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Effect of Lipid Source on the Physical and Sensory Quality of Baked Products

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EFFECT OF LIPID SOURCE ON THE PHYSICAL AND

SENSORY QUALITY OF BAKED PRODUCTS

by

Haoyuan Zhong

A thesis submitted in partial fulfillment
of the requirements for the degree of

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ABSTRACT

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Sensory Quality of Baked Products

by

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Utah State University, 2013

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shortenings, soybean oil, and interesterified soybean oil) on the physical and sensory

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character, melting point, onset melting temperature (T_{on}), and melting enthalpy (ΔH)

affect the physical qualities of baked products, such as batter density of cake, spread of

cookies, and breaking strength of pie crust. With a larger δ value (less plastic character),

less crystal structure is present in the lipid and fewer air bubbles were incorporated into

cake batter, which results in a denser batter. With a liquid character, lipid prevents water-

flour interaction by coating flour particles, which develops less gluten in pie crust,

indicated by its low breaking strength. The ΔH can be extrapolated to the amount of

crystalline material in the lipid: the larger ΔH, the more crystalline material. In cookie

production, a low ΔH make the lubricant effect of a lipid available earlier, resulting in a

larger cookie spread than the one observed in cookies made with a shortening with high ΔH values.

The effect of ultrasound (US)-treated interesterified soybean oil (IES) on the quality characteristics of baked goods was also evaluated. US-treated and non US-treated IES were prepared at 32°C and tempered for 48 h at 5 and 25°C. US-treated IES had smaller lipid crystals than non US-treated IES. In cakes, the highest cake batter density was obtained when non US-treated IES tempered at 5°C was used. This was a consequence of the larger lipid crystals obtained under this condition, which had less ability to incorporate air. In cookies, the fewer crystals (more fluid status) present in non US-treated IES tempered at 25°C led to a higher dough density, higher spread, and lower height in the final cookies. Similarly, in pie crust, the larger amount of lipid crystals in US-treated IES contributed to significantly higher height in final pie crust.

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PUBLIC ABSTRACT

The effect of commercial shortenings (butter, lard, margarine, all-purpose shortenings, soybean oil, and interesterified soybean oil) on the physical and sensory characteristics of baked products was evaluated. Results showed that lipid viscoelastic character, melting point, onset melting temperature (T_{on}), and melting enthalpy (ΔH) affect the physical qualities of baked products, such as batter density of cake, spread of cookies, and breaking strength of pie crust. With a larger δ value (less plastic character), less crystal structure is present in the lipid and fewer air bubbles were incorporated into cake batter, which results in a denser batter. With a liquid character, lipid prevents water-flour interaction by coating flour particles, which develops less gluten in pie crust, indicated by its low breaking strength. The ΔH can be extrapolated to the amount of crystalline material in the lipid: the larger ΔH, the more crystalline material. In cookie production, a low ΔH make the lubricant effect of a lipid available earlier, resulting in a larger cookie spread than the one observed in cookies made with a shortening with high ΔH values.

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LIST OF SYMBOLS, NOTATIONS, DEFINITIONS

APS: All-purpose shortening

B: Butter

CHD: Coronary heart disease

FDA: Food and Drug Administration

HDL: High density lipoprotein

IES: Interesterified soybean oil

L: Lard

M: Margarine

MUFA: Monounsaturated fatty acid

PUFA: Polyunsaturated fatty acid

SBO: Soybean oil

SFA: Saturated fatty acid

TAG: Triglyceride

TFA: Trans fatty acid

TPA: Texture profile analysis

USDA: United States Department of Agriculture

US: Ultrasound

CHAPTER I

INTRODUCTION

Introduction

Lipids are one of the main macromolecules present in foods and are usually referred to as oils and fats (Ghotra and others 2002). At ambient temperature, the term "fat" is used in reference to materials that are solid, while the term "oil" is used for those that are liquid (Bailey 1951). Physical properties of fats and oils mainly depend on their fatty acid composition (Gunstone 2008). A high content of saturated fatty acids in the triglyceride (TAG) molecules is associated with high melting point fats, while lipids that contain a high amount of unsaturated fatty acids have lower melting points. In general, most animal fats have high melting points and are solid at room temperature, while most plant oils have low melting points and are liquid at room temperature. However, some semi-solid tropical vegetable fats exist such as palm oil, palm kernel oil and cocoa butter (Gunstone 2008).

In the baking industry, a number of functions are induced by lipids (Stauffer 1998; Wainwright 1999; Ghotra and others 2002; Rogers 2004). They include: tenderization; mouthfeel; structural integrity; lubrication; air incorporation; heat transfer; and shelf life extension. Because of their functional properties (e.g. creaming ability), plastic shortenings, which are often made by partial hydrogenation, are commonly used in the baking industry (Reyes-Hernandez 2007; Zhou and others 2011). However, trans fat generated during the hydrogenation process increases the risk of coronary heart disease (Ascherio and Willett 1997; Dhaka and others 2011). The United States

Department of Agriculture (USDA) and the Food and Drug Administration (FDA)

recommend consuming less than 10% of calories from saturated fatty acids by replacing

them with monounsaturated and polyunsaturated fatty acids, and to reduce trans fat intake

as much as possible (US Department of Agriculture and US Department of Health and

Human Services 2010). In recent years, the food industry has been making efforts to

reduce trans fat by blending oils (high oleic and low linolenic) with fully hardened oils

(palm), or by randomizing through interesterification (Wassell and Young 2007; Jeyarani

and others 2009; Sahri and Dian 2011; Musavi and others 2011). However, because of its

supreme characters such as plasticity, which leads to desired physical qualities of baked

products, lipids containing trans fat are still widely used in food industry (Jeyarani and

others 2009).

For different physical qualities of baked products, extensive literature can be

found for cake (Berglund and Hertsgaard 1986; Vali and Choudhary 1990; NorAini and

others 1992; Dogan and others 2007; Rutkowska and Zbikowska 2010; Zhou and others

2011), cookies (Berglund and Hertsgaard 1986; Jacob and Leelavathi 2007) and pie

crusts (Matthews and Dawson 1963; Darweesh and others 1991) made with various lipid

sources. Very little information is available that correlates the physicochemical properties

of lipids with the physical qualities of baked products and their final consumer

acceptance. Consequently, understanding the physicochemical properties of lipid that in

turn influence the physical properties of baked products and the relationship to their

consumer acceptance is very important to both food scientists and food producers.

Previous research shows that the creaming ability of lipids used in baking is

largely affected by its crystalline form: small and tightly knit crystals have better

creaming ability (Joyner 1953; Baldwin and others 1971; Pyler 1988). High power ultrasound (US) has been used recently to generate small and even-sized crystals in anhydrous milk fat (Martini and others 2008), palm kernel oil (Suzuki and others 2010) and interesterified soybean oil (Ye and others 2011). Therefore US has the potential to be used in low saturated, no trans fats to improve the functional properties while maintaining their healthy profile. These healthier fats can be used as trans fats replacers.

Understanding the quality changes in baked products resulting from lipid sources that have been treated with US is very useful. However, the application is worthless to industry without consumers' approval. Although consumers desire healthier alternatives, they are unlikely to accept large sensory changes in food products. Products made with US treated lipids must deliver the same or better sensory attributes as their counterparts. Therefore, consumer sensory studies are needed to evaluate differences in consumer acceptance between baked products made with US treated and non US-treated lipid.

The purposes of this research are first to evaluate the effect of different commercial lipids (butter, margarine, all-purpose shortening, lard, soybean oil, and interesteried soybean oil) on the physical qualities of different baked products (cake, cookies and pie crust); and second to investigate the same physical qualities of baked products made from interesterified soybean oil treated with US (with and without US treatment). At the end, combining with consumer acceptance, we would be able to evaluate if US treatment on interesterified soybean oil would be an effective approach to replace lipids containing trans fat.

Hypothesis

The physical qualities and consumer acceptance of baked products (cake, cookies and pie crust) are affected by the type of lipid used (butter, margarine, all-purpose shortening, lard, soybean oil, interesterified soybean oil and US-treated interesterified soybean oil).

Objectives

Objective 1: To correlate the physicochemical characteristics of lipids to physical qualities and consumer acceptance of baked products made with commercial lipids.

Objective 2: To evaluate the effect of the physicochemical characteristics of US-treated and non US-treated interesterified soybean oil (IES) on the physical qualities of baked products.

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CHAPTER II

LITERATURE REVIEW

Lipid

Lipids are one of the main macromolecules present in foods and are usually referred to as oils and fats (Ghotra and others 2002). The term "fat" is used in reference to materials that are solid at ambient temperature, while the term "oil" is used for those that are liquid at ambient temperature (Bailey 1951). Physical properties of fats and oils mainly depend on their fatty acid composition (Gunstone 2008). A high content of saturated fatty acids (SFA) in the TAG molecules is associated with high melting point fats, while lipids that contain a high amount of unsaturated fatty acids have lower melting points. In general, most animal fats have high melting points and are solid at room temperature, while most plant oils have low melting points and are liquid at room temperature. However, some semi-solid tropical vegetable fats exist such as palm oil, palm kernel oil, and cocoa butter (Gunstone 2008).

Trans fat

Trans fatty acids (TFA) are unsaturated fatty acids that contain at least one double bond in the trans configuration (Dhaka and others 2011). TFA can be found in lipid sources naturally, as well as being created through industrial processes (Ghotra and others 2002; Tarrago-Trani and others 2006). Natural TFAs are found in most dairy products (e.g., conjugated linoleic acid) and offer beneficial health impacts such as their anti-obesitic and anti-carcinogenic effects (Ghotra and others 2002; Benjamin and Spener 2009). In the lipid industry, small amounts of TFAs result from the refining of edible oils

due to the high temperature used during the deodorization process (Tarrago-Trani and others 2006). However, the major source of TFAs is found in industrially produced products such as margarine and shortenings, where partial hydrogenation has been used to convert liquid oils (i.e., vegetable oil) into semi-solid or solid fats for different food applications (Ghotra and others 2002; Tarrago-Trani and others 2006; Reyes-Hernandez and others 2007). During hydrogenation, unsaturated fatty acids are transformed into saturated fatty acids by adding hydrogen to the double bonds (Ghotra and others 2002; Tarrago-Trani and others 2006). Depending on the conditions applied during this process, hydrogenation can be selective or non-selective. Selective hydrogenation favors the acids containing active methylene groups while non-selective hydrogenation does not have a preferred target (Ghotra and others 2002). As a result of both, partial hydrogenations are formed and trans-isomers are generated.

TFAs are reported to have many negative effects on human health such as to increase the risk of coronary heart disease (CHD), which is marked by an increase in the ratio of total cholesterol to high density lipoprotein (HDL), and a raise in plasma triglyceride concentration (Tarrago-Trani and others 2006; Dhaka and others 2011). Other health issues include increasing the level of lipoprotein, increasing the risk of breast and colon cancer, diabetes and obesity, and interfering with n-3 and n-6 fatty acid metabolism (Dhaka and others 2011).

Recently, consumers have become more concerned about the health implications of TFA consumption. Ascherio and Willet (1997) suggested that TFA intake can be reduced by lowering total fat intake. However, there is concern that this will lead to an insufficient intake of essential fatty acids (n-3 and n-6; Tarrago-Trani and others 2006).

In 2006, the FDA issued the final rule on TFA labeling, requiring companies to declare the content of TFA (0.5 g or more per serving) on the Nutrition Facts panel of food products in a separate line below SFA. Industry has responded by finding alternative ways to minimize TFA content in food products. Current process approaches include: genetic modification of edible oil seeds (Tarrago-Trani and others 2006), modification of the hydrogenation process, and interesterification. Other TFA alternatives include: the use of fractions high in solids from natural oils (i.e., coconut, palm kernel oils) and the use of blended oils (Dhaka and others 2011; Wassell and Young 2007; Dupont and others 1991; Jeyarani and others 2009). However, there were some cost and technical challenges that prevented the food industry from fully embracing them when they were created. For example, genetic modification of oil seeds' fatty acid composition results in the reduction of linoleic acid (n-6) and linolenic acid (n-3) intake, which are strongly protective against CHD (Tarrago-Trani and others 2006). Natural oils and blended oils, particularly tropical fats (e.g., coconut, palm kernel oils), contain SFA, which are believed to increase the risk of coronary heart disease (Dupont and others 1991). Lipids with reduced TFA and saturated fatty acids can be used as TFA replacements but they lack certain functional properties that are important to ensure food quality. Some of the physicochemical properties include texture, melting profile, and amount of solids. Therefore, food scientists continue to search for new technologies that will improve the nutritional profile of lipids while still maintaining the functional properties required by the food producer.

Cake

A traditional way of preparing cakes is to first mix sugar and shortening together while mixing up dry ingredients (flours, baking power, etc.) separately. Then during stirring, mixed dry ingredients and milk are added alternately into sugar-shortening mixture to form a cake batter.

As a porous food, cake quality largely depends on air incorporation. Plastic lipids contain solid crystals that can adsorb to air bubbles incorporated into batter during mixing and stabilize them. Previous research suggests that, along with the initial air incorporation, final cake density depends on the stability of air bubbles during baking (NorAini and others 1992; Stauffer 1998; Zhou and others 2011). As the oven is heated up, bubbles tend to migrate and expand, while lipid crystals (absorbed to the air bubbles during mixing) melt and form a uniform layer over the inside surface of the bubble, allowing bubble expansion without rupture (Brooker 1993; Zhou and others 2011). Melting that occurs too early or too late during this process will lead to aggregation and loss of air bubbles and a denser cake.

Shortenings containing trans fat usually have more plastic character, higher melting points and greater stability against oxidative rancidity (Jeyarani and others 2009). In cake production, these characters are highly important in initial air incorporation and air bubble protection during baking.

Cookies

Cookie preparation starts with the mixing of the ingredients into a "short" dough. In the first step a semi-stiff white cream is prepared by mixing the sugar, shortening and

water (from egg). In the second step, the flour is added with minimal mixing resulting in a cookie dough with minimal gluten development if any.

One major role of shortening in cookie dough is to eliminate gluten development by breaking the continuity of the protein and starch structure (Ghotra and others 2002). This effect varies with different shortening level and different liquid oil portion within a shortening. If the total shortening level or liquid oil portion within the shortening is high, water or sugar solution would be coated by shortening, resulting in less chance to interact with flour protein in the second step, therefore little gluten will be formed in final cookie (crisp or crumbly texture). On the other hand, with a low total shortening level or low liquid oil portion, more gluten will be formed and therefore resulting in a hard or chewy cookie texture. Hence for different texture requirements, different shortening will be selected.

A second function of shortening in cookies is aeration (less so than in cake making). Plasticity in shortening is required for this function since during the first creaming process, a plastic shortening can entrap and retain air that has a leavening effect (Jacob and Leelavathi 2007).

Another function shortening plays in cookies includes affecting cookie spread. The degree of spread resulting in the final cookie diameter is controlled by the spread rate and set time of the dough (Pareyt and Delcour 2008). Shortening functions as a lubricant in cookie dough, thus affecting spread rate: more shortening/more liquid oil portion gives a larger spread.

Pie crust

In pie crust production, shortening and flour are first pinched together. Then water is added to form the crust dough. During this process, the role of lipid is to prevent excessive gluten formation and create pockets in the dough (Stauffer 1998). Gluten in dough is formed by the interaction of flour and water (Patient 1994). The majority of gluten is formed when water is added in the second stage of mixing, after the shortening and flour have been combined. Lipids with a more fluid character tend to limit gluten development, since flour particles are covered by lipid and have less chance to interact with water (Pyler 1988). However, solid lipids are more likely to be coated by flour particles than vice versa, and form pockets of lipid within the dough. Therefore, flour proteins are able to interact with water, leading to increased gluten development and tougher pie crusts.

Additionally, the solid portion in lipids can create and maintain pockets in dough during rolling and baking. During baking, these pockets serve as nuclei for steam to accumulate and for dough to expand, leading to a desirable flaky texture in the finished crust. This is also very crucial for the final crust height.

Lipids in baking

Baked foods serve as one of the main staple food sources for consumers and lipids play an important role in the majority of baked products (Chung and Pomeranz 1983). When choosing a lipid source for baking, the nutritional characteristics of lipid and the ability of the lipid to impart a desired physical quality to the finished product need to be considered. One of the key dietary recommendations in the United States is to consume

less than 10 percent of calories from saturated fatty acids by replacing them with

monounsaturated and polyunsaturated fatty acids, and to reduce TFA intake as much as

possible (US Department of Agriculture and US Department of Health and Human

Services 2010). Therefore it is important to consider the nutritional characteristics of the

lipid sources included in food production. Usually, animal fats, such as lard, are more

saturated than plant oils such as soybean oil, and their polyunsaturated fatty acid (PUFA)

vs. SFA ratio is much lower (Chung and Pomeranz 1983). In addition to the nutritional

profiles, lipids should be selected according to their specific performance in the finished

product (Wainwright 1999). In general, lipids in baking contribute to products' quality

characteristics such as tenderness, moist mouthfeel, lubricity, flavor, structure and shelf

life. During processing, lipids affect air incorporation, lubrication and heat exchange in

the baked products (Baldwin and others 1971; Stauffer 1998; Wainwright 1999; Ghotra

and others 2002; Rogers 2004).

