leaven the product (Archilla, 1999). Also, the water content of final product influence eating quality and shelf life.

1.1.2 Dough Quality

In cookie making, the main ingredients are flour, water, sugar, fat, fat mimetics, emulsifier, salt etc. The dough quality and cookie quality are governed by the nature and quantity of the ingredients used.

Flour consists of moisture content, proteins, carbohydrates, lipid and fiber. Mostly, proteins and carbohydrates among its compositions play distinctive role on the flour quality, rheological and textural property of dough. Major ones of flour proteins are gliadins and glutenins, responsible for development of gluten network that forms the structure of dough; consequently affects the rheology of dough. In addition to function of proteins, the study conducted by Bram et al. (2008) concluded that higher gluten levels decreased dough piece weight, its density, stickiness and hardness. Moreover, higher gluten level causes decreasing cookie spread.

The study conducted by Petrofsky and Hoseney (1995) showed that hard wheat gluten doughs had low G' and G" values, indicating a possible less starch-gluten interaction and vice versa. Also, the G' and G" increased when proteins were added in the formula (flour and water), if the water concentration was kept constant (Maache-Rezzoug et al., 1998a).

Sugar improves texture,volume, appearance, color and affects moisture retention and viscosity. Sugar also contributes to incorporation of air into the fat during cookie dough preparation. Furthermore, according to the study of Bram et al. (2008), level of sugar in the cookie dough is important issue because cookie diameter increases and its height decreases with increasing level sugar. According to Olewnik and Kulp (1984), increase in the sugar concentration in a cookie dough reduces its consistency and cohesion.

The fat contributes to the plasticity of the dough and as a lubricant. Also when mixed with the flour before its hydration, the fat prevents the formation of a gluten network and produces a less elastic dough (Maache-Rezzoug et al., 1998b). Fat affects the dough machinability during process and the spread after cutting-out. Moreover, increase in fat amount added to dough raises air incorporation at creaming stage; thus, cookie dough with lower density is obtained. Furthermore, higher fat level lower dough hardness (Pareyt et al., 2009; Maache-Rezzoug et al., 1998a) and reduce elastic properties (Pareyt et al., 2010). The effect of fat on elastic properties of dough has been related to lubrication, which limits the formation of a gluten network (Maache-Rezzoug et al., 1998a).

Water is a solvent for sugar, salt, leavening agent, non-fat dry milk and other dry ingredients and regulates moisture content in the final product (Çıkrıkçı, 2013). It is necessary for hydrating proteins and carbohydrates that contributes to form structure of cookie by gelatinizing starch and for the development of a gluten network (Maache-Rezzoug et al., 1998a). Water has a complex role, since it determines the conformational state of biopolymers, affects the nature of interactions between the various constituents of the formula and contributes to dough structuring (Eliasson & Larsson, 1993). It is also an important parameter for rheological property of doughs (Webb et al., 1970). According to the study conducted by Hibberd (1970), the elastic (G') and loss (G") modulus are reduced when the water content is increased. Similarly, the study of (Maache-Rezzoug et al., 1998a) showed that adding water to the formula reduced the viscosity and increased dough extensibility. Rheological properties strongly depend on water content of dough (Milašinović Šeremešić et al., 2013). The result of study conducted by Hardt et al. (2014) shows that increasing water content of dough reduces both elastic and viscous moduli in dynamic oscillation measurements.

As in further example, Witczak et al. (2010) studied on the effects of maltodextrins on gluten-free dough and quality of bread and their result is that increasing level of maltodextrin in dough causes decreasing value of storage and loss moduli.

1.1.2.1 Rheology of Cookie Dough

Rheology is expressed as the study of the deformation and flow of matter (Bourne, 2002). It measures the relationships between stress, strain and time. Rheological measurements are composed of a strain (deformation) or a stress analysis at a constant frequency combined with a frequency analysis between 0.1 and 100 Hz.

Elastic materials have the inclination of solid materials and when the force is applied on them, they store all applied energy in materials to be able to return to their original shape whereas viscous materials have a very large resistance to motion or flow; thus, they are thick or sticky or adhesive and also, all energy added to viscous materials is dissipated into heat. In the light of these materials, Bourne defines the viscoelastic materials which exhibit some of the elastic properties of an ideal solid and some of the flow properties of an ideal liquid (Bourne, 2002) when exposed to deformation.

The energy stored in the material to recover itself when stress is applied is decided by the parameter of elastic modulus (G') while the energy dissipated into heat shows viscous modulus (G"). Storage (or elastic) modulus G' is defined as the stress component in phase with the shear strain (Bourne, 2002). On the contrary, the stress component 90 °out of phase with the shear strain is defined as the loss (or viscous) modulus G" (Bourne, 2002). If G' is significantly bigger than G", the dough shows predominating solid like behavior. Consequently, by comparing G' and G", information about viscoelastic properties of materials is reached and this information is valuable for the final cookie quality.

Any change of ingredients can affect in rheological and textural properties of cookie. Rheological properties strongly depend on water content of dough (Milašinović Šeremešić et al., 2013). Increase in water content of dough reduces both elastic and viscous moduli in dynamic oscillation measurements (Hardt et al., 2014). As in further example, Witczak et al. (2010) studied on the effects of maltodextrins on gluten-free dough and quality of bread and their result is that increasing level of maltodextrin in dough causes decreasing value of storage and loss moduli. Also, particle size of ingredients is another important point for the texture and rheology of product. For instance, Ahmed's study (2014) results in that particle size of beta-D-glucan has strong effect on the rheology of dough and dough indicates a predominating solid-like behavior.

1.1.3 Cookie Quality

Water binding property of flour is an important issue for the production of cookie having low moisture content. Thus, flour type which is soft white wheat flour, consisting of low protein content and low damaged starch due to their hydrophilic property is mainly preferred in cookie production (Edwards, 2007). Furthermore, flour does not provide flavor to cookie; but affects texture, hardness and shape of cookies (Manley, 2000). Quality of soft white wheat flour affects the diameter of cookie (Bram et al., 2008). Also, cookies in which soft wheat flour is used both show large spread and uniform surface cracking.

The effects of sugar quantity and its grain size on biscuit spreading were studied by Maache-Rezzoug et al. (1998a). They concluded that a fine grain size and a high concentration of sugar contribute to a significant spreading of the biscuit.

Throughout baking, the undissolved sugar progressively dissolves, and helps cookie spread (R. A. Miller & Hoseney, 1997). Moreover, he thinks that during baking, sugar recrystallizes at the surface of cookie and that leads to typical surface cracking pattern. Apart from these properties of sugar, it has an important function on delaying the starch gelatinization temperature. It shifts the starch gelatinization point to a higher temperature thus allowing the dough more time to rise in the oven due to providing more time to gluten for its stretching (Manley, 2000). In addition, in the medium where water is limited, sucrose competes with the starch and gluten for water; thus, so little or no starch gelatinization is observed during baking (Sanchez et al., 1995). As stated in the thesis of Çıkrıkçı (2013), sugar has so many roles on the surface appearance, browning and spreading during cookie production.

Cookie diameter increases when more fat is added to dough (Pareyt et al., 2009). According to the result of their study, higher fat levels results in higher spread rate. As fat melts and and sucrose dissolves during baking, mobility in the system increases and system mobility can probably be related to increased mobility. Cookie density decreases when fat levels increase (Maache-Rezzoug et al., 1998a) because more air is incorporated at the dough stage and expansion of the gas cells during baking is more pronounced (Pareyt et al., 2009). Cookie diameter increases when more fat is used in the formula.

If the proportion of water is too low, the dough becomes brittle, not consistent, and exhibits a marked crust effect due to rapid dehydration at the surface. Adding water to dough affects flavor, color, physical assets of baked products (Matz, 1968). Water used in formulation of cookie is removed during baking; however, the effects of water continue on cookie quality because it provides steam that leaven the product (Archilla, 1999). Also, the water content of final product influence eating quality and shelf life.

According to a study conducted by Conforti et al. (1996) on several fat replacers in cookies, increase in fat replacement resulted in increases in moisture content, color lightness and a decrease in tenderness of the product. The other major effect of an increase in fat replacement in cookies were increases in water activity and hardness (Zoulias et al., 2002). Moreover, preceding study about fat replacers showed that polydextrose, maltodextrins, and Simplesse are the most convenient ones among carbohydratebased fat mimetics in terms of properties of cookies even they results in high hardness cookies (Zoulias et al., 2002). Sudha, Srivastava, et al. (2007) stated that the effects of maltodextrin and polydextrose on the biscuit hardness. Also, Gallagher et al. (2003) studied on the development of reduced fat biscuits with the utilization of sugar and fat replacers and on their effects of biscuits on dimensions, color, and texture.

1.1.3.1 Texture of Cookie and Cookie Dough

Food textural properties are measured with the compression testing method using a mechanical texture analyzer. Compression test is conducted in two bite tests because of the imitation of mouth's biting action by texture analyzer. With this way, hardness, cohesiveness, adhesiveness, springiness, fracturability, brittleness etc. can be quantified.

Hardness is expressed as peak force in the first compression of product. Cohesiveness is defined that how well the product resists a second deformation relative to how it behaved under the first deformation, (Area 2/Area 1). Adhesiveness is explained as the different molecules or surfaces to cling to each other. Springiness is defined by how well a product goes back after deformed under the first compression.

There are many cookie procedure and formulation; thus, there is no one exact cookie type, i.e., there is no one right texture and many different types of textures are revealed (Bourne, 2002).

1.2 Consumption of Fatty Foods and Health Effects

The consumption of bakery products compels people to increase their daily fat intake which has been suggested to be less than 30% of total calorie intake in a day according to the U.S. Public Health Service (Sanchez et al., 1995).

Therefore, for a long time, consumption of large amount of fat through foods, in particular bakery products has become a dietary concern.

In the USA and most European countries, people gain nearly 40% of total calorie intake from daily fat consumption; while according to views of health professionals, daily fat consumption ought not to exceed 30% total calories in diet (Zoulias et al., 2000). The similar problem that is consumption of bakery products has been encountered in India. Indian people consume too much bread, cakes, pastries, and biscuits; consequently, most significant part of total calorie intake coming from bakery products is comprised by daily fat consumption, as well (O'Brien, 2008). As in many parts of the world, in Turkey, consumption of foods having high fat content, especially bakery products is quite high, too.

Additionally, excessive daily fat consumption results in various types of health problems such as the incidence of obesity, high blood cholesterol. According to Akoh (1998), high fat intake is associated with various health disorders such as obesity, cancer, high blood cholesterol, and coronary heart diseases, too. Thus, because of adverse effects of excessive dietary fat intake, many people have started to be aware about consuming fat. As O'Neil (1993) told before, the awareness of consumers induces the reduction of fat amount in their diet. G. D. Miller and Groziak (1996) also are of the same opinion with O'Neil, which is health conscious individuals altering their dietary habits and eating less fat. Likewise, the Third National Health and Nutrition Examination Survey (NHANES III) conducted in 1988-1991 indicates that there are 2%-reduction in daily fat intake of total calories from 36% to 34% of daily calories among American people as compared to survey (NHANES II) conducted in the years of 1976-1980 (Sanchez et al., 1995).

As the consumers become conscious in terms of health and nutrition, their tendency to reduced or low-fat foods has gradually increased and reduced or low-fat foods have gained gorgeous reputation. As a result, food industry has started to response to consumers' demands by putting various types of reduced or low-fat foods on the shelf of markets. Thereby, even fat has a crucial role in baking industry, efforts to reduce fat content of food products and to use various fat replacers in the place of fat have existed (Sudha, Srivastava, et al., 2007). The only way to succeed the goal of obtaining reduced or low-fat foods is that foods are modified by using fat substitutes (Sanchez et al., 1995); thus manufacturers have started to search for ideal fat replacers that taste and function like conventional fat without potential health risk (Akoh, 1998). Therefore, for food industry, fat replacement for many foods having high fat content, particularly bakery products, has already become irrevocable even the replacement of fat in the food systems leads to complexities with respect to gaining sensorial, textural, rheological characteristics provided by fats (Zoulias et al., 2000).

1.3 Functions of Fat in Baked Products

Fat is one of the major ingredients in cookie formulation since it has versatile functions for the product. In other words, fat component of cookie formulation has marked impact on the mechanical properties of cookies.

Fat provides flavor, mouth feel, taste and odor; it also makes a contribution to creaminess, appearance, palatability, texture and lubricity (Zoulias et al., 2000; O'Brien, 2008). Besides, there is an opinion that the types and amounts of fat affect flavor, texture and appearance of baked products (Sanchez et al., 1995). For instance, according to the conducted study, during mixing stage of dough, fats have the ability of entrapping and retaining air whereas liquid oils are dispersed into dough as in the fat particules and creamy form is not obtained well (Hartnett & Thalheimer, 1979). Thus, obtained dough do not have sufficient aeration property that influence the texture, appearance of cookie. Moreover, types and levels of fats have an significant effect on the rheological properties of cookie dough (Manohar & Rao, 1999). Fat also includes lipophilic flavor compounds that serve as a precursor for the development of flavor and stabilization of flavor (Tamime et al., 1999; Romeih et al., 2002). Unlike protein and carbohydrate, fat provides 9 kcal/g energy to diet.

As a consequence, since fat has functional properties that affect processing and eating quality of foods, these functions must be considered when fat level in the product is lowered (Napier, 1997).

1.4 Reduction of Fat in Cookies/Baked Products

Fat is the crucial component for bakery products, especially cookies because any changes in the amount of fat give rise to some alters in the sensorial, textural and rheological properties of the cookie.

There are many investigations and studies about the effect of fat reduction on the cookie quality. One of them belongs to Sudha, Srivastava, et al. (2007), which concludes that the spread of cookies reduced significantly and the thickness of them increased when fat level in the formulation was sufficiently reduced. Also, decrease in fat level leads to good dispersion of fat into dough which is not to be an obstacle for the formation of gluten network. Gluten proteins can make an intensive interaction with each other with lower fat level than required one in cookie formulation that causes to increase in dough hardness and elasticity (Maache-Rezzoug et al., 1998a). Since well dispersed fat allows the generation of more gluten cross linkings during baking the breaking strength of cookie increases (Pareyt et al., 2010). Similarly, hardness of cookie is correlative behavior with the increase in the breaking strength of cookie when the reduction of fat level occurs (Sudha, Srivastava, et al., 2007). Moreover, stiffness of cookie dough significantly decreased with the reduction of fat (Baltsavias et al., 1997). Furthermore, cookies resulted in chewy texture and low moisture content when the fat content of dough is reduced (Sanchez et al., 1995).

1.5 Fat Replacers

There are many ingredients currently developed to replace fat in food products because of increase in fat consumption in the modern life. Many various components have been used as fat replacers in order to utilize the unique properties and qualities of each bakery products (Sudha, Srivastava, et al., 2007). Therefore, foods are reformulated with fat replacers as an alternative to high fat foods, providing some fat-like functions (Tarr & Bixby, 1995; Sipahioglu et al., 1999).

Fat replacers are the substances used in the place of fat in food products. They are classified into two groups as follows; fat substitutes based on lipid and fat mimetics commonly based on protein or carbohydrate.

Fat substitutes, generally called as lipid-based substitutes, resemble to triglycerides in terms of physical and chemical and theoretically replace fat in foods on a 1:1 basis (Akoh, 1998). In other words, fat substitutes have a chemical structure slightly close to fat and show physicochemical properties similar to fat (Lipp & Anklam, 1998; Peters et al., 1997). Since they include lipophilic flavors, they can enhance the taste of foods as at least fats. Additionally, many lipid-based fat substitutes protect their stability during cooking or frying. Also, they are usually either indigestible or contribute low calorie.

On the other hand, fat mimetics are distinctly different from fat in terms of chemical structure because they are protein- or carbohydrate- based substitutes. Fat mimetics can only imitate desirable eating qualities or functional properties of triglycerides, but cannot replace fat on a gram-for-gram basis (Zoulias et al., 2000). As parallel to this opinion, Johnson (2000) states that fat mimetics have various functional properties that make an imitation of some physiochemical and sensorial properties of fats such as viscosity, mouthfeel, appearance. For fat mimetics, high temperatures are not convenient that results in denaturation or caramelization; so they cannot be used for frying but they are suitable for baking and retorting because they bind excessive water by adsorbing it (Akoh, 1998). Also, they include water-soluble flavors not lipid-soluble flavor compounds. Fat mimetics give the caloric value in the range of 0-4 kcal/g to food.

1.5.1 Lipid-Based Fat Substitutes

Lipid-based fat substitutes are macromolecules and either chemically synthesized to obtain structures similar to triglycerides or derived from triglycerides by enzymatic modifications (Giese, 1996).

There are many fat substitutes; but, some of them are very popular in food industry which are more studied and publicized than the others.

The most known one of them is Olestra. It is obtained by the transesterification or interesterification of sucrose composed of more than 16 carbons long chain fatty acids that isolated from fats and oils (Akoh, 1998). It has a large size and number of fatty acids that prevent its hydrolysis by lipases; thus, it cannot absorb from gastrointestinal tract.

On the other hand, Salatrim is smaller molecule as compared to Olestra because salatrim consists of the mixture of long- and short-chain fatty acids that esterified to a glycerol backbone (Archilla, 1999). It provides 5 kcal/g.

Besides, emulsifiers are commonly used in many food products such as margarines, baked products, frozen desserts, dairy products. According to Sipahioglu et al. (1999), they also provide and stabilize aeration, provide lubricity, complex with starch, interact with protein, modify the crystallization of other fats, promote and stabilize foam, control syneresis and control rheology.

1.5.2 Protein-Based Fat Substitutes

Protein-based fat substitutes are derived from various protein sources containing milk, egg, whey and wheat gluten proteins etc. Some of them are microparticulated (sheared under heat) to form microscopic round particles that make an imitation of mouthfeel and texture of fat (Akoh, 1998). They are generally used in dairy products. Additionally, they are not sufficiently heat stable, leading to denaturation of protein thus, they are not preferred for frying but they are used as an ingredient in foods that are subject to cooking, retorting and ultra-high processing (Akoh, 1998).

The most well-known of protein-based fat substitutes is Simplesse. Simplesse, given GRAS status, is obtained from whey protein concentrate through microparticulation process. It is not suitable for fried products but used in baked goods, salad dressing, mayonnaises, margarine, soup. Its caloric value on dry basis is 4 kcal/g while its calorie value is reduced to 1 kcal/g in hydrated gel form.

1.5.3 Carbohydrate-Based Fat Substitutes

For several years, carbohydrate-based substitutes, produced from cereal, grain and plants, have been used in foods to partially or fully replace fat because of exhibiting the similarity with the properties of fat due to binding water in terms of lubricant or flow in some food systems. Many are used as thickener and gelling agent in foods whereas some provide texture, mouth feel, and opacity (Giese, 1996). They form gel type structure by binding water and that results in lubricant and flow properties of similar to those of fat (Chugh et al., 2013). Additionally, desirable texture is obtained with using this type of fat mimetics and it do not form an obstacles in terms of toxicological potential (Chugh et al., 2013).

Some of them are digestible, giving 4 kcal/g energy while some are nondigestible, giving few calories. Some examples of these mimetics are polydextrose, pectin, cellulose, gums and starch derivatives (modified starches, dextrins).

Polydextrose, partially digestible carbohydrate, is one of the most preferred fat mimetics in food industry. Polydextrose is produced as a result of the random polymerization of glucose, sorbitol, citric acid and phosphoric acid (Archilla, 1999).

Gums, hydrophilic colloids, are negatively charged carbohydrates and have high molecular weight due to long chain polymers of monosaccharides. They are used as thickeners, stabilizers and gelling agents in food industry because they can easily dissolve in water.

Cellulose derivatives, which are powdered cellulose, microcrystalline cellulose, and sodium carboxymethylcellulose, methylcellulose and hydroxypropyl methylcellulose, are obtained by three types of processing as following: mechanical grinding, chemical grinding and wet mechanical disintegration and chemical derivitization (Archilla, 1999).

Pectin is a dietary fiber and is obtained from citrus peel and table sugar (Napier, 1997). They are composed of partial methyl esters of galacturonic acid and the percentage of methyl-esterified galacturonic acid units differs that leads to gaining different properties of pectin such as, gelling, dissolving in a water (Cho, 1999).

1.6 Carbohydrate-Based Fat Mimetics, particularly Maltodextrin, in Baked Products

Carbohydrate-based fat mimetics are frequently employed in baked products because of their imitation of fat functions. There are many studies about application of carbohydrate-based fat replacers in baked products and their effects on them. For instance, Sudha, Srivastava, et al. (2007) stated that the effects of maltodextrin and polydextrose on the biscuit hardness. Also, Gallagher et al. (2003) studied on the development of reduced fat biscuits with the utilization of sugar and fat replacers and on their effects of biscuits on dimensions, color, and texture.

Several carbohydrate-based fat mimetics have been employed to partially replace fat in cookies as well as in other bakery products. According to study of Freeman using polydextrose in cakes, brownies and chocolate cookies resulted in acceptable products having one third lower calories (Zoulias et al., 2000). However, some experiments indicated that 35% of fat substituted by polydextrose and some starch-based fat substitutes has at least adverse effects on physical properties of cookie as compared to 45% or 55% fat replacement (Sanchez et al., 1995).

Also, preceding study about fat replacers showed that polydextrose, maltodextrins, and Simplesse are the most convenient ones among carbohydrate-based fat mimetics in terms of properties of cookies even they results in high hardness cookies (Zoulias et al., 2000).

Additionally, experimental results of Inglett et al. indicated that there is no significant difference between the case where 50% of fat are replaced with beta-glucan and amylodextrins derived from oat flour and the case of full-fat ones and also product quality is decreased at higher addition of beta-glucan and amylodextrins (Chugh et al., 2013).

1.6.1 Maltodextrin

Maltodextrin is one of the most popular carbohydrate-based fat replacers. Maltodextrin is a non-sweet hydrolysate and a bulking agent with no side reactions (Sudha, Srivastava, et al., 2007).

Maltodextrin that is a GRAS ingredient is produced by the acid (usually hydrochloric acid) or enzymatic (alfa-amylase) hydrolysis of a starch. Starch hydrolysates, maltodextrins, include alfa-D-glucose units linked primarily by (1-4) glycosidic linkages with a DE of less than 20 and a general formula of $C_{6n}H_{(10n+2)}O_{(5n+1)}$ as shown in the Figure 1.1 (Kennedy et al., 1995). On the other hand, starch hydrolysates with a DE higher than 20 are known as various types of syrups.

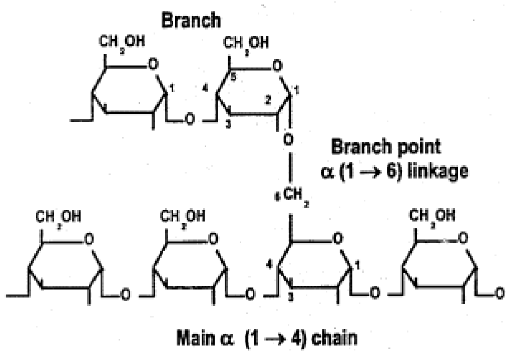

Figure 1.1: Chemical Sturucture of Maltodextrin (*TO: NDA 21-321, 7*, n.d.)

The average molecular weight and the degree of hydrolysis of maltodextrins alter to dextrose equivalence (DE) of 20; in other words, DE value of maltodextrin generally changes between 0 and 20. Dextrose equivalence of maltodextrin is described as a measure of reducing sugar content as glucose (Archilla, 1999). Consequently, DE value of maltodextrin increases, its molecular weight decreases.

Maltodextrins having different DE values show different physicochemical properties. More moisture absorption occurs with maltodextrin having higher DE (lower molecular weight) (Archilla, 1999). Additionally, the result of other study shows that the higher DE value is the higher solubility and sweetness are (Chugh et al., 2013). Similar to these views, as DE value increases, hygroscopicity, solubility, osmolality, and their effectiveness to reduce the freezing point rises whereas viscosity, cohesiveness, and coarse-crystal prevention increase with decreasing DE value (Dokic-Baucal et al., 2004; Y.-J. Wang & Wang, 2000). Even maltodextrins have the same DE value, they may show different properties since the production of maltodextrin, source of maltodextrin and amylose/amylopectin ratio of maltodextrin are different (Dokic-Baucal et al., 2004). In a brief, different or same molecular weights and DEs of maltodextrin give some functional properties to maltodextrin such as viscosity; binding, controlling water; and contributing smooth mouthfeel; building solid.

Additionally, maltodextrin shows characteristics similar to fat when water is available at sufficient level, forming gel-like matrix that results in lubricant and flow properties to product. This gel-like matrix results from the interactions between amylose fractions characterized by helical regions and branched linear chains of amylopectin molecules (Chronakis, 1998). Since maltodextrins are highly hydrophilic, they can form a gel; thus, they are preferable more for using in food industry as texture modifiers, thickeners, fat replacers.

Moreover, according to Chronakis (1998) since maltodextrins have a very small diameter (3-5 micrometer), they are similar to fat crystals, that results in fat-like behavior of maltodextrin. Therefore, maltodextrin can be used in obtaining emulsions as texture modifiers, bulking agents and especially in food emulsions to partially replace fat and is mostly preferred into fat-reduced food systems, especially used for the preparation of spread, margarine, salad dressing, baked goods, fillings, sauces and processed meat.

1.7 Emulsion

The aqueous phase of emulsion may contain water-soluble ingredients, including sugars, salt, acids, bases, surfactants, proteins and polysaccharides whereas the oil phase of one may contain lipids-soluble components, such as triacylglycerol, diacylglycerol, monoacylglycerol, fatty acids and vitamins (Akoh & Min, 2008). In food emulsions, interactions, resulted from a combination of covalent and physical interactions, among these ingredients give the final products physico-chemical properties such as appearance, stability, texture (Akoh & Min, 2008). Since the interaction between water and oil is unfavorable due to strong hydrogen bonding capability of water molecules with other water molecules but not with oil molecules, energy is required to keep together them in a food system (Akoh & Min, 2008). In other words, by forcing two different phases to hold together that increases the surface area between oil and water phases, thermodynamically unstable emulsions are obtained as shown in the Figure1.2 (Akoh & Min, 2008).

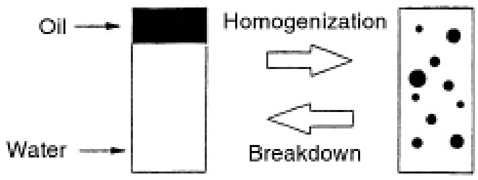

Figure 1.2: Emulsions are thermodynamically unstable systems (Akoh & Min, 2008).

1.7.1 Homogenization with High-Speed Blenders and Micro-Fluidization Process

The process in which emulsion is obtained from two immiscible liquids is called as homogenization. This process is conducted by mechanical device named as homogenizer.

In the preparation of emulsion, it is more effective to divide homogenization into two steps as seen from Figure 1.3. In first homogenization step; preparation of emulsion from two separate phases is referred to primary homogenization; on the other hand, second step includes the reduction in size of droplets in the emulsion obtained in previous step and is called as secondary homogenization (Akoh & Min, 2008). As a result, to create an emulsion, homogenization is necessary either in one step or in two steps due to the nature of oil and water.

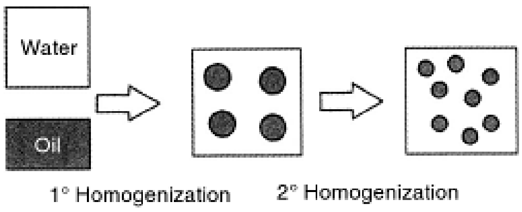

Figure 1.3: Homogenization process can be divided into two steps: primary homogenization and secondary homogenization (Akoh & Min, 2008).

1.7.1.1 High-Speed Blenders

High-speed blenders are employed for homogenization of the two immiscible liquids, oil and aqueous phase. The liquids in a few milliliters or several liters are put in a suitable container and mixed by stirrer at high speed for a while.

The size of the droplets in emulsion depends on homogenization time and rotational speed. As homogenization time and rotational speed increases, droplet size can decrease to lower limit of 2 micrometer. Thus, it can be said that with high-speed blender, droplet size is generally obtained between about 2 and 10 micrometer (McClements, 1998). Moreover, there is an issue requiring attention during using high-speed blender. While agitating with blender, blender generally rises temperature of the medium. Thus, controlling temperature of the medium may be necessary. As consequences, this type of blenders is useful for obtaining emulsions with low or medium viscosities.

1.7.1.2 Micro-Fluidization Process

Microfluidization process has been one of the novel technologies that help to preserve food quality and it has become a popular due to being applicable in wide industrial areas such as pharmaceutical, biotechnology, chemical, energy, and cosmetic as well as food industries.

This process provides stability and uniformity to products in addition to improving certain physicochemical properties such as texture and color of products (Çıkrıkçı, 2013). Because of its functional characteristics, it has been frequently preferred in many areas of food industry. Moreover, microfluidization treatment contributes to preserve and enhance the quality of food products with the help of high pressure up to 200 MPa. Products with higher consistency and smoother structure are obtained by reducing size of the particles (Çıkrıkçı, 2013).

Microfluidization process includes the combination of the forces of ultra-high pressure, high-velocity impact, high-frequency vibration, instantaneous pressure drop, intense shear, and cavitation in a very short time (Hu et al., 2011). These forces reduce mean diameter of droplets in dispersed phase of the emulsion resulting in more uniform distribution of foods (Pinnamaneni et al., 2003). Moreover, these forces lead to some changes in food products. Texture, color and sensory of foods are improved. Also, these changes affect the rheological and sensorial properties of food product (Ciron et al., 2011). Additionally, according to the study of T. Wang et al. (2012), the value of water holding capacity, swelling capacity, oil holding capacity and bulk density may change with such kind of processes. As the particle size is reduced by microfluidization, water holding capacity increases due to increase binding surface area of particles. Also, hydration properties of foods are important parameters in terms of their potential usage in food industry; thus, according to changes in hydration properties of foods, purpose of usage of foods may vary (Çıkrıkçı, 2013).