Butter

Butter is a water-in-oil (W/O) emulsion, produced by concentrating cream

separated from milk. In the past, butter was produced on farms by separating cream from

the surface of the milk that was left to stand overnight. Buttering itself was carried out in

special drums, called churns. The fat globules of the cream, which are surrounded by a

lipoprotein membrane in the milk, were partially broken and their fat united in larger

droplets or grains. After phase inversion induced by the beating, the butter grains were

separated, washed and pressed (Bockisch 1998). It was not easy to keep it as a hygienic

process: in most cases, the cream would have been souring by the time it was made into

butter, and the wooden equipment was extremely difficult to keep clean. The late

nineteenth century adopted mechanical separation, mechanical refrigeration and shelf-life

extension by heat treatment processer. In the beginning of the twenty-first century, batch

churning was replaced by a continuous churning processes. However, due to its high

saturated fatty acid content, which makes it is hard to work with during pumping, and its

low onset melting temperature, butter is no longer used widely in industry (Wilbey 2009).

Margarine

      Margarine is a fatty food that was designed to resemble butter in appearance,

character and composition, and is used as a substitute for or alternative to butter for its

low cost. Under the US FDA Standard of Identity, margarine is defined as a liquid or

plastic food consisting of a mixture of fat and water (21 CFR 166.110). The minimum

amount of fat permitted is 80% by weight, and any edible oil or fat may be used. As a

water-in-oil emulsion, margarine fats are generally blends of hydrogenated and non-

hydrogenated oils mixed in appropriate proportions for functional effect (Bumbalough

2000). To reach the correct PUFA:MUFA:SFA ratio, selective hydrogenation or blending

can be used to produce margarine (Dupont and others 1991). Since consumers are

increasingly concerned about trans fatty acids resulting from hydrogenation, margarine is

not as widely used and thus the demand for margarines with low saturates and low trans

fatty acids is increasing (Sahri and Dian 2011). Trans-free or low trans fat margarines can

be obtained by blending oils with fully hardened oils while maintaining their

physicochemical properties (Wassell and Young 2007).

All-purpose shortening

Shortenings are fats formulated from oil and base oil which are designed to break the continuity of protein and starch structure in baked products (Stauffer 1998). Though all-purpose shortening is designed to perform in a range of products and meet varied demands in baking manufacture, creaming and emulsifying capacity are the two most important applications (Wassell and Young 2007). Creaming contributes to the volume of the baked product by entrapping and retaining considerable volumes of air, while emulsification controls the moisture and liquid uptake. Two types of all-purpose shortenings are manufactured: with or without emulsifiers (Ghotra and others 2002). Unemulsified shortenings are especially suitable for cookies, crackers and frying, while emulsified shortenings are primarily used for icing, cakes, etc. where creaming performance is most desired. Partial hydrogenation or blending of oils are often used to produce all-purpose shortening with emulsifier to meet their different applications.

Ultrasound

Ultrasound are mechanical waves that use frequencies above the hearing range of the average person (~ > 18 kHz) (Soria and Villamiel 2010). The fundamental effect of ultrasound is to apply acoustic pressure to a medium in a sinusoidal manner. The acoustic wave generated depends on time, frequency, and the maximum pressure amplitude of the wave. The maximum pressure amplitude of the wave is directly proportional to the transducer power input (Patist and Bates 2008). Ultrasonic applications can be divided into two categories: low and high intensity applications. Low intensity ultrasound is usually used to provide information on the physicochemical

properties of food, such as firmness, ripeness, etc., while high intensity ultrasound (US) is commonly used to alter food properties, either physically or chemically (Martini and others 2008; Soria and Villamiel 2010). Examples of US application are: emulsification/homogenization, change of viscosity and texture, crystallization, extraction, etc. (Patist and Bates 2008; Soria and Villamiel 2010; Ashokkumar and others 2010). In the lipid application field, researchers have shown that US changes lipid physicochemical quality by inducing crystallization, which results in faster crystallization, smaller crystals and harder material in lipid sample (Martini and others 2008; Suzuki and others 2010; Ye and others 2011).

Physicochemical parameters for lipid

    DSC parameters (T_{on}, T_p and ΔH): T_{on} is the onset melting temperature, which represents the temperature point when the lipid starts to melt; T_p represents the highest temperature point the lipid reaches during the whole melting process; ΔH represents the total enthalpy in the whole melting process and is an indication of the amount of solid material present in the samples. Enthalpy values are expressed in J/g.

    Viscoelasticity parameters (G', G'' and δ): Viscoelasticity is the property of materials that exhibit both visous and elastic characteristics when undergoing deformation. Viscous materials resist shear flow and strain linearly with time when a stress is applied. Elastic materials strain when stretched and quickly return to their original state once the stress is removed. G' is the parameter to describe the elastic characteristic (solid-like) of a material: higher G' means more solid-like behavior. G'' is the parameter that describes the viscous (liquid-like) behavior of a material: higher G''

represents more liquid-like behavior. δ is the ratio of G'' to G' where higher δ represents more liquid-like behavior of a material.

Melting point: melting point of a lipid describes the temperature point at which it changes its solid status to liquid status.

Crystal size: crystal size of the solid fats, together with crystal structure, determines the plasticity of the shortening (Ghotra and others 2002). During creaming process, lipid crystals act as vehicles for the transfer of additional interfacial material to the surface of expanding bubbles during baking and thereby prevent the bubble rupture (Brooker 1993). It is believed that with the same solid mass in lipid, smaller and more crystals have better creaming ability than larger but fewer crystals.

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CHAPTER III

EFFECT OF LIPID TYPE ON THE PHYSICAL PROPERTIES AND

SENSORY QUALITY OF BAKED PRODUCTS

Abstract

The objective of this research was to evaluate the effect of lipid type (butter, lard, margarine, all-purpose shortenings, soybean oil, and interesterified soybean oil) on the physical and sensory characteristics of baked products. Results from our research showed that lipid viscoelastic character, melting point, melting onset temperature (T_{on}), and melting enthalpy (ΔH) affect physical qualities of baked products, such as batter density of cake and breaking strength of pie crust. With a larger δ value (less plastic character), less crystal structure is present in the lipid and fewer air bubbles are incorporated into cake batter, which results in a denser batter. With a liquid character, lipid prevents water-flour interaction by coating flour particles, which develops less gluten in pie crust and results in a pie crust with low breaking strength. During baking, product characteristics are affected by lipid melting point and ΔH as well. In cookie production, a low melting temperature and a low ΔH make the lubricant effect of a lipid available earlier, resulting in a larger cookie spread. In pie crust production, lipid with a high melting temperature or a high ΔH stays in pie crust dough in the form of pockets. Combined with the amount of developed gluten, pie crusts resulted in different heights. T_{on} of lipid affects the stabilization of entrapped air bubbles in cake batter and cookie dough. If lipid melts around the time when air bubbles start expanding, a uniform layer will be formed over the inside surface of bubble, allowing bubble expansion without rupture. Too high or too

low T_{on} will fail to stabilize bubbles. In cake production, failure to stabilize air bubbles will result in a dense cake. In cookie production, different degrees of air incorporation combined with the influence from cookie spread, will result in different cookie heights.

Introduction

Baked products serve as one of the main staple foods for consumers, and lipids play an important role in the quality of these products from a nutritional and functional standpoint (Chung and Pomeranz 1983; Wainwright 1999). In general, lipids in baking contribute to product characteristics such as tenderness, moisture, mouthfeel, lubricity, flavor, structure, and shelf life. During processing, lipids affect air incorporation, lubrication, and heat exchange (Stauffer 1998; Rogers 2004). For example, in pie crusts lipids with a proper solid character and melting point help contribute to desirable flakiness and tenderness (Ghotra and others 2002). In cakes, lipids play a predominant role in determing the final cake structure (Hartnett and Thalheimer 1979. This affects the volume and texture of the finished cake (Stauffer 1998). A homogeneous cake crumb that contains small aerated pores is considered a desirable cake quality (Rutkowska and Zbikowska 2010). Air incorporation is equally important in cookies (Rogers 2004) and lipid type influences cookie spread (Wainwright 1999).

In addition to the role of food lipids in food processing and quality, these macromolecules play an important role in the nutritional quality of the product. During the last two decades consumers have become aware of the nutritional quality of foods and demand foods low in calories and formulated with healthy lipid sources. The United States Department of Agriculture and the Food and Drug Administration recommend

consuming less than 10 % of calories from saturated fatty acids by replacing them with monounsaturated and polyunsaturated fatty acids, and to reduce trans fat intake as much as possible (US Department of Agriculture and US Department of Health and Human Services 2010). In general, animal fats (e.g. lard) are more saturated than plant oils (e.g. soybean oil) and the ratio of PUFA to SFA is much lower (Chung and Pomeranz 1983).

Trans fatty acids (TFAs) have been used in the past to achieve ideal physical properties in food products since their 3-dimensional crystal network provides the appropriate texture and oxidation stability (Reyes-Hernandez and others 2007). TFAs are unsaturated fatty acids that contain at least one double bond in the trans configuration (Dhaka and others 2011). Specific TFAs (ie CLA) are formed naturally by bacteria populating the rumen of ruminants (Ghotra and others 2002). However, the majority of TFAs are produced industrially during the partial hydrogenation of oil, a common process used to obtain specific solid-to-liquid ratio in lipids for different applications (Ghotra and others 2002; Tarrago-Trani and others 2006). Industrially produced TFAs are reported to have many negative effects on human health, such as increasing the risk of coronary heart disease (CHD) by raising plasma triglyceride concentration and interfering with n-3 and n-6 fatty acid metabolism (Tarrago-Trani and others 2006; Vandana and others 2011). These and other health issues have heightened consumer awareness of the presence of trans fats in food products. Several studies have discussed the performance of trans fat substitutes, such as hydrocolloids, fiber (Hazen 2011), omega-3 fats (Duxbury 2005), and lipid blends (Wassell and Young 2007). Little information is available comparing the effect of "traditional" baking lipids (e.g. butter, lard, soybean oil) on the

quality of baked products to the effectiveness of interesterified soybean oil, and how these effects relate to the physicochemical properties of these lipids.

The objective of this study was to evaluate the effect of six lipid sources (butter, margarine, soybean oil [SBO], lard [L], all-purpose shortening [APS] and interesterified soybean oil [IES]) on the baking performance of three baked products (cake, cookies, and pie crust), and to determine whether correlations exist between the physical and sensory properties of the baked products and the physicochemical properties of the lipid sources.

Materials and Methods

Starting materials: Commercial lipids were purchased from local grocery stores: Morrell Manteca Snow Cap hydrogenated lard (L), Crisco pure vegetable oil (soybean oil; SBO), Crisco all-vegetable shortening (APS), Kroger Value Spread (65% vegetable oil; water content: 15.7%; M; USDA national agricultural database), Member's Mark salted sweet cream butter (water content: 15.9% by wt; B; USDA national agricultural database), and refined, bleached, fully hydrogenated deodorized interesterified soybean oil (ADM, product number 762400; IES).

Preparation of baked products: Baked products formulations are shown in Table 1. All products were prepared in triplicate according to the following methods.

Cake: Cakes were made following the standard creaming method (Gisslen 2008). Briefly, dry ingredients (cake flour, baking powder, and salt) were mixed together, while sugar and shortening were mixed separately at medium speed setting (4) using a 5 quart stand mixer (Viking Professional Series, 800W; Viking Corporation, Greenwood, MS) followed by an increase in speed to the maximum setting (12) for 2 min with eggs and

vanilla extract added at this point. The milk and dry mixture were added alternately and mixed at medium speed setting (3) for approximately 25 sec. Approximately 450 g of batter was transferred to a 12 cm × 22 cm aluminum loaf pan and placed immediately into a preheated deck oven (Model CN60; General Electric Company, Fairfield, CN) for 40 min at 185 °C. Inverted sheet trays were used to create an air gap and prevent bottom crusts from burning.

Cookies: Cookies were made using the standard creaming method (Gisslen 2008). Dry ingredients (flour, salt and baking powder) were combined while the shortening and sugar were mixed using a 5 quart Viking stand mixer at a maximum speed setting (12) for 2 min. Vanilla extract and eggs were added and the speed was decreased to high setting (10) for 1 min. The dry ingredient mixture was added and stirred by hand just until fully incorporated (approximately 30 strokes). The cookie dough was portioned using a #70 scoop (15 ml) onto a half sheet tray lined with parchment paper, and baked in a preheated deck oven for 10 min at 190°C.

Pie crust: Pie crusts were made following a standard flaky dough procedure (Gisslen 2008). Flour and salt were mixed with the lipid and pinched in by hand until "pea size" (2 mm diameter) clumps were formed. Water was added and the dough was tossed just until it held together (approximately 20 strokes). Dough was rolled to a thickness of 2 mm using roller guides then cut into approximately 10 cm x 3 cm strips. Pie dough was placed on a full sheet tray lined with parchment paper, then baked in a preheated deck oven for 9 min at 220 °C.

Table 1 - Recipe formulations for cake, cookie, and pie crust. Lipid source used was B=butter; APS=all-purpose shortening; L=lard; SBO=soybean oil; M=margarine; IES= interesterified soybean oil

	Ingredient Weight (g)		
	Cake (2 loaves)	Cookie (1 dozen)	Pie crust (thickness of 2 mm)
Lipid	110	110	50
Flour	300a	130b	100b
Salt	5	3	2
Sugar	230	150	-
Baking powderc	10	3	-
Vanilla	5	3	-
Egg	100	50	-
Liquid	250d	-	20e

a Cake flour (8.5% protein)
b All-purpose flour (10% protein)
c Double-acting baking powder (sodium acid pyrophosphate, sodium bicarbonate, corn
  starch and monocalcium phosphate)
d Whole milk
e Cold water (1 °C)

Quality properties of baked products

     Cake: Density, water activity, and moisture content were measured. Density was calculated in both cake batter and finished cake (Funk and others 1969) as g/cm3. A crystallization dish was filled with cake batter then weighed. Exact volume of each dish was determined based on the maximum weight of water held. A representative sample of the finished cake (approximately 1 cm^3) was cut from the center of the loaf and weighed to determine its density.

     Water activity and moisture content were measured in the finished cakes after 1 hour and after 1 week. Water activity was measured using a 4TE water activity meter (Decagon Devices Inc, Pullman, WA). Moisture content was determined using a MA150 programmable moisture analyzer with a ceramic heating element (Startorius

Mechatronics, Bohemia, NY). Samples (approximately 2 g) were dried at 110˚C to a constant weight.

Cookies: Dough density, cookie spread and height, water activity and moisture content were measured. Dough density was measured by weighing an individual portion of dough (a scoop of approximately 1 ml). The exact volume of each portion was determined by reading the volume of water that was displaced in a graduated cylinder. It was then calculated from these measurements as g/cm^3.

The spread and height of the finished cookies were measured using AACC Official Method 10-50D (1983). Cookies were allowed to cool thoroughly for about 2 min, then centered over a template with concentric rings placed 2 mm apart. The spread was calculated as the average distance from the center as read in each of 4 quadrants. Cookie height was taken in the center of each cookie using a digital caliper (Carrera Precision CP9807-TF; Max Tool LLC, La Verne, CA). Water activity and moisture content were measured in the finished cookies after 1 hour and after 1 week, as described for cakes.

Pie crust: Breaking strength, percent shrinkage, crust height, highest point, oiliness, water activity and moisture content were measured. Breaking strength was measured on each 10 cm x 3 cm pie crust strip. The measurement was taken with a Bailey shortometer attached to a Chatillon portion control scale (32 oz $\times$ ¼ oz; Chatillon, Largo, FL). Peak breaking force was determined in oz-force and then converted to Newtons.

Percent shrinkage was determined based on the area change in each pastry strip as measured before and after baking (Dreher and others 1983). Crust height and highest point were taken as the average of 4 readings (taken at the center points on each side of

the crust strip) and the highest point on the same crust with a digital caliper (Dreher and others 1983). Oiliness of the crust was taken as the weight difference of the parchment paper liner before and after baking, where 7-8 strips were baked on a single pan. Water activity and moisture were measured in the finished crust after one hour and one week as described above for cakes.

Sensory characteristics of baked products

Consumer acceptance of baked products formulated with four of the lipids (butter, margarine, APS, and IES) was evaluated using a 9-point hedonic scale for overall, appearance, and texture acceptability (see Appendix A for questionnaire). Products made from lard and SBO were eliminated from the sensory evaluation tests due to their obvious differences in appearance and evident greasy mouthfeel. Samples were prepared the day before serving. They were cut into individual sizes and served in 2 oz sample cups. Cakes were served in cubes (approximate 1 cm^3); cookies were served in quarters (1/4 of the original cookie); and pie crusts were served in 4 cm^2 squares, which were cut before baking. Samples were placed in 2 oz sample cups. Lids were used in cake samples. Serving cups were labeled with 3-digit randomized numbers generated by SIMS 2000 software and presented in a randomized and balanced manner (see Appendix B for sampling plan). Samples were presented to each taster under normal light to account for color difference in the product. Consumers were asked to taste one sample, rinse their mouth with distilled water and then taste the next sample. Separate tests were performed for each product (cake, cookie, and pie crust), each with approximately 120 consumers. A 9-point hedonic scale (1. dislike extremely; 2. dislike very much; 3. dislike moderately; 4.

dislike slightly; 5. neither like nor dislike; 6. like slightly; 7. like moderately; 8. like very

much; 9. like extremely) was used to rate the degree of liking (overall, appearance, and

texture) on each product. Demographic information such as gender and age group were

collected, along with additional consumer comments. Hedonic ratings were collected

using SIMS2000 (version 6.0, Morristown, NJ) and analyzed using SAS 9.2.