1.8 Objective of the Study

Recently, a high increase in the population consuming bakery products, critical adverse effects against human health resulted from these fatty foods and becoming conscious about the consumption of high caloric foods have prompted food manufacturers to reduce the fat level in foods and to develop the replacement of fat with alternative ingredients. Therefore, in this study in the place of fat, maltodextrin (DE18), which is often used in bakery products and provides the properties given by fat to product, was preferred.

Maltodextrin has the capability of contributing smooth mouth-feel like fat, controlling water and body building; thus, as long as sufficient water is available in the medium, MD18 forms gel-like matrix resulting in the structure of product.

Consequently, it influences the texture of the product. Thus, in this research, percentage of fat was reduced by 25% and in the place of fat, both MD18 (0 %, 3.75%, and 7.5%) and water (7.5%, 3.75%, and 0%) with changing percentages were employed for obtaining maltodextrin-water solution that was used in cookie formulation. Thereby, the purpose of this study was to investigate the effects of maltodextrin with various percentages on the rheological and textural properties of cookie and its dough. Because texture and rheology of product are important parameters in terms of quality, it was aimed to compare textural and rheological properties of cookie samples in this study.

Another objective of this study was to investigate the effects of microfluidization, which was used for obtaining emulsions, on the rheological and textural properties of cookie and its dough from bakery products.

Lastly, the third objective of this study was to examine the impacts of utilization of different types of fats in cookie formulation on the properties of both cookie and cookie dough. Palm olein (PON) and palm stearin (PS) types of fat were used in the experimental studies conducted throughout the thesis. The same procedure was followed in the preparation of cookie dough with both types of fats.

CHAPTER 2

METHODS & MATERIALS

2.1 Materials

Wheat flour, sugar, non-fat dry milk (NFDM), baking powder (sodium bicarbonate) and salt were taken from Ulker Biscuit Industry Co. Inc. (Ankara, Turkey). Two types of shortenings, Palm Olein (PON) and Palm Stearin (PS), which were used in the cookie production and carbohydrate based fat replacer, Maltodextrin (DE=18), were received from Sunar Co. Inc. (Adana, Turkey). Polyglycerol polyricinoleate emulsifier was purchased from Danisco Foreign Trade Co. Ltd. (Istanbul, Turkey).

2.2 Methods

2.2.1 Preparation of Control Cookie Doughs

All cookies were prepared according to standard AACC Method 10-52 - Micro Sugar-Snap Cookies. The control cookie recipe based on 100 g wheat flour consisted of 60% sugar, 3% non-fat milk powder, 2.5% sodium bicarbonate, 30% fat - Palm Olein (PON) - Palm Stearin (PS), 0.47% salt, 21.75% water as shown in Table 2.1.

For the preparation of control cookies, firstly, sucrose, non-fat milk powder and sodium bicarbonate were mixed with Kitchen Aid Mixer. After mixing dry ingredients, PON/PS, which had been stored at room temperature or melted

Table 2.1: Control Cookie Dough Recipe-AACC Method 10-52 - Micro Sugar-Snap Cookies

Ingredients *Based on 100 g wheat flour*	**Weight percentage (%)**
Sugar	60
Non-fat milk powder	3
Sodium bicarbonate	2.5
Fats-(Melted or not)PON/PS	30
Salt	0.47
Total water	21.75

and cooled down to $20-25\,°C$, was added to dry mixture and mixed to obtain creamy phase. To ensure good interaction between sugar and fat, mixing was conducted in three steps. Initial mixing was done at low speed- at 2nd level of Kitchen Aid Mixer - for 1 min, then mixing continued at medium speed- at 4th level of it - for 1 min and finally at high speed- at 6th level of it - for 20 seconds. Then, water and salt were added to creamy mixture and mixed again at medium speed- at 4th level of the mixer- for 3 min to get a smooth cream. Later, flour was poured into cream, followed by 180 seconds of mixing and mixed at medium speed- at 4th level of the mixer - for 25 seconds to get the control cookie doughs which were denoted as PON/PS. Also, doughs were obtained from melted PON and melted PS, named as Melted PON and Melted PS, respectively. Doughs were scraped from the bowl and the temperature of doughs was measured as 20 ± 2°C. After that, doughs were divided into two. The half of the doughs were used for experimental analysis within the day whereas other half were wrapped up with aluminum foil and stayed in the refrigerator at +4°C for 7 days for the purpose of making a cookie after 7-days storage. Thus, these 7-days stored doughs would be named as 'PON day7' and 'MeltedPON day7' while remaining parts of doughs were named as 'PON day0' and 'MeltedPON day0' (Table 2.2).

Doughs, which would be used for analyses within the day, were sheeted between 6 mm thick gauge strips and cut into a round shape with the usage of 60 mm inside diameter cutter. At the end, round dough pieces were obtained and the rest of the pieces were left for using in experimental analysis. Then, dough

Table 2.2: Naming of Doughs According to Types of Fat Used in The Preparation of Control Cookie Dough

The day when experimental analyses were conducted	Names belonging to control doughs and cookies	
	Palm Olein (PON)*	Palm Stearin (PS)**
0th day	PON day0 MeltedPON day0	PS day0 MeltedPS day0
7th day	PON day7 MeltedPON day7	PS day7 MeltedPS day7

**Control cookie dough and its cookie contained palm olein fat type.*
***Control cookie dough and its cookie contained palm stearin fat type.*

pieces were weighed in the range of 20-25 g and round shaped doughs were transferred on baking tray. Round shaped doughs were baked at 180 ± 2°C for 5 min. After baking, cookies were removed from tray and placed on the batch to cool. Then, the cookies were cooled for 1 hour at room temperature and then, they were again weighed and noted for the study. Finally, the cooled cookies were packaged with zip lock bags.

To see the impact of different types of fat on the properties of cookie and its dough, the same procedure of preparation of cookie doughs was replicated with PS and MeltedPS, instead of PON and MeltedPON. While doughs that would be used in the cookie preparation within the day were called as PS day0 and MeltedPS day0, ones that would be stored in refrigerator during 7 days were denoted as PS day7 and MeltedPS day7 (Table 2.2). Experiments were conducted in triplicate for each type of cookie doughs.

2.2.2 Preparation of Cookie Doughs with Emulsified Fats

2.2.2.1 Preparation of Cookie Doughs without Microfluidization

To observe the effect of maltodextrin having dextrose equivalence of 18 (MD18) on the properties of cookie and its dough, percentage of PON/PS in the control cookie formulation was reduced by 25% and replaced with MD18 solution added to the cookie dough formulation using three different maltodextrin percentages

(0%, 3.75%, and 7.5%). Therefore, cookie doughs consisted of PON/PS in constant percentage of 22.5%, while they contained MD18 in 0%, 3.75% and 7.5% and added water in 7.5%, 3.75% and 0% respectively (Table 2.3). Thereby, dough types obtained by modified formulation were respectively called as PON1, PON2, PON3; PS1, PS2, PS3 with respect to their MD18 percentages present in the emulsions (Table 2.4).

Table 2.3: Modified Cookie Dough Recipe

Ingredients based on 100 g wheat flour	**PON1/PS1 %**	**PON2/PS2 %**	**PON3/PS3 %**
Sugar	60	60	60
Non-fat milk powder	3	3	3
Sodium bicarbonate	2.5	2.5	2.5
Salt	0.47	0.47	0.47
Water*	21.75	21.75	21.75
Fats (PON/PS)	22.5	22.5	22.5
MD18	0	3.75	7.5
Added Water**	7.5	3.75	0
Polyglycerol polyricinoleate	0.06	0.06	0.06

* *Water amount existed in the cookie dough formulation.*
** *Water amount was added to prepare MD-water solution.*

Table 2.4: Emulsion Formulation

Ingredients based on 100 g wheat flour	**PON1/PS1 %**	**PON2/PS2 %**	**PON3/PS3 %**
Fats (PON/PS)	22.5	22.5	22.5
MD18	0	3.75	7.5
Water	7.5	3.75	0
Polyglycerol polyricinoleate	0.06	0.06	0.06

According to the modified cookie dough formulation, 22.5% of PON/PS and fixed amount of emulsifier were added to mixture of sugar, milk powder and sodium bicarbonate. Mixing procedure was applied to obtain creamy form as in the control cookie preparation and then, water and MD18 with changing percentages and salt were added to cream. In other words, 0%, 3.75% and 7.5% of MD18 and respectively 7.5%, 3.75% and 0% water and constant 0.47% salt were added to obtain six types of doughs. Then, flour was poured into bowl and mixing as in the control dough recipe was continued. Finally, after doughs were obtained, half of each type of cookie doughs was wrapped up with aluminum foil to store in refrigerator for 7 days, which are denoted as PON1 day7, PON2 day7, PON3 day7, PS1 day7, PS2 day7, PS3 day7 and remaining doughs were employed in cookie making within the day, which are called as PON1 day0, PON2 day0, PON3 day0, PS1 day0, PS2 day0, and PS3 day0 according to their MD18 percentages (Table 2.5). Experiments were conducted in triplicate for each type of cookie doughs.

Table 2.5: Naming of doughs according to the percentage of maltodextrin

The day when experimental analyses were conducted	Names belonging to doughs and cookies	
	PON	PS
0th day	PON1 day0* PON2 day0** PON3 day0***	PS1 day0 PS2 day0 PS3 day0
7th day	PON1 day7 PON2 day7 PON3 day7	PS1 day7 PS2 day7 PS3 day7

**Cookie/Cookie dough containing palm olein fat type and 0% MD without MF process*
***Cookie/Cookie dough containing palm olein fat type and 3.75% MD without MF process*
****Cookie/Cookie dough containing palm olein fat type and 7.5% MD without MF process*

2.2.2.2 Preparation of Cookie Doughs with Microfluidization

In order to see how microfluidization process affected the properties of cookie and its dough, firstly, emulsions were obtained (Table 2.4). MD18 at 0%, 3.75% and 7.5% were dissolved in water at 7.5%, 3.75% and 0% respectively, at $40 - 45°C$ and gel forms were obtained by stirring (Table 2.4). Then, 22.5% of PON/PS, which had been melted before, was poured into each gel form of MD18 with 0.06% polyglycerol polyricinoleate. Ingredients were the same as in the Table 2.3, with only difference of using microfluidizer process (MF) and the order of steps in cookie making procedure. After that, six types of heterogeneous mixtures were homogenized for 10 min at 4th level of high-speed homogenizer (IKA T 18 digital ULTRA-TURRAX) as shown in the Figure 2.1a to successfully disperse water droplets containing MD in fat and to obtain homogenized emulsions.

(a) IKA T 18 digital ULTRA-TURRAX (*Lab Dispersing Devices*, n.d.)

(b) Microfluidizer (MF)

Figure 2.1: Homogenizer Instruments

Next, the emulsions were passed through high-pressure homogenizer, MF equipment (M-110Y, Microfluidics, USA) as seen from Figure 2.1b at 1000 bar and 60°C to obtain well-dispersed water droplets containing MD in emulsions resulted from micro and nano water-MD droplets.

As shown in the Figure 2.1b, microfluidizer had a container where fluid flowed and two parallel micro streams into which fluid was forced to split and flow by pressure. Then, these two micro streams were colliding with each other at extremely high speeds with the help of pressure. Formation of turbulence and shear were observed in these micro streams because of clash cavitations (Yuce, 2011). Consequently, not only high shear rate but also extreme impact forces resulting in the formation of fine particles were applied to micro streams (McCrae, 1994). Under these conditions, emulsions, which had been already prepared with high-speed homogenizer, were poured into input reservoir and pumped into the nozzles at 1000 bar. Microfluidized emulsions at nearly 60°C were collected from output reservoir. They were cooled down to $20 - 25$°C to be used in the preparation of cookie. After cooling step of microfluidized emulsions, they were used in the preparation of cookie doughs with the same procedure as in the control cookie dough formulation. While half of each doughs was stored at +4°C for 7 days, which are named as MF PON1 day7, MF PON2 day7, MF PON3 day7; MF PS1 day7, MF PS2 day7, MF PS3day7, remaining parts of doughs were utilized for making cookies, which are named as MF PON1day0, MF PON2day0, MF PON3day0; MF PS1day0, MF PS2day0, MF PS3day0 (Table 2.6). Each experiment was performed in triplicate.

Table 2.6: Naming of doughs according to the exposure of microfluidization process and the percentage of maltodextrin

The day when experimental analyses were conducted	Names belonging to doughs and cookies	
	PON	PS
0th day	MF PON1 day0* MF PON2 day0** MF PON3 day0***	MF PS1 day0 MF PS2 day0 MF PS3 day0
7th day	MF PON1 day7 MF PON2 day7 MF PON3 day7	MF PS1 day7 MF PS2 day7 MF PS3 day7

**Cookie/Cookie dough containing palm olein fat type and 0% MD with MF process*

***Cookie/Cookie dough containing palm olein fat type and 3.75% MD with MF process*

****Cookie/Cookie dough containing palm olein fat type and 7.5% MD with MF process*

2.2.3 Dough Analysis

2.2.3.1 Dough Rheology Analysis

Oscillatory rheological measurement of cookie dough samples was conducted by using TA rheometer (AR 200ex, Sussex, UK). After resting of 0-day doughs for 15 min, and after 7-days storage in refrigerator of doughs, both sample types were cut in a small standard circular form and were placed in 2 mm gap between the stainless steel plates with 20 mm diameter. All measurements were conducted at constant temperature of 20°C by using parallel plate geometry. Then, frequency sweep test, one of the dynamic (Oscillatory) tests, was conducted between 0.1 and 20 Hz under constant shear strain rate (0.2%) and constant selected temperature. Finally, the results of elastic (G’) and loss (G”) moduli of dough samples were obtained. Each rheological experiment was done three times.

2.2.3.2 Dough Texture Analysis

The physical properties of food products were usually tested by compression test revealing the textural properties of products such as hardness, springiness, fracturability, resilience, and other parameters. In this study, hardness and cohesiveness parameters of cookie dough were measured by the Texture Analyzer (The TA.XTPlus, England). The hardness, the peak force of the first compression, was usually seen at the point of the deepest compression of the product for most products (Bourne, 2002). On the other hand, the comparison of performance of the product under the second and the first deformation of the product gave the cohesiveness. It was measured as the area of work during the second compression divided by the area of work during the first compression (Refer to Area 2/Area 1 in Appendix B) (Bourne, 2002).

The textures of 0-day and 7-days cookie doughs were measured by the Texture Analyzer, using cylindrical probe with 1 cm diameter. With texture analyzer, hardness and cohesiveness of doughs were measured. Firstly, cookie dough was flattened in gauge strips having a thickness of 1 cm and cut to 3 cm diameter. Thus, all cookie dough samples had 3 cm diameter and 1 cm height. Then, round-shaped dough piece was placed on platform of texture analyzer for measurement. Movement of probe was adjusted 15 mm. After that, the measurement was conducted at 2 mm/s pre-test speed, at 2 mm/s test speed with 75% strain target mode which means that 75% of dough height was compressed by the probe. The probe continued compressing dough during 75 s, and finally returned back to its starting position. The measurements were performed in triplicate for each set. Finally, average of three results was taken and their texture profile analyses were conducted according to Bourne (1978) and hardness (1st bite), cohesiveness of doughs were measured.

2.2.4 Cookie Analysis

2.2.4.1 Cookie Texture Analysis

Both types of cookies, which were made by 0-day doughs and 7-day doughs, were measured in terms of hardness by using texture analyzer (The TA.XTPlus, England) at two times: the day when they were made, and after they were kept in zip lock bags for 7 days. 0-day and 7-days hardnesses (g) of cookies were evaluated considering the texture analyzer results. The cookies were placed on the platform of texture analyzer to be broken with the probe and the distance from the platform of the probe was adjusted in 10 mm just about return back to the position. To measure the hardness of cookies, break mode was chosen as a level; break detect was chosen as a return; and break sensitivity was adjusted as 10 g. Also, measurement was done at a 1 mm/s pre-test speed; at a 1 mm/s test speed and finally at a 10 mm/s post-test speed. Analysis was conducted for two cookies randomly chosen from each cookie set having triplicate.

2.2.4.2 Moisture Content Determination

In order to calculate moisture contents (%) of the cookies, the doughs were weighed and after baking (0th day) and storing in zip lock bag at room temperature for 7 days, cookies were also weighed. Then, the cookies put in an oven for 24 h. The temperature of oven was 103°C. Moisture contents (%) of cookie and dough samples were calculated based on dry weight basis.

$$Moisture\ content\ (\%)\ of\ dough = \{[W_{dough} - W_{oven\ cookie}] / [W_{oven\ cookie}]\} \times 100 \tag{2.1}$$

$$Moisture\ content\ (\%)\ of\ cookie = \{[W_{cookie} - W_{oven\ cookie}] / [W_{oven\ cookie}]\} \times 100 \tag{2.2}$$

2.2.4.3 Scanning of Cookie

In order to show the visual differences and similarities that were resulted from changing cookie formulation parameters which are shortening type, maltodextrin percentage and usage of micro-fluidization, cookies were placed on the glass of a scanner (CanoScan Lide 110, Tokyo, Japan).

2.2.4.4 Size Determination

In order to evaluate the change in size of diameter and height of cookies and to assess the effects of shortening type, percentage of maltodextrin and usage of micro-fluidization on the cookie size, Vernier caliper was used for all cookie types and their replications. For two samples chosen from each cookie set, diameter and height measurement with vernier caliper was done and three data were taken from one cookie.

2.2.4.5 Color Determination

For the color of the cookies, colorimeter (Cr-10, Konica Minolta, Japan) was used. CIE L^*, a^*, and b^* color scale was used. Total color change (ΔE) was calculated from the following equation;

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

White paper was chosen as the reference point and L_0, a_0 and b_0 which were 90, 2.5 and -7.6, respectively stood for its L^*, a^* and b^* values.

2.2.4.6 Statistical Analysis

Analysis of variance, ANOVA, was used ($p \leq 0.05$) for the analysis of experimental results through MINITAB (Version 16) software. ANOVA served the purpose of deciding if there was a significant difference among cookie and its dough sample types or not. If there was a significant difference in samples, means of samples were compared by the Tukey Single Range test ($p \leq 0.05$).

CHAPTER 3

RESULTS AND DISCUSSION

Emulsified fats were obtained with reduction of fat of dough by 25% and replacement of 25% of fat with maltodextrin in three different levels: 0%, 3.75%, and 7.5%, respectively either with or without microfluidization process to observe the effect at the first stage of mixing. Following that process, parts of the emulsified fats with three different percentages of maltodextrin were employed in the preparation of cookie dough. Dough (0-day dough) was analyzed at 0, 7 days of storage. Then, both 0-day and 7-day cookie doughs were examined in terms of the rheological and textural properties to investigate the effect of microfluidization process and maltodextrin effect. In other words, viscoelastic properties of cookie doughs were interpreted considering microfluidization process and levels of maltodextrin, at the same time hardness, cohesiveness of cookie doughs were also examined. The hardness of cookies prepared from 0-day and 7-day doughs were evaluated by changing the maltodextrin level employed, while the effect of replacement of fat by maltodextrin and the effect of microfluidization process on the moisture content of both cookie dough and cookie were evaluated. Finally, the impact of the microfluidization process and percentages of maltodextrin on color and the height and diameter of cookies were evaluated and the observations and experimental results were reflected within this study.

3.1 Dough Texture and Dough Moisture Content

The effect of maltodextrin (MD) and microfluidization process (MF) on both 0-day and 7-day dough hardness with PON was presented in Figure 3.1. 0-day and 7-day doughs made from PON and Melted PON showed the similar results in terms of hardness; in other words, there was no significant difference observed between PON and Melted PON doughs in terms of the 0-day and 7-day hardness by reference to ANOVA results ($p \leq 0.05$). Thus, the use of Melted PON during preparation of cookie dough did not significantly affect dough quality.

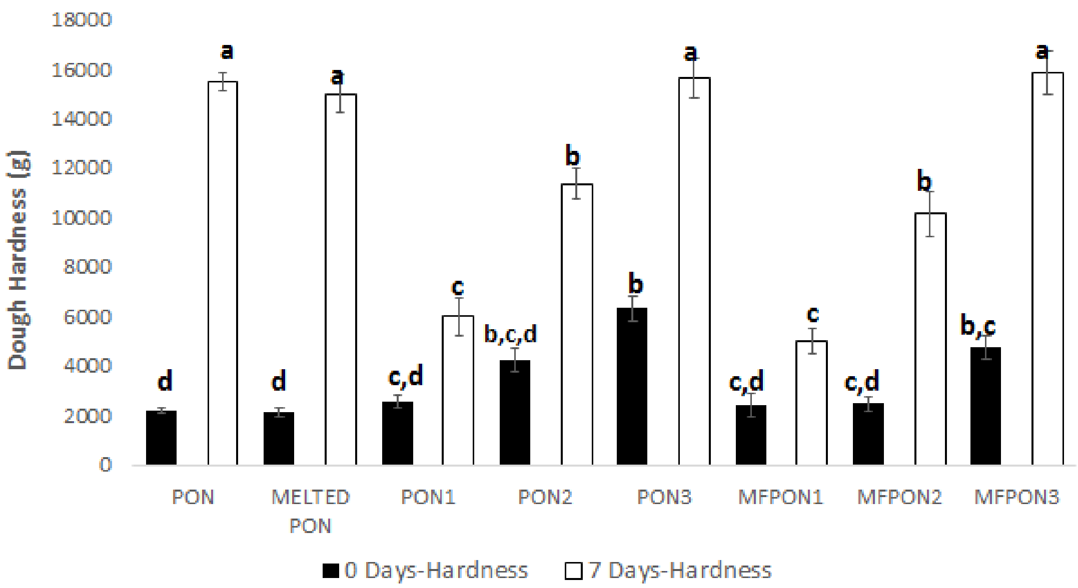

Figure 3.1: The Effects of MD and MF Process on the 0-day and 7-day Dough Hardness with PON

Dough including PON had nearly 2000 g 0-day hardness as a control group whereas 7-day dough hardness with PON is nearly 15500 g. There was a significant increase (61% max.increase in dough without MF, 68% max.increase in one with MF) on the hardness of 7-day doughs observed ($p \leq 0.05$). This increase could be explained with the fat crystallization during storage of dough for 7 days at refrigerator. During storage, the crystallization behavior changed crystal morphology and network structure of the system; thus, the final product could be affected in the same way, too (Tan & Man, 2002). Also, fat created a three-dimensional network, resulting in the increase in fat hardness (Hadnađev, Dokić, et al., 2011). Harder fat made cookie dough harder. As a result of this, the texture of product was highly affected by fat hardness.

The study of Sudha, Srivastava, et al. (2007) related low calorie soft dough biscuits, fat in the biscuit formulation was reduced from 20% (control) to 10%, 8%, and 6% levels, showed that the hardness of biscuit dough value increased when fat content in the biscuit formulation was reduced. In a parallel to this result, when doughs without MF process were compared, PON3 (including %7.5 MD) was not significantly different from PON2 (including %3.75 MD); but, higher from PON1 (including %0 MD) for 0-day hardness ($p \leq 0.05$). However, when 7-day hardness was considered, it was possible to observe that PON3 was significantly different from PON2 and PON1 shown in the Figure 3.1 ($p \leq 0.05$). Therefore, it could be inferred that increasing MD at %0, %3.75, and %7.5 percentages increased dough hardness (Figure3.1). This was an expected result because adding MD gel made the network more intense, leading to strengthen the structure of the dough. Moreover, these results were keeping with the findings by (Hadnađev, Hadnađev, et al., 2011) who showed that 15% fat replacement level with two types of maltodextrin gels lead to significant increase in firmness of product. In the study, it was also stated that viscoelastic property of product is affected by the addition of MD in the same manner, which leads to increase in elastic and viscous moduli by fat replacement as indicated in Section 3.2.

That is, fat replacement used in dough recipe increased the hardness of the dough (Hadnađev et al., 2014). The another study in which fat was reduced by 50%, 60%,and 70% and replaced with poydextrose (PD) and maltodextrin (MD) indicated that the RWAM (research water absorption meter) values showed that cookie dough containing MD or PD was harder than the doughs without MD or PD (Sudha, Srivastava, et al., 2007). Moreover,reducing fat by 25% could contribute to the increase in hardness and elasticity of dough because when less fat was present in the dough, gluten proteins could intensively interact with water and formed intensive network leading to strong structure (Pareyt et al., 2010). Furthermore, in the study related to fat reduced confectionery filling systems with 15 g/100 g MD gels and 20 g/100 g MD gels, textural measurement showed that reduced fat systems containing 15 g/100 g MD gels expressed higher firmness values in comparison to confectionery filling systems with 20 g/100 g MD gels. The reason might be lower water activity value of concentrated 20 g/100 g MD systems than 15 g/100 g MD gel which resulted in reduced water migration (Hadnađev et al., 2014). In the study of O'Brien (2008), similar result was found. According to this study, water uptake of flour, in presence of insufficient quantity of fat, would lead to dough hardness.

In addition to the effect of MD gel on the dough hardness, there was no significant difference in terms of hardness between cookie doughs with and without MF at different MD levels (Figure 3.1) when the effect of MF on hardness for 0-day and 7-day doughs was considered ($p \leq 0.05$). That is, MF did not have a significant effect on the dough hardness. However, MF process had more effect on the dough hardness as the MD% increased. On the other hand, decreasing effect of MF on the 0-day dough hardness could be seen at 3.75% and 7.5% of MD. For instance, at 3.75% of MD, MF process reduced dough hardness by almost 45% compared to dough without MF process and it had also reducing effect by 25% at 7.5% of MD because MF treatment formed smaller particles with the effect of high pressure (Higaki et al., 2001) which made dough softer.

The Figure 3.2 indicated the effects of MD and MF processes on the 0-day and 7-day hardness of dough with PS. In Figure 3.2, 0-day hardness of PS1 was significantly lower (nearly 43%) from the those of PS2 and PS3 ($p \leq 0.05$). Similarly, when the doughs with MF process were considered, MFPS1 was significantly lower (nearly 48%) from the other two. However, all PS and MFPS doughs at each MD percentage were not significantly different from each other ($p \leq 0.05$). That is, there was no significant difference between with and without MF process in terms of 0-day hardness of dough. It could be possible to see the effect of MF process on dough hardness when higher level MD was used because MF was active when MD gel concentration was high and the levels of 0%, 3.75%, and 7.5% MD could be insufficient to exhibit the performance of MF on the hardness. Additionally, the lowest 0-day hardness of dough was nearly 5500 g; however, the highest hardness of dough was around 10500 g.

When the Figure 3.1 was compared with Figure 3.2, how PS and PON influenced the hardness of dough was observed. PS fat type increased the hardness of dough more than PON due to high solid fat content of PS. The hardness of a fat strongly affected the texture of fatty food products (Brunello et al., 2003) and this effect depended largely on the amount of solid fat present in the network (Foubert et

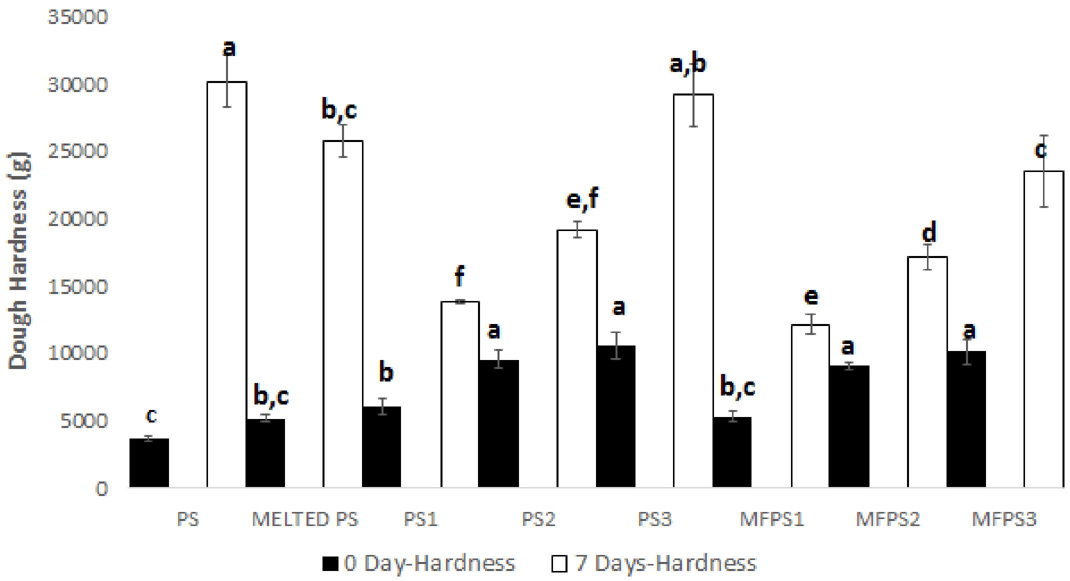

Figure 3.2: The Effects of MD and MF Process on the 0-day and 7-day Dough Hardness with PS

al., 2006). Therefore, a gradual increase was observed in both 0-day and 7-day hardness of doughs when PS was used rather than PON. For instance, in the Figure 3.1, the lowest 0-day hardness of dough with PON was around 2000 g and the highest 0-day hardness of dough with PON was around 6000 g while the lowest 0-day hardness of dough with PS was nearly 4000 g and the highest value of 0-day hardness of dough with PS was 10500 g shown in the Figure 3.2.