Physicochemical properties of lipid sources

Fatty acid composition and functional properties (texture, thermal behavior,

melting point, and viscoelasticity) of the fatty acids methylates were measured. The fatty

acid methyl ester (FAME) composition of the lipids used in this research was analyzed

and quantified as described by Ye and others (2011) using gas chromatography on a

Shimadzu 2010 GC equipped with a flame ionization detector (Shimadzu, Columbia,

MD). The hardness of the lipid network formed was measured by texture profile analysis

(TPA) using a TA. XT Plus texture analyzer (Texture Technologies Corp., Scarsdale,

NY) as previously described by Suzuki and others (2010). A differential scanning

calorimeter (DSC; DSC 2910, TA Instrument, New Castle, DE) was used to evaluate the

melting behavior of the crystallized material as described by Ye and others (2011). The

melting point of lipids was determined by AOCS Official Method Cc 1-25 (2007). A TA

Instruments AR-G2 Magnetic Bearing Rheometer (TA Instruments, AR-G2, New Castle,

DE) was used to evaluate the viscoelastic properties of the material.

Statistical analysis

Physicochemical properties of baked products and lipids were measured in

triplicate. Correlations between the hedonic evaluation (consumer tests), physicochemical

properties of the baked products and functional properties of the lipids were determined

by statistical analysis software (SAS) version 9.2 (SAS Institute Inc, Cary, NC) and

Prism 4 (GraphPad Software, Inc., La Jolla, CA). Two-way ANOVA and REGWQ

pairwise comparison method were used in SAS to analyze for differences at $\alpha = 0.05$

significance level (see Appendix C, Appendix D for SAS code and ANOVA Data).

Results and Discussion

The FAME composition of different lipids used in this research is shown in Table

2. The major component of butter is palmitic acid (C16:0) which is approximately 32%

of the total fat. Oleic acid (C18:1) is the predominant fatty acid in lard and margarine

(37% and 57%, respectively), while SBO, APS, and IES contain predominantly linoleic

acid (C18:2; 53%, 44%, and 42%, respectively). APS and IES have approximately the

same content of SFA, MUFA, and PUFA, with slightly higher values of SFA for IES due

to higher stearic acid content. In addition, IES contains less palmitic acid, oleic and

linoleic acid. Functional properties of the different lipids used in this research are

summarized in Table 3. The lipid sources with the lowest melting points are margarine

($31.0 \pm 1.9°C$) and butter ($33.0 \pm 0.8°C$), while APS has the highest ($43.7 \pm 1.9°C$).

Similarly, the peak melting temperature (T_p) is observed to be the highest in APS. It is

interesting to note that even though APS and IES have similar chemical composition in

terms of SFA, MUFA and PUFA, their melting points are significantly different (p<0.05)

with IES having a melting point approximately 7°C lower. Fats with similar FAME

composition might have different physicochemical properties due to differences in their

triglycerides composition. IES has the highest δ value (p < 0.05), which indicates that this

Table 2 - FAMEs composition of lipid sources. SF: Saturated Fatty Acid, MUFA: Monounsaturated Fatty Acid, PUFA: Polyunsaturated Fatty Acid. Values are reported as average ± standard deviation.

Fatty Acid	Amount (%)					
	Butter	Lard	Margarine	SBO	APS	IES
C4:0	0.73±0.07	-	-	-	-	-
C6:0	0.86±0.04	-	-	-	-	-
C8:0	0.79±0.02	0.01±0.00	-	-	0.00±0.00	-
C10:0	2.32±0.05	0.08±0.00	-	-	0.00±0.00	-
C12:0	2.99±0.07	0.08±0.00	0.01±0.00	0.00±0.00	0.05±0.00	-
C14:0	11.03±0.28	1.39±0.01	0.07±0.00	0.07±0.00	0.20±0.00	0.08±0.00
C16:0	32.35±0.97	24.79±0.00	10.35±0.01	10.28±0.02	14.88±0.00	10.58±0.01
C16:1	1.35±0.23	2.12±0.15	0.05±0.00	0.08±0.00	0.06±0.00	0.08±0.00
C18:0	14.16±0.25	15.24±0.08	8.10±0.10	4.28±0.00	10.58±0.00	21.59±0.24
C18:1	28.31±1.33	37.26±0.21	56.85±0.11	21.92±0.00	21.56±0.03	17.32±0.01
C18:2	3.49±0.13	16.00±0.06	20.05±0.01	52.96±0.01	44.35±0.05	41.55±0.15
C18:3	0.67±0.02	0.63±0.01	2.79±0.00	8.06±0.00	6.02±0.00	6.55±0.04
C20:0	0.21±0.00	0.26±0.01	0.36±0.00	0.37±0.00	0.38±0.01	0.39±0.00
C20:1	0.22±0.01	0.68±0.01	0.22±0.00	0.02±0.01	0.22±0.02	0.17±0.00
C20:2	0.07±0.00	0.65±0.00	0.01±0.00	0.05±0.00	0.04±0.00	0.03±0.00
C20:3	0.24±0.00	0.27±0.02	0.04±0.00	0.03±0.00	0.03±0.00	0.02±0.00
C22:0	0.14±0.00	0.44±0.02	0.97±0.03	1.73±0.00	1.52±0.05	1.51±0.05
C22:4	0.06±0.00	0.13±0.00	0.04±0.02	0.04±0.00	0.01±0.00	0.02±0.00
C24:0	0.04±0.00	-	0.10±0.00	0.11±0.00	0.10±0.00	0.09±0.01
SFA	65.61	42.27	19.95	16.84	27.71	34.24
MUFA	29.87	40.06	57.12	22.02	21.84	17.57
PUFA	4.52	17.67	22.93	61.14	50.45	48.17

Table 3 - Functional properties of lipids: TPA (Texture Profile Analysis), DSC measurement (T_{on}, T_p, ΔH) and viscoelastic parameters (G', G'', δ). SBO is not included in these measurements since it is liquid at room temperature. All samples were measured at 5 °C while IES was measured at 25 °C.

Physicochemical properties	Butter	Lard	Margarine	APS	IES
Melting point (°C)	33.0±0.8c	36.7±1.0b	31.0±1.9c	43.7±1.9a	36.4±0.4b
G' (Pa, 10^4)	183±0.34a	84±0.19bc	95±0.13b	15±0.00cd	0.02±0.00d
G'' (Pa, 10^3)	339±0.80a	175±0.36b	154±0.26bc	18±0.01bc	0.06±0.00c
δ	10.7±0.6bc	12.1±0.2b	9.71±0.30c	7.16±0.37d	17.0±0.2a
TPA (g force)	495±123a	207±53b	170±45bc	43±10c	N/A
T_{on} (°C)	8.33±0.30d	25.9±0.4c	26.1±1.4c	41.5±1.0a	34.7±2.3b
T_p (°C)	12.3±0.1e	32.2±0.2c	31.70±0.01d	47.75±0.06a	46.33±0.04b
ΔH (J/g)	13.68±0.27c	36.28±0.32a	12.02±0.63c	22.05±0.54b	6.46±0.65d

N/A: low saturated shortening was not included in the TPA measurement due to its soft texture. T_{on}: onset melting temperature; T_p: peak melting temperature; ΔH: enthalpy of melting process; G': storage modulus; G'': loss modulus.
*Data is shown as mean ± standard deviation; values within rows sharing the same letter are not significantly different ($p > 0.05$).

fat has a higher viscoelastic behavior. Conversely, APS has the least viscoelastic character of the lipids examined, with the lowest δ value ($p < 0.05$) due to the lower G'' value obtained. G'' is the loss modulus obtained from small deformation experiments; therefore low values of G'' suggest that when the sample is subjected to shear rate, a lower loss of energy is experienced after the deformation. When considered in conjunction with the TPA results, which measures the hardness of lipid (the bigger the value, the harder the lipid), we have an overview of lipids' texture profiles. It is interesting to note that even though APS has the lowest δ value (lower viscoelastic behavior) it is also the softer sample (low TPA value). The low hardness found for APS is also corroborated by its low G' value. These results suggest that APS has a

plastic/rubbery and malleable texture since it can be easily deformed by the TPA analysis (low hardness, low G') but some energy is recovered after the deformation is released (low G").

DSC was used in this study to examine the melting behavior of lipids. Onset melting temperature (T_{on}) of butter was significantly lower than the others, consistent with its higher proportion of short-chain fatty acids (Table 2). The highest T_{on} observed for APS is most likely due to interesterification, as this is known to raise the melting point of blended lipids (Yassin and others 2003). Melting enthalpies (ΔH) were found to be significantly different from each other, with the exception of butter and margarine.

The highest ΔH observed in lard might due to the high portion of its saturated fatty acids. Interestingly, with a higher portion of saturated fatty acids, butter has lower ΔH than lard. This might be explained by its higher portion of short chain fatty acids that don't require large amount of energy to melt. The lowest ΔH was observed in IES. It is important to note here that physicochemical properties reported in Table 3 were measured at 5°C for all samples with the exception of IES. These conditions were chosen to match the baking conditions used to make the products. This means, all shortening were kept at 5°C until used, while the IES was kept at 25°C (room temperature). This difference in temperature explains the low physicochemical values observed for IES when compared to the other lipids.

Quality characteristics of cakes: Cake batter made with SBO was denser than batters made with other lipids ($p < 0.05$), with the exception of lard (Figure 1A). Plastic lipids contain solid crystals that can adsorb to air bubbles incorporated into batter during mixing and stabilize them. SBO, with no crystal structure at room temperature, was

unable to hold air bubbles in the batter during mixing. This results in its high batter density. On the other hand, APS has the highest melting point (Table 3) therefore significant amount of crystals are present during batter formation which stabilize air bubbles resulting in a significantly lower ($p<0.05$) batter density. In addition, APS contains added emulsifier which aids in the incorporation of air and the dispersion of lipid crystals (Painter 1981). This results in large initial air incorporation and therefore less dense cake batter (Pyler 1988). Figure 2A shows relationship found between batter density and δ values. It confirms our results from Figure 1A, that with a lower δ (more plastic character), APS has a lower batter density. However, when δ values are above ~10 (butter, lard, and interesterified soybean oil), batter density is not affected by the δ value of the lipid used.

Carbon dioxide from leavening agents and steam accumulate in air bubbles which expand until the cake batter reaches its set point, where protein coagulation and starch gelatinization prevent further expansion. This results in a final cake with lower density than the original batter (Figures 1A and 1B). Interestingly, despite the differences seen in batter density, no significant differences ($p > 0.05$) were found in cake density, with the exception of the cake formulated with SBO (Figure 1B). Previous research suggests that the density of the final cake depends not only on the initial air incorporation, but also on the stability of these air bubbles in batter during baking (NorAini and others 1992; Stauffer 1998; Zhou and others 2011). As the oven is heated up, bubbles tend to migrate and expand, while lipid crystals (adsorbed to the air bubbles during mixing) melt and form a uniform layer over the inside surface of the bubble, allowing bubble expansion without rupture (Brooker 1993; Zhou and others 2011) resulting in a stable bubble. Since

APS and IES had the highest T_{on} in this research (Table 3), it is possible that the lipids remain in the crystalline state and were unable to form the uniform layer of liquid fat needed to stabilize bubbles, resulting in large, unstable bubbles that either collapsed or escaped from the surface of the batter. Therefore, even with significantly different batter densities, no significant differences were found between their cake densities. Without crystal structure at room temperature, liquid SBO is unable to hold air bubbles, let alone stabilize them. This results in high values both in its batter density and cake density. This agrees with previous studies that cakes made from liquid oil had greater firmness than cakes made from lipids with more solid characters (Vali and Choudhary 1990; Zhou and others 2011). The relationship of batter density and cake density is shown in Figure 2B. As expected, they have a positive relationship (R^2=0.91). This agrees with Hartnett and Thalheimer's observation (1979) that denser cake batter typically leads to a denser cake.

The moisture content of cake (fresh and stored for 1 week) made from different lipids is shown in Figure 1C. Fresh cake (shaded columns) made with margarine had the highest moisture content ($p < 0.05$), followed by cakes made with APS and IES. Cake formulated with butter, lard and SBO had similar initial moisture contents. After one week storage, cake made with margarine retained the most moisture, while cake made with APS and IES had the lowest moisture contents ($p < 0.05$). Interestingly, the moisture content of cake made with butter did not change with time, consistent with previous reports (Gelinas and others 1999).

Fresh cake made with margarine and APS had similarly high Aw, while the lowest Aw was seen in cake made with butter (Figure 1D). After one week storage, all Aw values decreased, and cakes made with APS had the lowest value ($p < 0.05$). To

Figure 1 - Effect of lipid type (B=butter; APS=all-purpose shortening; L=lard; SBO=soybean oil; M=margarine; IES= interesterified soybean oil) on cake. Batter density (A), cake density (B), cake moisture content (C), water activity (D) and consumer acceptance (E). Column values from. Fig. 1A, 1B, 1C and 1D represent the average of triplicate batches ± standard deviations. Values sharing the same letter are not significantly different (p > 0.05). Fig. 1C and 1D show measurements from fresh cakes (shaded columns) and cakes stored one week (white columns). Column values from Fig. 1E represent the average values from consumer taste tests (n=120). 1. Dislike extremely; 3. Dislike moderately; 5. Neither like nor dislike; 7. Like moderately; 9. Like extremely.
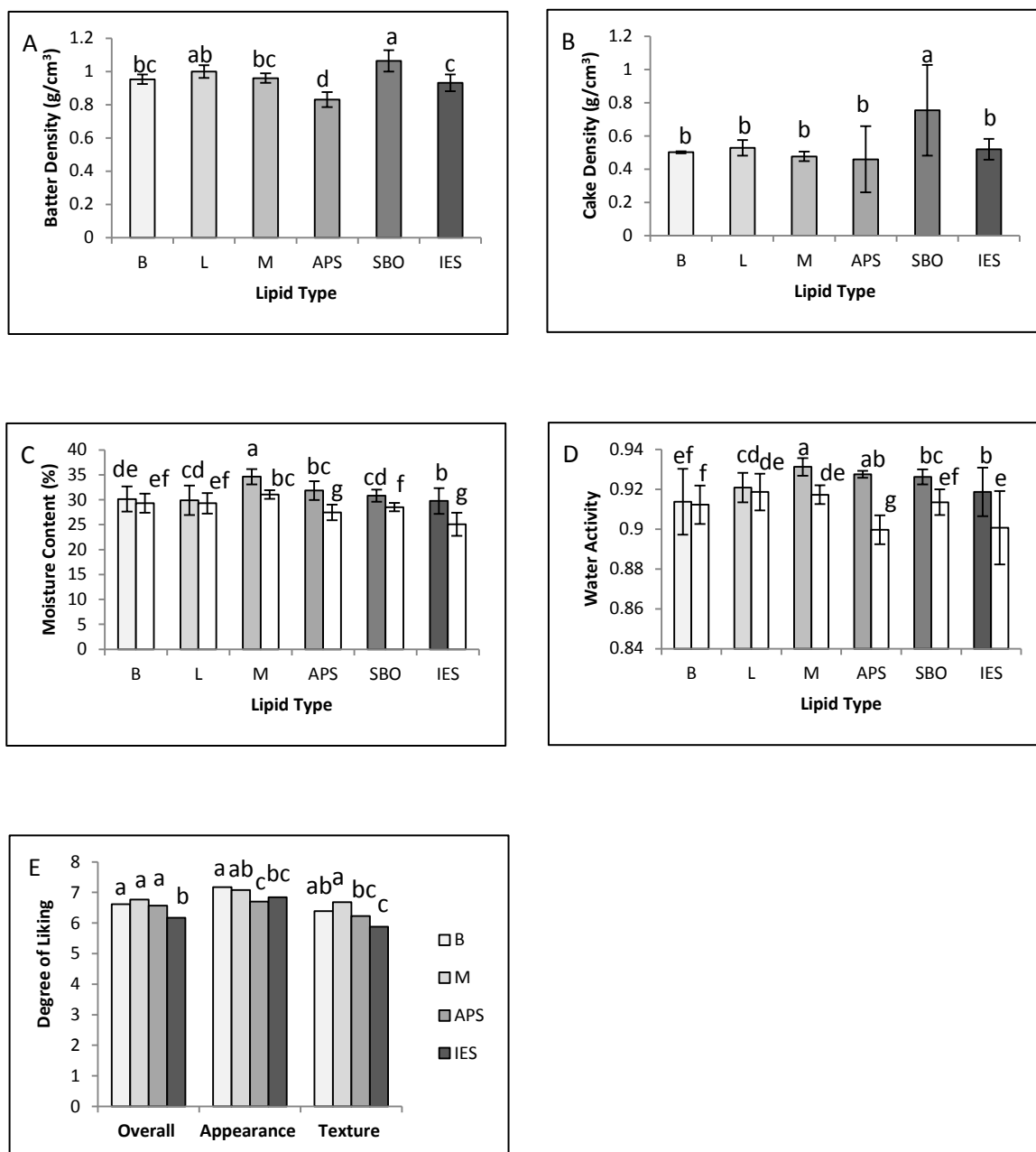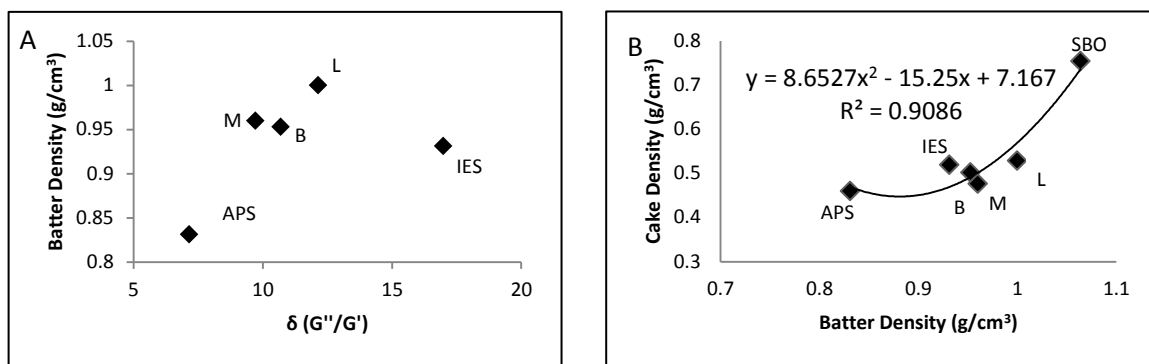
Figure 2 - Relationships between batter density and δ (A), and cake and batter density (B). B=butter; APS=all-purpose shortening; L=lard; SBO=soybean oil; M=margarine; IES= interesterified soybean oil.

evaluate consumer acceptance of the cake, 65 male and 55 female participated in the sensory test. Among the participants, 60% belonged to the 18-25 age group; 25% belonged to the 26-35 age group; 7.5% to the 36-45 age group; 3.3 to the 45-55 age group, and 4.2% were above 56 years of age.