In the Figure 3.2, 7-day hardness of doughs was significantly higher than that of the other types of doughs as these doughs were stored in the refrigerator for 7 days, with the highest value at around 30000 g. One of the reasons of this significant increase in dough hardness was that fat in the dough crystallized during 7 day storage at $4°C$. The crystallization of fat caused denser crystal network and the structure of this network made dough harder. This change in hardness was explained by polymorphism. This polymorphism was also seen in another study which examined the effects of storage time on the hardness of fat blends treated with MF process under 60 MPa (Han et al., 2014). The X-ray results of this study showed the existence of β' form crystals after 5 day storage at 0°C and β' form and small size caused firmer crystal network consisting of the interactions between fat phase and solid dispersed phase. Another reason for highly increase in hardness of dough was that MD gel replaced with fat had rigid structure during storage at 4°C. When the ingredients of cookie were considered, besides the effect of MD gel and fat crystallization on harder 7-day dough, sucrose and flour might be taken into consideration. As the dough was stored at refrigerator, sucrose could act as hardener for crystallization. Moreover, gluten network consisting of hydrating flour with water might be more rigid during cooling which led to increase in hardness of 7-day dough. The reason for rigid structure of gluten network was also explained in the study of (Lagrain et al., 2005) in which indicated that the decrease in apparent viscosity of gluten suspensions exposed to cooling was due to protein aggregates resulting in rigid structure.

The Figure 3.1 showed all types of doughs obtained when the formulation of cookie dough was altered. In order to evaluate the relation between hardness and moisture content of these doughs, this Figure 3.3 type was used.

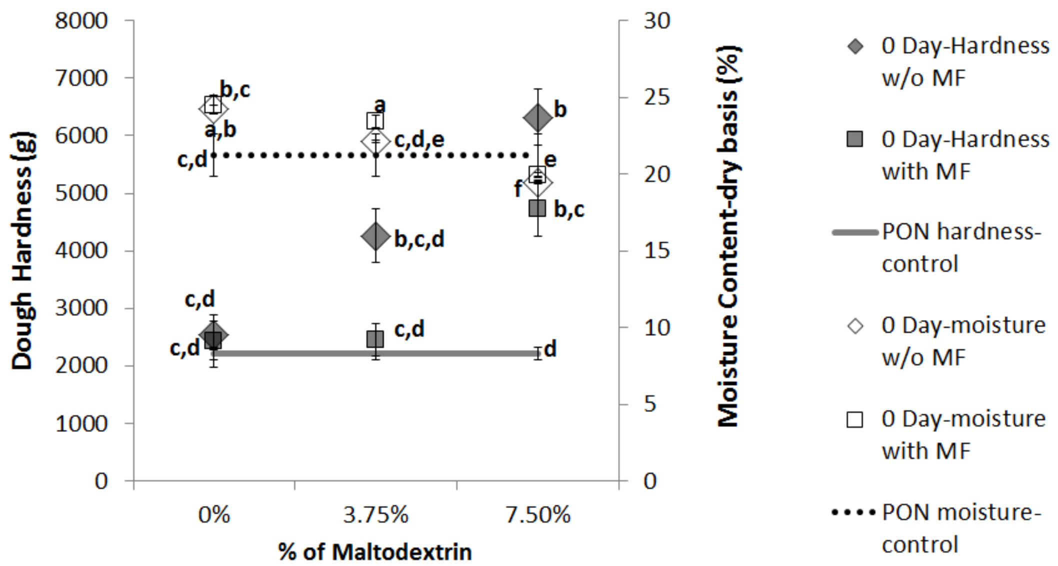

Figure 3.3: Hardness and Moisture Content of 0-day Doughs including PON being evaluated in terms of the Percentages of Maltodextrin

In the Figure 3.3, no significant difference was observed between 0-day moisture contents of PON1 and MFPON1 doughs containing 0% MD while moisture content of PON2 dough containing 3.75% MD was lower than that of MFPON2 dough and the similar reduction was observed when the moisture contents of PON3 and MFPON3 containing 7.5% MD were compared ($p \leq 0.05$). Moreover, while hardness of dough increased with increasing percentage of MD used in the place of fat (Table 2.3); moisture contents of doughs decreased with increasing MD level but still moisture contents of doughs were higher than that of control dough. In other words, increase in the amount of MD led to reduction on 0-day moisture content of doughs including both with MF and without MF processes because it was related to how much water added in the formulation (Table 2.3). Consequently, moisture contents of PON1 and MFPON1 doughs had the highest values, almost 24.5% when compared to the other doughs, PONs and MFPONs, at 3.75% and 7.5% of MD.

According to the ANOVA results, there was no significant difference in terms of moisture content between the doughs with MF and without MF at 0% and 3.75% MD; however, there was a significant difference in terms of moisture content between the doughs with MF and without MF at 7.5% MD. According to the Figure 3.4, as the MD amount increased in dough, amount of additional water, used for making MD gel, decreased, leading to decrease in moisture content of doughs containing high MD. Since MD binded water freely present in dough to form network, if MD present at high amount, high denser network and more rigid structure were formed. That resulted in decrease in moisture content of doughs containing MD at high percentage 3.4. The result of the study showed that the use of MD had an increasing effect on the dough hardness and decreasing effect on the moisture content of doughs containing MD compared to control dough and dough containing Melted PON. Also, MF process did not significantly change the moisture contents of doughs. In parallel to that, the moisture content ranged from nearly 23% to about 18%.

The same correlation was observed for the cookies made of 0- and 7- day doughs with PS, too. In Figures 3.5 and 3.6, there was no significant difference between the doughs with and without MF process in terms of 0-day and 7-day moisture contents ($p \leq 0.05$). However, there was an exception for 7-day moisture content of dough containing 7.5% MD ($p \leq 0.05$). Also, both 0-day and 7-day moisture contents of dough was inversely correlated with the increment in the percentage of MD. Moisture content decreased as the use of MD amount increased and it was related to that how much water added in the formulation. Also, while the

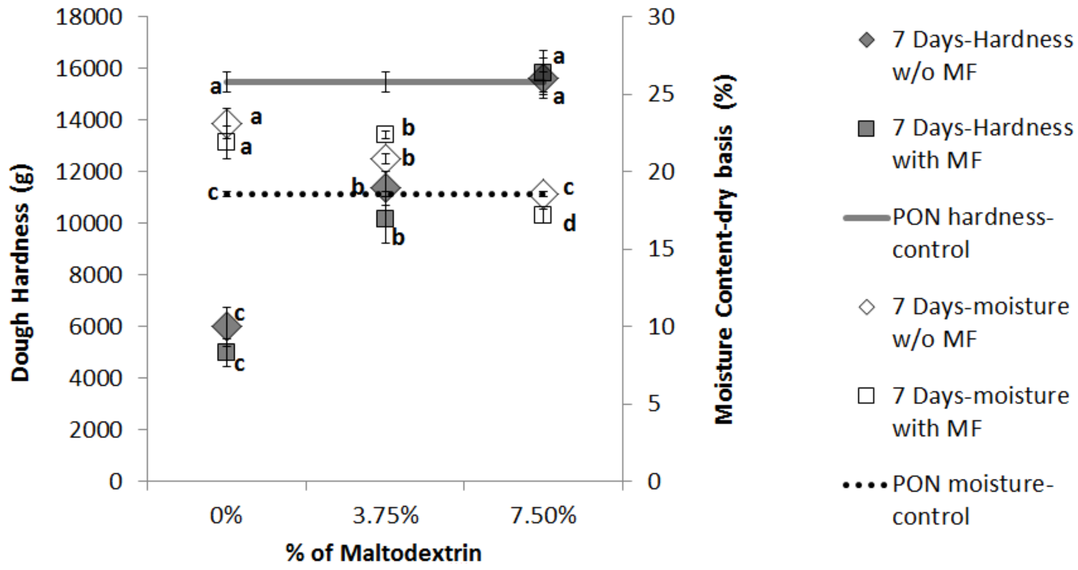

Figure 3.4: Hardness and Moisture Contents of 7-day Doughs including PON being evaluated in terms of the Percentages of Maltodextrin

dough contained nearly 23% of 0-day moisture content and nearly 22% of 7-day moisture content as the highest value, it contained about 18% of 0-day moisture content and 16% of 7-day moisture content as the lowest value.

Some changes were observed in 0-day cohesiveness when the MD amount was sufficiently high in the dough (Figure 3.7). As the percentage of MD increased, 0-day cohesiveness of doughs without and with MF process decreased. Similarly, in the study carried out by (Sudha, Srivastava, et al., 2007), when fat was replaced with MD, cohesiveness of the dough decreased to some extent. However, 0-day cohesiveness was not significantly different between PON2 and PON3 and also MFPON2 and MFPON3 ($p \leq 0.05$).

The cohesiveness was high in the control dough, PON1 and MFPON1 since intermolecular stickiness of doughs was high that was binding between molecules of dough was stronger while the cohesiveness of doughs containing MD was lower. The reason was that MD plays a role as a functionally inert matter that was an obstacle for strong intermolecular binding. Therefore, in the presence of MD, binding between molecules of dough was weaker, leading to reduction in cohesiveness of dough. The result could be explained by water distribution in the dough because starch and fat affected the water distribution in the cookie

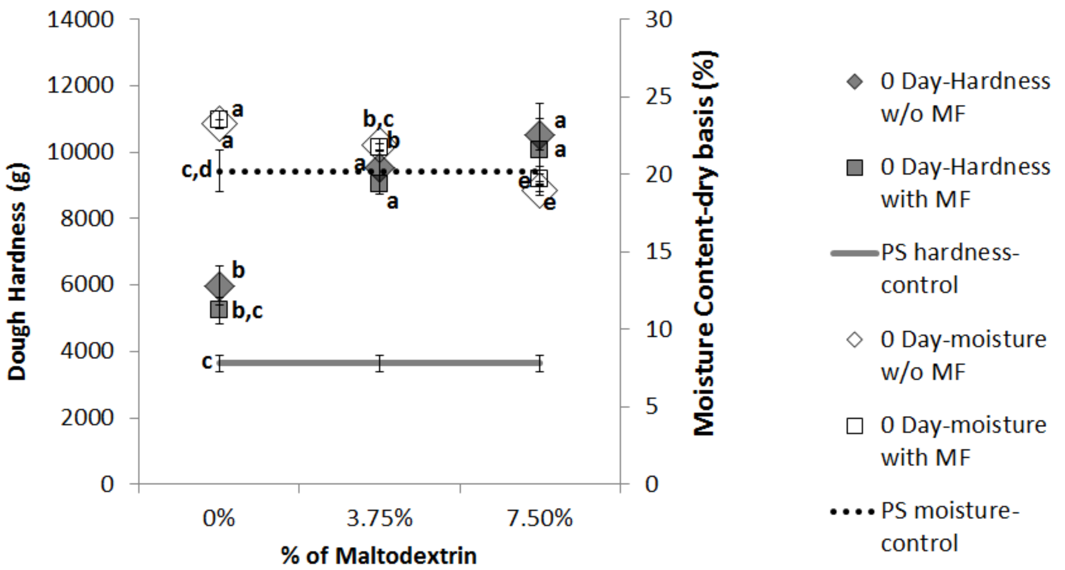

Figure 3.5: Hardness and Moisture Contents of 0-day Doughs including PS being evaluated in terms of the Percentages of Maltodextrin

(Assifaoui et al., 2006). Therefore, these components should have been taken into consideration since they influenced cohesive property of dough (Sudha, Srivastava, et al., 2007).

Furthermore, PON1 is significantly difference in terms of 7-day cohesiveness from PON2 and PON3 ($p \leq 0.05$). Similarly, MFPON1 is significantly difference from 7-day cohesiveness of MFPON2 and MFPON3 ($p \leq 0.05$). As the percentage of MD raises cohesiveness of dough reduces in the Figure 3.7. Having a low cohesiveness is generally observed when dough includes high amount of MD. It can be explained that MD has a reducing effect on the cohesiveness of dough even though cookies are characterized by a highly cohesive structure (Maache-Rezzoug et al., 1998a). Also, in the Figure 3.7, MF process does not have any effect on both 0-day and 7-day cohesiveness; thus, there is no significant difference between the dough processed with MF and the dough processed without MF ($p \leq 0.05$).

As similar to cohesiveness of doughs prepared with PON, increase in the MD percentage decreased both 0-day and 7-day cohesiveness of doughs prepared with PS. In the Figure 3.8, PS1 was significantly different from PS2 and PS3 in terms of 0-day and 7-day cohesiveness ($p \leq 0.05$). MFPS1 was significantly

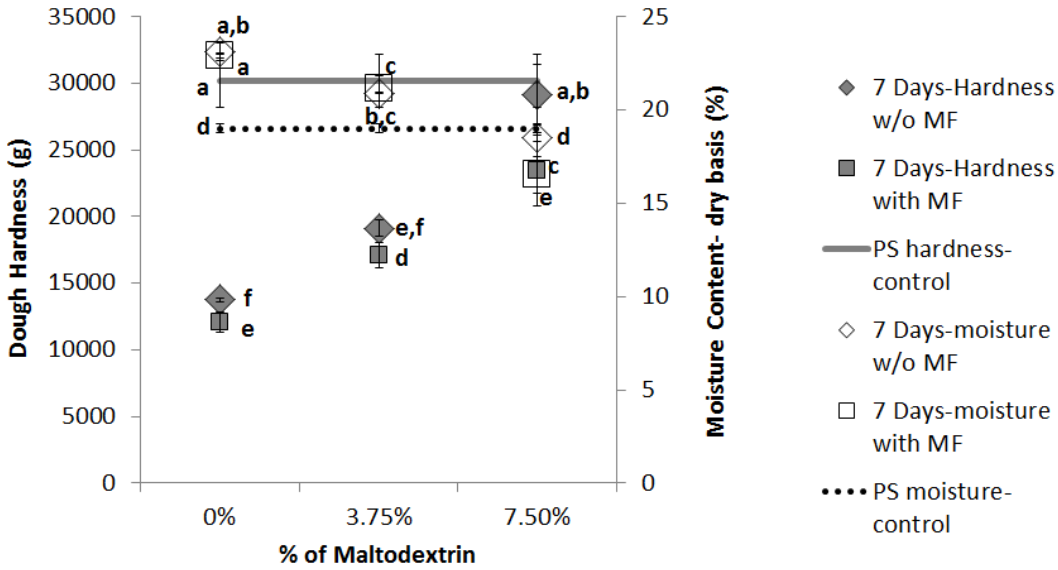

Figure 3.6: Hardness and Moisture Contents of 7-day Doughs including PS being evaluated in terms of the Percentages of Maltodextrin

different from MFPS2 and MFPS3, as well ($p \leq 0.05$). This difference between dough cohesiveness came from changing in the amount of MD. When MD was available in a sufficient amount in the dough, differences between cohesiveness were significantly observed and the doughs had lower cohesiveness, accordingly. As in the example of PS2 and PS3 or MFPS2 and MFPS3 for 0-day cohesiveness, there was no significant difference between them ($p \leq 0.05$). The reason could be that there was no sufficient increase in the MD.

By contrast with MD, according to ANOVA, there was no significant difference in terms of cohesiveness between the doughs with MF and without MF at each MD percentage. Thus, it could be inferred that MF did not have any impact on the 0-day and 7-day cohesiveness of doughs.

3.2 Dough Rheology

3.2.1 Elastic Property of Doughs

Elastic modulus (G') of 0-day dough samples containing emulsions prepared with palm olein with different maltodextrin percentages and by different meth-

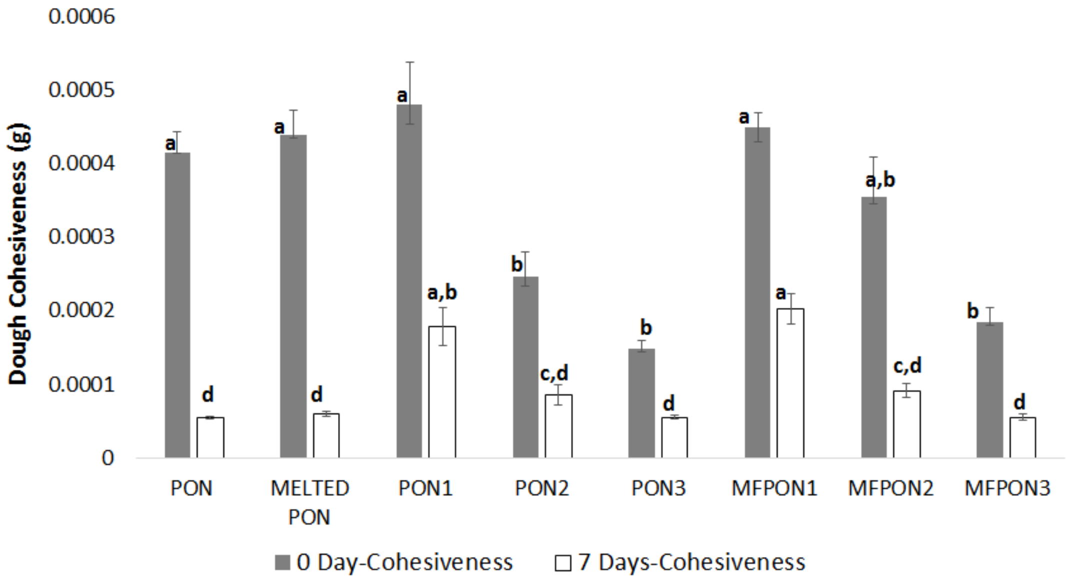

Figure 3.7: The Effects of MD and MF Process on the 0- day and 7-day Cohesiveness of Doughs including PON

ods (see Figure 3.9). The increase in the percentage of MD led to increases in elastic modulus of 0-day doughs (see Figure 3.9). That is, decreasing water content of dough increased elastic modulus of dough. In parallel to this result, there was a general consensus that as water content increased both elastic and viscous moduli decreased (Milašinović Šeremešić et al., 2013). This was associated with the use of MD in the formulation. When less amount MD was used, water content was high, which increased elastic modulus values as found in the study of (Milašinović Šeremešić et al., 2013). Moreover, the replacement of palm olein with emulsions prepared with maltodextrin at 0%, 3.75%, and 7.5% resulted in harder cookie dough samples. According to the study conducted by (Hadnađev et al., 2014), increase in the amounts of MD gel in blends resulted in increased in the hardness values of regardless of maltodextrin type. As seen in the Figures 3.21, 3.22 and the other cookie hardness figures, cookie hardness increased with increasing percentages of MD.

Furthermore, the replacement of PON by microfludized emulsions increased in elastic modulus of dough. This might be due to the fact that microfludization process affected water droplets containing MD, and reduced droplet size, leading to increase the apparent viscosity and this resulted in higher elastic behavior

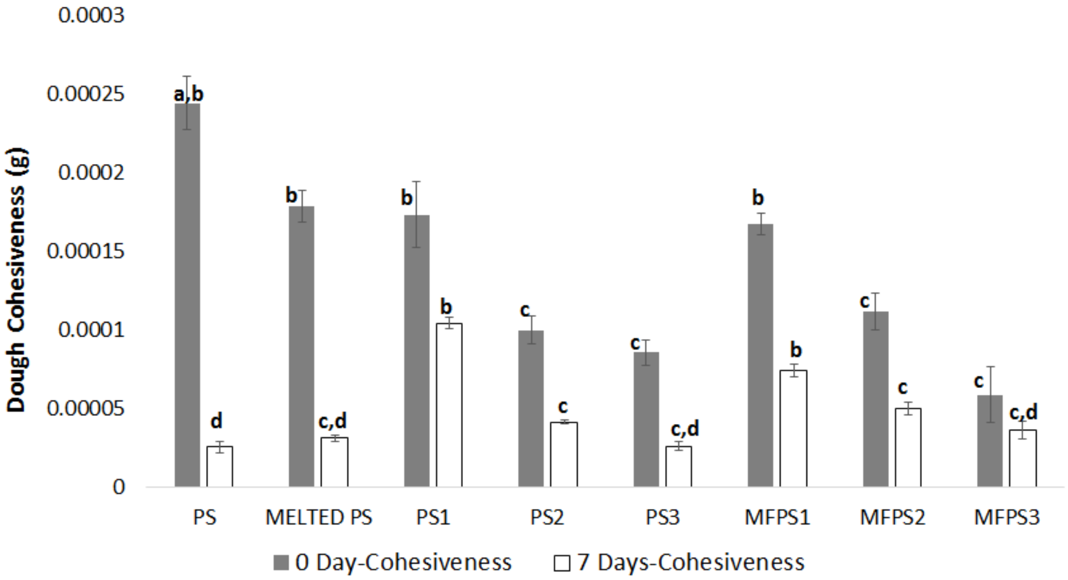

Figure 3.8: The Effects of MD and MF Process on the 0- day and 7-day Cohesiveness of Doughs including PS

(Vanderghem et al., 2007).

G' values of control dough were lower as compared to elastic modulus of the doughs made from maltodextrin (see Figure 3.9). This was because fat prevented the formation of gluten network and produced a less elastic dough (Faubion & Hoseney, 1990). Also, G' values of dough (PON1) containing maximum amount of water; i.e., containing 0% MD were the lowest. On the other hand, the highest elastic modulus value was obtained in the dough sample (MFPON3) containing 7.50% MD and treated by microfludization process because MF process decreased particle size that increased surface area and this resulted in increase in viscosity; consequently, increase in elastic modulus. However, according to the study carried out by Maache-Rezzoug et al. (1998a), a highly elastic dough was not desirable in cookie making. Therefore, the dough (PON3) containing 7.5% MD without MF process might be the best solution in terms of elastic modulus.

Elastic modulus of cookie dough with PON stored for 7 days as a function of MD percentages were shown in Figure 3.10. On the other hand, there was a progressive increment on the elastic modulus of doughs with increasing maltodextrin amount. In a study conducted by Hadnađev et al. (2014), it was at

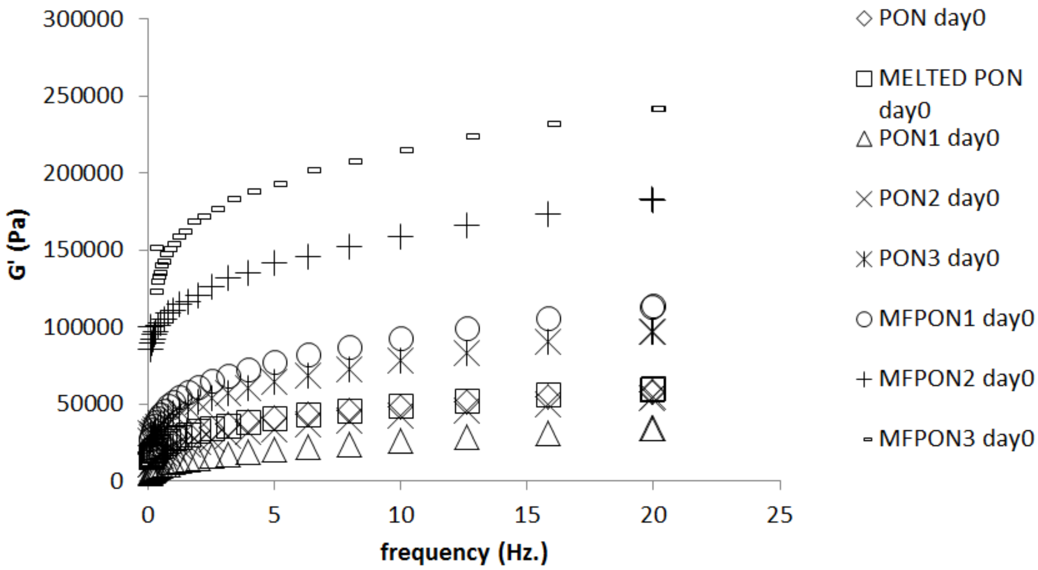

Figure 3.9: The Effects of MD and MF Process on the Elastic Modulus of 0-day Doughs including PON

each frequency complex modulus which was the combination of the storage and loss moduli increased with increasing maltodextrin gel concentration meaning that at higher concentrations, maltodextrin gels exhibited stronger viscoelastic properties. In addition to that, increasing elastic modulus demonstrated increasing strength of cookie dough samples as Yıldız (2014) indicated in her study as well. Moreover, sharp increase in G' values of the samples, especially PON and Melted PON, was observed after the doughs stored for 7 days and the highest elastic modulus value was obtained with Melted PON. The reason might be that fat crystallization highly occurred during melting palm olein as well during the storage at refrigerator. In addition to these factors that increased in elastic modulus of dough, sucrose crystallization and MD or starch retrogradation might be observed and made denser the dough; consequently, increased the viscosity and also increased the elastic modulus.

Elastic modulus values of 0-day dough samples prepared with the replacement of PS by emulsions with different MD percentages were given in Figure 3.11. When compared with Figure 3.9, the samples which contained PS showed higher storage modulus values than the samples including PON. The reason was that fat level, fat type, solid fat content and fat polymorphism influence fat crystal

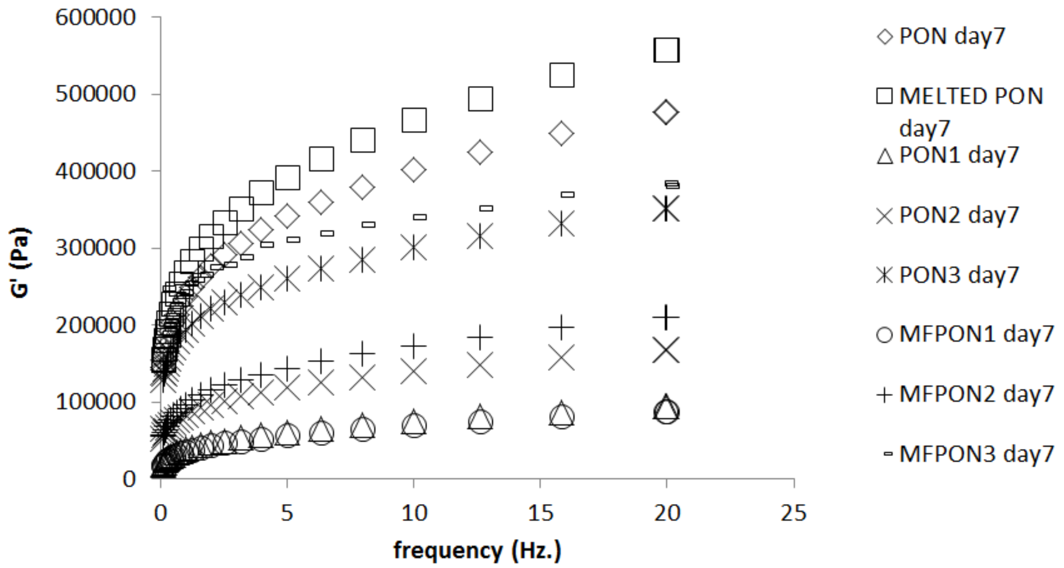

Figure 3.10: The Effects of MD and MF Process on the Elastic Modulus of 7-day Doughs including PON

network (Deman, 2000) which had a significant effect on the rheological characteristics of cookie dough and on the properties of baked cookies as well (Chugh et al., 2013). Moreover, the other study carried out on behalf of evaluating the physical and chemical properties of different types of shortenings showed similar results in terms of higher dominated effect of PS than PON on the storage and loss moduli (Ariffin et al., 2011). In this study, it was found that the sample which contained 100% of palm oil did not have high storage modulus (G'); however, the sample which contained 100% of palm stearin had very high storage modulus. It was obvious that both studies show similar results. Both could be explained by the fact that palm stearin in the formulations produced a progressive increase in the viscosity values resulted in increase in elastic behaviour of dough (Ariffin et al., 2011). The presence of palm stearin had a direct influence on both the elastic and viscous behaviors of the shortenings (Ariffin et al., 2011) because PS had higher solid fat content than PON and that led to increase viscosity; consequently, increased elastic modulus of dough with PS.

Elastic modulus of 0-day doughs also increased with MD concentration (see Figure 3.11). Further increases in elastic modulus was also observed at higher MD percentages in another study (Hadnađev, Hadnađev, et al., 2011) because there was an increase in the solid amount (MD) in the dough formulation. In this study, product containing reduced fat with 15%, 30% and 50% MD gel showed sticky behavior in comparison to control sample. That is, maltodextrin gel addition resulted in significant increase in apparent viscosity value that led to significant increase in elastic modulus. All these studies indicated that rheological behavior was mainly controlled by the properties of maltodextrin phase (Hadnađev, Dokić, et al., 2011).

The G' values of dough samples at the same percentage MD prepared without microfluidization were higher than those prepared with microfluidization. These rheological results of doughs were also parallel to dough hardness as shown in Figure 3.1. The highest elastic modulus value was obtained in the dough sample (PS3) containing 7.5% MD and emulsion without microfluidization. Moreover, G' values of control dough were close to the G' of PS1.

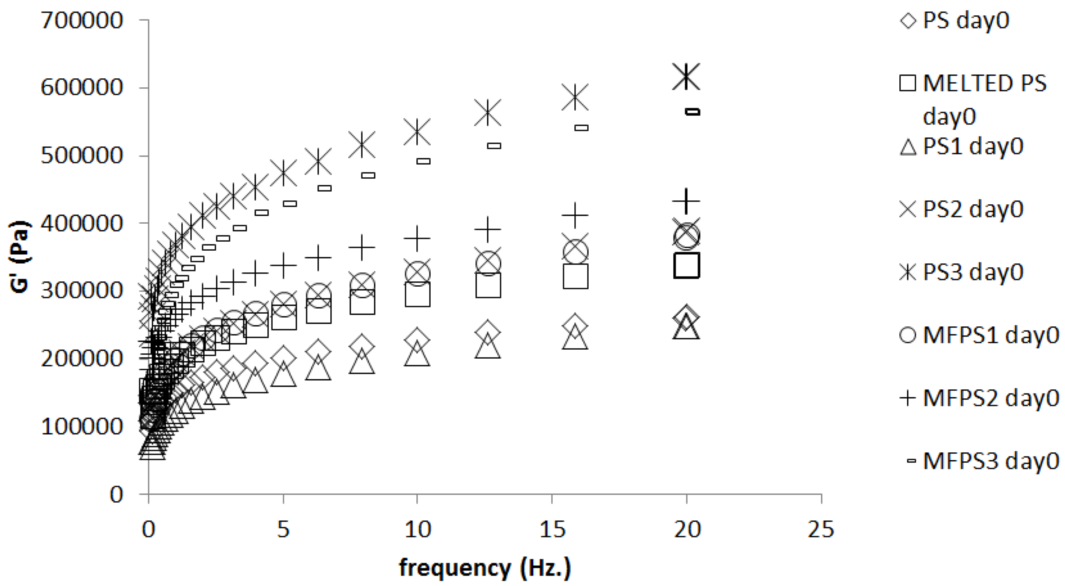

Figure 3.11: The Effects of MD and MF Process on the Elastic Modulus of 0-day Doughs including PS

In the Figure 3.12, elastic modulus of 7-day dough samples containing emulsions prepared with palm stearin with different maltodextrin percentages and by different methods were indicated. The G' values of the 7-day doughs prepared with and without microfludization at the same MD percentage approximated to each other. Consequently, it could be inferred that there was no microfluidization effect on the elastic modulus of 7-day doughs. Also, contrary to the Figure 3.11, higher G' values were obtained due to 7-day storage at refrigerator. The highest elastic modulus values were obtained in the dough samples of Melted PS and PS3.

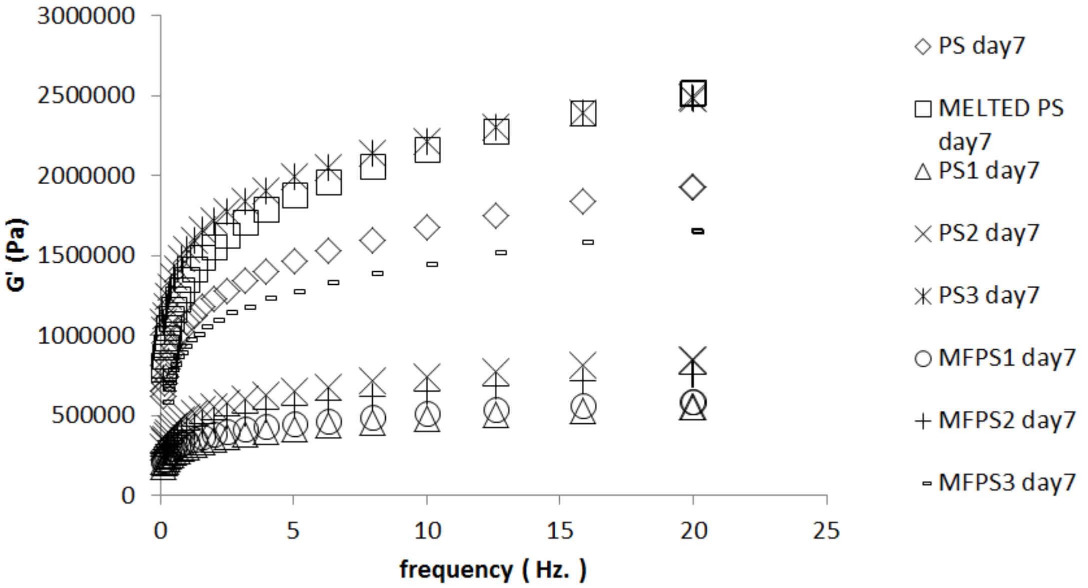

Figure 3.12: The Effects of MD and MF Process on the Elastic Modulus of 7-day Doughs including PS

In a past study concluding similar results compared to current thesis results, MD gel addition showed increase in apparent viscosity, yielded stress value and elastic modulus compared to control (Hadnađev, Hadnađev, et al., 2011). Also, the application of MF process increased G' of dough in Figures 3.9–3.12. This could be explained with the results of the other investigation conducted by Ciron et al. (2010). In this investigation, MF process disrupted fat globules and consequently reduces size of globules. Thus, there was an increase in their surface area that increased the interaction between fat globules and other ingredients. This allowed the viscosity of dough to increase because better interaction between reduced sized fat globules and MD gel took place due to the application of MF process and use of emulsifier (Ciron et al., 2010). Therefore, increase in the viscosity of dough led to increase in G' value. However, according to ANOVA results (see Appendix C), when the elastic modulus of dough with MF was compared to that of dough without MF, effect of MF on increase in elastic modulus was less significant compare to use of MD. In other words, the use MD is more effective on elastic modulus than the application of MF.

3.2.2 Viscous Property of Doughs

The Figure 3.13 showed that viscous modulus of 0-day dough samples containing emulsions prepared with palm olein with different maltodextrin percentages and by different methods. Similar to the Figure 3.9, G" values also were to be increase as the concentration of MD was increased. In other words, decreasing water content of dough increased elastic and viscous modulus of dough. Water played an important role in determining the viscoelastic properties of dough. Both G' and G" decreased as water content increased (Amjid et al., 2013). Moreover, when G' and G" values of doughs were compared, G" values were lower than those of G', i.e., the dough samples were more elastic rather than viscous in character.

Furthermore, the replacement of palm stearin by microfluidized emulsions resulted in higher G" values as expected. The highest viscous modulus value was obtained in the dough sample (MFPON3) containing 7.5% MD with microfluidization process. On the contrary, the lowest elastic and viscous moduli belonged to PON1 due to containing high level water as compared to the others and control cookie doughs (PON and Melted PON) followed PON1 in terms of low elastic and viscous moduli (Duman, 2013).

In the Figure 3.14, viscous modulus of 7-day dough samples containing emulsions prepared with palm olein with different maltodextrin percentages and by different methods were indicated. The G" values of 7-day doughs prepared with and without microfludization at the same MD percentage were approximated to each other. Also, G" values of the samples, especially PON and Melted sharply increased after the doughs stored for 7 days. The highest viscous modulus value was obtained in the dough sample (Melted PON).

Viscous modulus values of 0-day dough samples prepared with the replacement

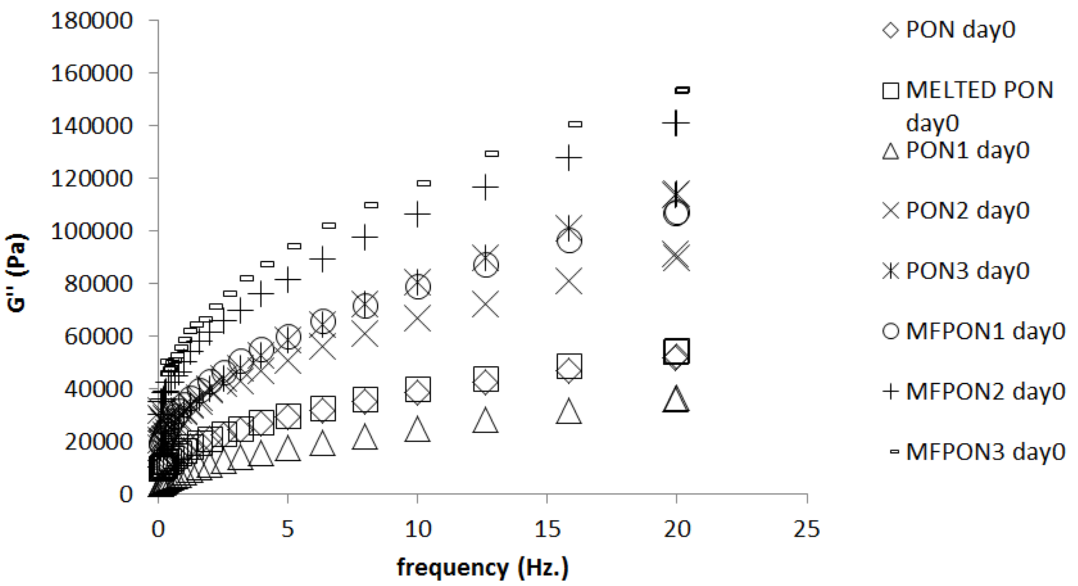

Figure 3.13: The Effects of MD and MF Process on the Viscous Modulus of 0-day Doughs including PON

of palm stearin by emulsions with different MD percentages were given in Figure 3.15. Similar to the Figure 3.13, when the percentage of MD in the emulsions prepared with and without microfluidization increased, viscous modulus of 0-day doughs also increased. Since viscoelastic properties of dough were strongly influenced by the amount and the type of fat present (Goldstein & Seetharaman, 2011) there were increments in the values of loss modulus of 0-day doughs when PS fat type was preferred instead of PON. When the results with PS were compared to the Figure 3.13, G" values were found to increase as PS was used in the dough samples instead of PON. The similar trend was also observed in the Figure 3.11. This could probably due to the higher viscosity resulted in increase in viscous behavior of dough. These values showed that the presence of palm stearin had a direct effect on the both elastic and viscous behaviours of the dough.

The Figure 3.16 showed viscous modulus of 7-day dough samples containing emulsions prepared with palm stearin with different maltodextrin percentages and by different methods. After 7-day storage of the dough samples, G" values for all samples increased sharply. Melted PS and PS3 were close to each other. This indicated that the storage of doughs led to increase in viscous behavior.

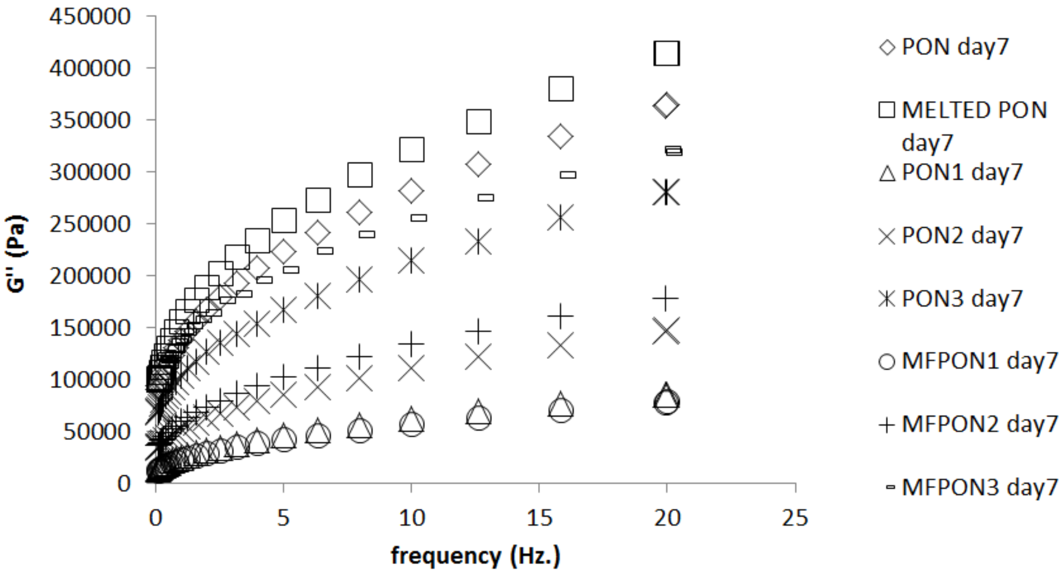

Figure 3.14: The Effects of MD and MF Process on the Viscous Modulus of 7-day Doughs including PON

3.3 Cookie Hardness

The 0th day and 7th day hardness of cookies made from 0-day doughs containing PON with different MD percentages were shown in Figure 3.21. When 0-day hardness of control cookie was compared to those of cookies prepared by the replacement of fat with different level MD, there was an increase in the cookie hardness (Figure 3.17). The same result was observed with the study conducted by Pareyt et al. (2009). As the percentage of MD increased, cookie hardness increased.

0- day hardness of cookies with MF and without MF are significantly different for both 0% and 3.75% MD; however, the hardness of cookies at 7.5% MD was not significantly different from each other ($p \leq 0.05$) (Figure 3.17). Also, it could be seen that there was an obvious reducing effect of MF on the cookie hardness, especially at 0% and 3.75% MD. With the use of MF process, 0th cookie hardness reduced at around 43% and 87% respectively. Moreover, the hardness of cookie without MF at 0% MD was significantly different from those without MF at 3.75% MD and 7.5% MD ($p \leq 0.05$).

Moreover, there was no significant difference between the cookies with MF and

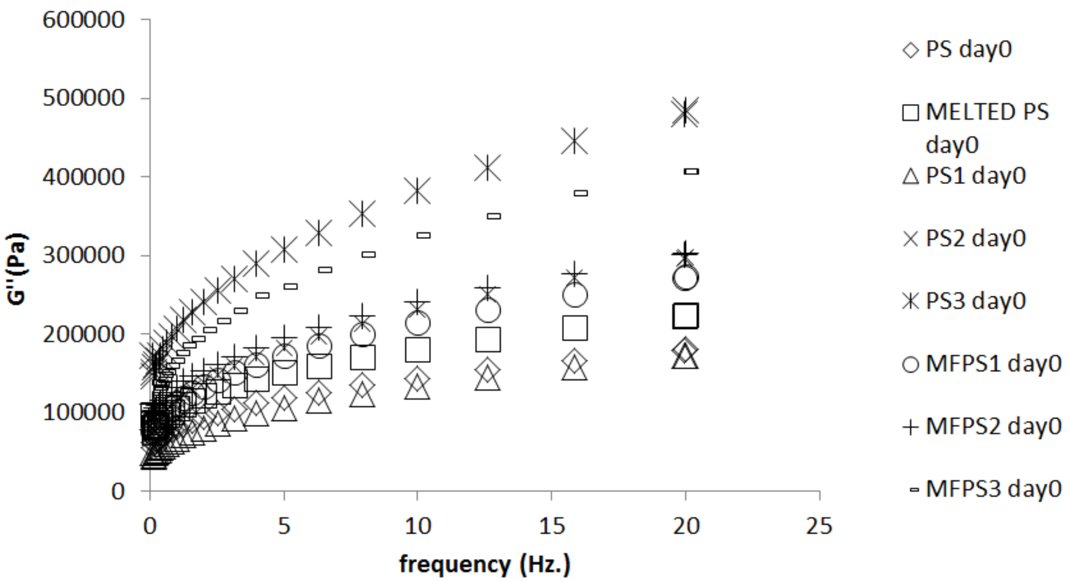

Figure 3.15: The Effects of MD and MF Process on the Viscous Modulus of 0-day Doughs including PS

without MF at different MD percentages for the effect of MF on the 7th day hardness ($p \leq 0.05$). Also, there was no significant difference between the cookies without MF at different MD percentages on the 7th day hardness ($p \leq 0.05$). According to rheology result in the Figure 3.10, after 7 day storage the effect of MF was not significantly observed ($p \leq 0.05$). Thus, it was expected that the effect of MF on the cookie hardness was not observed. However, the cookie with MF at 0% MD was not significantly different from the cookie with MF at 3.75% MD while it was significantly different from the cookie with MF at 7.5% MD ($p \leq 0.05$).

The 0th day and 7th day hardness of cookies made from 7-day doughs containing PON with different MD percentages were shown in Figure 3.18. When the Figure 3.18 was compared with the Figure 3.17, there was an increment in the 0-day hardness of the control cookie by 37.5% because of 7 day storage of the doughs at refrigerator.

Moreover, there was no significant difference for the 0-day hardness between the cookies with MF and without MF at different percentages ($p \leq 0.05$). In other words, MF did not have any considerable impact on the 0- day hardness. In addition, MF did not have any significant effect on the 7-day hardness of

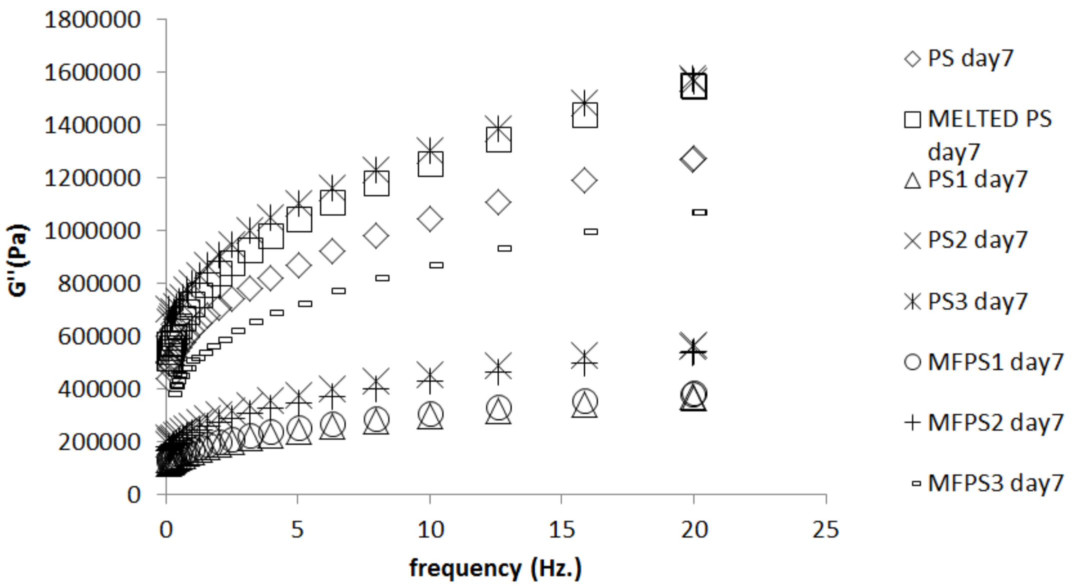

Figure 3.16: The Effects of MD and MF Process on the Viscous Modulus of 7-day Doughs including PS

the cookies at each MD percentage ($p \leq 0.05$). Also, there was no significant difference between the cookies with MF at different MD percentages for the 7-day hardness. Likewise, there was no significant difference between the cookies without MF at each MD percentages for the hardness. Therefore, it could be inferred that MD did not have any effect on the 7-day hardness of cookie made from 7-day dough (Figure 3.18).

The 0th day and 7th day hardness of cookies made from 0-day doughs containing PS with different MD percentages were shown in Figure 3.18. The hardness values of the cookies depended on the percentage of fat replacement; consequently, hardness of cookies generally increased with fat replacement (Zoulias et al., 2002). When hardness of control cookie was compared to those of cookies prepared by the replacement of fat with different level MD, there was an increase in the cookie hardness as seen from the Figure 3.19. This was in agreement with earlier result by Sudha, Srivastava, et al. (2007). MF did not have significant effect on the hardness of the cookies at each MD percentage ($p \leq 0.05$).

The 0th day and 7th day hardness of cookies made from 7-day doughs containing PS with different MD percentages were shown in Figure 3.20. When the hardness of the cookies made from 7 day doughs was compared with the hardness of the

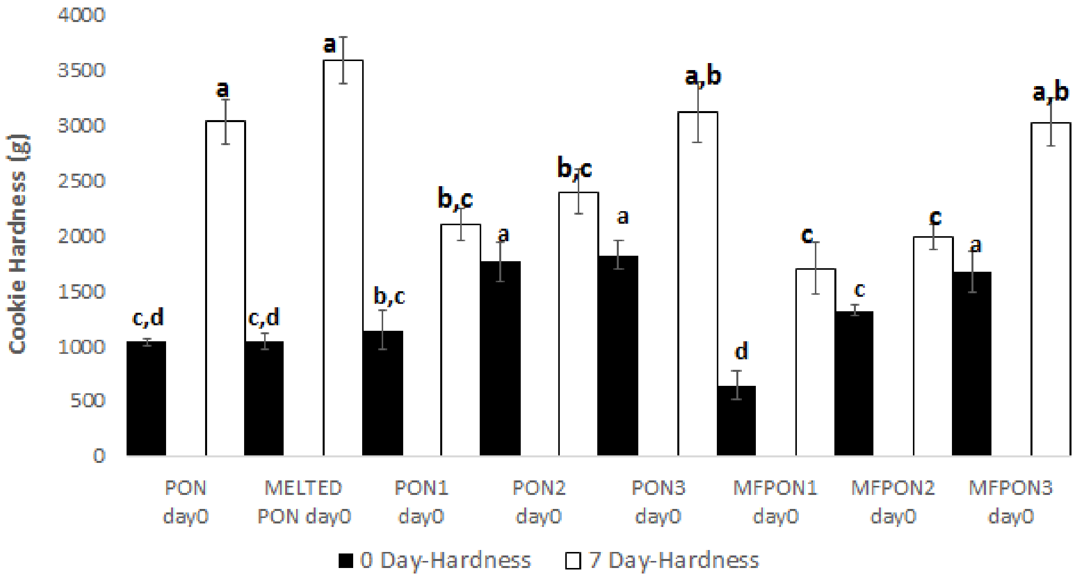

Figure 3.17: The Effects of MD and MF Process on the 0- and 7- day Hardness of Cookies Prepared from 0-day Doughs with PON

ones made from 0 day doughs, the increase in the hardness of the control cookie was observed at nearly 35% because of the effect of 7 day storage of doughs at refrigerator. However, there was no significant effect of MF process for the 0th day hardness between the cookies with MF and without MF at different MD percentages ($p \leq 0.05$). In other words, MF process did not have any effect on the hardness. Also, there was no significant difference for the hardness among the cookies without MF at each MD percentages ($p \leq 0.05$). So, increase in the MD amount did not result in significantly increase in the hardness of the cookies without MF. However, the significant effect of increment in the percentages of MD was only observed in the hardness of the cookie with MF at 7.5% MD.

When the 7-day hardness of the control cookie was compared with the 0-day hardness of control cookie, there was an increment in the hardness of the control cookie at around 28% due to 7-day storage of the cookies at room temperature. The increase in the hardness was an expected result throughout the staling period of the cookies.

The Figure 3.21 indicated the 0th day hardness and the moisture content values of cookies made from 0-day doughs containing PON with different MD percentages. There was no significant difference between the cookies at 0% MD for

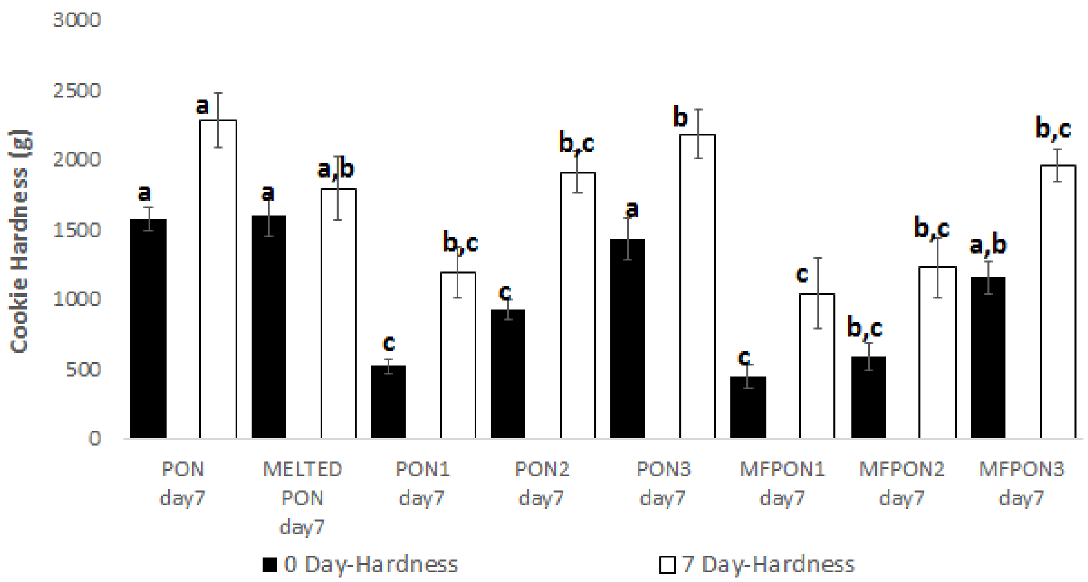

Figure 3.18: The Effects of MD and MF Process on the 0- and 7- day Hardness of Cookies Prepared from 7-day Doughs with PON

the effect of MF on the 0th day moisture content (see Figure 3.21). Similarly, MF had no significant effect on the moisture content between the cookies at 7.5% MD. However, MF significantly showed its effect on the 0th day moisture content of cookies containing 3.75% MD. Also, the moisture contents of cookies prepared 0-day doughs with MF were higher than those of cookies prepared without MF. That was because the hydration properties increased with decreasing particle size. Since the smaller fiber particles increased the surface area for better water absorption, they had higher swelling capacity (Sowbhagya et al., 2007). In addition, as the percentage of MD increased, 0th day moisture content of cookies slightly decreased. However, moisture contents of all the cookies prepared from emulsions were higher than that of control cookie. It was an expected result because according to the study conducted by Pimdit et al. (2008) the addition of fat replacer increased the moisture content of the reduced fat products. This was because fat replacer generally absorbed more water (Akoh, 1998). Consequently, as MD percentage increased, hardness of cookie increased; but, moisture content of cookie decreased.

The Figure 3.22 indicated the 7th day hardness and the moisture content values of cookies made from 0-day doughs containing PON with different MD percentages. When 0-day hardness of cookie was compared with 7-day hardness of

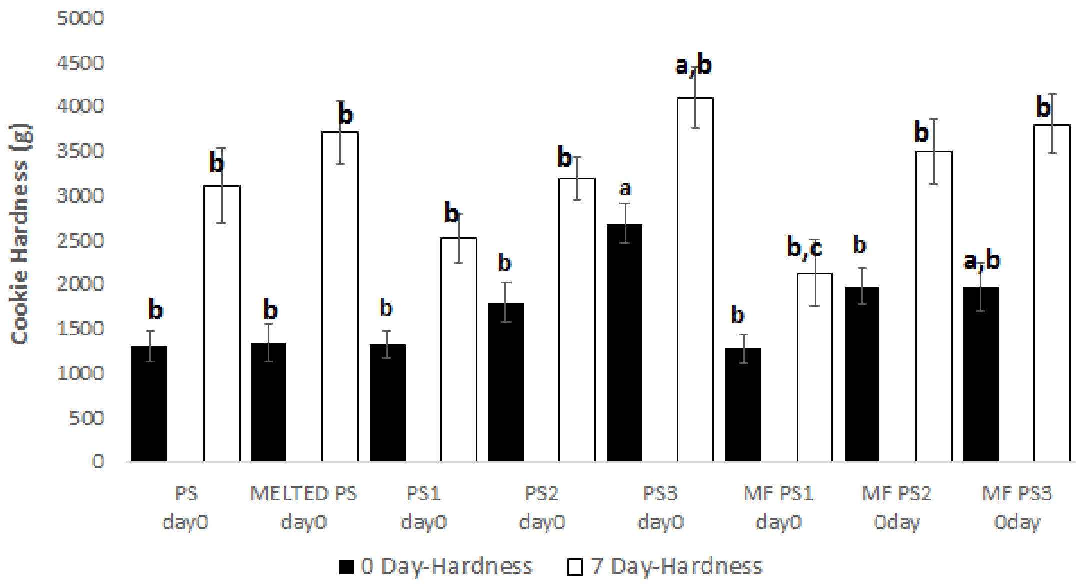

Figure 3.19: The Effects of MD and MF Process on the 0- and 7- day Hardness and Moisture Contents of Cookies Prepared from 0-day Doughs with PS

cookie, after 7-day storage of cookies at room temperature, cookie hardness at 7th day increased as expected because as water loss increased, cookie hardness increased (Figure 3.22). For instance, there was an increase in the 7-day hardness of the control cookie at around 67%. On the contrary, there was a reduction in the moisture content after 7 day storage and 7th day moisture content of cookie was reduced by 9%. Furthermore, MF did not have a significant effect on 7th day the moisture content of the cookies with MF and without MF at 0% and 7.5% MD while it significantly affected the moisture content of the cookies at 3.75% MD ($p \leq 0.05$). The cookie with MF at 0% MD was significantly different for moisture content from the cookies with MF and without MF at 3.75% and 7.5% MD.

The Figure 3.23 indicated the 0th day hardness and the moisture content values of cookies made from 7-day doughs containing PON with different MD percentages. The maximum 0-day moisture content was nearly 14% for the cookies at 0% MD and the lowest one at 7.5% MD was nearly 10%. The effect of the MF was significantly observed on the moisture content between the cookies with MF and without MF at 3.75% and 7.50% MD ($p \leq 0.05$) (Figure 3.23). MF did not affect the moisture content of the cookies containing 0% MD. However, when the MD percentages increased, MF showed its reducing effect on the moisture

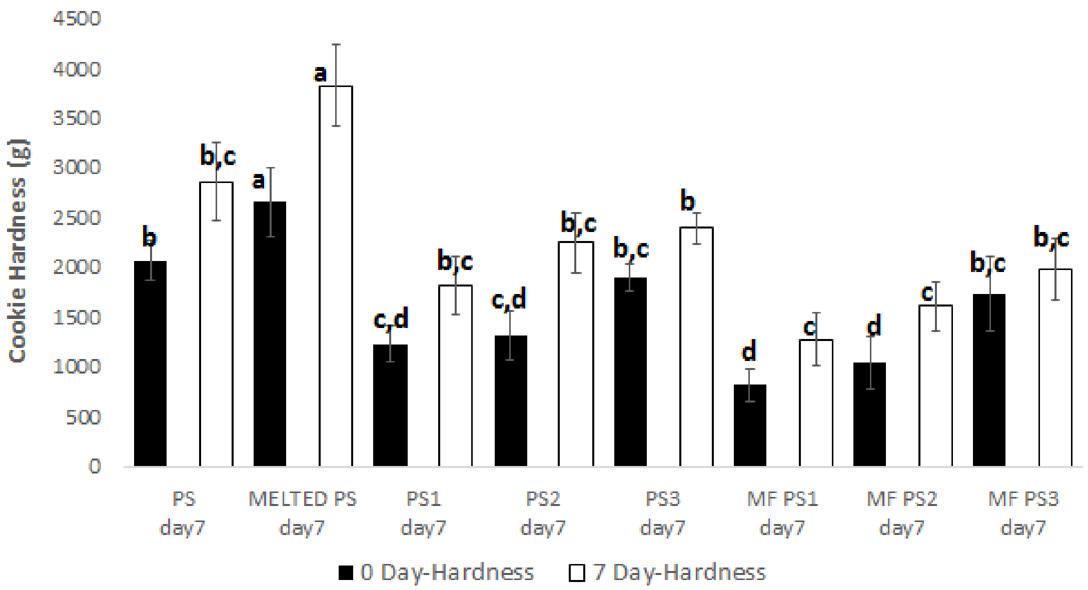

Figure 3.20: The Effects of MD and MF Process on the 0- and 7- day Hardness and Moisture Contents of Cookies Prepared from 7-day Doughs with PS

content of the cookies at 3.75% and 7.5% MD and approximately 10% and 17% decrease in moisture content were observed, respectively. Moreover, the cookie without MF at 0% MD was not significantly different from the cookie without at 3.75% MD; however, it was significantly different from the cookie without MF at 7.5% MD ($p \leq 0.05$). The considerable effect of the MD was observed for the moisture content at 7.5% MD. In general, moisture content was slightly reducing with increasing MD percentages and that resulted in increase in hardness of cookie.