All consumers recruited for the panel were consumers of cakes. Results show that 32.5% of the participants consumed cake less than once a month; 59.2% consumed cake at least once a month, and 8.3% consumed cake at least once a week. Results from the consumer test are shown in Figure 1E and product pictures are shown in Appendix F. Cakes made with butter, margarine and APS were not rated significantly different (p >0.05) in overall acceptability and cakes made with IES were the least preferred in this attribute. Even though no significant differences were found in the overall acceptability between cakes formulated with butter margarine and APS, the degree of liking in terms of appearance was significantly lower for APS (p < 0.05). In summary, none of the cakes were found to be unacceptable in overall, appearance, and texture since all scores fall in the range of 6 to 8 on the hedonic scale. Despite the fact that cake made with IES was not

significant different from other cakes in batter density, cake density, moisture content and water activity consumers' comments pointed out that IES cake was dry, dense and had an unpleasant crumbly texture, which might explain the low rating in the sensory evaluation.

Most of these differences were found in appearance and texture of the product which might be explained by the extremely low viscoelastic parameters of IES and its low ΔH values suggesting that few crystals are present in the lipid matrix. This lack of crystals in IES might be responsible for obtaining a cake with slightly higher density, lower moisture content and lower water activity, especially when compared to cakes formulated with margarine. These quality parameters can explain the results obtained in the appearance and texture rating obtained for these samples.

Quality characteristics of cookies: Cookies made from butter, margarine and SBO had similarly large spreads, while cookies made with APS had a significantly lower spread ($p < 0.05$; Figure 3A). Butter and margarine produced relatively flat cookies, while those made with APS and IES were significantly taller ($p < 0.05$) than any others (Figure 3B).

Generally, expansion due to leavening and the flow rate of the cookie dough affect cookie spread (Hoseney and Rogers 1994). Cookie spread in turn affects cookie height. After cookie dough is put in the oven, it starts to expand until it reaches its setting time (the point at which the dough stops spreading due to protein coagulation and starch gelatinization). Previous research suggests that lipid type is not an essential variable for cookie spread (Rogers 2004; Vetter and others 1984). However, it does affect cookie spread by providing a lubricant effect, which in turn affects flow rate (Pareyt and others 2010). Basically, the earlier the lipid melts during the baking process, the larger the

cookie spread and flatter cookie will be. Therefore cookies made from liquid oils, such as the SBO used in this study, tend to have larger spreads and lower heights (Jacob 2007). For solid fats, the melting temperature and ΔH value are major factors influencing its lubricant effect (Menjivar and Faridi 1994). For example, butter and margarine, with low ΔH values and melting temperatures, melt quickly during baking and yield cookies with increased spread and decreased heights (Table 2, Figure 3A, 3B). Despite its similar melting temperature, lard, with a high ΔH value, did not exhibit a lubricating effect until later in the baking process as it requires increased energy input to melt completely. Similarly, with a high melting temperature, APS starts lubricating later in the baking process. Therefore cookies made with lard and APS start spreading later than cookies made with butter and margarine, resulting in their lower spreads and higher heights. Since these physicochemical parameters of IES were measured at 25 °C, it does not fit in our discussion here. Figure 4A shows the relationship between lipid melting temperature and cookie spread (p = 0.0031; r = 0.8285).

In addition to cookie spread, the degree of air incorporation also contributes to cookie height. Cookie dough densities range from 0.83 ± 0.16 g/cm3 to 1.31 ± 0.38 g/cm3 with lard, margarine and IES having similarly higher densities than other lipids (Figure 3C). Cookie dough containing a chemical leavening agent starts to expand around 30°C due to the formation and expansion of leavening gasses (Doescher and others 1987). As with cakes, lipid with the right melting temperature is necessary for expansion of bubbles without rupture (NorAini and Miskandar 2007). Therefore lipids that begin melting too early in the baking process (before 30°C) are not able to adsorb to the bubbles, which allows air to escape before dough expansion can begin, resulting in
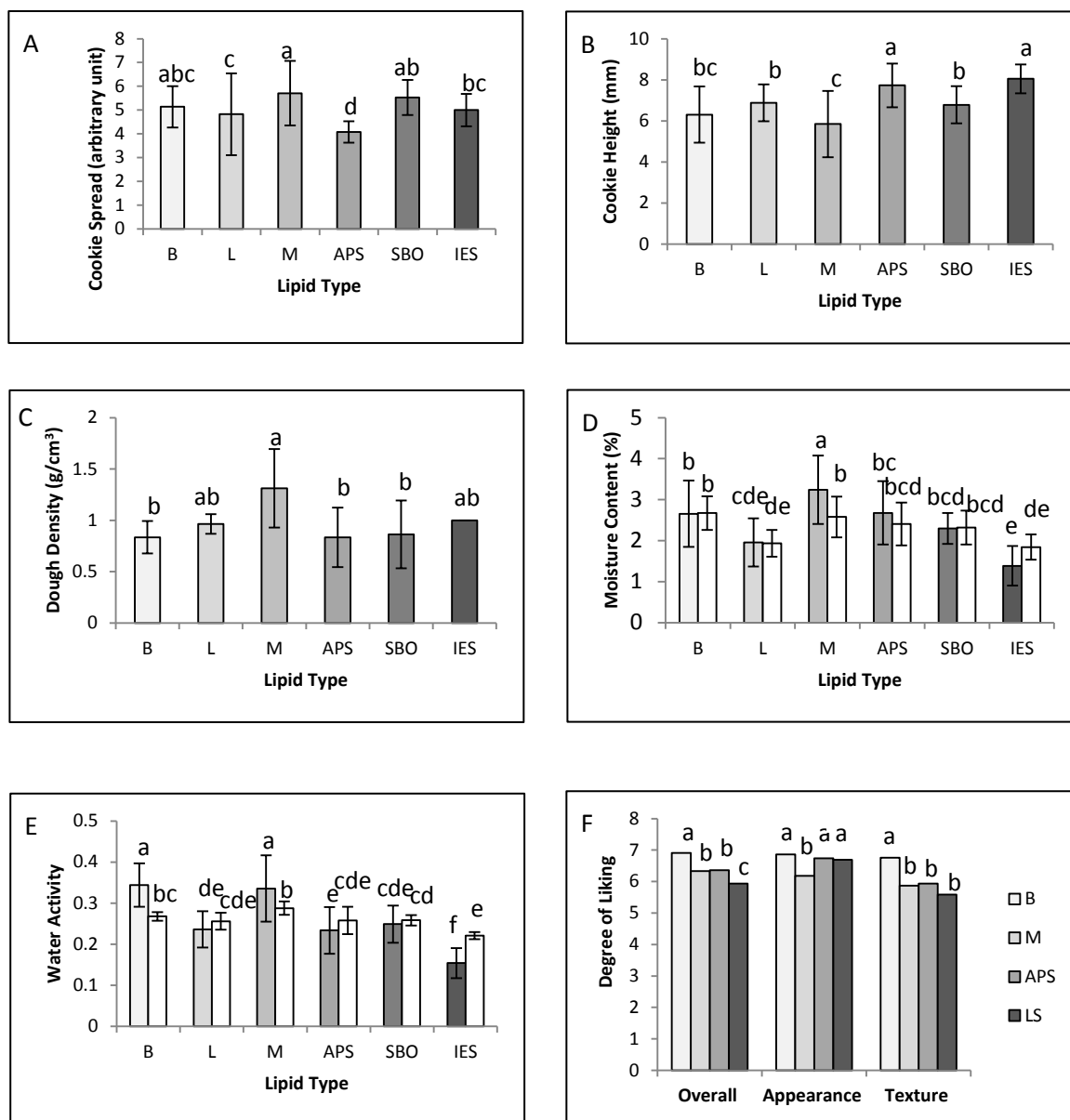
Figure 3 - Effect of lipid type (B=butter; APS=all-purpose shortening; L=lard; SBO=soybean oil; M=margarine; IES= interesterified soybean oil) on cookie. Spread (A), cookie height (B), cookie dough density (C), moisture content (E), water activity (F) and consumer acceptance (F). Column values from Fig. 3A, 3B, 3C, 3D and 3E represent the average of triplicate batches ± standard deviations. Values not sharing a letter are significantly ($p < 0.05$) different based on a 2-way ANOVA test. Fig. 3D and 3E show the measurements from fresh and 1-week stored cookies, with shaded columns represent fresh cookie and white columns represent stored cookies. Column values from Fig. 3F represent the average values from consumer taste tests (n=108). 1. Dislike extremely; 3. Dislike moderately; 5. Neither like nor dislike; 7. Like moderately; 9. Like extremely.
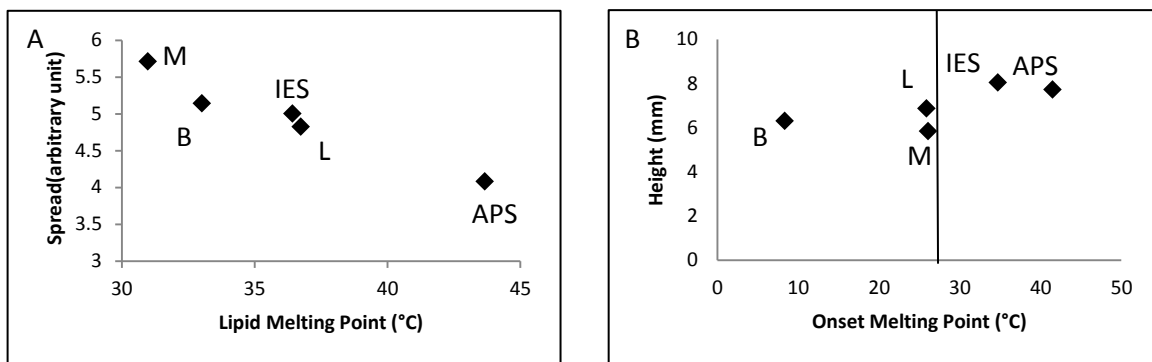
Figure 4 - Cookie spread vs. lipid melting point (A) and plot of cookie height vs. lipid melting point (B). B=butter; APS=all-purpose shortening; L=lard; M=margarine; IES= interesterified soybean oil.

bubble rupture and lower cookie height. Cookie dough made with lard and IES had similar air incorporations in cookie dough (Figure 3C). However, with a lower onset temperature (25.9°C; Table 3) lard starts melting in an early stage of baking, losing its ability to remain adsorbed to trapped bubbles before the cookie dough began to expand, while with a higher onset temperature (34.7°C; Table 3), IES was able to stabilize these expanding bubbles. This results in cookies with similar spreads (Figure 3A), but significantly different heights ($p < 0.05$; Figure 3B). The relationship of lipid T_{on} and cookie height is shown in Figure 4B ($p < 0.0001$; r = -0.7517).

Moisture contents of cookie made with different lipids were below 3.5% (Figure 3D).The moisture content of cookies containing 2% moisture or lower either remained constant (L) or increased after one week storage (IES). On the other hand, the moisture content of cookies with higher moisture (>2%) either remained constant (B and SBO) or decreased (M and APS) after 1 week of storage. This indicates their tendency of coming to equilibrium moisture content over time. Similar pattern was observed from cookie water activity (Figure 3E).

In sensory evaluation, 108 consumers (52.8% male and 47.2% female) participated in the test. The age distribution of consumers was: 56.5% between 18-25 years old; 22.2% between 26-35 years old; 7.4 between 36-45 years old; 8.3% between 45-55 years old and 5.6% above 56 years old. All participants were consumers of cookies, where 3.7% of the participants reported consumption of cookies less than once per month; 36.1% of the participants reported consuming cookies at least once a month; 50% of the participants reported to have cookies at least once a week; and 10.2% of the participants reported to have cookies at least once a day. Results from the sensory test show that in overall acceptance, cookies made with butter had the highest rating while cookies made with IES was rated the lowest ($p < 0.05$; Figure 3F). Margarine and APS resulted in cookies with similar ratings. In appearance judgment, cookies made with butter, APS and IES had similarly high ratings while cookie made with margarine was rated significantly low ($p < 0.05$). In texture judgment, butter cookies had a significantly high rating while the other three lipids had similarly low ratings.

The highest ratings of cookies made with butter in overall could be due to its superior flavor and texture. Since the sample was presented in quarters, the actual spread and height of a whole cookie could not be evaluated by consumers. However, most comments pointed out the buttery flavor and the appropriate chewiness of cookies made with butter. Additionally, previous research indicated that lauric acid (C12:0) increased the dispersion of aroma (Rutkowska and Zbikowska 2010). Butter contains the highest amount of lauric acid (2.99%, Table 3) among other lipid sources therefore it is possible that the amount of lauric acid aided in delivering its unique buttery flavor. For cookie made with IES, some consumers complained about the dryness and the crumbliness of

the cookie, which might explain its lowest rating in overall evaluation. This is in accordance to the lower moisture and water activity values of the cookie reported in Figure 3D and E. Based on our subjective observation during baking, cookies made with margarine had a yellowish color, which might contribute to its significantly lowest rating in appearance (Appendix F). Additionally, some consumers addressed that margarine samples were filmy and thin, which might have negative impact in the appearance. This "filmy" and "thin" aspect of cookies formulated with margarine correlates well with the high spread and low height reported in Figure 3A and B.

Quality characteristics of pie crusts: In pie crust production, the role of lipid is to prevent excessive gluten formation and create pockets in the dough (Stauffer 1998). Gluten in dough is formed by the interaction of flour and water (Patient 1994). Lipid with a more fluid character tends to limit gluten development, since flour particles are covered by lipid and have less chance to interact with water (Pyler 1988). However, solid lipids are more likely to be coated by flour particles than vice versa and form pockets of lipids within the dough. Therefore, flour proteins are able to interact with water, leading to increased gluten development. The majority of gluten is formed when water is added in the final stages of mixing, after the lipid and flour have been combined. Additionally, lipids can create and maintain pockets in dough during rolling and baking.

During the cooking of pie crust, as temperature in the oven increases the pockets of lipid dispersed throughout the dough melt and leak out of the baking matrix leaving a gap, allowing air and steam to accumulate and expand. The size and number of these pockets directly influence the final flakiness and height of the baked pie crust. Breaking strength, an indicator of pie crust toughness, is directly influenced by gluten

development, with more gluten development resulting in a tougher crust (Hirahara and

Simpson 1961). In the current study, pie crust made with margarine had the highest

breaking strength (p < 0.05), followed by pie crust made with butter. Crusts containing

SBO and IES were significantly less tough (Figure 5A). The toughness of the crusts made

with margarine and butter is not surprising, as both of these lipid sources contain

significant amounts of water (approximately 16% by weight; USDA National Nutrient

Database for Standard Reference). However, with the lowest T_{on} (8°C; Table 3), a larger

proportion of the lipid in butter is in a liquid state at room temperature. This liquid

fraction was able to coat flour particles during the first stages of mixing, resulting in less

gluten development than the one observed in margarine. Therefore, pie crusts produced

with butter showed a lower breaking strength than margarine (p <0.05; Figure 5A). The

low breaking strengths of pie crusts made with SBO & IES was due to their liquid status.