The Figure 3.24 showed the 7-day hardness and the moisture content values of cookies made from 7-day doughs containing PON with different MD percentages. There was a significant effect of MF on the moisture content between the cookies with MF and without MF at 3.75% and 7.5% MD ($p \leq 0.05$). The cookies with MF were significantly different from each MD percentages and as the MD percentage raised, moisture content decreased from 13.6% to 8.81%; however, 7-day hardness of cookie made from 7-day dough increased.

The Figure 3.25 showed the 0-day hardness and the moisture content values of cookies made from 0-day doughs containing PS with different MD percentages. When compared with Figure 3.21, it was clearly seen that there was an increment

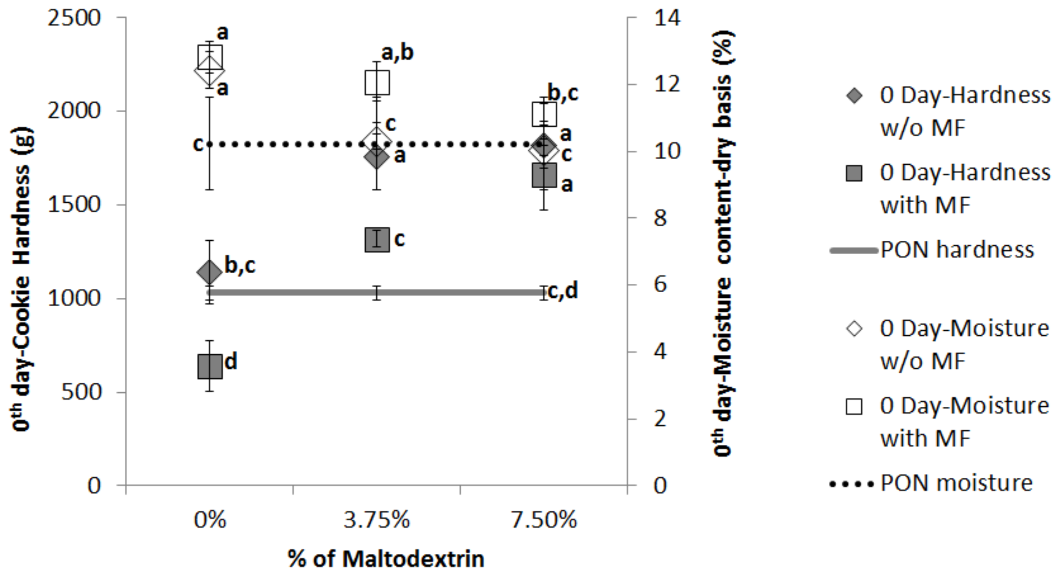

Figure 3.21: The 0th day Hardness and Moisture Contents of 0-day Doughs including PON being evaluated in terms of the Percentages of Maltodextrin

in the 0-day cookie hardness at around 23% because of the use of PS instead of PON. However, the use of PS rather than PON in the cookie did not affect moisture content.

In the Figure 3.25, there was a significant difference for the moisture content between the cookies with MF and without MF at 0%; however, there was no a significant difference for the moisture content between the cookies with MF and without MF at 3.75% and 7.50%. Also, the effect of MD on the 0-day hardness of the cookie without MF was significantly observed after 3.75% MD. There was no significant effect of MD on the 0-day hardness on the cookie with MF at each MD percentages. It could be inferred that the amount of fat replaced by maltodextrin solution at different percentages might be increased. Furthermore, the effect of MD on the moisture content was clearly observed on the cookies without MF process at each MD percentages. As MD percentage raised, moisture content of the cookies without MF reduced while 0-day hardness of cookie increased.

The Figure 3.26 showed the 7 th day hardness and moisture content values of the cookies prepared from 0-day doughs containing PS with different MD percentages. There was an increment in the 7-day hardness of the control cookie at nearly 56% when compared with the 0-day hardness of control cookie (Figure

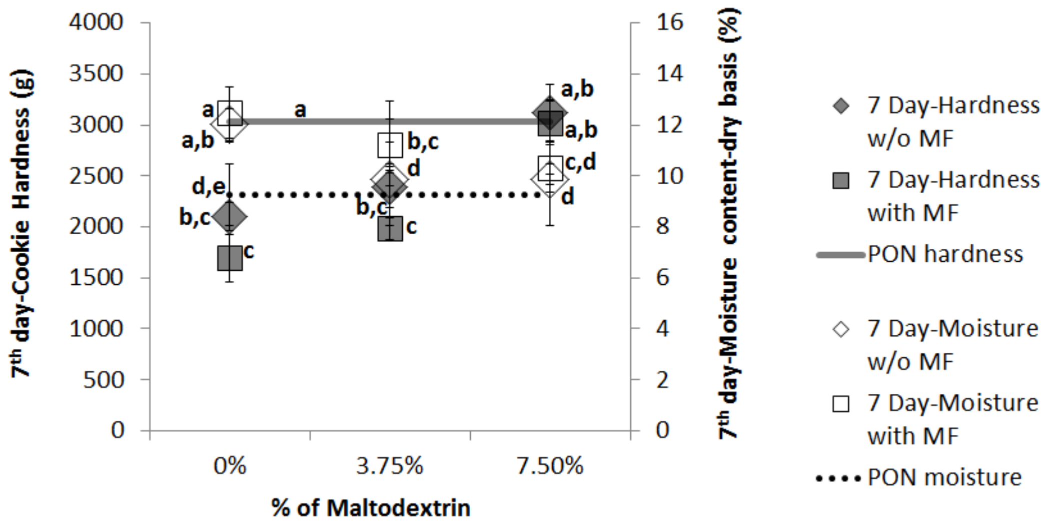

Figure 3.22: The 7th day Hardness and Moisture Contents of 0-day Doughs including PON being evaluated in terms of the Percentages of Maltodextrin

3.25) because of 7-day storage of cookies at room temperature. It was expected that the cookies were harder after 7-day staling period due to water loss. Also, during this storage period, there was a reduction in the moisture content of the control cookie at around 15%. In fact, this reduction in the moisture content of the cookies led to being harder cookies. That is why hardness of control cookie was increasing by 56% while the moisture content of the control cookie was declining by 15% during 7-day storage.

In the Figure 3.26, MF process did not have a remarkable effect on the 7-day hardness and moisture content of the cookies at each different MD percentage. There was no significant difference for both the 7-day hardness and moisture content between the cookies with MF and without MF at 0%, 3.75% and 7.5% of MD ($p \leq 0.05$).

There was no significant effect of MD for the hardness between the cookies at each MD percentage ($p \leq 0.05$). MD had a significant effect on the moisture content of cookies without MF at different percentages ($p \leq 0.05$). In other words, as the percentage of MD increased, moisture content of cookies declined. Moreover, the cookie with MF at 0% MD was not significantly different from the cookie with MF at 3.75% MD; but, was significantly different from the cookie

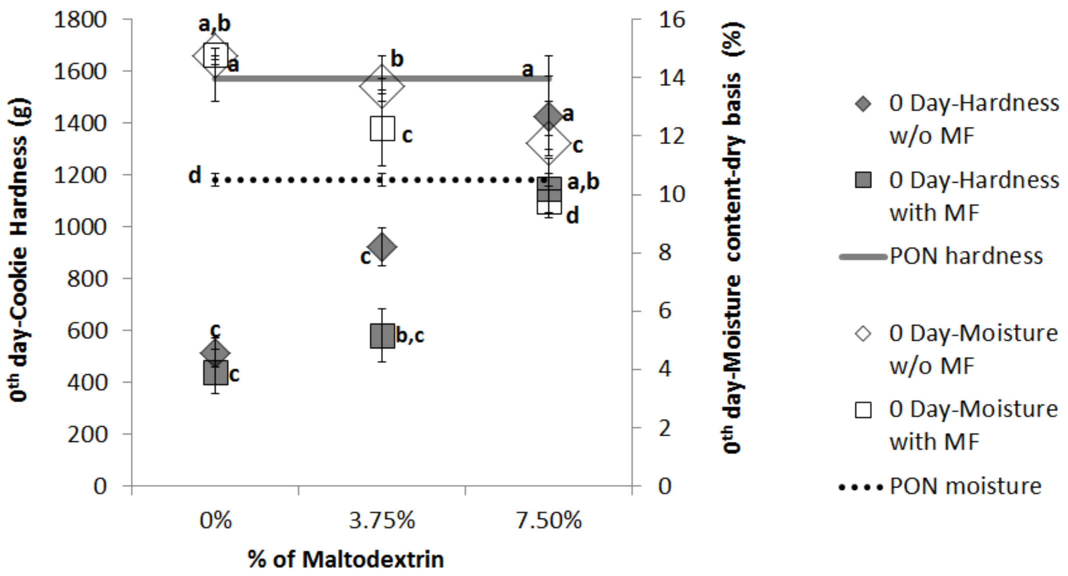

Figure 3.23: The 0th day Hardness and Moisture Contents of 7-day Doughs including PON being evaluated in terms of the Percentages of Maltodextrin

with MF at 7.5% MD.

The Figure 3.27 indicates the 0 th day hardness and the moisture content values of the cookies prepared from 7 day doughs with different MD percentages. The increase in the MD amount did not significantly result in the increase in the hardness of the cookies. Moreover, the 0th day moisture content of the control cookie was not affected by these storage period at the refrigerator. The considerable effects of MF process and percentages of MD on the moisture content were only observed on the cookies containing 7.5% MD.

The Figure 3.28 indicated the 7-day hardness and the moisture content values of the cookies prepared from 7-day doughs with different MD percentages. There was an increment in the hardness of the control cookie at around 28% due to 7-day storage of the cookies at room temperature. However, during staling period, changing in the moisture content of the control cookie was nearly 1.36% with reduction. Moreover, MF process did not have a considerable effect on both the hardness and moisture content of the cookies because there was no significant difference between the cookies with MF and without MF at each MD percentage. The increase in the MD percentages did not significantly affect the hardness and moisture content of the cookies at different MD percentages as well.

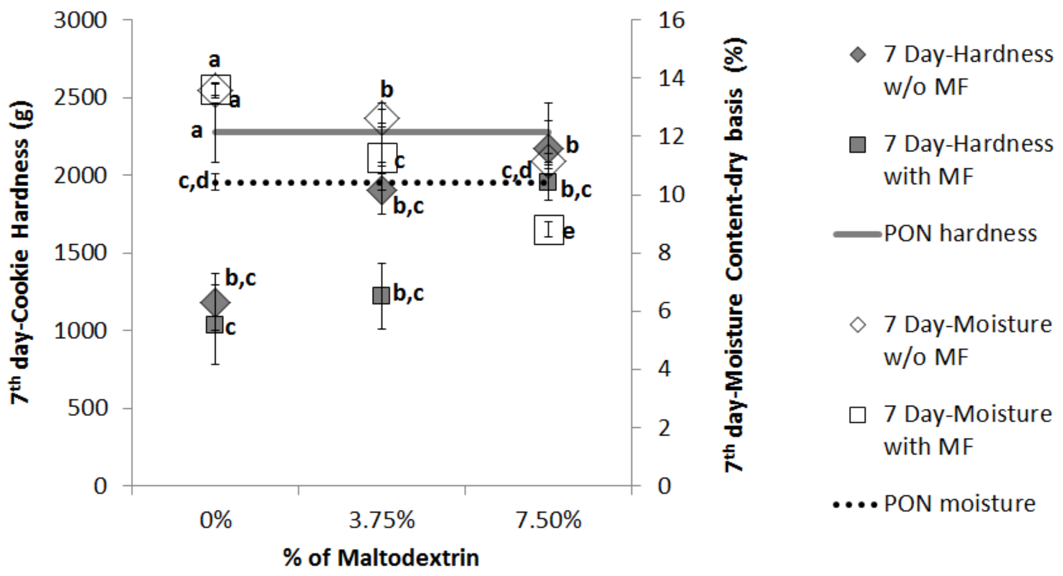

Figure 3.24: The 7th day Hardness and Moisture Contents of 7-day Doughs including PON being evaluated in terms of the Percentages of Maltodextrin

3.3.1 Comparison of Dough and Cookie in terms of Hardness

When dough hardness was compared with cookie hardness, there was a correlation between them (Figure 3.29) (Figure 3.30). When there was an increase in dough hardness, an increase was also shown in cookie hardness. In other words, increase in dough hardness due to the use of MD with increasing level resulted in increase in cookie hardness and decreased in dough hardness due to the application of MF process led to reduction in cookie hardness.

3.4 Water Loss in the Cookies

When the replacement of fat with MD at 0%, 3.75%, and 7.5% was conducted, cookies containing MD had higher moisture content than control cookie due to amount of water in the emulsion. After 7 day storage of cookies at room temperature, water loss in the control cookie prepared from 0-day dough was quite high compared to the cookies containing MD as shown in the Figure 3.31. It was nearly 1%. Cookies containing MD at different percentages had lower water loss. This might be because maltodextrin retrogradation was not observed during 7 day storage. According to the results of the study conducted by Sobolewska-

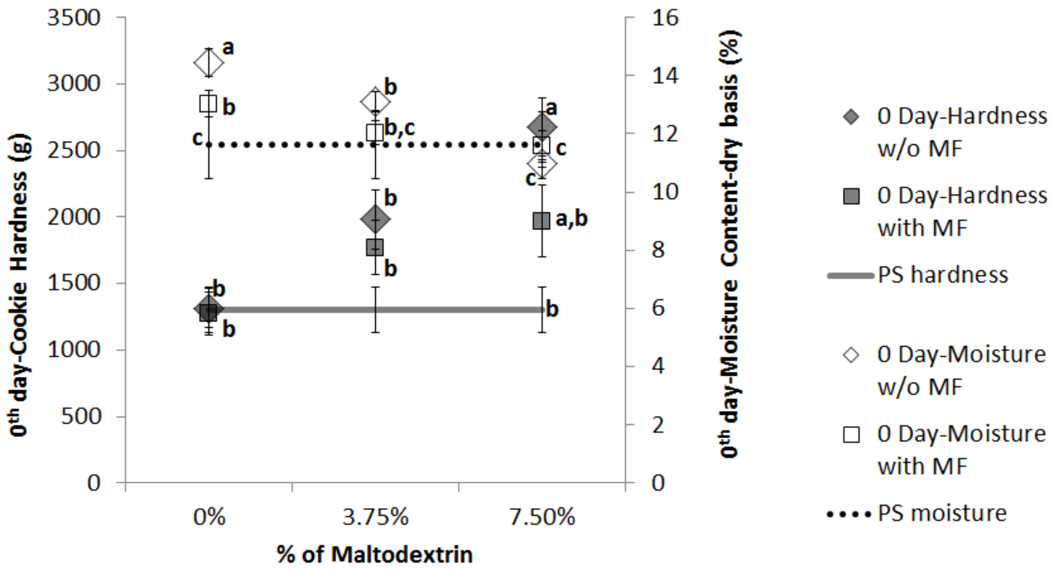

Figure 3.25: The 0th day Hardness and Moisture Contents of 0-day Doughs including PS being evaluated in terms of the Percentages of Maltodextrin

Zielińska and Fortuna (2010), maltodextrin at low concentrations (6, 9, 26, 29%) retarded the retrogradation of starch. Also, maltodextrins having high dextrose equivalence value had much less tendency to retrogradate (Eliasson & Larsson, 1993). Moreover, emulsifier, one of the surfactants, used in the cookie dough hinder retrogradation (Sobolewska-Zielińska & Fortuna, 2010). Consequently, the water was not free since water bounded by maltodextrin was still in the network and was not expelled. Therefore, water loss occured in the cookies containing MD at small level and was around 0.4%.

On the other hand, the situation was different in the cookies prepared from the doughs stored for 7 days at refrigerator. The cookies containing MD had still higher moisture content than control cookie and water loss in these cookies was higher than that of control cookie. However, at this time, water loss in the control cookie was quite low than those of cookies containing MD at different levels and it was lower than 0.2%. It might be because of stored at refrigerator of dough. During storage at refrigerator, most of the water present in the cookies including MD was evaporated. Thus, water loss in the cookies including MD was highly observed after 7 day storage at room temperature.

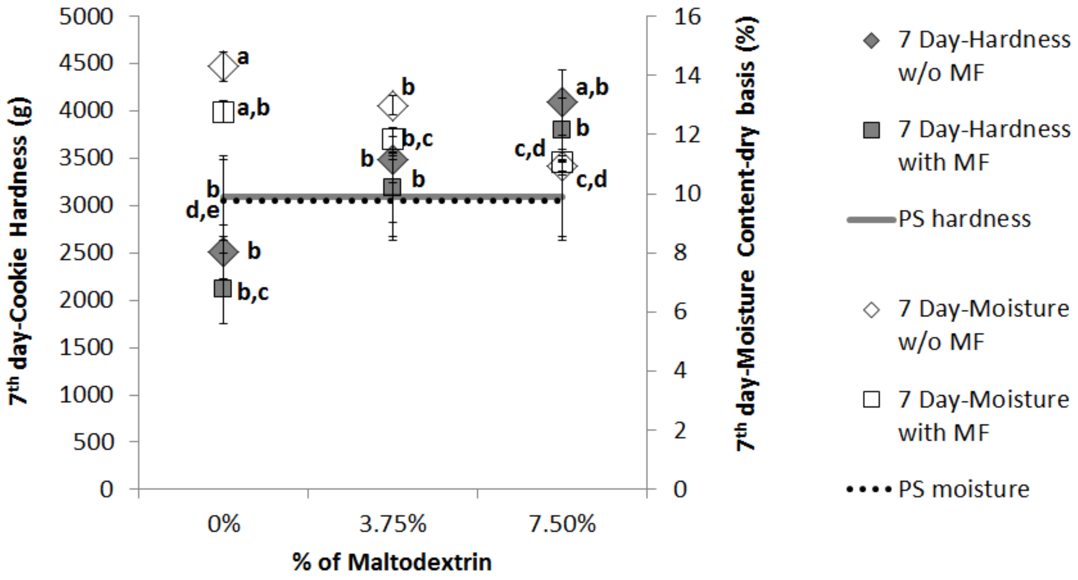

Figure 3.26: The 7th day Hardness and Moisture Contents of 0-day Doughs including PS being evaluated in terms of the Percentages of Maltodextrin

3.5 Change in Height and Diameter

In the Figure 3.35, there was no significant difference between 0-day height and 7-day height ($p \leq 0.05$). Storage of cookies during 7 days did not result in any significant changes in terms of the height of the cookies. Moreover, the doughs with MF and without MF were significantly different from the control doughs. The control group, PON day0 and Melted PON day0, had the lowest height value with the range of 0.9-1.0 cm whereas PON1 day0 and MFPON1 day0 had the highest height values with 1.31 cm and 1.48 cm, respectively since these doughs consisted of more water than the others that led to rise up the cookie during baking. Furthermore, the use of MD in cookie dough reduced the height of cookie as compared to the use of water in the place of MD (0% MD) (Figure 3.35). PON1 was significantly different from PON2 and PON3 or similarly, MFPON1 was significantly different from MFPON2 and MFPON3 ($p \leq 0.05$). On the other hand, the use of MD increased the height of the cookie when compared with the control group. Also, as shown in the Figure 3.35 MF process did not significantly affect the height of cookies by contrast with the effect of MD.

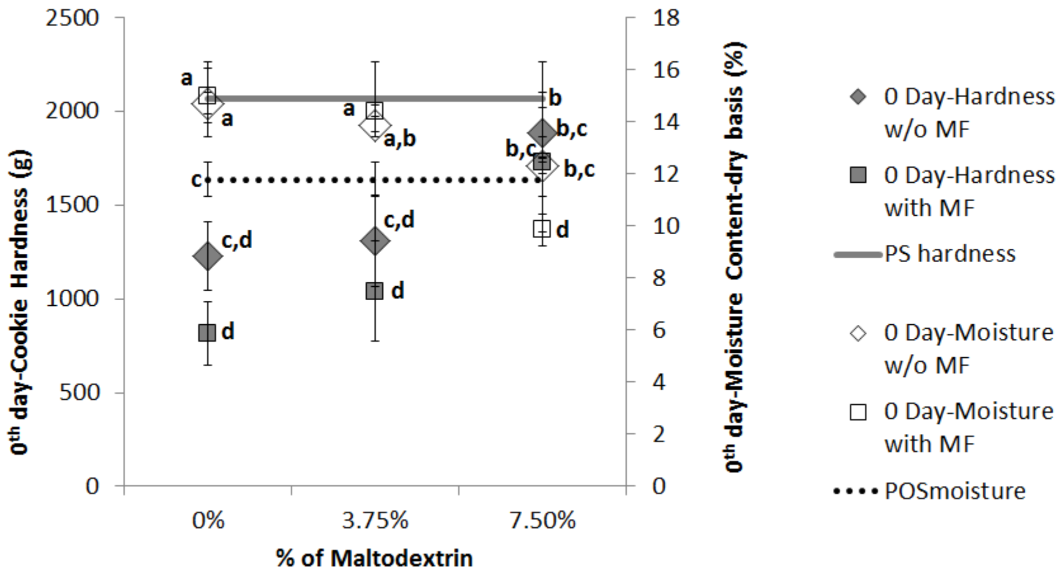

Figure 3.27: The 0th day Hardness and Moisture Contents of 7-day Doughs including PS being evaluated in terms of the Percentages of Maltodextrin

The Figure 3.36 showed the changes in 0-day and 7-day heights of the cookies made from the dough stored during 7 days at the refrigerator. When it was compared with the Figure 3.35, the heights of the cookies made from 7-day doughs were higher than those of cookies made from 0-day doughs. For instance, PON day0 had 0.9 cm height while PON day7 had 1.08 cm height. Also, there was no significant difference between 0-day height and 7-day height of cookies ($p \leq 0.05$). In other words, storage at room temperature of the cookies did not lead to considerable changes in the cookie height. Moreover, there is no significant difference between the cookies with MF and without MF ($p \leq 0.05$). Therefore, it could be inferred that MF process does not affect changing in the height for both 0 and 7 days. Moreover, the heights of PON3 day7 and MFPON3 day7 were not significantly different from each other; however, their heights were significantly different from the others when they compared to the remaining cookies ($p \leq 0.05$). In other words, when 7.5% MD was used, the cookies showed the highest height value.

The use of MD gel in the place of fat increased the height of cookies made from 0-day doughs compared to the heights of PS day0 and Melted PS day0 cookies (Figure 3.37), as well. PS1 day0 was not significantly different from PS2 day0 in

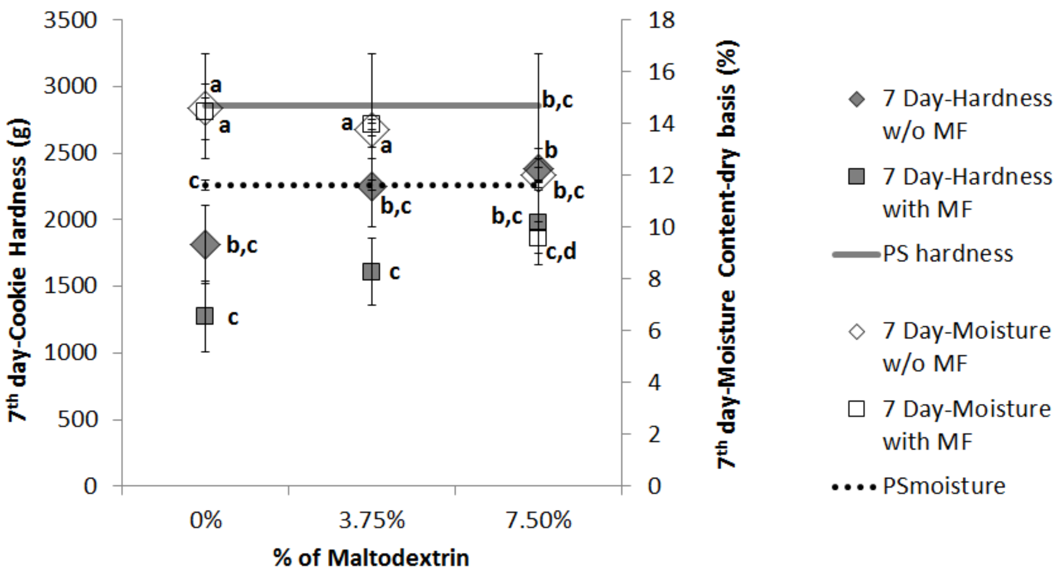

Figure 3.28: The 7th day Hardness and Moisture Contents of 7-day Doughs including PS being evaluated in terms of the Percentages of Maltodextrin

terms of 0-day height while it was significantly different from the 0-day height of PS3 day0 ($p \leq 0.05$). When the percentage of MD was sufficiently high, the difference in height was considerably seen with increasing values. Moreover, 0-day and 7-day heights of PS day0 cookies were not significantly different from those of MFPS day0 except the cookies containing 7.5% MD ($p \leq 0.05$). MF process did not significantly affect the 0-day and 7-day heights except the height belonging to the dough with 7.5% MD. Therefore, MF showed its decreasing effect only on the height of the cookie containing 7.5% MD.

In Figure 3.38, there was no significant difference between both 0-day and 7-day heights of the cookies ($p \leq 0.05$). As the percentage of MD increased, there was no significant difference between the height values of cookies at 0% and 3.75% MD. Similarly, MF process had no considerable effect on the cookie heights because there was no difference between the heights of cookies with MF and without MF ($p \leq 0.05$).

The Figure 3.39 showed the 0th day hardness and diameter values of cookies prepared from 0-day doughs containing PON with different MD percentages. The results regarding cookie hardness was evaluated in Section 3.3. According to Figure 3.39, control cookie containing 25% more fats than cookies including

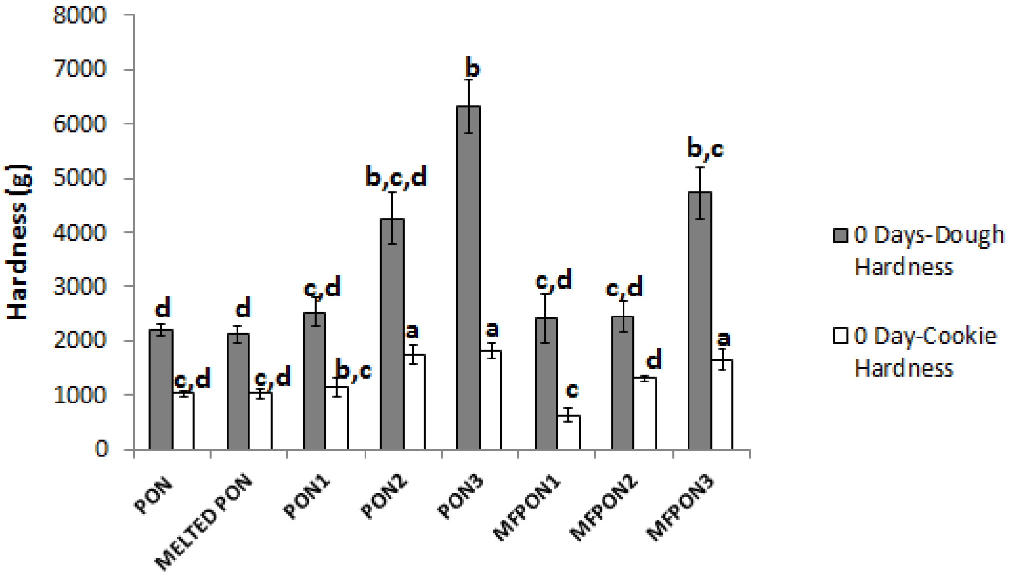

Figure 3.29: Comparison between Hardness of Cookie made from 0-day Dough and Hardness of 0-day Dough with PON

MD had the highest diameter value because of the having less elastic property of dough (Zoulias et al., 2000) shown in Section 3.2. According to Jacob and Leelavathi (2007), increase in cookie diameter with higher fat levels might be probably clarified with the effect of fat on air incorporation during dough making. They claimed that the amount of air incorporation lower the dough density and decreased the dough viscosity, which resulted in larger cookie diameter.

When the 0-day diameter values of cookies including MD at different levels were evaluated, there was no significant difference between the cookies without MF including MD at 0%, 3.75% and 7.5% ($p \leq 0.05$). In other words, increase in the percentage of MD from 0% to 7.5% did not result in any observable changes in 0-day diameters of cookies without MF and this value was around 7 cm. However, the 0-day diameters of cookies with MF at 0%, 3.75% and 7.5% of MD were significantly different from each other ($p \leq 0.05$). Among the cookies made from 0-day doughs, the cookie with MF at 3.75% MD had the highest diameter at around 7.6 cm while the cookie with MF at 0% MD had the lowest diameter value at around 6.37 cm. Also, MFPON2 had the closest hardness and diameter values of the control with 1300 g and 7.6 cm.

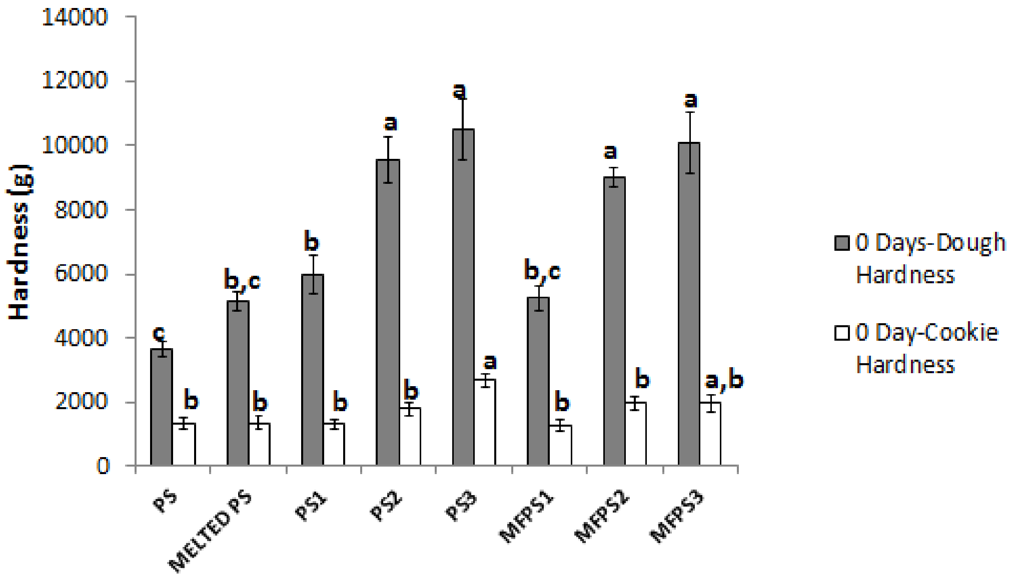

Figure 3.30: Comparison between Hardness of Cookie made from 0-day Dough and Hardness of 0-day Dough with PS

The Figure 3.40 showed the 0th day hardness and diameter values of cookies prepared from 7-day doughs containing PON with changing MD percentages. When compared with the Figure 3.39, there was no change in the diameter of the cookies and it was around 7 cm. There was no significant difference for the diameter between the cookies without MF at different MD percentages. On the other hand, there was a significant difference for the diameter between the cookies with MF at each MD percentage. Also, the cookie with MF containing 0% MD had highest diameter value at around 7.3 cm whereas the cookie with MF containing 3.75% MD had the lowest diameter value at around 6.8 cm.

The Figure 3.41 showed the 0th day hardness and diameter values of cookies prepared from 0-day doughs including PS with changing MD percentages. When compared to the Figure 3.39, there was no remarkable change in the diameter of the control cookie while using PS instead of PON in the cookie. When control cookie was compared to the cookies containing MD at different levels, diameter was influenced in the same manner as in the case of PON used in cookie in Figure 3.39, which resulted in reduction in cookie diameter with fat replacement. Consequently, the use of MD in cookie had a decreasing effect on the diameter compared to the control cookie similar to the findings of Zoulias et al. (2000).

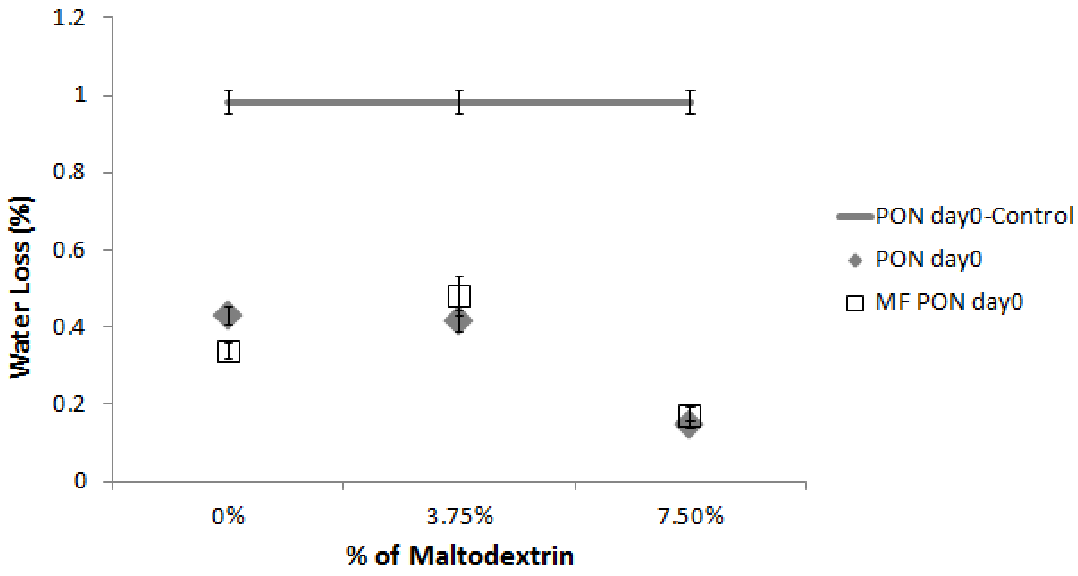

Figure 3.31: The Change in Water Loss of Cookies made from 0-day Doughs with PON during 7-day Storage at Room Temperature

Their study showed that there is not significant difference in diameter between control and other fat reduced cookies.

Also, there was no significant difference for the diameter between the cookies both with MF and without MF at different MD percentages ($p \leq 0.05$). The highest diameter value was around 6.8 cm belonging to the cookie with MF at 7.5% whereas the lowest one was around 6.2 cm.

The Figure 3.42 showed the 0th day hardness and diameter values of cookies prepared from 7-day doughs including PS with changing MD percentages. When compared to the Figure 3.41, there were almost no changes in the diameters of the cookies made from 7-day doughs. The diameters of cookies made from 7-day doughs changed from 7.0 cm to 6.8 cm. It could be inferred that 7-day storage of dough did not have any impact on the diameter. Also, there was no significant difference for the diameter between the cookies without MF at different MD percentages. Therefore, it could be inferred that there was no considerable effect of the MD on the diameter. On the other hand, there was a significant difference for the diameter between the cookie with MF at 0% MD and the cookie with MF at 3.75% and 7.5% MD. Also, the cookie with MF containing 0% MD had highest diameter value at around 7.3 cm whereas the

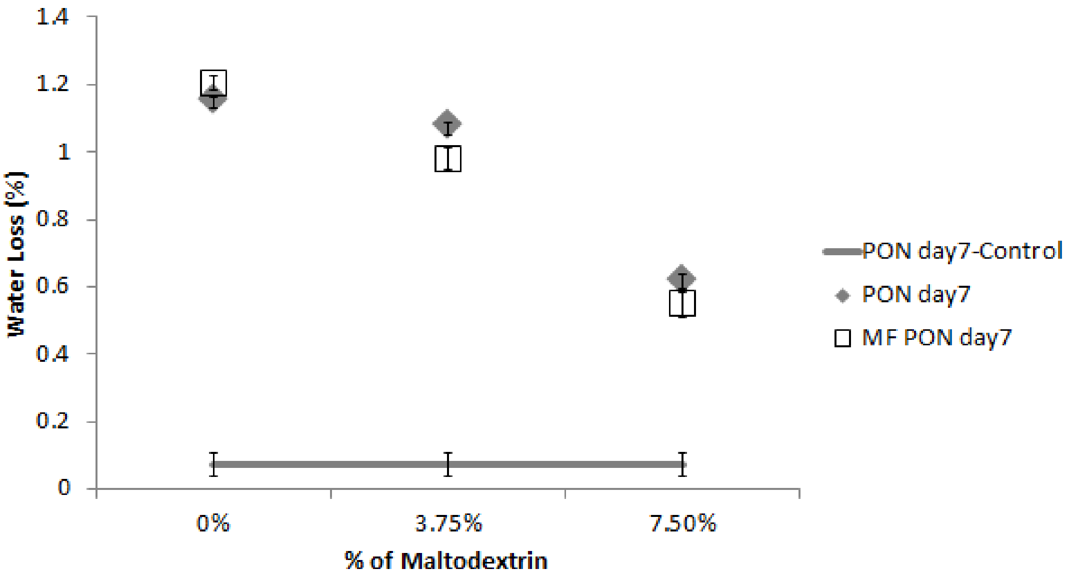

Figure 3.32: The Change in Water Loss of Cookies made from 7-day Doughs with PON during 7-day Storage at Room Temperature

cookie with MF containing 3.75% MD had the lowest diameter value at around 6.8 cm.

3.6 Color Determination

The effect of MD concentration and MF process on color of 0-day cookie surface with PON were shown in the Figure 3.43. In the samples prepared without MF process, with the addition of MD, slightly increase of ΔE values was observed; however, this change remained nearly the same after 3.75% of MD. Thus, it could be inferred that increase in MD levels did not affect the change in the color of cookies. On the other hands, in the cookies prepared with MF process while MD percentages increased from 0% to 7.5%, ΔE values of cookies also slightly increased. Consequently, there was no significant effect of MD at each level on the change in cookie color ($p \leq 0.05$). Moreover, there is no significant effect of the use of MF process on the change in cookie color ($p \leq 0.05$); however, the cookies with MF process were a little bite darker than the cookie without MF process. If the significant difference was not observed for one of the properties

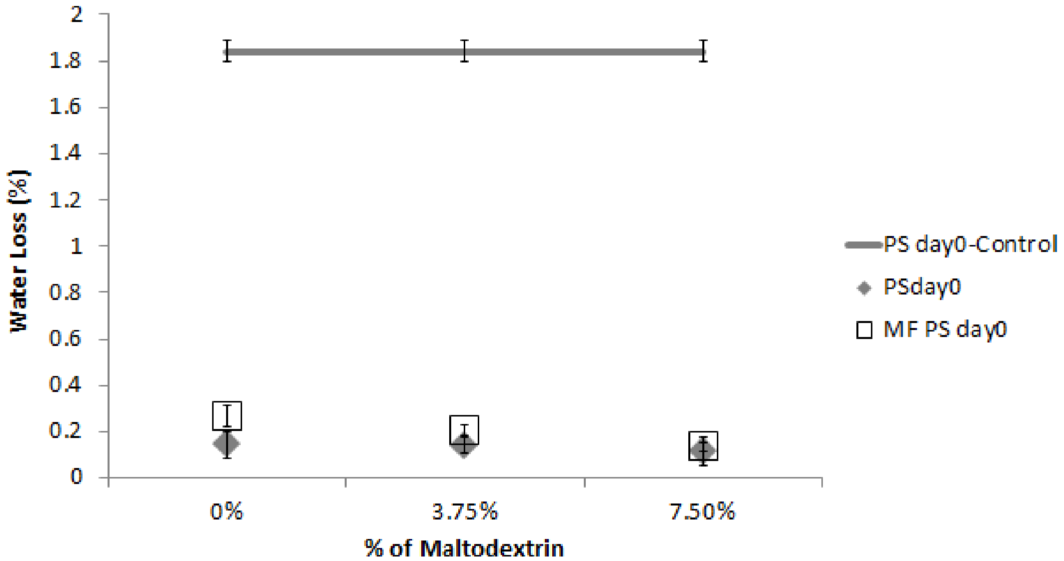

Figure 3.33: The Change in Water Loss of Cookies made from 0-day Doughs with PS during 7-day Storage at Room Temperature

determining the cookie quality, the levels of MD used in the place of fat could be increased. In addition, of all cookies, control cookie had the highest ΔE value, that is, control cookie had the darkest color.

In the Figure 3.44, there was no significant change in color of cookies ($p \leq 0.05$) when the cookies were prepared from 7-day doughs. Colors of all cookies resembled to control cookie. According to ANOVA results of the samples without MF, while there was no significantly difference between 0% MD and 7.5% MD, there was significantly difference between 0% MD and 3.5% MD ($p \leq 0.05$). In the cookies with MF process, the cookies of 0% MD and 3.5% MD had the similar ΔE values, however, after 3.5% MD, there was slightly increase in ΔE value. This meant that the addition of certain amount of MD for the samples with MF process had slight effect on the color. If the addition of MD increased, it might be possible to clearly see the color change in cookies.

The effect of MD concentration and MF process on color of cookie prepared from 0-day dough with PS were shown in the Figure 3.45. The change in color of cookie was as much as that of control cookie. Thus, it could be inferred that there was no significant effect of MD on the cookie color. However, the effect of

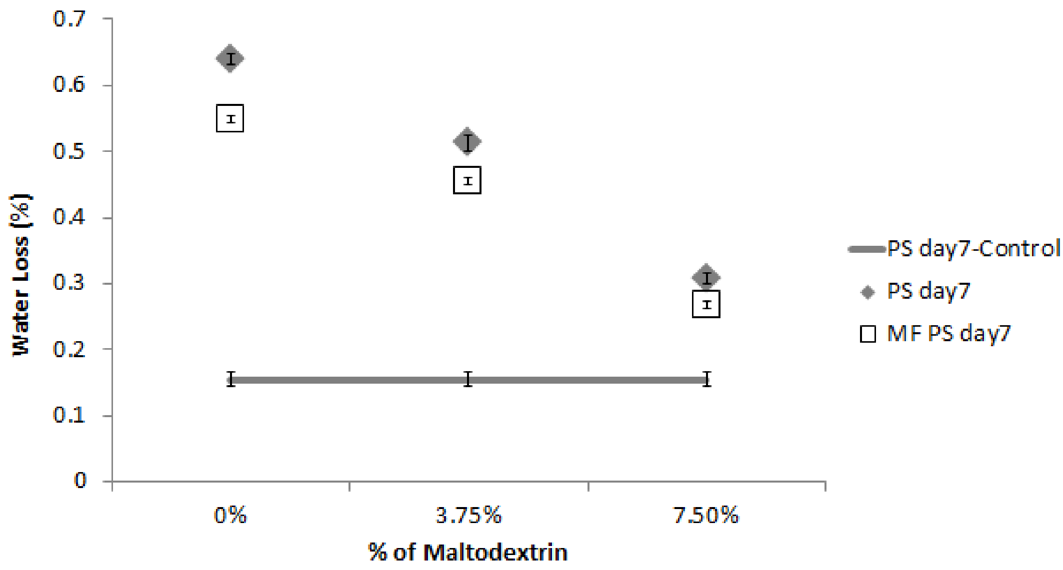

Figure 3.34: The Change in Water Loss of Cookies made from 7-day Doughs with PS during 7-day Storage at Room Temperature

MF process on the color change of cookie was only observed when PS was used in cookie making ($p \leq 0.05$). MF process increased change in delta E value of cookie; that is, MF maked the color of cookie darker (Çıkrıkçı, 2013).

The effect of MD concentration and MF process on color of cookie surface prepared from 7-day dough with PS were shown in the Figure 3.46. Increase in the MD level of cookie did not result in any change in the color of cookie. Also, MF process did not have any effect on the change of cookie color.

Moreover, there were some factors that affected the color of products such as time, baking temperature, composition, humidity in oven etc. (Deep Narayan et al., 2012). Furthermore, maillard and caramelization reactions resulting from the interaction between sugar and proteins in the cookie at high temperature contributed to develop the color of cookie (Anil, 2007). Also, photos of cookies were present in Appendix A.

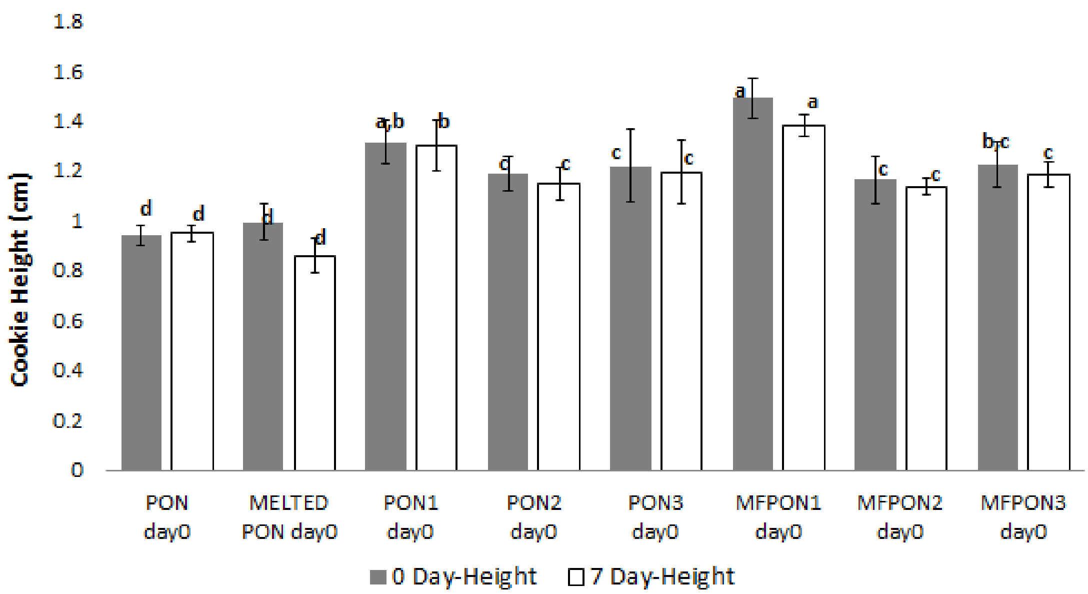

Figure 3.35: The Effect of MD and MF Process on the Height of the Cookies made from 0-day Doughs with PON

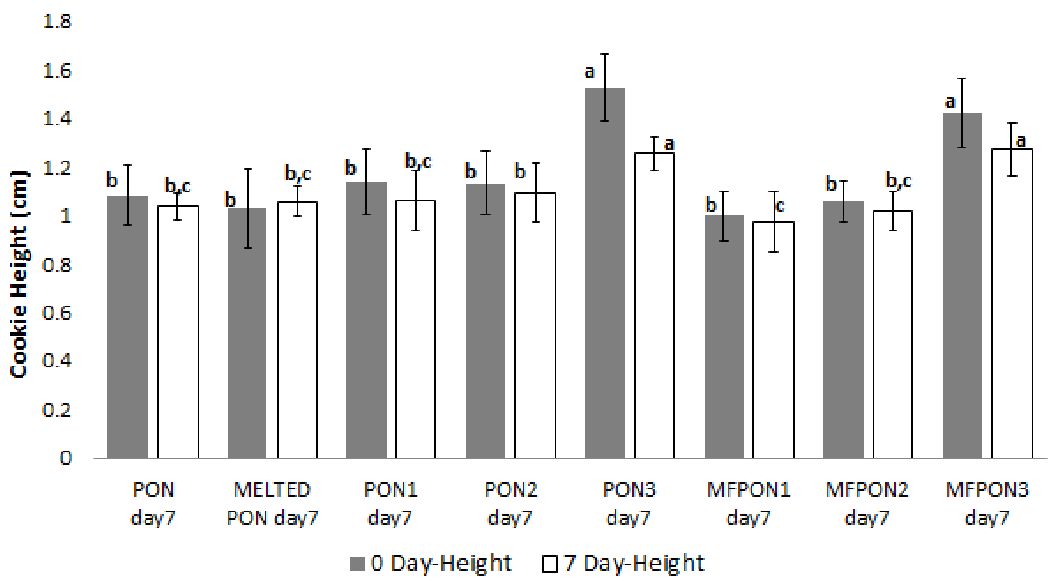

Figure 3.36: The Effect of MD and MF Process on the Height of the Cookies made from 7-day Doughs with PON

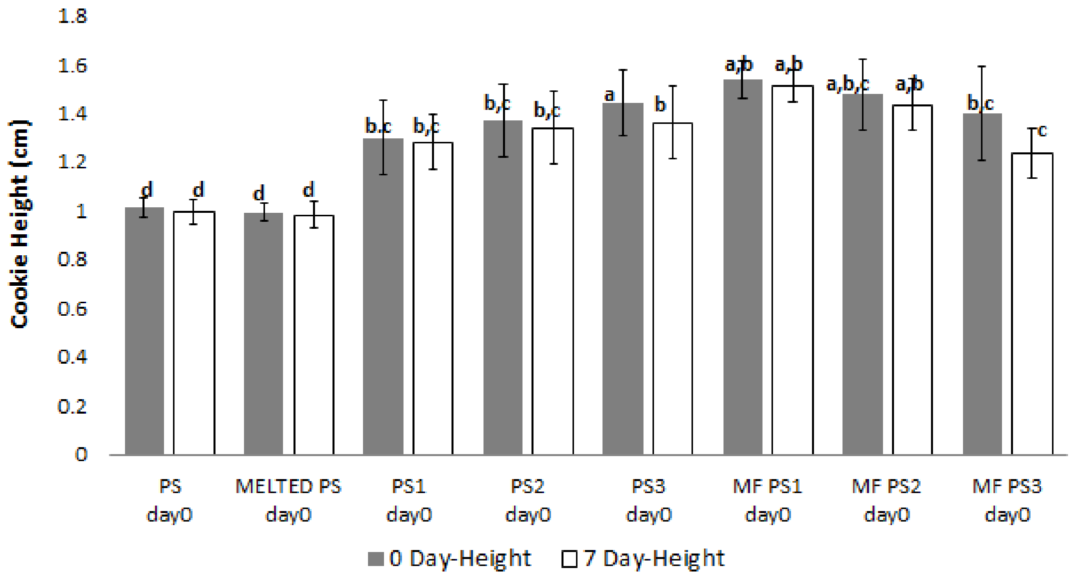

Figure 3.37: The Effect of MD and MF Process on the Height of the Cookies made from 0-day Doughs with PS

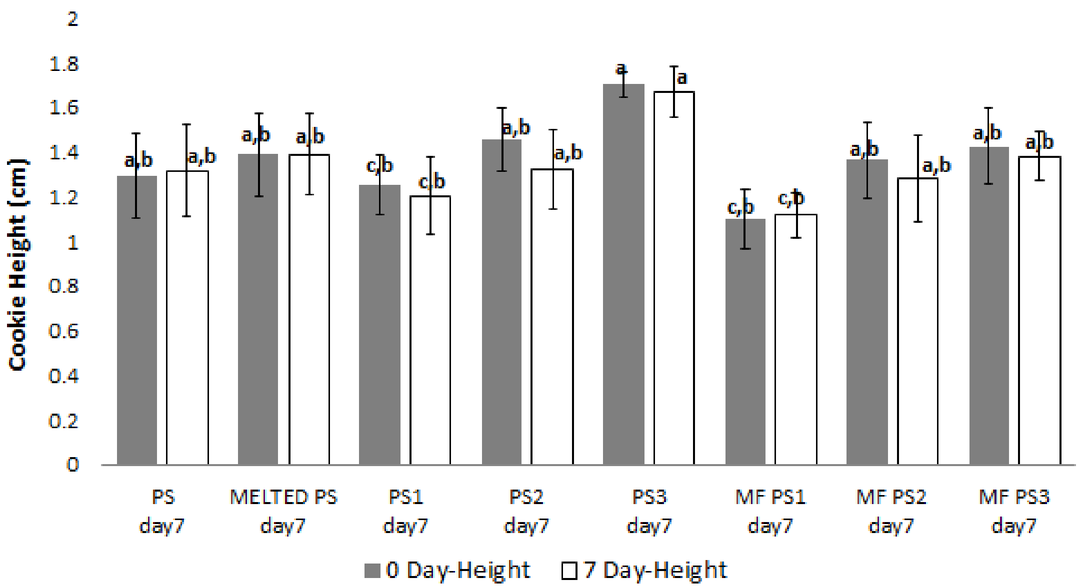

Figure 3.38: The Effect of MD and MF Process on the Height of the Cookies made from 7-day Doughs with PS

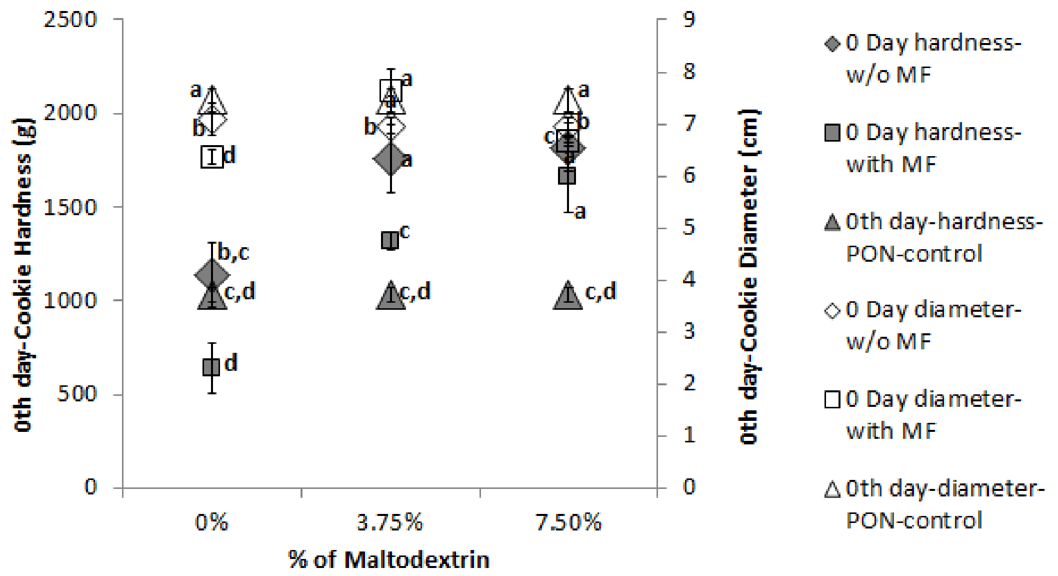

Figure 3.39: The Effect of MD and MF Process on the 0th day Hardness and Diameter of Cookies made from 0-day Doughs with PON

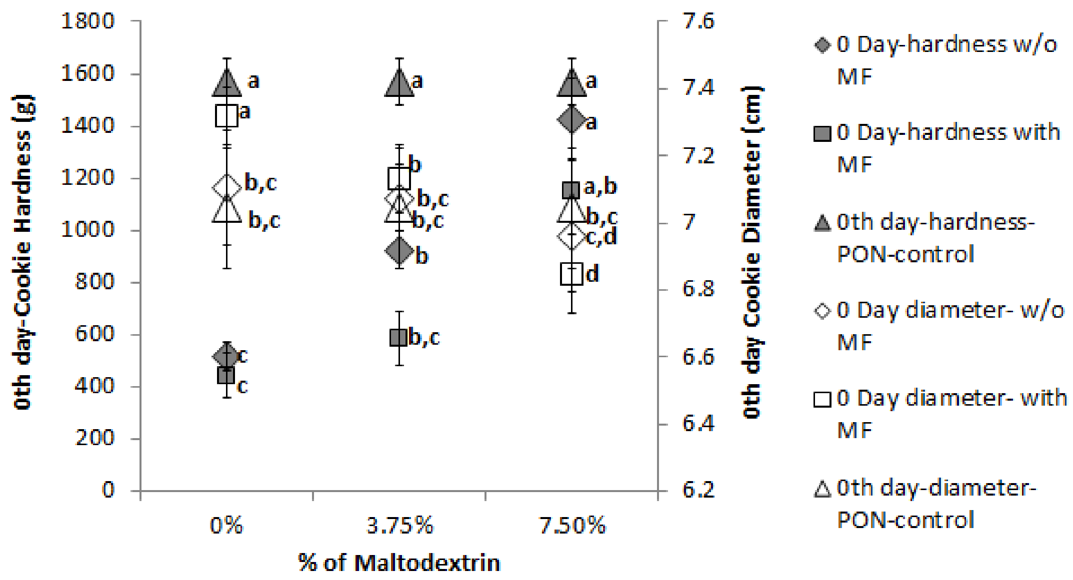

Figure 3.40: The Effect of MD and MF Process on the 0th day Hardness and Diameter of Cookies made from 7-day Doughs with PON

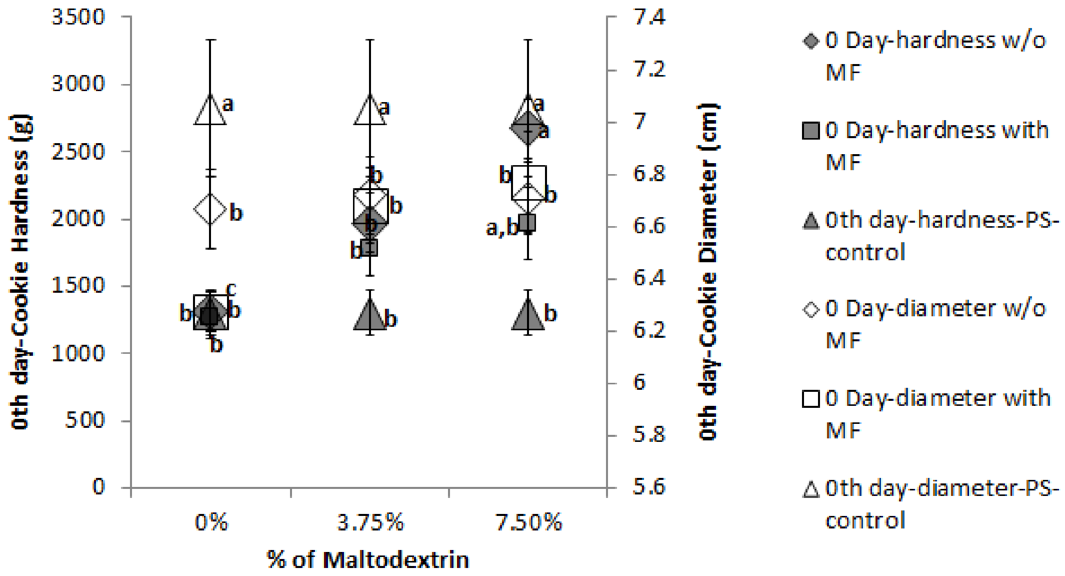

Figure 3.41: The Effect of MD and MF Process on the 0th day Hardness and Diameter of Cookies made from 0-day Doughs with PS