They more effectively coated the flour particles during mixing, greatly limiting gluten

development. Pie crusts made with lard, APS and IES were significantly taller than those

made with butter, margarine, and SBO (Figure 5B, p < 0.05). With the liquid status of

SBO, no pockets were formed during kneading, so expansion could not occur during

baking. Therefore pie crust made with SBO had the lowest height. The mid-range heights

of pie crusts made with butter and margarine were likely due to excessive gluten

formation, preventing the expansion of pie crust during baking. This is verified by their

high breaking strengths (Figure 5A). The ideal pie crust is a balance between gluten

development and the presence of lipid pockets. The high melting points of lard and APS

(Table 3, 36.7 °C and 43.7 °C) as well as their high ΔH (Table 3, 36.28J/g and 22.05J/g)

allowed them to stay in the formed pockets longer. Combining with their moderately

developed gluten, they help with accumulation of steam and expansion of pie crust during baking. This results in layered pie crust with highest heights. This same condition was found in pie crust made with IES, which contains both observable liquid and solid portions in a fluid state. The liquid portion could coat flour particles limiting gluten development, while the solid portion was able to form pockets in the dough. This is reflected in its high height and low breaking strength (Figure 5A & B).

In the measurement of highest point, pie crust made with margarine had the highest value while pie crust made with lard and SBO had the lowest value (Figure 5C). Moisture contents of fresh pie crust were all below 6% (Figure 5D). After 1 week storage, pie crust with 3% initial moisture or above either remained constant (B) or decreased (M) its moisture content. Pie crust whose initial moisture is below 3% increased its moisture content. Similar observation is seen from the water activity of pie crust (Figure 5E).

In industry, the words "mealy", "flaky" and "tough" are typically used to describe different characteristics of pie crusts. "Mealy" refers to flat, crumbly crusts that contain very little gluten and show no expansion, as seen with the SBO crust (Figure 6). "Flaky" is used to describe crusts with a layered texture and moderate gluten development. Lard, APS, and IES produced crusts of this type (Figure 6). "Tough" pie crusts are harder and chewier crusts with very little expansion, resulting from excessive gluten development.
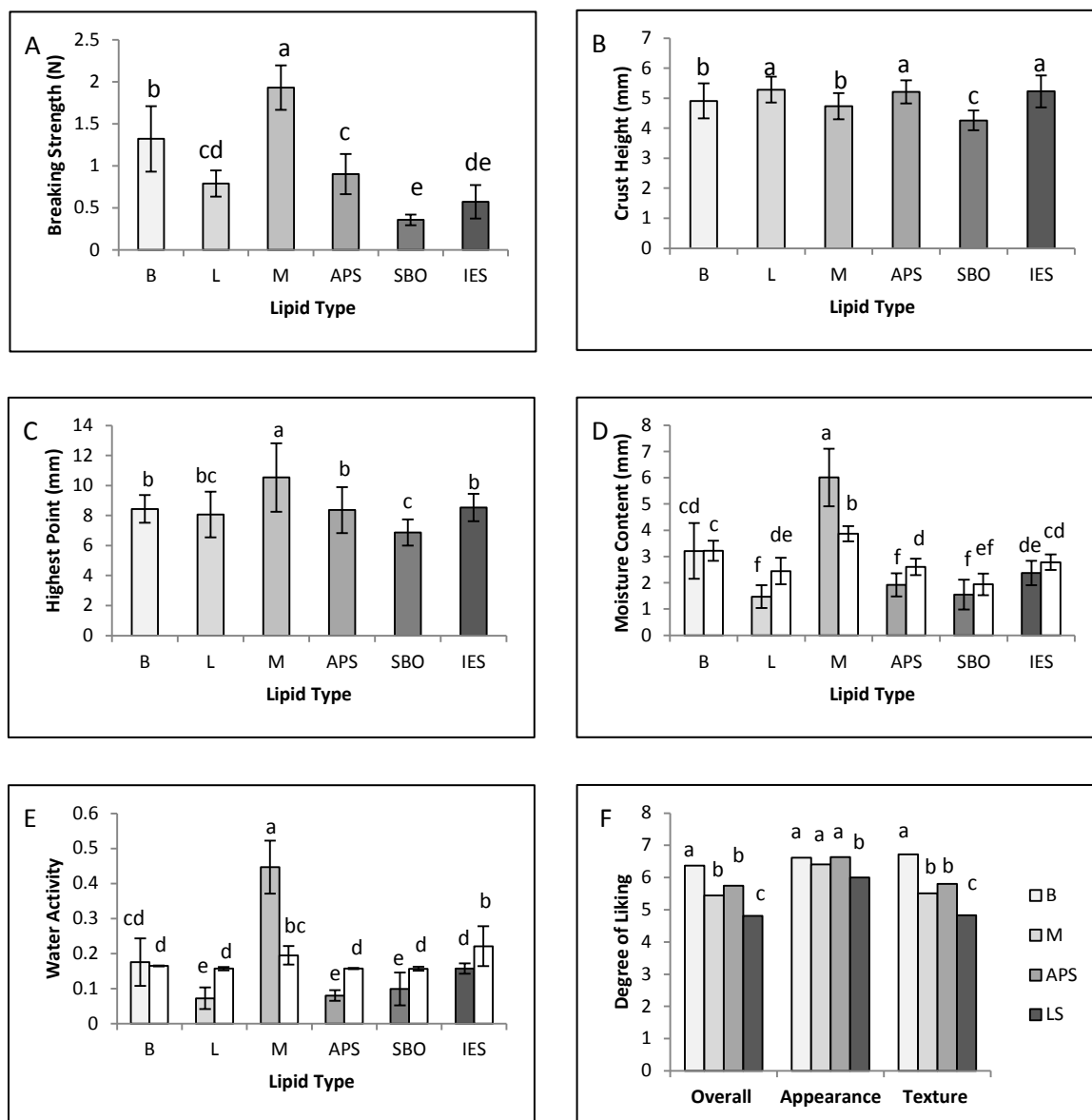
Figure 5 - Effect of lipid type (B=butter; APS=all-purpose shortening; L=lard; SBO=soybean oil; M=margarine; IES= interesterified soybean oil) on pie crust. Breaking strength (A), height (B), highest point (C), moisture content (D), water activity (E) and consumer acceptance (F). Column values from Fig. 5A, 5B, 5C, 5D and 5E represent the average of triplicate batches ± standard deviations. Values not sharing a letter are significantly ($p < 0.05$) different based on a two-way ANOVA test. Fig. 5D and 5E show the measurements from fresh and one-week stored pie crusts, with shaded columns represent fresh pie crusts and white columns represent stored pie crusts. Column values from Fig. 5F represent the average values from consumer taste tests (n=100). 1. Dislike extremely; 3. Dislike moderately; 5. Neither like nor dislike; 7. Like moderately; 9. Like extremely.
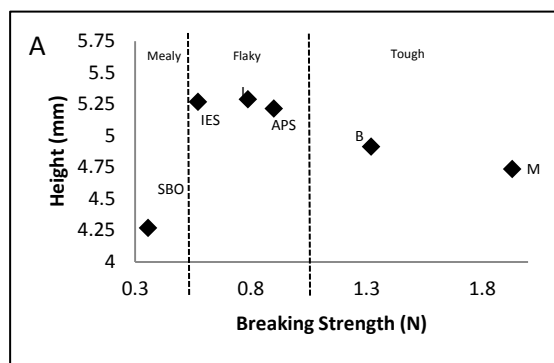
Figure 6 - Plot of breaking strength vs. height for pie crusts. B=butter; APS=all-purpose shortening; L=lard; SBO=soybean oil; M=margarine; IES= interesterified soybean oil.

Crusts made with butter and margarine, with their high breaking strengths and moderate heights, fall into this category (Figure 6).

In sensory evaluation, 100 consumers participated (55% male and 45% female). The age distribution of consumers was: 60% between 18-25 years old; 20% between 26-35 years old; 6% between 36-45 years old; 4% between 46-55 years old and 10% above 56 years old. Only 2% of consumers reported they never tasted pie before. Among other consumers, 68% of the participants reported consumption of pie less than once a month; 29% of the participants reported consuming pie at least once a month; and 1% of the participants reported to have pie at least once a week. Pie crust made from butter had highest rating in overall and texture ($p < 0.05$; Figure 5F). Pie crusts made with IES received the lowest rating in overall, appearance, and texture ($p < 0.05$). According to Figure 6, it might indicate that consumers prefer pie crust to be tougher. Since pie crust made with IES falls on the border line between "mealy" and "flaky", but closer to "mealy", it might also indicate that people don't prefer mealy pie crust. In appearance

rating, pie crust made with butter, margarine and APS were not significantly different (p > 0.05; Appendix F).

The lowest ratings of pie crust made with IES might due to its crumbly texture which comes from its underdeveloped gluten. Even though pie crusts formulated with IES fell into the flaky category as reported in Figure 6, it has a low breaking strength and was indeed very crumbly. The high ratings of pie crust made with butter might due to its texture and buttery flavor. About 26 out of 100 people in their comments pointed out the desirable flakiness of this sample. About 24 out of 100 people commented on its rich buttery or milky flavor. With the result from previous research, the lowest onset melting temperature of butter might be another contribution. It causes butter to melt and dissolve faster, which delivers a good mouth feel. To sum up, even pie crust made with butter fell into tough texture category, they were still liked most by consumers. This might indicate that to consumers, the first criteria during their tasting was pie crust flavor, which followed by texture.

Conclusion

Lipid viscoelastic character affects batter density in cake as well as breaking strength in pie crust. With a larger δ value (less plastic character), less crystal structure is presented in lipid and fewer air bubbles were incorporated into cake batter, which results in a denser batter. With a liquid character, lipid prevents the water-flour interaction by coating flour particles, which develops less gluten in pie crust indicated by its low breaking strength.

During baking, products characteristics are affected by lipid melting point and ΔH as well. In cookie production, a low melting temperature and a low ΔH make the lubricant effect of a lipid available earlier, resulting in a larger cookie spread. In pie crust production, a higher melting temperature along with a higher ΔH allows lipid crystals stay in pie crust dough as pocket forms longer. Depending on the different amount of developed gluten, pie crusts result in different heights.

T_{on} of lipid affects the stabilization of entrapped air bubbles in cake batter and cookie dough. If lipid melts around the time when air bubbles start expanding, a uniform layer will be formed over the inside surface of bubble, allowing bubble expansion without rupture. Too high or too low T_{on} will fail to stabilize bubbles. In cake production, this will result in a dense cake. Combined with the influence from cookie spread in cookie production, different cookie heights will result. In the three products within our study, the moisture content and water activity had a tendency to come to equilibrium over time.

In our consumer taste tests, consumer described all three products made with IES as either dry or crumbly. All three products made with butter had better overall performances. Cookies and pie crusts made with butter were described as having a desirable chewiness and flakiness, respectively. This may be due in part to the low T_{on} and high lauric acid (C12:0) content in butter,which allow faster melting and aid in the dispersion of aroma. The lowest appearance rating of cookies made with margarine might be due to its yellowish color and the thin character.

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CHAPTER IV

EFFECT OF HIGH INTENSITY ULTRASOUND-TREATED LIPID ON THE

PHYSICAL PROPERTIES AND SENSORY QUALITY OF BAKED PRODUCTS

Abstract

IES was treated with high intensity ultrasound (US) to generate small lipid crystals and harder materials. IES samples were crystallized at 32°C and tempered for 48h at 5 and 25°C. US-treated and non US-treated IES was used to produce baked products such as cakes, cookies, and pie crust. The highest cake batter density was obtained in cakes formulated with non US-treated IES tempered at 5°C. This result can be explained by the large lipid crystals obtained in this shortening, which lack the ability to incorporate air. In cookies, the highest dough density and cookie spread, and the lowest cookie height were obtained in samples formulated with non US-treated IES tempered at 25°C. This is a consequence of fewer crystals (more fluid status) present in this shortening. Pie crust formulated with US-treated IES resulted in a significantly taller pie crust. This is related to the higher amount of lipid crystals present in this shortening.

The lower storage temperature, 5°C, resulted in a higher solids content. This characteristic also resulted in baked products with different properties. In cake, the higher amount of lipid crystals obtained in IES tempered at 5°C resulted in more air incorporation into the batter and smaller pores in final cakes. Cakes formulated with IES at 5°C exhibited higher resistant force in compression tests. The finer porous texture might also be the explanation for consumer's higher rating on cakes formulated with the IES tempered at 5°C. However, the higher amount of lipid crystals in the IES sample

tempered at 5°C resulted in a lipid with lower mobility, especially during the mixing step

by hand. This resulted in no significant differences in cookie dough made with the IES

sample tempered at 5°C. In pie crust, the higher solids content in the lipid sample lead to

more gluten development in crust, preventing the expansion of air pockets during baking,

and resulting in a lower crust height than observed in crust made with IES tempered at

25°C.

Introduction

Ultrasound are mechanical waves that use frequencies above the hearing range of

the average person ($\sim > 18$ kHz) (Soria and Villamiel 2010). The fundamental effect of

ultrasound is to apply acoustic pressure to a medium in a sinusoidal manner. The acoustic

wave generated depends on time, frequency, and the maximum pressure amplitude of the

wave. The maximum pressure amplitude of the wave is directly proportional to the

transducer power input (Patist and Bates 2008). Usually ultrasonic applications can be

divided into two categories: low and high intensity applications. Low intensity ultrasound

is usually used to provide information on the physicochemical properties of food, such as

firmness, ripeness, etc., while high intensity ultrasound (US) is commonly used to alter

food properties, either physically or chemically (Martini and others 2008; Soria and

Villamiel 2010). Examples of US application are: emulsification/homogenization, change

of viscosity and texture, crystallization, extraction, etc. (Patist and Bates 2008; Soria and

Villamiel 2010; Ashokkumar and others 2012). In the lipid application field, researchers

have shown that US changes lipid physicochemical quality by inducing crystallization,

which results in faster crystallization, smaller crystals and harder material in lipid sample (Martini and others 2008; Suzuki and others 2010; Ye and others 2011).

In the baking industry, lipids influence product characteristics in many ways, including: air incorporation, lubrication, heat transfer, tenderness, moisture, mouthfeel, flavor, structure, and shelf life (Stauffer 1998; Rogers 2004). The physicochemical qualities (i.e. solid-liquid ratio, lipid crystal size, melting point, etc.) of lipids affect their performances in these functions. For example, in pie crusts lipids with a proper solid character and melting point help contribute to desirable flakiness and tenderness (Ghotra and others 2002). In cakes, the size and amount of lipid crystals play a predominant role in determing structure (Hartnett and Thalheimer 1979). This affects the volume and texture of the finished cake (Stauffer 1998; Rutkowska and Zbikowska 2010). Air incorporation is equally important in cookies (Rogers 2004). In addition, cookie spread may be also affected by lipid type (Wainwright 1999).

One of the commonly used methods to obtain specific solid-to-liquid ratio in industry is partial hydrogenation (Ghotra and others 2002; Tarrago-Trani and others 2006). However, this leads to the generation of trans fatty acids (TFAs), which are reported to have many negative effects on human health such as increasing the liklihood of coronary disease and breast cancer (Tarrago-Trani and others 2006; Vandana and others 2011; Przybylski and Aladedunye 2012). These adverse nutritional properties of TFA have raised consumers' awareness of trans fats presented in food products. As of January 2006, the US Food and Drug Administration (FDA) requires that the Nutrition Facts panel list the amount of trans fat if one serving contains ≥ 0.5g. In the food and edible oil industries, a number of technologies have been developed and are currently in

use in products with minimal to zero TFA content. Examples include: modification of hydrogenation process; genetic modification of oil seeds fatty acid composition; use of tropical oils (eg, palm oils, palm kernel oil and coconut oil); and interesterification of mixed fats (Tarrago-Trani and others 2006).

Previous research has addressed how high intensity ultrasound (US) can alter lipids texture physically, by generating harder lipid material (Martini and others 2008; Suzuki and others 2010; Ye and others 2011). Therefore, this technology has the potential to be used as an alternative process in healthy lipid sources with low saturated fatty acids and low TFA, while still possessing the physical qualities needed for food production. Little information is available comparing the effect of the different physical properties in fats obtained as a consequence of sonication on the quality of baked products, and how these effects relate to consumer acceptance.

The aim of this research is to study the effect of lipids with the same chemical composition, but different physical properties generated by ultrasound, on the physical and sensory quality of baked products.

Materials and methods

Starting material: Refined, bleached, fully hydrogenated, deodorized interesterified soybean oil (ADM, product number 762400; IES) was used in this research. US as described in Ye and others (2011) was used on IES to generate harder networks. In short, approximately 100 grams of IES was weighed and placed at 80°C in an incubator for 30 min to ensure complete melting of the sample. The IES sample was then agitated for 10 min in a cell maintained at 32°C. US was applied when sample become observably

turbid. Samples were collected at 90 min and then stored at two temperatures conditions (5°C and 25°C) for 48 h. Major ingredients used to formulate the baked products were purchased from the local grocery store.

Preparation of baked products: Baked product formulations are shown in Table 1. All products were prepared according to the following methods in triplicate. Samples were then stored in clear plastic box (to simulate retail storage conditions) for 7 days for water activity and moisture content measurements.

Cake: Cakes were made following the standard creaming method (Gisslen 2008). Briefly, dry ingredients (cake flour, baking powder, and salt) were mixed together, while sugar and lipid were mixed separately at medium speed setting (4) using a 5 quart stand mixer (Viking Professional Series, 800W; Viking Corporation, Greenwood, MS) followed by an increase in speed to the maximum setting (12) for 2 min with eggs and vanilla extract added at this point. Milk and dry mixture were added alternately and mixed at medium speed setting (3) for approximately 25 sec. Approximately 450g of batter was transferred to a 12 cm × 22 cm aluminum loaf pan and placed immediately into a preheated deck oven (Model CN60; General Electric Company, Fairfield, CN) for 40 min at 185°C. Inverted sheet trays were used to create an air gap and prevent bottom crusts from burning.

Cookies: Cookies were made using the standard creaming method (Gisslen 2008). Dry ingredients (flour, salt, and baking powder) were combined while the lipid and sugar were mixed using a 5 quart Viking stand mixer at a maximum speed setting (12) for 2 min. Vanilla extract and eggs were added and the speed was decreased to high setting (10) for 1 min. The dry ingredient mixture was added and stirred by hand just until fully

incorporated (approximately 30 strokes). The cookie dough was portioned using a #70 scoop (15 ml) onto a half sheet tray lined with parchment paper, and baked in a preheated deck oven for 10 min at 190°C.

Pie crust: Pie crusts were made following a standard flaky dough procedure (Gisslen 2008). Flour and salt were mixed with the lipid and pinched in by hand until "pea size" (2 mm diameter) clumps were formed. Water was added and the dough was tossed just until it held together (approximately 20 strokes). Dough was rolled to a thickness of 2 mm using roller guides then cut into approximately 10 cm x 3 cm strips. Pie dough was placed on a full sheet tray lined with parchment paper, then baked in a preheated deck oven for 9 min at 220°C.

Quality properties of baked products

Cake: Density, compression force, water activity, and moisture content were measured. Density was calculated in both cake batter and finished cake as g/cm^3 (Funk and others 1969). A crystallization dish was filled with cake batter then weighed. Exact volume of each dish was determined based on the maximum weight of water held. A representative sample of the finished cake (approximately 1 cm^3) was cut from the center of the loaf and weighed to determine its density. Compression test was performed by a Texture Analyzer (Food Technology Corporation, Sterling, VA). Cake center was cut into a cylinder shape (1 cm diameter, 1 cm height) then was placed on a 7.5 cm diameter platen. It was then pressed with a 50 N cell load in speed of 200 mm/min, into half height twice. The peak force was recorded.

Water activity and moisture content were measured in the finished cakes after one hour and after one week. Water activity was measured using a 4TE water activity meter (Decagon Devices Inc, Pullman, WA). Moisture content was determined using a MA150 programmable moisture analyzer with a ceramic heating element (Startorius Mechatronics, Bohemia, NY). Samples (approximately 2 g) were dried at 110˚C to a constant weight.

Cookie: Dough density, cookie spread and height, fracturability, water activity and moisture content were measured. Dough density was measured by weighing an individual portion of dough (a scoop of approximately 1 ml). The exact volume of each portion was determined by reading the volume of water that was displaced in a graduated cylinder. It was then calculated from these measurements as g/cm^3.

The spread and height of the finished cookies were measured using AACC Official Method 10-50D (1983). Cookies were allowed to cool thoroughly for 2 min, then centered over a template with concentric rings spaced 2 mm apart. The spread was calculated as the average distance from the center as read in each of 4 quadrants. Cookie height was taken in the center of each cookie using a digital caliper (Carrera Precision CP9807-TF; Max Tool LLC, La Verne, CA). Fracturability was measured by a Texture Analyzer (Food Technology Corporation, Sterling, VA). A probe moved in a constant speed of 200mm/min from top of a single cookie towards the center of cookie. Resistant force was measured as the maximum force required to break cookie. Water activity and moisture content were measured in the finished cookies after one hour and after one week, as described for cakes.

Pie crust: Breaking strength, crust height, water activity and moisture content were measured. Breaking strength was measured on each 10 cm x 3 cm pie crust strip with a consistent speed of 200 mm/min. The measurement was taken with a Texture Analyzer (Food Technology Corporation, Sterling, VA). Peak breaking force was determined in millinewtons and then converted to Newtons.

Crust height was taken as the average of 4 readings taken at the center points on each side of the crust strip with a digital caliper (Dreher and others 1983). Water activity and moisture were measured in the finished crust after one hour and one week as described above for cakes.

Sensory characteristics of baked products

Consumer acceptance: Products made with sonicated and non-sonicated IES stored at different temperatures (5°C and 25°C) were evaluated separately using consumer acceptance tests. Within each taste test, panelists were given products that were made with the same lipid crystallized under different conditions (with and without US treatment) and stored at each temperature (4 samples total). A separate panel was performed for cake, cookies, and pie crust. Panelists were asked to evaluate product acceptance in terms of overall acceptability, appearance, and texture characteristics (see Appendix B for questionnaire). Samples were prepared the day before serving. They were served as individual sizes: cakes were served in cubes (approximate 1 cm^3); cookies were served in quarters (1/4 of the original cookie); and pie crusts were served in 4 cm^2 squares, which were cut before baking. Samples were presented to panelists in 2 oz sample cups. Lidded cups were used for cake samples. Serving cups were labeled with 3-

digit randomized numbers generated by SIMS 2000 software (version 6.0, Morristown, NJ) and presented in a randomized and balanced manner (see Appendix B for sampling plan). Samples were presented to each taster under normal light to account for color difference in the product. Consumers were asked to taste one sample, rinse their mouth with distilled water and an unsalted cracker, then taste the next sample. Separate tests were performed for each product (cake, cookie, and pie crust), each with approximately 120 consumers. A 9-point hedonic scale (1. dislike extremely; 2. dislike very much; 3. dislike moderately; 4. dislike slightly; 5. neither like nor dislike; 6. like slightly; 7. like moderately; 8. like very much; 9. like extremely) was used to rate the degree of liking (overall, appearance, and texture) for each product. Demographic information such as gender and age group were collected, along with additional consumer comments. Hedonic ratings were collected using SIMS 2000 (version 6.0, Morristown, NJ) and analyzed with SAS 9.2 (SAS Institute Inc, Cary, NC).

Physicochemical properties of lipid sources

Fatty acid composition of the bulk lipids was analyzed by quantifying the fatty acid methyl ester (FAME) content as described by Ye and others (2011) using gas chromatography on a Shimadzu 2010 GC equipped with a flame ionization detector (Shimadzu, Columbia, MD). Functional properties (thermal behavior and viscoelasticity) of the lipids under each condition (5°C with US, 5°C without US, 25°C with US, 25°C without US) were collected by a differential scanning calorimeter (DSC; DSC 2910, TA Instrument, New Castle, DE), and a TA Instruments AR-G2 Magnetic Bearing Rheometer (TA Instruments, AR-G2, New Castle, DE) at room temperature respectively.

The crystal morphology was recorded during crystallization. A drop of lipid sample was taken from the crystallization cell at different times and placed between a slide and a cover-slide to evaluate crystals' microstructure during crystallization using a polarized light microscope (PLM, Olympus BX 41, Tokyo, Japan) with a digital camera (Olympus, Infinity 2, Lumenera) attached.

Statistical analysis

Physicochemical properties of baked products were measured in triplicate. Lipids physicochemical properties were measured in duplicate. Two-way ANOVA and REGWQ pairwise comparison method were used in statistical analysis software (SAS) version 9.2 (SAS Institute Inc, Cary, NC) to analyze for differences at $p = 0.05$ significance level (see Appendix C, Appendix E for SAS code and ANOVA Data II).

Results and Discussion

Table 4 presents the FAME composition of IES. The major component of this lipid is linoleic acid (C18:2) which is approximately 42% of the total fat. Stearic acid (C18:0) is the second major component (approximately 22%), followed by oleic acid (C18:1; approximately 17%). The total amount of saturated fat in IES was approximately 34%. Functional properties of IES used in this research are summarized in Table 5. No differences were found in G' between US-treated IES and non US-treated IES under 5°C storage conditions. When samples were tempered at 25°C US-treated IES had significantly higher G' than non US-treated IES ($p < 0.05$). G' is the storage modulus obtained from small deformation experiments, and a higher value indicates that a higher amount of energy is stored after the deformation and a more solid-like material. G" is the

Table 4 - FAME composition of IES

Fatty Acid	Percentage
C14:0	0.08 ± 0.00
C16:0	10.58 ± 0.01
C16:1	0.08 ± 0.00
C18:0	21.59 ± 0.24
C18:1	17.32 ± 0.01
C18:2	41.55 ± 0.15
C18:3	6.55 ± 0.04
C20:0	0.39 ± 0.00
C20:1	0.17 ± 0.00
C20:2	0.03 ± 0.00
C20:3	0.02 ± 0.00
C22:0	1.51 ± 0.05
C22:4	0.02 ± 0.00
C24:0	0.09 ± 0.01
Total	100

loss modulus obtained from the same deformation experiments. High values of G''

suggest more liquid-like materials.

Non US-treated IES had a more liquid-like characteristic than US-treated IES at

5°C (larger G'' value; Table 5); however, for the 25°C storage condition, US-treated IES

had a more liquid-like characteristic than non US-treated IES. Figure 7 shows the

microstructure of IES crystals obtained after crystallizing the material at 32°C with and

without US treatment and tempering for 48 h at 5 and 25°C. For 5°C IES (US-treated and

non US-treated IES), it is possible that both IES (with and without US treatment) had

significant amount of crystalized material; at 5 °C, therefore, no significant differences

were found from their G' value.

Also it might be possible that the more solid-like behavior of the sample tempered

at 25°C was due to these smaller crystals generated by US treatment (larger G' value).

Table 5 - Physical properties of US-treated IES and non US-treated IES: DSC measurement (T_{on}, T_p, ΔH) and viscoelastic parameters (G', G'').

Physicochemical properties	US-treated IES(w)		Non US-treated IES(wo)	
	5 °C	25 °C	5 °C	25 °C
G' (Pa, $\times 10^4$)	171.40±0.29a	4.50±0.13b	461.10±6.45a	0.01±0.00c
G'' (Pa, $\times 10^3$)	217.80±1.84b	3.20±0.00c	460.00±10.49a	0.02±0.00d
T_{on} (°C)	34.31±0.41c	35.44±0.15ab	34.87±0.00bc	35.89±0.23a
T_p (°C)	43.47±0.16b	42.85±0.23b	46.46±0.78a	46.58±0.18a
ΔH (J/g)	7.28±0.00a	4.95±0.045b	7.30±0.20a	4.67±0.24b

*T_{on}: onset melting temperature; T_p: peak melting temperature; ΔH: enthalpy of melting process; G': storage modulus; G'': loss modulus.
*Data is shown as mean ± standard deviation; values within rows sharing the same letter are not significantly different ($p > 0.05$).
*w: with US treatment; wo: without US treatment

The more liquid-like behavior observed in IES samples tempered at 5°C could be explained by its larger crystals. However, it is hard to explain the more liquid-like behavior observed in US-treated IES tempered at 25 °C (larger G'' value) based on its crystal size.

Peak melting temperature (T_p) of IES was significantly reduced ($p \leq 0.05$) by US treatment for samples tempered at 5°C and 25°C. However, the enthalpy of IES with US treatment was not significantly different from the one observed in IES without US treatment in both storage conditions. This suggests that even though US generated smaller crystals, the total amount of crystalline mass after tempering remains constant.

Quality characteristics of cakes: Cake batter made with 5°C non US-treated IES was significantly denser than US-treated IES ($p < 0.05$, Figure 8A). No significant differences in batter density were found between cakes formulated with non US-treated IES sample stored at 5 and 25°C. Although the total amount of crystals in IES did not change with US treatment (no significant differences were found in ΔH between

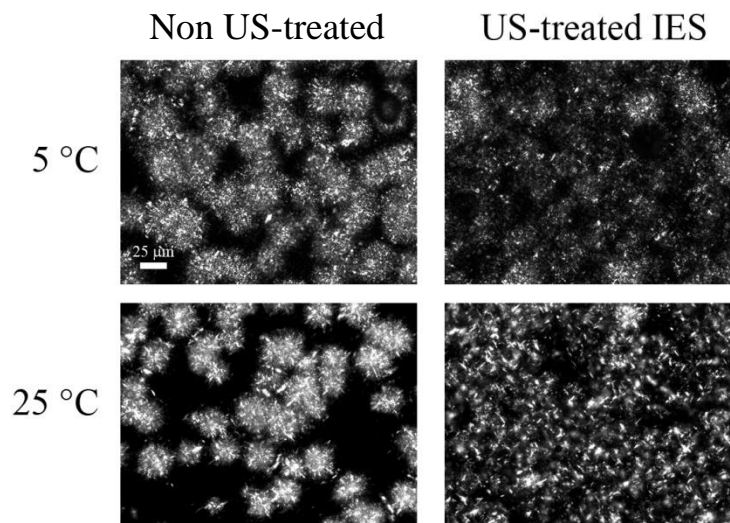Non US-treated   US-treated IES

5 °C

25 °C

25 µm

Figure 7 - Microscopic comparison pictures of US-treated IES and non US-treated IES crystallized at 32°C and stored for 48 hours at 5°C and 25°C (the white bar in the top left picture represents 25 microns).

treatments under each storage condition; Table 5), the smaller crystals present in US-treated IES (Figure 7) have a better chance to adsorb to air bubbles incorporated into batter during mixing and stabilize them. It also confirms the finding from Brooker (1993) that large number of very small crystals would be expected to convey more interface to the surface of expanding bubbles, and, as a consequence, produce greater improvement to the volume of baked products, than the same mass of much larger, but fewer crystals (Brooker 1993). The higher batter density observed for samples formulated with non US-treated 5°C IES might be a consequence of the larger lipid crystals present in this sample as observed in the picture (Figure 7).

Accordingly, significantly lower (p = 0.05) batter densities in samples formulated with US-treated 5°C IES might be a consequence of the smaller crystals obtained as a consequence of sonication (Figure 7). It is interesting to note that there is no significant

difference (p > 0.05) between the cake batter densities obtained from samples tempered at 25˚C (whether formulated with the US-treated or non US-treated IES). It is likely that under higher storage temperature, lipid has lower total amount of crystals (low ΔH, Table 5).

During baking, with the accumulation of carbon dioxide from leavening agents and steam, cake batter expands until it reaches its set point, where further expansion is prevented by protein coagulation and starch gelatinization. This results in final cakes with lower density than their original batter (Figure 8A and 8B). Similar to previous findings (Chapter III), despite these differences in batter density, no significant differences (p > 0.05) were found in cake density (Figure 8B, Appendix F) as a function of lipid treatment. Previous research suggests that along with the initial air incorporation, final cake density also depends on the stability of air bubble during baking (NorAini and others 1992; Stauffer 1998; Zhou and others 2011). As the oven is heated up, bubbles tend to migrate and expand, while lipid crystals (adsorbed to the air bubbles during mixing) melt and form a uniform layer over the inside surface of the bubble, allowing bubble expansion without rupture (Brooker 1993; Zhou and others 2011) resulting in a stable bubble in final cake. Too early or too late of melting will lead to the loss of air bubble and a denser cake. In our research, T_p of US-treated IES at 5 and 25°C was significantly lower than non US-treated IES (Table 5). Even though 5°C US-treated IES contribute to a significantly lower initial batter density than non US-treated IES, it is possiblethat it was released at a too early stage, which was before air bubbles start to expand. Therefore, without the protection from the lipid layer, air bubbles either

collapsed or escaped from the surface of the batter. This resulted in a similar cake density made with US-treated and non-treated IES.

As expected, the relationship between batter density and cake density fits in the relationship described in our previous research (Figure 8C). Without sonication, 25°C IES had similar batter density as the non US-treated IES used in the previous research. However, the density of the cake made with the non US-treated IES tempered at 25°C was much lower. This might be due to the treatment process, which involved melting and recrystallizing the shortening. Similarly, sonicated IES samples tempered at both 5 and 25°C had batter densities similar to that seen with untreated IES, but lower cake densities. This might be explained by the presence of smaller lipid crystals in US-treated IES samples, which have a lower T_p (Table 5) and were able to incorporate more air. Interestingly, for 5°C non US-treated IES, it doesn't fit in this trend.

Interestingly, with similar cake density, the compressibility is significantly different between storage temperatures under the same sonication conditions. Cakes formulated with IES tempered at 5°C had significantly higher (p = 0.05) resistant force than IES tempered at 25°C in both US-treated IES and non US-treated IES (Figure 8C). This indicates that cake formulated with IES tempered at 5°C were tougher than the ones formulated with IES tempered at 25°C. From a material science point of view, porous food materials usually consist of pores that are connected to each other through an interconnected network (Sozer and others 2011). When this network is characterized by open pores, it results in a relatively softer material (lower compressive strength) compared to food materials with closed or smaller pores (Sozer and others 2011). Cake is considered a porous food material. The 5°C storage condition generates more lipid
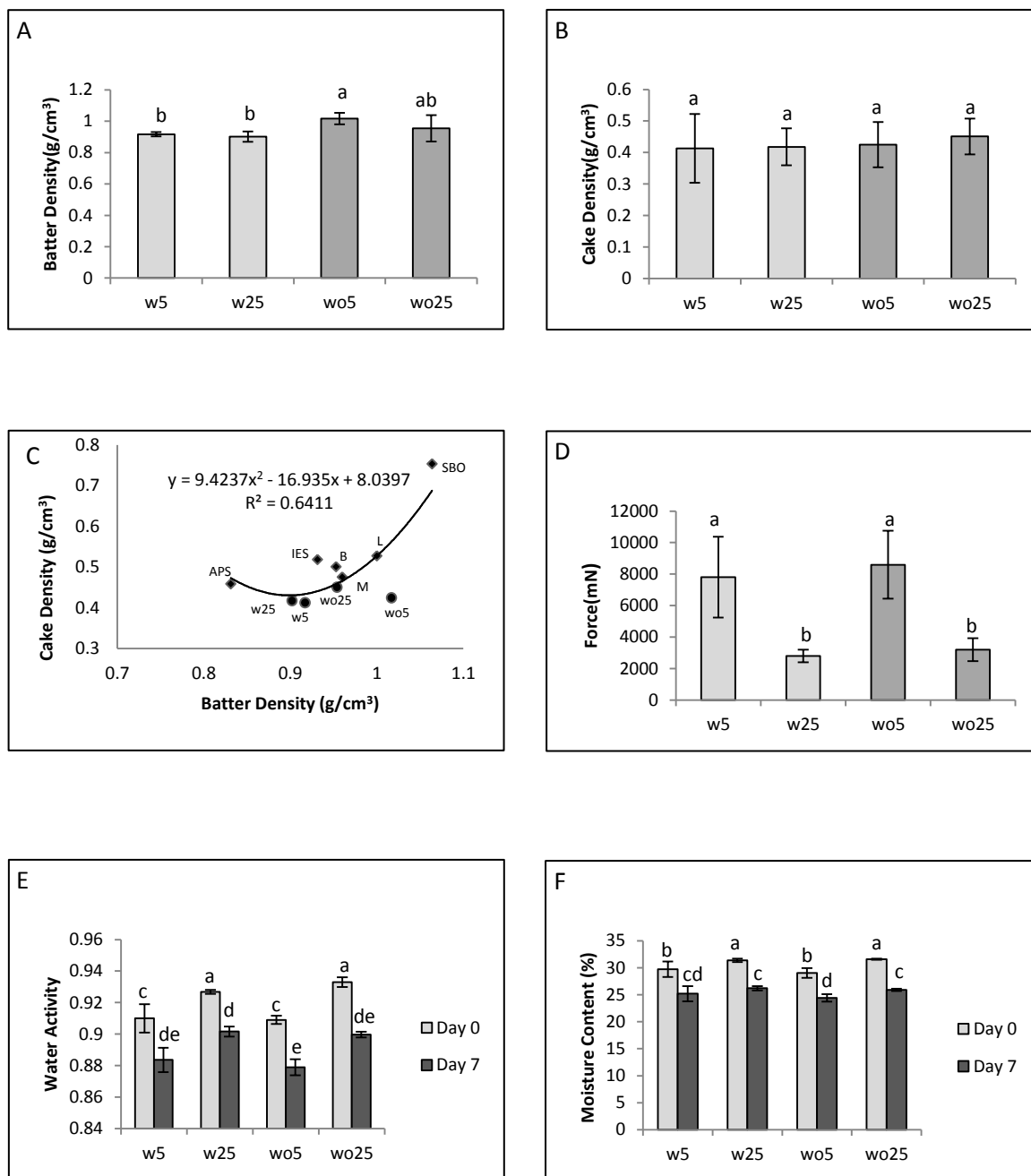
Figure 8 - Physical quality parameters and consumer acceptability of cakes formulated with US-treated IES (w) and non US treated (wo) IES tempered for 48 h at 5 and 25 °C. Physical parameters reported are: batter density (A); cake density (B); relationship between batter density and cake density (C); compression resistant force (D); water activity (E), moisture content (F).
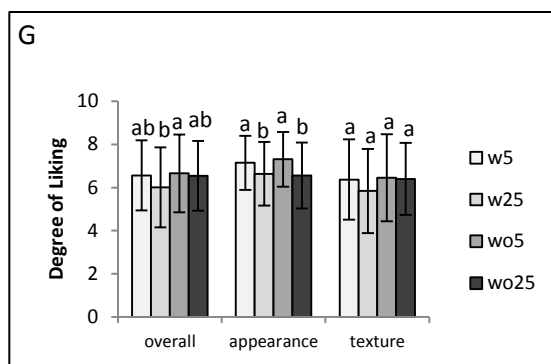
Figure 8 (cont.) - Physical quality parameters and consumer acceptability of cakes formulated with US-treated IES (w) and non US treated (wo) IES tempered for 48 h at 5 and 25 °C. Physical parameter reported is: consumer acceptance (G).

crystals, as evidenced by the ΔH values reported in Table 5. Therefore it is reasonable to speculate that these extra lipid crystals contribute to higher air adsorption and generation of smaller pores in the final cake. Hence these cakes had higher resistant force in compression test. It is therefore likely that the toughness of the final cake is related to the total amount of lipid in the shortening and not to the size of the crystals present in the lipid network. This could also explain the significantly high appearance ratings of cake made with IES stored at 5°C obtained by our sensory taste test, where fine porous cake with finer texture is considered to be most desirable (Figure 8G). Additionally, it is possible that the higher lipid crystal content in IES tempered at 5°C (meaning less lipid was present in a liquid state) allowed more gluten development leading to a tougher cake.

The water activity and moisture content of fresh cake and cake stored for one week (Figure 8E, 8F) were not affected by the type of IES used in terms of sonication. However, for each sonication condition (US-treated and non US-treated) water activity and moisture content of fresh cake made with IES tempered at 5 °C is significantly lower ($p = 0.05$) than fresh cake made with IES tempered at 25 °C. This might be due to the

more porous and finer texture of cake made with the IES tempered at 5°C, allowing

moisture to transfer into environment. This could also be influenced by the amount of

gluten formed, as water is effectively removed from the batter matrix during gluten

development.

Consumer taste tests were conducted separately for each storage temperature (5°C

and 25°C). Since each consumer panel generally represents opinions of the whole

population, it is reasonable to compare the results for all four lipids (w5, w25, wo5,

wo25). In the overall rating of our sensory taste test, cake made with US-treated IES and

non US-treated IES had similar ratings at both 5°C and 25°C storage condition ($p > 0.05$,

Figure 8F). Similar ratings were found from appearance (Appendix F). However, for

appearance rating, within each sonication treatment, cakes formulated with IES tempered

Table 6 - Demographic information of consumer panelists participated in cake taste tests

Gender		
	5°C	25°C
Male	51.3	47.5
Female	48.7	52.5
Age (%)		
	5°C	25°C
18-25	64.7	41.7
26-35	26.9	25.0
36-45	1.70	11.7
45-55	4.20	7.50
>56	2.52	14.2
Frequency of consumption (%)		
	5 °C	25 °C
Never	0.00	0.00
Less than once a month	38.7	42.5
At least once a month	54.6	49.2
At least once a week	6.72	8.30
About once a day	0.00	0.00
More than once a day	0.00	0.00

at 25°C were significantly less liked than cakes formulated with IES tempered at 5°C. This might be due to the higher air incorporation in cake made with 5 °C IES, which resulted in better mouthfeel in cake. In the texture rating, no significant differences were found between all cakes (Figure 8F).

The demographic information of each consumer panel is presented in Table 6. Generally, more males participated in our cake taste test. Since these taste tests were held in a college environment, 18 – 25 age group has the most percentage, 64.7% and 41.7% for 5°C and 25°C, respectively, taste test. All the participants were regular consumers of cake and indicated that they consumed cake less than once a month, at least once a month, or at least once a week, but under once a day.

Quality characteristics of cookies: In cookies formulated with IES stored at 5°C, no significant differences were found in dough density between US-treated IES and non US-treated IES (Figure 9A). However, cookie dough made with non US-treated IES stored at 25°C was significantly denser ($p < 0.05$) than the one formulated with US-treated IES stored at 25°C (Figure 9A). Similar to what was happening during cake batter preparation, the size of solid crystals in US treated IES contributes to air incorporation in cookie dough. Therefore, under 25°C storage condition, US treatment made smaller crystal sizes in IES, which resulted in better air incorporation and significantly lower dough density.

Cookies made with US-treated IES resulted in significantly higher height and lower spread ($p < 0.05$; Figure 9B, 9C; Appendix F) compared to the cookies formulated with the non US-treated IES for both storage temperatures. The degree of spread resulting in final cookie diameter is controlled by the spread rate and set time (Pareyt and Delcour

2008). Set time is determined by the level of free water in dough that can act as solvent

and the strength of the dough (Ram and Singh 2004). In our research, the only variable is

the lipid that is used. Therefore, the spread degree is largely determined by the spread

rate. The fluid character of non US-treated IES contributed to a higher spread rate and

therefore significantly larger spread. In turn, with a larger spread, lower cookie heights

resulted. Fresh cookies made with non US-treated IES had higher moisture content for

both storage conditions ($5°C$ and $25°C$, Figure 9E). In general, after one week storage, no

significant differences were found between cookies made with US-treated and non US-

treated IES, which might indicate the migration of moisture reached equilibrium

eventually. A similar situation was found in the water activity values of the cookies: fresh

cookies made with non US-treated IES had higher water activity in both tempering

conditions. However, after one week storage, significant differences remained in cookies

made with non US-treated IES stored at $5°C$; while no significant difference was found

between cookies made with US-treated IES and non US-treated IES stored at $25°C$

(Figure 9F).

When the cookies were tested for consumer acceptance, no significant differences

were found between US-treated and non US-treated IES in each storage condition ($5°C$

and $25°C$, Figure 9F). However, cookies made with $25°C$ IES were rated significantly

higher than cookies made with $5°C$ IES in overall and texture. Since $25°C$ IES has

significantly lower amount of solid crystals (significantly lower enthalpy), it is possible

that this more fluid-like characteristic breaks the continuity of gluten in cookies and

contributes to a more desirable texture (softer). This can also be confirmed by the
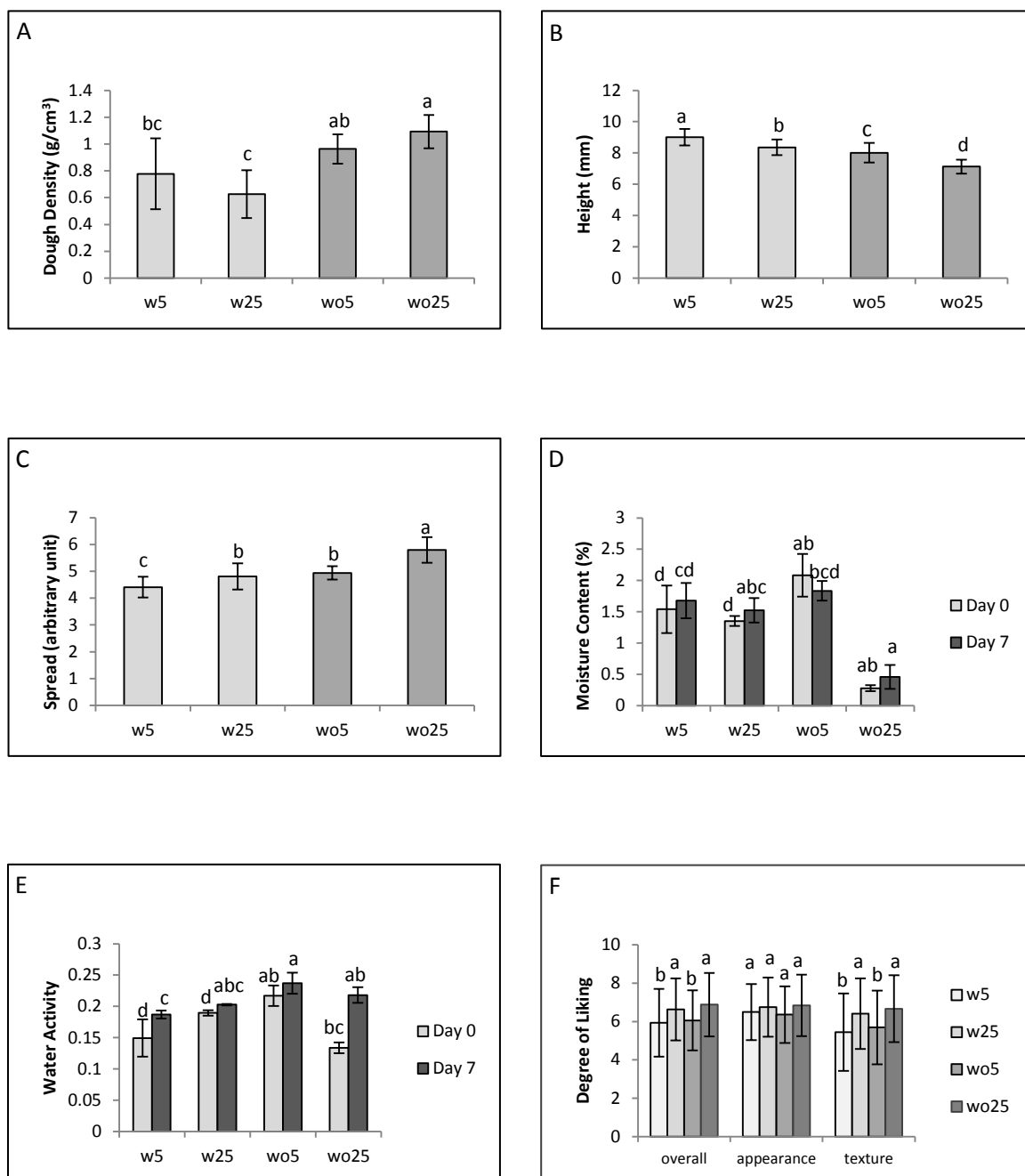
Figure 9 - Physical quality parameters and consumer acceptability of cookies formulated with US-treated IES (w) and non US treated (wo) IES tempered for 48 h at 5 and 25 °C. Physical parameters reported are: cookie dough density (A); cookie height (B); cookie spread (C); moisture content (D); water activity (E); and consumer acceptance (F).

Table 7 - Demographic information of consumer panelists participated in cookie taste tests.

Gender		
	5 °C	25 °C
Male	58.3	47.5
Female	41.7	52.5
Age (%)		
	5 °C	25 °C
18-25	65.8	62.5
26-35	26.6	14.2
36-45	3.33	9.17
45-55	2.50	7.50
>56	1.67	6.67
Frequency of consumption (%)		
	5 °C	25 °C
Never	0.83	0.83
Less than once a month	7.50	7.50
At least once a month	35.0	37.5
At least once a week	53.3	41.7
About once a day	2.50	10.8
More than once a day	0.83	1.67

fracturability test: cookies made with non-US treated IES could not be measured due to their hard texture (the load cell for the texture analyzer was overloaded).

The demographic information of the participants in the sensory taste test is shown in Table 7. Consumers that participated in the cookies test were almost equally distributed between male and females with values of 58.3% and 47.5% for 5°C and 25°C respectively. Young people (18 − 25 years old) still dominated the taste test since it was held on campus. All participants were consumers of cookies.

Quality characteristics of pie crust: Pie crusts made with US-treated IES had significantly higher heights than non-US treated IES at both 5°C and 25°C storage condition (Figure 10A; Appendix F). As previously discussed in Chapter III, crust height is a balance between steam expansion and gluten formation. The role of lipids in pie crust

formulation is to prevent excessive gluten development and create pockets in dough (Stauffer 1998). During the first step of crust preparation, when lipid and flour are kneaded together, portions of the lipid are present as distinct pieces embedded in the dough, creating nuclei for steam accumulation and expansion. Depending on the amount of gluten developed when water is added, pie crust ends up being different heights. Even though the total portion of lipid crystals is similar for each storage condition (Table 5), it is possible that the more liquid like status of non US-treated IES resulted in fewer distinct pieces within the pie dough. This leads to fewer nuclei in the dough and lower heights in the final pie crust. For US-treated IES, pie crust had significantly higher height when formulated with IES stored at 25°C than when formulated with IES stored at 5°C (Figure 10A). This might indicate that with US treatment, the more solid character of IES stored at 5°C allows more flour-water interaction, which leads to more gluten development. This excessive gluten development suppresses steam expansion. Therefore even with the same US treatment, IES stored at 5°C resulted in pie crusts with significantly lower heights than those produced with IES stored at 25°C.

Interestingly, the breaking strength of pie crust made with non US-treated IES stored at 5°C was significantly higher (p < 0.05) than those formulated with the US-treated IES stored at 5 °C (Figure 10B). No significant differences were found in the breaking strength of the pie crusts formulated with the IES stored at 25°C. The relationship between crust height and breaking strength is shown in Figure 10C. With a significant difference in breaking strength under 5°C (non-US treated IES had higher breaking strength than US treated IES), pie crusts made with IES tempered at 5°C (both treatments) fall into the same category – "flaky." This might indicate that under the 5°C
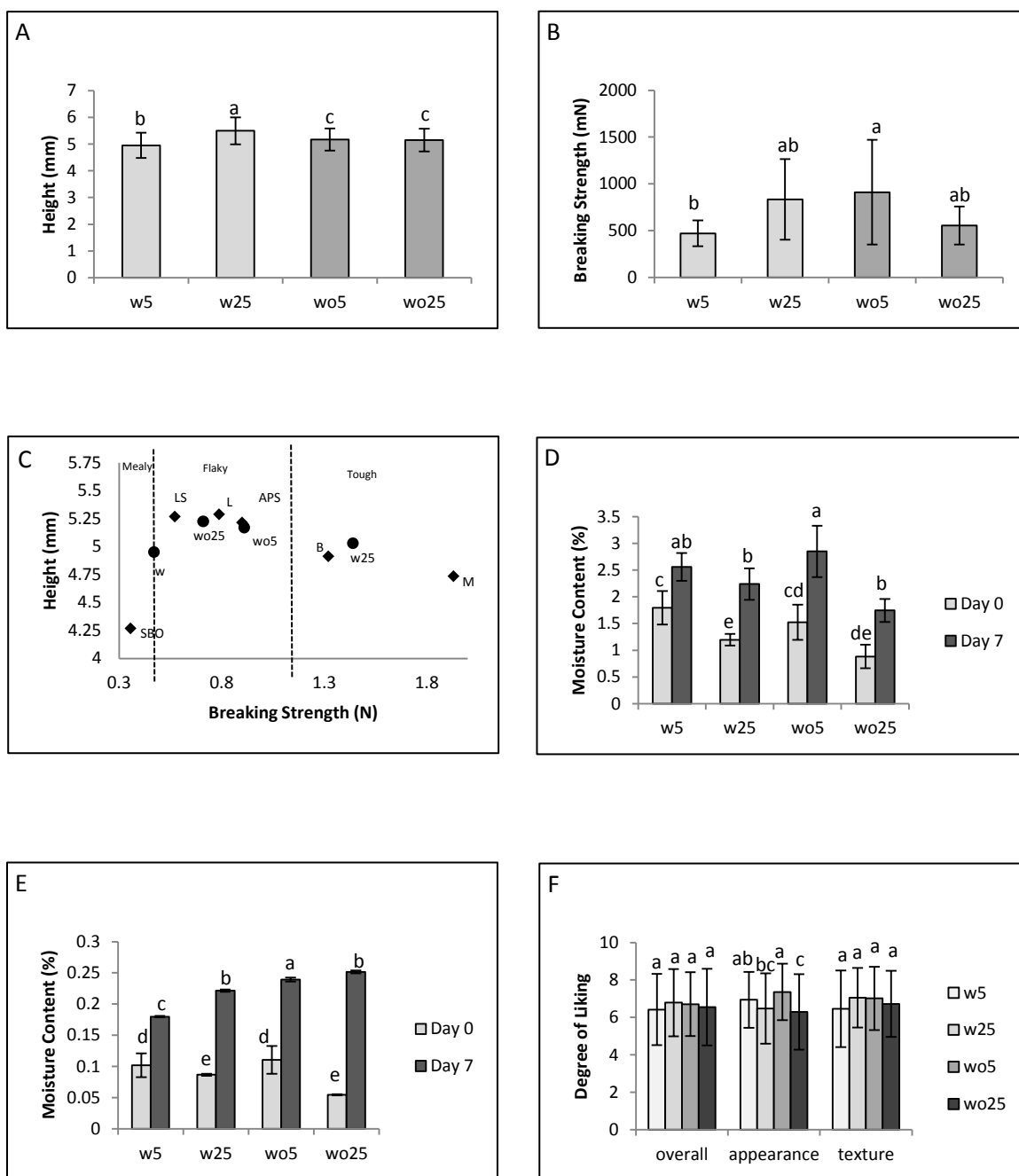
Figure 10 - Physical quality parameters and consumer acceptability of pie crust formulated with US-treated IES (w) and non US treated (wo) IES tempered for 48 h at 5 and 25°C. Physical parameters reported are: pie crust height (A); breaking strength (B); height vs. breaking strength (C); moisture content (D); water activity (E) and consumer acceptance (F).

storage condition, sonication treatment on IES does not make a difference in the quality

of final products. However, with sonication treatment, IES tempered at 25°C made pie

crusts that fall into "flaky" category, while non-US treated IES pie crusts fall into "tough"

category. This might be due to the more solid character seen in the US treated IES,

allowing larger chunks of solid lipid to remain in the dough, which serve as nuclei for

steam to expand, resulting in a flaky pie crust.

Moisture content and water activity of pie crust increased significantly after one

week storage for both the 5°C and 25°C storage temperatures (US-treated and non US-

treated IES; Figures 10D and E). This might be due to the low moisture content in pie

crust, which has a tendency to absorb moisture from environment to reach equilibrium.

No significant differences (p > 0.05) were found in overall and texture ratings by

consumers (Figure 10E). In appearance rating, no significant differences were found

between US-treated and non US-treated IES for each storage condition. However, pie

crusts made with non US-treated IES stored at 5°C had a significantly higher rating than

pie crust made with the IES sample stored at 25°C in appearance (Figure 10F). This

might be due to the larger crystal portion of US-treated IES stored at 5°C that contributed

to more gluten development, flakier texture, and lower height. Pie crusts formulated with

non US-treated IES stored at 25°C were the least liked in terms of appearance. The

demographic information is summarized in Table 8. Approximately the same amount of

male participated in both of our taste test (5°C and 25°C; 55.8% and 55.8% respectively).

Since both taste tests were conducted on a university campus, the 18-25 age grouphad the

largest percentage (65.83% and 37.5% for 5°C and 25°C, respectively). About 1.67% and

1.7% reported that they had never consumed pie before (5°C and 25°C taste tests,

Table 8 - Demographic information of consumer panelists participated in pie crust taste tests

Gender		
	5 °C	25 °C
Male	55.8	55.8
Female	44.2	44.2
Age (%)		
	5 °C	25 °C
18-25	65.8	37.5
26-35	20.8	28.3
36-45	3.33	10.8
45-55	4.17	9.20
>56	5.83	14.2
Frequency of consumption (%)		
	5 °C	25 °C
Never	1.67	1.70
Less than once a month	60.8	72.5
At least once a month	36.7	22.5
At least once a week	0.83	3.30
About once a day	0.00	0.00
More than once a day	0.00	0.00

respectively). Most people reported to consume pie less than once a month (60.83% and 72.5% for 5°C and 25°C, respectively).

Conclusion

US treatment and storage temperature affects the physical qualities of IES. US treatment generates smaller crystals while lower storage temperature (5°C) retains larger amount of solid crystals. Being affected by the combination of these two conditions, different physical qualities of the final baked products are obtained.

For IES tempered at 5°C, the smaller lipid crystals in US-treated IES were able to incorporate more air bubbles; therefore its cake batter had significantly lower density than cake batter made with non US-treated IES. This change in cake batter was detected

by consumers in the final cake (even though no significant differences were found in the physical quality measurement): consumers like cake made with 5°C more than cake made with 25°C IES. For pie crust, with larger amount of small lipid crystals present, US-treated IES contributed to a significantly higher height in pie crust in both storage conditions (5°C and 25°C). However, when it is translated to consumers, consumers were able to detect pie crust made with non US-treated IES. They favored pie crust made with 5°C non US-treated IES more than 25°C non US-treated IES. For cookies, the large amount of lipid crystals in US-treated IES contributed to its higher height and lower spread. Consumers tended to like cookies made with 25°C IES more than cookies made with 5°C IES.

These results indicated that US application on lipid changes lipid crystal size. This change is able to be translated to baked products physical qualities (cake batter desity, pie crust height, cookie spread and height). However, from consumer's perspective, the change on lipid crystal size is not detectable. Instead, for different storage conditions (5 °C vs. 25 °C), the differences in lipid (different total lipid crystal amount) is more detectable in baked products.

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CHAPTER V

SUMMARY AND FUTURE RESEARCH

Summary

This research examined how physicochemical qualities (i.e., G', G'', ΔH, T_{on}, and T_p) of different lipids influence the physical qualities of baked products (cake, cookie, and pie crust).

In cake, a lipid with a plastic character is preferred to make a fluffy cake batter. In this research, T_{on} can be used as one of the criteria to choose the right lipid when baking cakes. With a T_{on} value of 35°C, the lipid can successfully retain air bubbles in cake, producing a desirable fine and tender cake texture. For cookies, melting point and ΔH are critical to determine the availability of lipids' lubrication effect, which in turn influences cookies' set time (spread and height). For pie crust production, to produce a flaky crust, a lipid with both liquid and solid portions is needed. With a higher melting temperature, the solid portion of the lipid will remain as pockets in dough (where stream can accumulate and expand during baking), while the liquid portion prevents excessive gluten development.

US treatment in IES generates smaller lipid crystals. Under the same tempering temperature, these changes in microstructure was not translated well enough to the final baked products to be detectable by consumers. However, due to the difference in the total amount of lipid crystals (resulting from the different tempering temperatures), consumers were able to detect the differences in the final baked products made from lipid with the same sonication condition but different tempering temperatures.

By understanding how physicochemical qualities, storage temperature of, and sonication condition on shortenings affect physical qualities of final baked products, it might be possible to incorporate the knowledge into tailoring the characteristics of shortenings to meet producers' needs. With the desirable microstructure in IES created by US treatment, US can be considered as an alternative for food producers to produce trans-free food products.

Future Research

Possible future research would be to continue using US in different lipid samples, such as palm oil and palm kernel oil, and use the model from this research to evaluate the effect of US on these lipid samples. Also sensory descriptive testing of the baked products could be performed to evaluate the attributes of these baked products, which would help us have a better understanding of these slight changes in physical characteristics in these products caused by the type of lipid used.

APPENDICES

Appendix A: Affective Panel SIMS Instructions and Questionnaire

Questionnaire Code.......: CAKE7/9

Questionnaire Description: Consumer Hedonic on Cake (HIU vs. without HIU)

Questionnaire Type.......: Affective

Notes: THIS IS THE CONSUMER TASTE TEST FOR SUMMER 2012.

Page Number: 1

   Attribute Sequence Number: 1

      Attribute Type...........: MultiMedia

      Seen With Relative Sample: 1

      Question/Instruction:

      Multimedia Type: Picture

          C:\Program Files (x86)\SIMS2000\WELCOMESCREEN.JPG

   Attribute Sequence Number: 2

      Attribute Type...........: Page Break

      Seen With Relative Sample: 1

Page Number: 2

   Attribute Sequence Number: 3

      Attribute Type...........: Instruction Box

      Seen With Relative Sample: 1

      Instruction:

      Please Read Carefully Before Starting.

      1.) For each sample, verify that the sample you are tasting matches the sample
number on the top left of the computer screen.

      2.) After tasting each sample, answer the

      questions and leave a comment. You may do this by clicking in the comments box
and typing in your comments using the keyboard under the desk.

      3.) Remember to rinse your mouth with water between each sample.

      4.) You will be asked to rank the samples in order of preference at the end of the
test, so remember which order you like them in!

      5.) If you have any questions, you may ask the attendant by the door or open the
window.

      6.) Please click on the hand at the top of the screen to continue.

      You are now ready to begin the test, so click the hand and begin!

   Attribute Sequence Number: 4

      Attribute Type...........: Page Break

      Seen With Relative Sample: none

Page Number: 3

Attribute Sequence Number: 5
    Attribute Type...........: Instruction Box
    Seen With Relative Sample: none

    Instruction:
    Please rate the following 3 characteristics of this sample.
    <WEBTEXTGRID;YES;30;100;Dislike
    Extremely;;Dislike
    Somewhat;;Neutral;;Like Somewhat;;Like
    Extremely>
Attribute Sequence Number: 6
    Attribute Type...........: Hedonic
    Attribute Export Label...: Appearance
    Seen With Relative Sample: none
    Question/Instruction:
    Appearance:
    Hedonic Labels on Questionnaire are, by Seen Order in Label(n):
     Label(1) = Dislike Extremely (Ret value: 1)
     Label(2) =   (Ret value: 2)
     Label(3) = Dislike Somewhat   (Ret value: 3)
     Label(4) =   (Ret value: 4)
     Label(5) = Neutral   (Ret value: 5)
     Label(6) =   (Ret value: 6)
     Label(7) = Like Somewhat   (Ret value: 7)
     Label(8) =   (Ret value: 8)
     Label(9) = Like Extremely   (Ret value: 9)
    Hedonic Type: Horizontal
Attribute Sequence Number: 7
    Attribute Type...........: Hedonic
    Attribute Export Label...: Texture
    Seen With Relative Sample: none
    Question/Instruction:
    Texture:
    Hedonic Labels on Questionnaire are, by Seen Order in Label(n):
     Label(1) = Dislike Extremely (Ret value: 1)
     Label(2) =   (Ret value: 2)
     Label(3) = Dislike Somewhat   (Ret value: 3)
     Label(4) =   (Ret value: 4)
     Label(5) = Neutral   (Ret value: 5)
     Label(6) =   (Ret value: 6)

Label(7) = Like Somewhat   (Ret value: 7)
Label(8) =   (Ret value: 8)
Label(9) = Like Extremely   (Ret value: 9)
Hedonic Type: Horizontal
Attribute Sequence Number: 8
Attribute Type...........: Hedonic
Attribute Export Label...: Overall
Seen With Relative Sample: none
Question/Instruction:
Overall:
Hedonic Labels on Questionnaire are, by Seen Order in Label(n):
  Label(1) = Dislike Extremely (Ret value: 1)
  Label(2) =   (Ret value: 2)
  Label(3) = Dislike Somewhat   (Ret value: 3)
  Label(4) =   (Ret value: 4)
  Label(5) = Neutral   (Ret value: 5)
  Label(6) =   (Ret value: 6)
  Label(7) = Like Somewhat   (Ret value: 7)
  Label(8) =   (Ret value: 8)
  Label(9) = Like Extremely   (Ret value: 9)
Hedonic Type: Horizontal
Attribute Sequence Number: 9
Attribute Type...........: Comment
Attribute Export Label...: Comments
Seen With Relative Sample: none
Comment Type: Required
Question/Instruction:
Please comment briefly on the characteristics of this sample (i.e. appearance,
texture and overall):
Attribute Sequence Number: 10
Attribute Type...........: Ranking
Attribute Export Label...: Ranking of samples
Seen With Relative Sample: Last Sample
Question/Instruction:
Please rank the samples in order of
preference (1=most liked).
Rank Type: Sample Preference Rank, all of the samples presented.
Attribute Sequence Number: 11
Attribute Type...........: Page Break
Seen With Relative Sample: Last Sample

Page Number: 4
   Attribute Sequence Number: 12
      Attribute Type...........: Instruction Box
      Seen With Relative Sample: Last Sample
      Instruction:
      Please take a moment to answer a few questions about yourself.
   Attribute Sequence Number: 13
      Attribute Type...........: Hedonic
      Attribute Export Label...: Gender
      Seen With Relative Sample: Last Sample
      Question/Instruction:
      What is your GENDER?
      Hedonic Labels on Questionnaire are, by Seen Order in Label(n):
       Label(1) = Male   (Ret value: 1)
       Label(2) = Female (Ret value: 2)
      Hedonic Type: Horizontal
   Attribute Sequence Number: 14
      Attribute Type...........: Hedonic
      Attribute Export Label...: Age
      Seen With Relative Sample: Last Sample
      Question/Instruction:
      What is your AGE?
      Hedonic Labels on Questionnaire are, by Seen Order in Label(n):
       Label(1) = 18-25 (Ret value: 1)
       Label(2) = 26-35 (Ret value: 2)
       Label(3) = 36-45 (Ret value: 3)
       Label(4) = 46-55 (Ret value: 4)
       Label(5) = >56   (Ret value: 5)
      Hedonic Type: Horizontal
   Attribute Sequence Number: 15
      Attribute Type...........: Hedonic
      Attribute Export Label...: Frequency of consumption
      Seen With Relative Sample: Last Sample
      Question/Instruction:
      How often do you eat cakes?
      Hedonic Labels on Questionnaire are, by Seen Order in Label(n):
       Label(1) = Never   (Ret value: 1)
       Label(2) = Less than once a month (Ret value: 2)
       Label(3) = At least once a month   (Ret value: 3)

          Label(4) = At least once a week   (Ret value: 4)
          Label(5) = About once a day   (Ret value: 5)
          Label(6) = More than once a day   (Ret value: 6)
        Hedonic Type: Horizontal
     Attribute Sequence Number: 16
        Attribute Type............: Page Break
        Seen With Relative Sample: Last Sample

Page Number: 5
     Attribute Sequence Number: 17
        Attribute Type...........: Instruction Box
        Seen With Relative Sample: Last Sample
        Instruction:
        Thank You for Participating in our Taste Test!
        Open the window and push the tray through.
        Don`t forget to pick up your complimentary Aggie Ice Cream Coupon as you exit.
        Look forward to seeing you in our future
        Taste Tests!
        PLEASE CLICK END TO FINISH.

Appendix B: Randomized Sampling Plan for Affective Panels

ROTATION PLAN: BY SAMPLE SET				
Experimental Definition: CAKE7/9				
Rep: 1				
Sample Set	PanelistID	Panelist Name	Sample Order (Sample#/Sample Code)	
1	0000000001	Resp # 1	1-762	2-862
2	0000000002	Resp # 2	2-648	1-837
3	0000000003	Resp # 3	2-431	1-643
4	0000000004	Resp # 4	1-248	2-694
5	0000000005	Resp # 5	1-419	2-792
6	0000000006	Resp # 6	2-239	1-532
7	0000000007	Resp # 7	2-382	1-153
8	0000000008	Resp # 8	1-257	2-791
9	0000000009	Resp # 9	2-485	1-732
10	0000000010	Resp # 10	1-864	2-692
11	0000000011	Resp # 11	1-397	2-832
12	0000000012	Resp # 12	2-297	1