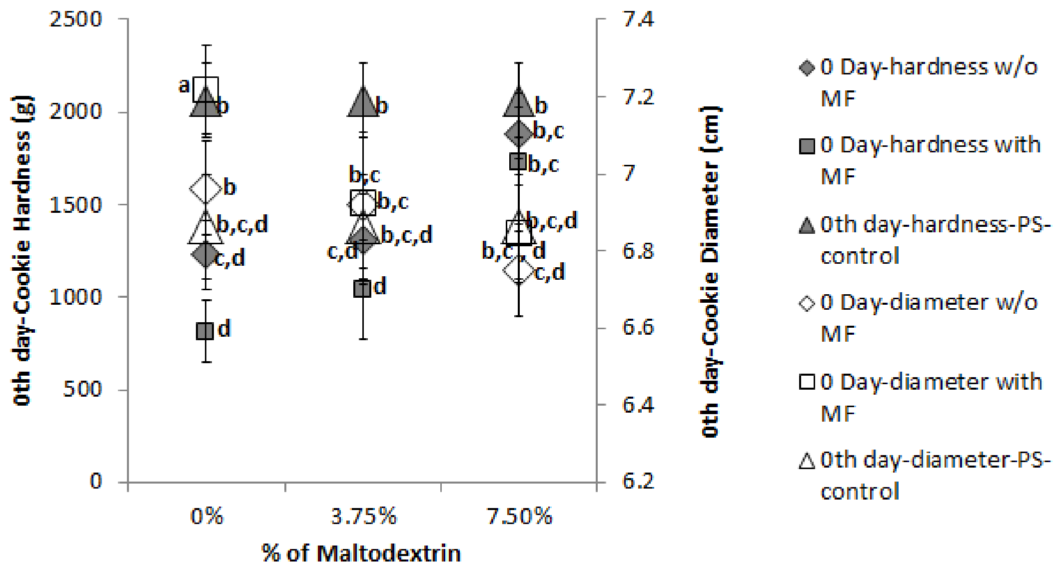

Figure 3.42: The Effect of MD and MF Process on the 0th day Hardness and Diameter of Cookies made from 7-day Doughs with PS

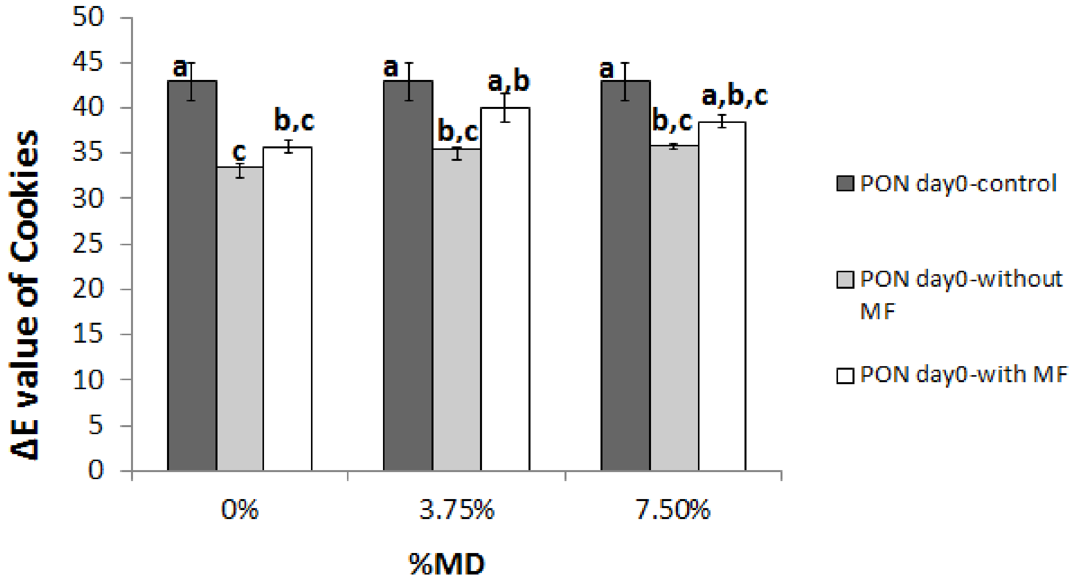

Figure 3.43: The Effect of MD Concentration and MF Process on Color of Cookie Surface prepared from 0-day dough with PON

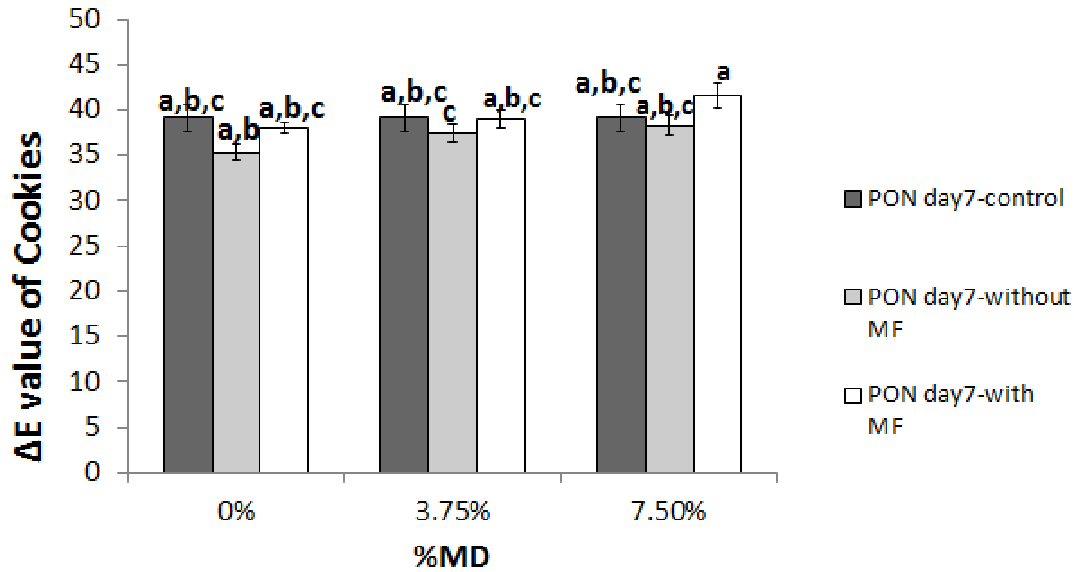

Figure 3.44: The Effect of MD Concentration and MF Process on Color of Cookie Surface prepared from 7-day dough with PON

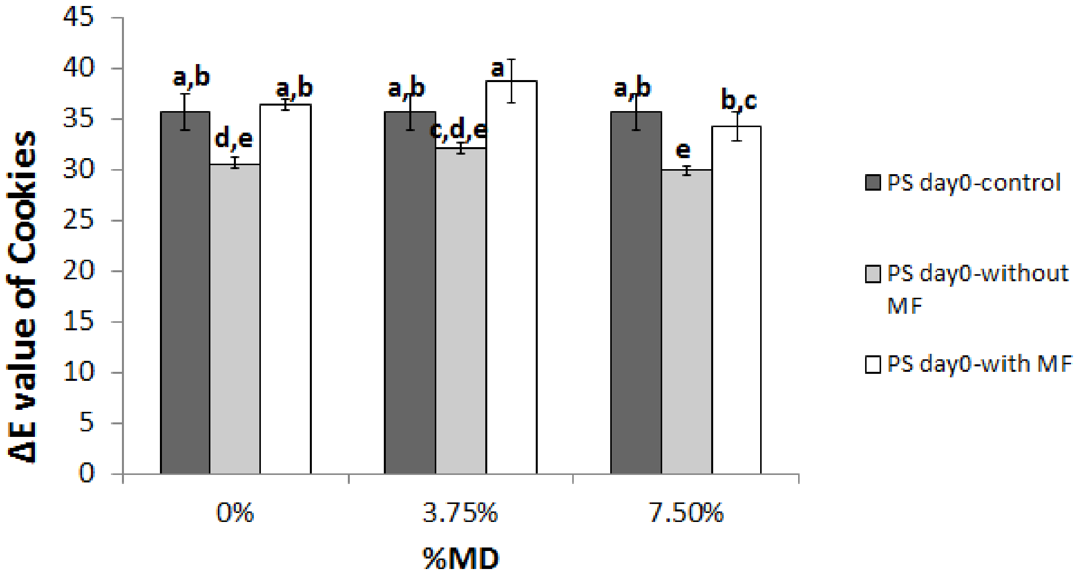

Figure 3.45: The Effect of MD Concentration and MF Process on Color of Cookie Surface prepared from 0-day dough with PS

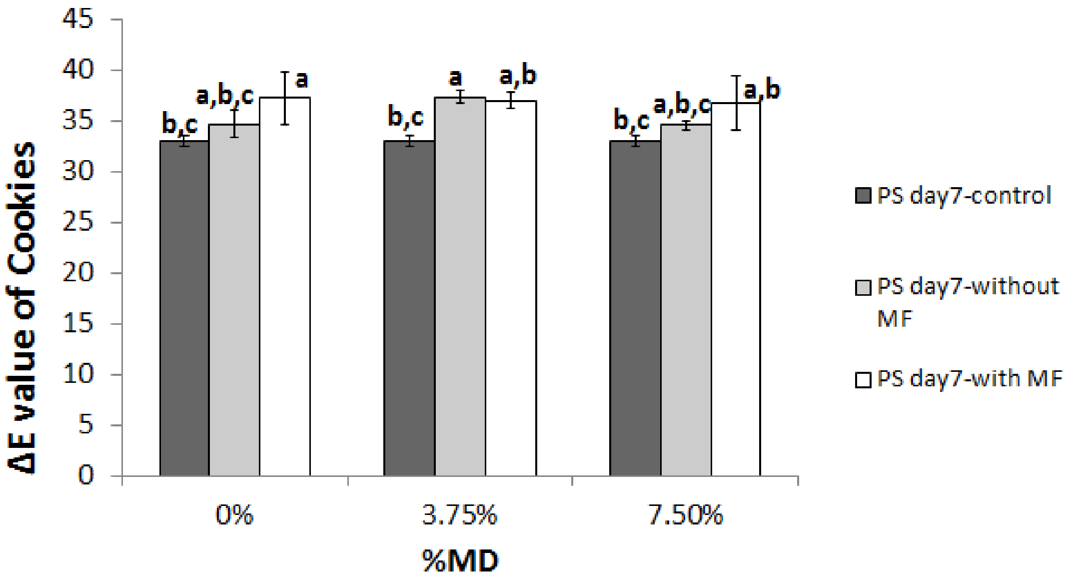

Figure 3.46: The Effect of MD Concentration and MF Process on Color of Cookie Surface prepared from 7-day dough with PS

CHAPTER 4

CONCLUSION AND RECOMMENDATION

In this thesis, the effects of microfluidization and maltodextrin with various percentages on the rheological and textural properties of cookie and cookie dough and the effects of utilization of different types of fats (PON and PS) on the properties of both cookie and cookie dough were investigated.

When the texture profiles of cookie dough were investigated in terms of hardness and cohesiveness, it was seen that hardness of both 0-day and 7-day doughs containing PON increased as the percentage of maltodextrin increased. When PS was used instead of PON in dough making, similar trend was also observed. However, increase in the amount of maltodextrin led to reduction in the moisture content of doughs both with MF and without MF processes. MF did not have a significant effect on the moisture contents of doughs. Control dough containing only PON or PS had the highest cohesiveness value. However, replacement of fat with maltodextrin at different percentages decreased cohesiveness of doughs. In addition, microfluidization did not have any significant effect on both 0th and 7th day cohesiveness of doughs.

According to the rheology results, elastic modulus (G') was higher than viscous modulus (G") which signified the prevalence of elastic features over viscous characteristics of the samples in all cases. That is, the doughs exhibited predominating solid-like behavior. Moreover, the elastic and viscous moduli were low in the control doughs containing PON or PS. It was observed that the use of maltodextrin at 0%, 3.75%, and 7.5% increased both storage and loss moduli in all samples. Furthermore, the G' and G" of doughs containing maltodedextrin at 0%, 3.75%, and 7.5% were increasingly affected by the application of microfluidization.

As the texture profiles of cookies were investigated in terms of hardness, it was observed that there was a significant effect of maltodextrin at 0%, 3.75%, and 7.5% observed on the hardness of cookies including PON whereas the significant effect of maltodextrin was not observed on the cookie hardness when PS was used. However, it was observed that there was an increase in the hardness of cookies containing PS with the increasing percentages of maltodextrin. The significant effect of microfluidization was not generally observed on the 0th and 7th day hardness of cookies prepared from both 0-day and 7-day doughs except the cookie made from 0-day dough with PON. The replacement of fat with maltodextrin at different percentages increased the moisture content of the cookies compared to control cookie.

There were no significant changes in the heights of all types of cookies after 7 day storage. Moreover, microfluidization process did not have any significant effect on the height. In diameter measurement, there was no significant difference between the cookies without MF at 0%, 3.75%, and 7.5% MD. However, there was a significant difference in diameter between cookies with MF at different MD percentages. Therefore, it could be inferred that changes in the MD percentages affected the diameter of the cookies with MF process. On the other hand, MF process did not have any significant effect on the diameter of cookies.

The increase of MD levels in the cookie and the use of MF process did not have any significant effect on the change of the cookie color. The significant effect of MF was only observed with the cookie prepared from 0-day dough including PS.

It could be concluded that 0-day doughs containing PON were preferred in the cookie making instead of doughs stored at refrigerator for 7 days because when doughs were stored, textural and rheological properties of doughs were dramatically affected. Moreover, since the use of PS in cookie led to significant increase in the hardness of both dough and cookie, it was not preferable. Furthermore, the use of microfluidization at 0%, 3.75%, and 7.5% MD was not required for the cookie making because no significant effect on hardness and size of cookie was observed. On the contrary, using maltodextrin (MD18) was a good option for fat replacement in cookie making in terms of textural and rheological properties. When 3.75% MD was used, the cookie with 20% less calorie (PON2) was obtained, compared to control cookie.

For further study, it is recommended to examine the utilization of microfluidized maltodextrin at higher percentages in cookie samples.

REFERENCES

Ahmed, J. (2014). Effect of particle size and temperature on rheology and creep behavior of barley β-d-glucan concentrate dough. *Carbohydrate Polymers*, *111*(0), 89 - 100.

Akoh, C. C. (1998). Fat replacers. *Food technology*, *52*(3), 47–53.

Akoh, C. C., & Min, D. B. (2008). *Food lipids: Chemistry, nutrition, and biotechnology, third edition.* CRC press.

Amjid, M. R., Shehzad, A., Hussain, S., Shabbir, M. A., Khan, M. R., Shoaib, M., et al. (2013). A comprehensive review on wheat flour dough rheology. *Pakistan Journal of Food Sciences*, *23*(2), 105–123.

Anil, M. (2007). Using of hazelnut testa as a source of dietary fiber in breadmaking. *Journal of Food Engineering*, *80*(1), 61 - 67.

Archilla, L. L. (1999). *Evaluation of a maltodextrin gel as a partial replacement for fat in a high-ratio white-layer cake formulation.* Master's thesis, the Faculty of the Virginia Polytechnic Institute and State University.

Ariffin, A. A., Mohamud, Y., Karim, R., Boo, H. C., Chin, N. L., & Che Man, Y. (2011). Rheological, chemical and DSC thermal characteristics of different types of palm oil/palm stearin-based shortenings. *International Food Research Journal*, *18*(1), 189–200.

Assifaoui, A., Champion, D., Chiotelli, E., & Verel, A. (2006). Characterization of water mobility in biscuit dough using a low-field ^{1}H NMR technique. *Carbohydrate Polymers*, *64*(2), 197 - 204.

Baltsavias, A., Jurgens, A., & Van Vliet, T. (1997). Rheological properties of short doughs at small deformation. *Journal of Cereal Science*, *26*(3), 289–300.

Bourne, M. C. (1978). Texture profile analysis [food acceptability]. *Food technology*.

Bourne, M. C. (2002). *Food texture and viscosity: Concept and measurement*. Academic Press.

Bram, Wilderjans, E., Goesaert, H., Brijs, K., & Delcour, J. A. (2008). The role of gluten in a sugar-snap cookie system: A model approach based on gluten–starch blends. *Journal of Cereal Science*, *48*(3), 863 - 869.

Brunello, N., McGauley, S. E., & Marangoni, A. (2003). Mechanical properties of cocoa butter in relation to its crystallization behavior and microstructure. *LWT - Food Science and Technology*, *36*(5), 525 - 532.

Cauvain, S. P., & Young, L. S. (2008). *Baked products: Science, technology and practice*. John Wiley & Sons.

Cho, S. S. (1999). *Complex carbohydrates in foods*. CRC press.

Chronakis, I. S. (1998). On the molecular characteristics, compositional properties, and structural-functional mechanisms of maltodextrins: A review. *Critical reviews in food science and nutrition*, *38*(7), 599–637.

Chugh, B., Singh, G., & Kumbhar, B. (2013). Development of low-fat soft dough biscuits using carbohydrate-based fat replacers. *International Journal of Food Science*, *2013*.

Ciron, C. I. E., Gee, V., Kelly, A., & Auty, M. (2010). Comparison of the effects of high-pressure microfluidization and conventional homogenization of milk on particle size, water retention and texture of non-fat and low-fat yoghurts. *International Dairy Journal*, *20*(5), 314–320.

Ciron, C. I. E., Gee, V. L., Kelly, A. L., & Auty, M. A. (2011). Effect of microfluidization of heat-treated milk on rheology and sensory properties of reduced fat yoghurt. *Food Hydrocolloids*, *25*(6), 1470 - 1476.

Conforti, F. D., Charles, S. A., & Duncan, S. E. (1996). Sensory evaluation and consumer acceptance of carbohydrate-based fat replacers in biscuits. *Journal of Consumer Studies & Home Economics*, *20*(3), 285–296.

Deep Narayan, Y., Neharika, T., & Kappat Valiyapeediyekkal, S. (2012). Effect of partially de-oiled peanut meal flour (DPMF) on the nutritional, textural, organoleptic and physico chemical properties of biscuits. *Food and Nutrition Sciences*, *2012*.

Deman, J. M. (2000). Relationship among chemical, physical, and textural properties of fats. *Physical properties of fats, oils, and emulsifiers*, 79–95.

Dokic-Baucal, L., Dokic, P., & Jakovljevic, J. (2004). Influence of different maltodextrins on properties of O/W emulsions. *Food Hydrocolloids*, *18*(2), 233–239.

Duman, B. (2013). *Production of cacao micro and nano fibers and utilization in cakes.* PhD thesis, Middle East Technical University.

Edwards, W. P. (2007). *The science of bakery products.* Royal Society of Chemistry, Cambridge, UK.

Eliasson, A.-C., & Larsson, K. (1993). *Cereals in breadmaking: a molecular colloidal approach.* Marcel Dekker, New York, NY, USA.

Faubion, J., & Hoseney, R. C. (1990). The viscoelastic properties of wheat flour doughs. In *Dough rheology and baked product texture* (pp. 29–66). Springer.

Foubert, I., Vereecken, J., Smith, K. W., & Dewettinck, K. (2006). Relationship between crystallization behavior, microstructure, and macroscopic properties in trans containing and trans free coating fats and coatings. *Journal of agricultural and food chemistry*, *54*(19), 7256–7262.

Gallagher, E., O'Brien, C., Scannell, A., & Arendt, E. (2003). Use of response surface methodology to produce functional short dough biscuits. *Journal of food Engineering*, *56*(2), 269–271.

Giese, J. (1996). Fats, oils, and fat replacers. *Food Technology*, *50*(4), 77–84.

Goldstein, A., & Seetharaman, K. (2011). Effect of a novel monoglyceride stabilized oil in water emulsion shortening on cookie properties. *Food research international*, *44*(5), 1476–1481.

Hadnađev, M., Dokić, L., Hadnađev, T. D., Pajin, B., & Krstonošić, V. (2011). The impact of maltodextrin-based fat mimetics on rheological and textural characteristics of edible vegetable fat. *Journal of Texture Studies*, *42*(5), 404–411.

Hadnađev, M., Hadnađev, T. D., Dokić, L., Pajin, B., Torbica, A., Šarić, L., & Ikonić, P. (2014). Physical and sensory aspects of maltodextrin gel addition used as fat replacers in confectionery filling systems. *LWT-Food Science and Technology*, *59*(1), 495–503.

Hadnađev, M., Hadnađev, T. D., Torbica, A., Dokić, L., Pajin, B., & Krstonošić, V. (2011). Rheological properties of maltodextrin based fat-reduced confectionery spread systems. *Procedia Food Science*, *1*, 62–67.

Han, L., Li, L., Li, B., Zhao, L., Liu, G., Liu, X., & Wang, X. (2014). Effect of high pressure microfluidization on the crystallization behavior of palm stearin—palm olein blends. *Molecules*, *19*(4), 5348–5359.

Hardt, N., Boom, R., & van der Goot, A. (2014). Wheat dough rheology at low water contents and the influence of xylanases. *Food Research International*, *66*(0), 478 - 484.

Hartnett, D., & Thalheimer, W. (1979). Use of oil in baked products—part I: Background and bread. *Journal of the American Oil Chemists' Society*, *56*(12), 944-947.

Hibberd, G. (1970). Dynamic viscoelastic behaviour of wheat flour doughs. *Rheologica Acta*, *9*(4), 501–505.

Higaki, K., Ueno, S., Koyano, T., & Sato, K. (2001). Effects of ultrasonic irradiation on crystallization behavior of tripalmitoylglycerol and cocoa butter. *Journal of the American Oil Chemists' Society*, *78*(5), 513–518.

Hoseney, R. C., et al. (1994). *Principles of cereal science and technology* (No. Ed. 2). American Association of Cereal Chemists (AACC).

Hu, X., Zhao, M., Sun, W., Zhao, G., & Ren, J. (2011). Effects of microfluidization treatment and transglutaminase cross-linking on physicochemical, functional, and conformational properties of peanut protein isolate. *Journal of agricultural and food chemistry*, *59*(16), 8886–8894.

Jacob, J., & Leelavathi, K. (2007). Effect of fat-type on cookie dough and cookie quality. *Journal of food Engineering*, *79*(1), 299–305.

Johnson, B. R. (2000). Whey protein concentrates in low-fat applications. *US Dairy Export Council*, *2*, 1–6.

Kennedy, J., Knill, C., & Taylor, D. (1995). Maltodextrins. In M. Kearsley & S. Dziedzic (Eds.), *Handbook of starch hydrolysis products and their derivatives* (p. 65-82). Springer US.

Çıkrıkçı, S. (2013). *Production of micro and nano fibers from hazelnut skin and utilization in cakes.* Master's thesis, METU, Ankara.

Kweon, M., Donelson, T., Slade, L., & Levine, H. (2010). Micro-sugar-snap and micro-wire-cut cookie baking with trans-fat and zero-trans-fat shortenings. *Cereal Chemistry*, *87*(5), 415–419.

Lab dispersing devices. (n.d.). http://www.unitedscientific.co.za/index.php

/ika-laboratory-equipment/dispersing-devices. (Visited on 05/05/2015)

Lagrain, B., Brijs, K., Veraverbeke, W. S., & Delcour, J. A. (2005). The impact of heating and cooling on the physico-chemical properties of wheat gluten–water suspensions. *Journal of Cereal Science*, *42*(3), 327–333.

Lipp, M., & Anklam, E. (1998). Review of cocoa butter and alternative fats for use in chocolate—part A: Compositional data. *Food Chemistry*, *62*(1), 73–97.

Maache-Rezzoug, Z., Bouvier, J.-M., Allaf, K., & Patras, C. (1998a). Effect of principal ingredients on rheological behaviour of biscuit dough and on quality of biscuits. *Journal of Food Engineering*, *35*(1), 23 - 42.

Maache-Rezzoug, Z., Bouvier, J.-M., Allaf, K., & Patras, C. (1998b). Study of mixing in connection with the rheological properties of biscuit dough and dimensional characteristics of biscuits. *Journal of food engineering*, *35*(1), 43–56.

Manley, D. J. R. (2000). *Technology of biscuits, crackers and cookies*. Woodhead Publishing Limited.

Manohar, R. S., & Rao, P. H. (1999). Effect of emulsifiers, fat level and type on the rheological characteristics of biscuit dough and quality of biscuits. *Journal of the Science of Food and Agriculture*, *79*(10), 1223–1231.

Matz, S. A. (1968). *Cookie and cracker technology*. Westport, Conn., Avi Pub. Co.

McClements, D. J. (1998). *Food emulsions: Principles, practice, and techniques*. CRC press.

McCrae, C. H. (1994). Homogenization of milk emulsions: use of microfluidizer. *International Journal of Dairy Technology*, *47*(1), 28–31.

Milašinović Šeremešić, M., Dokić, L., Nikolić, I., Radosavljević, M., & Šoronja Simović, D. (2013). Rheological and textural properties of short (cookie) dough made with two types of resistant starch. *Journal of Texture Studies*, *44*(2), 115–123.

Miller, G. D., & Groziak, S. M. (1996). Impact of fat substitutes on fat intake. *Lipids*, *31*(1), S293–S296.

Miller, R. A., & Hoseney, R. (1997). Factors in hard wheat flour responsible for reduced cookie spread 1. *Cereal chemistry*, *74*(3), 330–336.

Napier, K. (1997, October). *Fat replacers - the cutting edge of cutting calories* (Tech. Rep.). American Council on Science and Health.

O'Brien, R. D. (2008). *Fats and oils: formulating and processing for applications*. CRC press.

Olewnik, M., & Kulp, K. (1984). The effect of mixing time and ingredient variation on farinograms of cookie doughs. *Cereal chemistry (USA)*.

O'Neil, E. (1993). Low-fat products. *Meat Focus International*, *2*, 70.

Pareyt, B., Brijs, K., & Delcour, J. A. (2010). Impact of fat on dough and cookie properties of sugar-snap cookies. *Cereal chemistry*, *87*(3), 226–230.

Pareyt, B., Talhaoui, F., Kerckhofs, G., Brijs, K., Goesaert, H., Wevers, M., & Delcour, J. A. (2009). The role of sugar and fat in sugar-snap cookies: Structural and textural properties. *Journal of Food Engineering*, *90*(3), 400–408.

Peters, J. C., Lawson, K. D., Middleton, S. J., & Triebwasser, K. C. (1997). Assessment of the nutritional effects of olestra, a nonabsorbed fat replacement: summary. *The Journal of nutrition*, *127*(8), 1719S–1728S.

Petrofsky, K., & Hoseney, R. (1995). Rheological properties of dough made with starch and gluten from several cereal sources. *Cereal Chemistry*, *72*(1), 53–57.

Pimdit, K., Therdthai, N., & Jangchud, K. (2008). Effects of fat replacers on the physical, chemical and sensory characteristics of puff pastry. *Kasetsart Journal - Natural Science*, *42*(4), 739-746.

Pinnamaneni, S., Das, N., & Das, S. (2003). Comparison of oil-in-water emulsions manufactured by microfluidization and homogenization. *Pharmazie*, *58*(8), 554-558.

Romeih, E. A., Michaelidou, A., Biliaderis, C. G., & Zerfiridis, G. K. (2002). Low-fat white-brined cheese made from bovine milk and two commercial fat mimetics: chemical, physical and sensory attributes. *International Dairy Journal*, *12*(6), 525 - 540.

Sanchez, C., Klopfenstein, C., & Walker, C. (1995). Use of carbohydrate-based fat substitutes and emulsifying agents in reduced-fat shortbread cookies. *Cereal Chemistry*, *72*(1), 25–29.

Sipahioglu, O., Alvarez, V., & Solano-Lopez, C. (1999). Structure, physico-chemical and sensory properties of feta cheese made with tapioca starch and lecithin as fat mimetics. *International dairy journal*, *9*(11), 783–789.

Sobolewska-Zielińska, J., & Fortuna, T. (2010). Retrogradation of starches and maltodextrins of origin various. *Acta Sci. Pol., Technol. Aliment*, *9*, 71–81.

Sowbhagya, H., Suma, P. F., Mahadevamma, S., & Tharanathan, R. (2007). Spent residue from cumin – a potential source of dietary fiber. *Food Chemistry*, *104*(3), 1220 - 1225.

Sudha, M., Srivastava, A., Vetrimani, R., & Leelavathi, K. (2007). Fat replacement in soft dough biscuits: Its implications on dough rheology and biscuit quality. *Journal of Food Engineering*, *80*(3), 922–930.

Sudha, M., Vetrimani, R., & Leelavathi, K. (2007). Influence of fibre from different cereals on the rheological characteristics of wheat flour dough and on biscuit quality. *Food Chemistry*, *100*(4), 1365–1370.

Tamime, A., Muir, D., Shenana, M., Kalab, M., & Dawood, A. (1999). Processed cheese analogues incorporating fat-substitutes 2. rheology, sensory perception of texture and microstructure. *{LWT} - Food Science and Technology*, *32*(1), 50 - 59.

Tan, C., & Man, Y. C. (2002). Differential scanning calorimetric analysis of palm oil, palm oil based products and coconut oil: effects of scanning rate variation. *Food chemistry*, *76*(1), 89–102.

Tarr, B., & Bixby, S. (1995). Proteinaceous grain-based fat substitute. *Trends in Food Science & Technology*, *6*(9), 317 -.

TO: NDA 21-321, 7. (n.d.). http://www.fda.gov/ohrms/dockets/ac/01/briefing/3775b1 _07_Medical%20Review.htm. ((Visited on 04/27/2015))

Vanderghem, C., Danthine, S., Blecker, C., & Deroanne, C. (2007). Rheological properties of microfluidized oil-in-water emulsions stabilized by dairy components. In *98th aocs annual meeting & expo.*

Wang, T., Sun, X., Zhou, Z., & Chen, G. (2012). Effects of microfluidization process on physicochemical properties of wheat bran. *Food Research International*, *48*(2), 742 - 747.

Wang, Y.-J., & Wang, L. (2000). Structures and properties of commercial maltodextrins from corn, potato, and rice starches. *Starch - Stärke*, *52*(8-9), 296–304.

Webb, T., Heaps, P., Eggitt, P. R., & Coppock, J. (1970). A rheological investigation of the role of water in wheat flour doughs. *International Journal of Food Science & Technology*, *5*(1), 65–76.

Wehrle, K., Gallagher, E., Neville, D. P., Keogh, M. K., & Arendt, E. (1999). Microencapsulated high-fat powders in biscuit production.

Zeitschrift für Lebensmitteluntersuchung und-Forschung A, *208*(5-6), 388–393.

Witczak, M., Korus, J., Ziobro, R., & Juszczak, L. (2010). The effects of maltodextrins on gluten-free dough and quality of bread. *Journal of food engineering*, *96*(2), 258–265.

Yıldız, E. (2014). *Production of hazelnut skin micro and nano fibers and utilization in biscuits.* Unpublished doctoral dissertation, Middle East Technical University.

Yuce, O. (2011). *Application of high dynamic microfluidization to improve some quality parameters and stability of orange juice*. Unpublished master's thesis, METU, Ankara.

Zoulias, E., Oreopoulou, V., & Tzia, C. (2000). Effect of fat mimetics on physical, textural and sensory properties of cookies. *International Journal of Food Properties*, *3*(3), 385–397.

Zoulias, E., Oreopoulou, V., & Tzia, C. (2002). Textural properties of low-fat cookies containing carbohydrate-or protein-based fat replacers. *Journal of Food Engineering*, *55*(4), 337–342.

APPENDIX A

PHOTOGRAPHS OF COOKIE SAMPLES

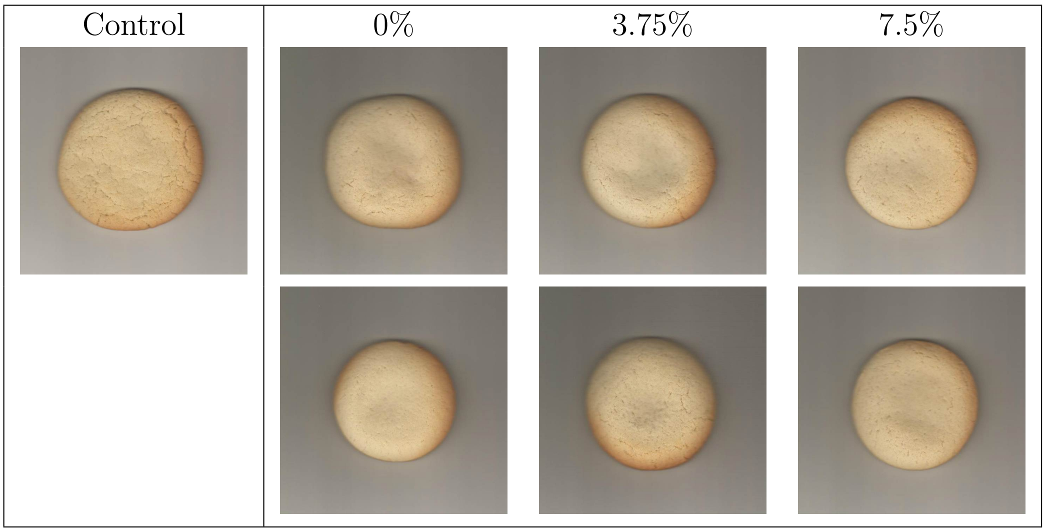

Figure A.1: The photo on the left top corner shows the control cookie, PON day0, made from 0-day dough. The other photos on the top indicate how different percentages of maltodextrin (DE18) affect the cookies when they are not exposed to MF, PON1 day0, PON2 day0, PON3 day0, respectively and the bottom three photos represent how the same percentages of maltodextrin (DE18) affect the cookies with MF, MFPON1 day0, MFPON2 day0 and MDPON3 day0, respectively.

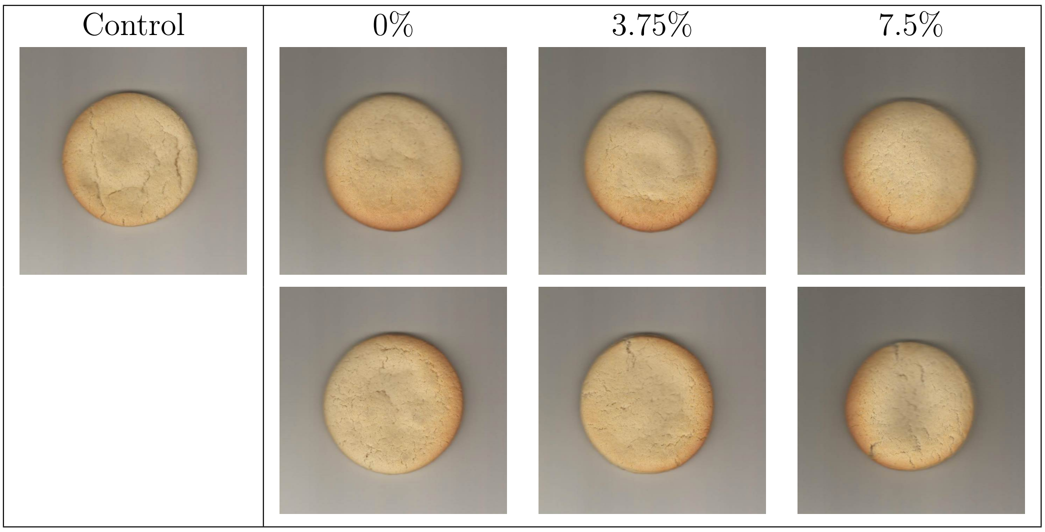

Figure A.2: The photo on the left top corner shows the control cookie, PON day7, made from 7-day dough. The other photos on the top indicate how different percentages of maltodextrin (DE18) affect the cookies when they are not exposed to MF, PON1 day7, PON2 day7, PON3 day7, respectively and the bottom three photos represent how the same percentages of maltodextrin (DE18) affect the cookies with MF, MFPON1 day7, MFPON2 day7 and MDPON3 day7, respectively.

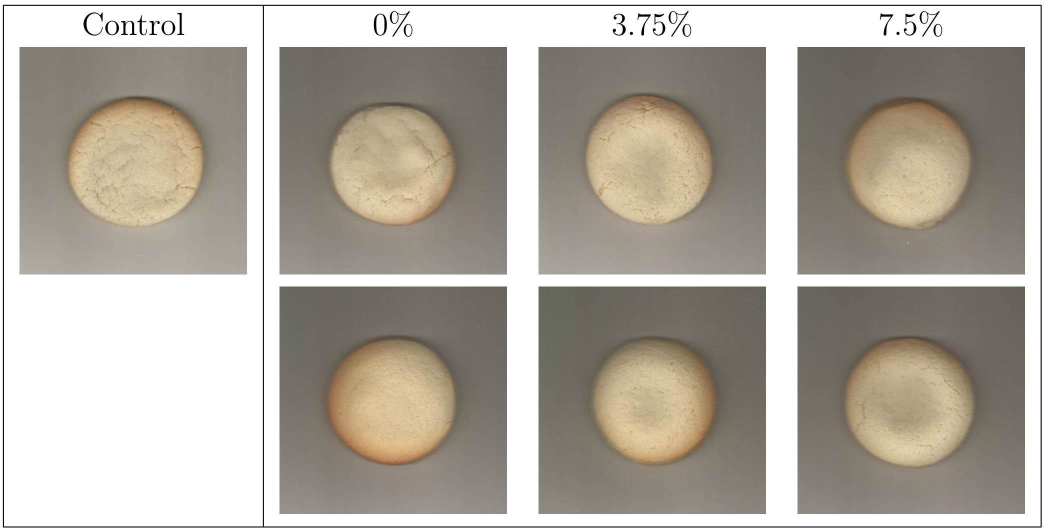

Figure A.3: The photo on the left top corner shows the control cookie, PS day0, made from 0-day dough. The other photos on the top indicate how different percentages of maltodextrin (DE18) affect the cookies when they are not exposed to MF, PS1 day0, PS2 day0, PS3 day0, respectively and the bottom three photos represent how the same percentages of maltodextrin (DE18) affect the cookies with MF, MFPS1 day0, MFPS2 day0 and MDPS3 day0, respectively.

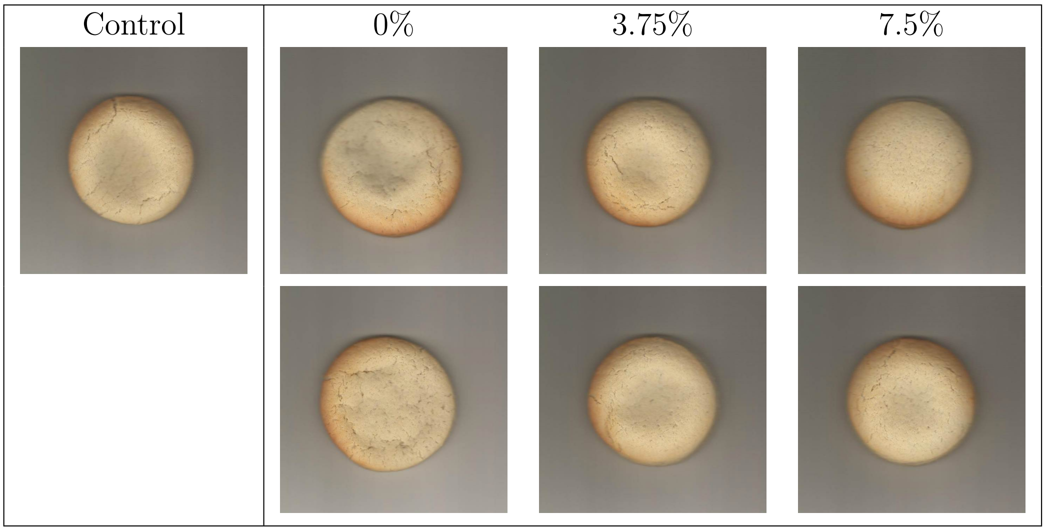

Figure A.4: The photo on the left top corner shows the control cookie, PS day7, made from 7-day dough. The other photos on the top indicate how different percentages of maltodextrin (DE18) affect the cookies when they are not exposed to MF, PS1 day7, PS2 day7, PS3 day7, respectively and the bottom three photos represent how the same percentages of maltodextrin (DE18) affect the cookies with MF, MFPS1 day7, MFPS2 day7 and MDPS3 day7, respectively.

APPENDIX B

A FIGURE RELATED TO CALCULATIONS OF TEXTURE ANALYSIS

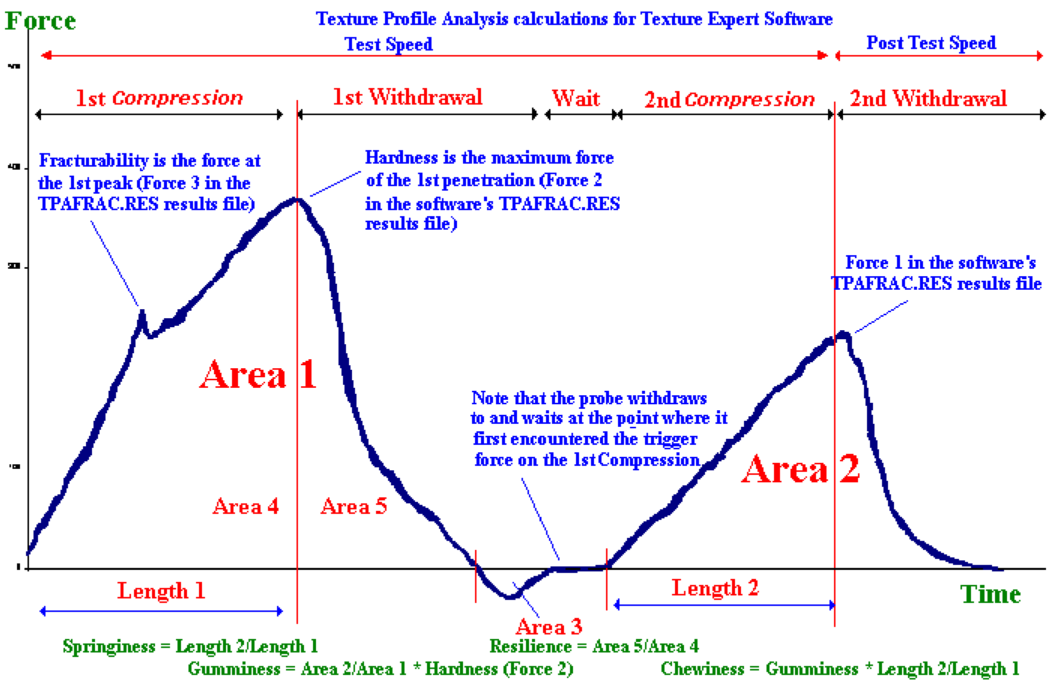

Figure B.1: Texture Profile Analysis (Bourne, 2002)

APPENDIX C

RESULTS OF ELASTIC AND VISCOUS MODULI OF DOUGH

One-way ANOVA: G' versus Sample name

Source	DF	SS	MS	F	P
Sample name	7	5.39350E+11	77050028702	150.05	0.000
Error	192	98589074285	513484762		
Total	199	6.37939E+11			

S = 22660   R-Sq = 84.55%   R-Sq(adj) = 83.98%

Grouping Information Using Tukey Method

Sample name	N	Mean	Grouping
7	25	174865	A
6	25	125561	B
5	25	63109	C
4	25	53935	C
0	25	33941	D
1	25	33656	D
3	25	27287	D
2	25	16519	D

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Sample name

One-way ANOVA: G p versus Sample name

Source	DF	SS	MS	F	P
Sample name	2	18550670350	9275335175	36.31	0.000
Error	72	18392191818	255447109		
Total	74	36942862168			

S = 15983   R-Sq = 50.21%   R-Sq(adj) = 48.83%

Grouping Information Using Tukey Method

Sample name	N	Mean	Grouping
4	25	53935	A
3	25	27287	B
2	25	16519	B

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Sample name

Source	DF	SS	MS	F	P
Sample name	2	1.56838E+11	78419111298	79.07	0.000
Error	72	71405241977	991739472		
Total	74	2.28243E+11			

S = 31492   R-Sq = 68.72%   R-Sq(adj) = 67.85%

Grouping Information Using Tukey Method

Sample name	N	Mean	Grouping
7	25	174865	A
6	25	125561	B
5	25	63109	C

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Sample name

Source	DF	SS	MS	F	P
Sample name	1	1010900	1010900	0.01	0.941
Error	48	8791640490	183159177		
Total	49	8792651390			

S = 13534   R-Sq = 0.01%   R-Sq(adj) = 0.00%

Grouping Information Using Tukey Method

Sample name	N	Mean	Grouping
0	25	33941	A
1	25	33656	A

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Sample name

Source	DF	SS	MS	F	P
Sample name	7	92223020013	13174717145	20.71	0.000
Error	192	1.22138E+11	636136601		
Total	199	2.14361E+11			

S = 25222   R-Sq = 43.02%   R-Sq(adj) = 40.94%

Grouping Information Using Tukey Method

Sample name	N	Mean	Grouping
7	25	80737	A
6	25	69208	A B
5	25	49065	B C
4	25	48327	B C
3	25	45430	C D
1	25	24584	D E
0	25	24114	D E
2	25	14222	E

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals

One-way ANOVA: G dp versus Sample name

Source	DF	SS	MS	F	P
Sample name	1	2761297	2761297	0.01	0.906
Error	48	9320864184	194184670		
Total	49	9323625481			

S = 13935   R-Sq = 0.03%   R-Sq(adj) = 0.00%

Grouping Information Using Tukey Method

Sample name	N	Mean	Grouping
1	25	24584	A
0	25	24114	A

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals

One-way ANOVA: G dp versus Sample name

Source	DF	SS	MS	F	P
Sample name	2	17878484299	8939242150	18.21	0.000
Error	72	35336439354	490783880		
Total	74	53214923653			

S = 22154   R-Sq = 33.60%   R-Sq(adj) = 31.75%

Grouping Information Using Tukey Method

Sample name	N	Mean	Grouping
4	25	48327	A
3	25	45430	A
2	25	14222	B

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals

One-way ANOVA: G dp versus Sample name

Source	DF	SS	MS	F	P
Sample name	2	12848330651	6424165326	5.97	0.004

```
Error        72  77480923849  1076123942
Total        74  90329254501

S = 32804   R-Sq = 14.22%   R-Sq(adj) = 11.84%
```

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Grouping Information Using Tukey Method

Sample
name     N   Mean  Grouping
7       25  80737  A
6       25  69208  A B
5       25  49065    B

Means that do not share a letter are significantly different.


Tukey 95% Simultaneous Confidence Intervals
```

One-way ANOVA: G p versus Sample name

```
Source       DF           SS           MS       F      P
Sample name   2  6.96523E+11  3.48262E+11  164.05  0.000
Error        72  1.52851E+11   2122933746
Total        74  8.49374E+11

S = 46075   R-Sq = 82.00%   R-Sq(adj) = 81.50%

Grouping Information Using Tukey Method

Sample
name     N    Mean  Grouping
7       25  276898  A
6       25  118590    B
5       25   46102      C

Means that do not share a letter are significantly different.


Tukey 95% Simultaneous Confidence Intervals
```

One-way ANOVA: G p versus Sample name

```
Source       DF           SS           MS      F      P
Sample name   2  3.97782E+11  1.98891E+11  87.60  0.000
Error        72  1.63468E+11   2270390975
Total        74  5.61250E+11

S = 47649   R-Sq = 70.87%   R-Sq(adj) = 70.07%


Grouping Information Using Tukey Method

Sample
name     N    Mean  Grouping
4       25  223018  A
3       25  100362    B
2       25   49514      C

Means that do not share a letter are significantly different.
```

Tukey 95% Simultaneous Confidence Intervals

One-way ANOVA: G p versus Sample name

Source	DF	SS	MS	F	P
Sample name	1	20961963756	20961963756	1.48	0.229
Error	48	6.77873E+11	14122358181		
Total	49	6.98835E+11			

S = 118838   R-Sq = 3.00%   R-Sq(adj) = 0.98%

Grouping Information Using Tukey Method

Sample name	N	Mean	Grouping
1	25	323105	A
0	25	282154	A

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals

One-way ANOVA: G p versus Sample name

Source	DF	SS	MS	F	P
Sample name	7	2.17929E+12	3.11327E+11	60.12	0.000
Error	192	9.94193E+11	5178086315		
Total	199	3.17348E+12			

S = 71959   R-Sq = 68.67%   R-Sq(adj) = 67.53%

Grouping Information Using Tukey Method

Sample name	N	Mean	Grouping
1	25	323105	A
0	25	282154	A B
7	25	276898	A B
4	25	223018	B
6	25	118590	C
3	25	100362	C D
2	25	49514	D
5	25	46102	D

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals

One-way ANOVA: G dp versus Sample name

Source	DF	SS	MS	F	P
Sample name	7	8.60255E+11	1.22894E+11	30.82	0.000
Error	192	7.65671E+11	3987869200		
Total	199	1.62593E+12			

S = 63150   R-Sq = 52.91%   R-Sq(adj) = 51.19%

Grouping Information Using Tukey Method

Sample name	N	Mean	Grouping
1	25	209305	A
0	25	185416	A B
7	25	184403	A B
4	25	140439	B
6	25	84133	C
3	25	71905	C
2	25	37810	C
5	25	34838	C

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals

One-way ANOVA: G dp versus Sample name

Source	DF	SS	MS	F	P
Sample name	1	7133474383	7133474383	0.77	0.383
Error	48	4.41825E+11	9204692646		
Total	49	4.48959E+11			

S = 95941   R-Sq = 1.59%   R-Sq(adj) = 0.00%

Grouping Information Using Tukey Method

Sample name	N	Mean	Grouping
1	25	209305	A
0	25	185416	A

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals

One-way ANOVA: G dp versus Sample name

Source	DF	SS	MS	F	P
Sample name	2	1.36602E+11	68301067017	31.28	0.000
Error	72	1.57229E+11	2183739666		
Total	74	2.93831E+11			

S = 46731   R-Sq = 46.49%   R-Sq(adj) = 45.00%

Grouping Information Using Tukey Method

Sample name	N	Mean	Grouping
4	25	140439	A
3	25	71905	B
2	25	37810	C

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals

One-way ANOVA: G dp versus Sample name

Source	DF	SS	MS	F	P
Sample name	2	2.90450E+11	1.45225E+11	62.76	0.000
Error	72	1.66616E+11	2314116436		
Total	74	4.57066E+11			

S = 48105   R-Sq = 63.55%   R-Sq(adj) = 62.53%

Grouping Information Using Tukey Method

Sample name	N	Mean	Grouping
7	25	184403	A
6	25	84133	B
5	25	34838	C

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals

One-way ANOVA: G p versus Sample name

Source	DF	SS	MS	F	P
Sample name	2	2.20070E+11	1.10035E+11	12.61	0.000
Error	72	6.28143E+11	8724205865		
Total	74	8.48213E+11			

S = 93403   R-Sq = 25.95%   R-Sq(adj) = 23.89%

Grouping Information Using Tukey Method

Sample name	N	Mean	Grouping
7	25	364264	A
6	25	296025	B
5	25	231596	C

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals

One-way ANOVA: G p versus Sample name

Source	DF	SS	MS	F	P
Sample name	2	9.03850E+11	4.51925E+11	57.24	0.000
Error	72	5.68435E+11	7894933893		
Total	74	1.47228E+12			

S = 88853   R-Sq = 61.39%   R-Sq(adj) = 60.32%

Grouping Information Using Tukey Method

Sample name	N	Mean	Grouping
4	25	411126	A
3	25	233283	B
2	25	147534	C

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals

One-way ANOVA: G p versus Sample name

Source	DF	SS	MS	F	P
Sample name	1	29701425265	29701425265	8.63	0.005
Error	48	1.65293E+11	3443598610		
Total	49	1.94994E+11			

S = 58682   R-Sq = 15.23%   R-Sq(adj) = 13.47%

Grouping Information Using Tukey Method

Sample name	N	Mean	Grouping
1	25	222837	A
0	25	174092	B

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals

One-way ANOVA: G p versus Sample name

Source	DF	SS	MS	F	P
Sample name	1	29701425265	29701425265	8.63	0.005
Error	48	1.65293E+11	3443598610		
Total	49	1.94994E+11			

S = 58682   R-Sq = 15.23%   R-Sq(adj) = 13.47%

Grouping Information Using Tukey Method

Sample name	N	Mean	Grouping
1	25	222837	A
0	25	174092	B

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals

One-way ANOVA: G p versus Sample name

Source	DF	SS	MS	F	P
Sample name	7	1.44846E+12	2.06922E+11	29.17	0.000
Error	192	1.36187E+12	7093077062		
Total	199	2.81033E+12			

S = 84220   R-Sq = 51.54%   R-Sq(adj) = 49.77%

Grouping Information Using Tukey Method

Sample name	N	Mean	Grouping
4	25	411126	A
7	25	364264	A B
6	25	296025	B C
3	25	233283	C D
5	25	231596	C D
1	25	222837	D
0	25	174092	D E
2	25	147534	E

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Sample name

One-way ANOVA: G dp versus Sample name

Source	DF	SS	MS	F	P
Sample name	7	5.96375E+11	85196453777	18.08	0.000
Error	192	9.04665E+11	4711794473		
Total	199	1.50104E+12			

S = 68643   R-Sq = 39.73%   R-Sq(adj) = 37.53%

Grouping Information Using Tukey Method

Sample name	N	Mean	Grouping
4	25	261728	A
7	25	223873	A B
6	25	168098	B C
3	25	153916	C D
5	25	145337	C D E
1	25	131010	C D E
0	25	102580	D E
2	25	89476	E

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals

One-way ANOVA: G dp versus Sample name

Source	DF	SS	MS	F	P
Sample name	1	10102790040	10102790040	5.56	0.023
Error	48	87237798868	1817454143		
Total	49	97340588908			

S = 42632   R-Sq = 10.38%   R-Sq(adj) = 8.51%

Grouping Information Using Tukey Method

Sample

name	N	Mean	Grouping
1	25	131010	A
0	25	102580	B

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals

One-way ANOVA: G dp versus Sample name

Source	DF	SS	MS	F	P
Sample name	2	3.78721E+11	1.89361E+11	32.83	0.000
Error	72	4.15347E+11	5768710088		
Total	74	7.94068E+11			

S = 75952   R-Sq = 47.69%   R-Sq(adj) = 46.24%

Grouping Information Using Tukey Method

Sample name	N	Mean	Grouping
4	25	261728	A
3	25	153916	B
2	25	89476	C

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals

One-way ANOVA: G dp versus Sample name

Source	DF	SS	MS	F	P
Sample name	2	81639650797	40819825399	7.31	0.001
Error	72	4.02080E+11	5584439077		
Total	74	4.83719E+11			

S = 74729   R-Sq = 16.88%   R-Sq(adj) = 14.57%

Grouping Information Using Tukey Method

Sample name	N	Mean	Grouping
7	25	223873	A
6	25	168098	B
5	25	145337	B

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals

One-way ANOVA: G p versus Sample name

Source	DF	SS	MS	F	P
Sample name	2	7.33636E+12	3.66818E+12	75.00	0.000
Error	72	3.52128E+12	48906701079		
Total	74	1.08576E+13			

S = 221149   R-Sq = 67.57%   R-Sq(adj) = 66.67%

Grouping Information Using Tukey Method

Sample name	N	Mean	Grouping
7	25	1085807	A
6	25	473334	B
5	25	381024	B

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals

One-way ANOVA: G p versus Sample name

Source	DF	SS	MS	F	P
Sample name	2	2.56806E+13	1.28403E+13	135.76	0.000
Error	72	6.80994E+12	94582491400		
Total	74	3.24906E+13			

S = 307543   R-Sq = 79.04%   R-Sq(adj) = 78.46%

Grouping Information Using Tukey Method

Sample name	N	Mean	Grouping
4	25	1682710	A
3	25	555505	B
2	25	352365	B

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals

One-way ANOVA: G p versus Sample name

Source	DF	SS	MS	F	P
Sample name	1	1.42034E+12	1.42034E+12	6.07	0.017
Error	48	1.12360E+13	2.34083E+11		
Total	49	1.26563E+13			

S = 483821   R-Sq = 11.22%   R-Sq(adj) = 9.37%

Grouping Information Using Tukey Method

Sample name	N	Mean	Grouping
1	25	1559018	A
0	25	1221932	B

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals

One-way ANOVA: G p versus Sample name

Source	DF	SS	MS	F	P
Sample name	7	5.13377E+13	7.33395E+12	65.29	0.000
Error	192	2.15672E+13	1.12329E+11		
Total	199	7.29049E+13			

S = 335155   R-Sq = 70.42%   R-Sq(adj) = 69.34%

Grouping Information Using Tukey Method

Sample name	N	Mean	Grouping
4	25	1682710	A
1	25	1559018	A
0	25	1221932	B
7	25	1085807	B
3	25	555505	C
6	25	473334	C
5	25	381024	C
2	25	352365	C

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals

One-way ANOVA: G dp versus Sample name

Source	DF	SS	MS	F	P
Sample name	7	1.70108E+13	2.43012E+12	54.00	0.000
Error	192	8.64104E+12	45005435225		
Total	199	2.56519E+13			

S = 212145   R-Sq = 66.31%   R-Sq(adj) = 65.09%

Grouping Information Using Tukey Method

Sample name	N	Mean	Grouping
4	25	965764	A
1	25	894508	A B
0	25	755196	B C
7	25	635693	C
3	25	325478	D
6	25	298839	D
5	25	218647	D
2	25	207417	D

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals

One-way ANOVA: G dp versus Sample name

Source	DF	SS	MS	F	P
Sample name	1	2.42598E+11	2.42598E+11	2.74	0.104
Error	48	4.24630E+12	88464684391		
Total	49	4.48890E+12			

S = 297430   R-Sq = 5.40%   R-Sq(adj) = 3.43%

Grouping Information Using Tukey Method

Sample name	N	Mean	Grouping
1	25	894508	A
0	25	755196	A

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals

One-way ANOVA: G dp versus Sample name

Source	DF	SS	MS	F	P
Sample name	2	8.32495E+12	4.16248E+12	108.11	0.000
Error	72	2.77204E+12	38500507787		
Total	74	1.10970E+13			

S = 196215   R-Sq = 75.02%   R-Sq(adj) = 74.33%

Grouping Information Using Tukey Method

Sample name	N	Mean	Grouping
4	25	965764	A
3	25	325478	B
2	25	207417	B

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals

One-way ANOVA: G dp versus Sample name

Source	DF	SS	MS	F	P
Sample name	2	2.44858E+12	1.22429E+12	54.32	0.000
Error	72	1.62270E+12	22537529886		
Total	74	4.07128E+12			

S = 150125   R-Sq = 60.14%   R-Sq(adj) = 59.04%

Grouping Information Using Tukey Method

Sample name	N	Mean	Grouping
7	25	635693	A
6	25	298839	B
5	25	218647	B

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals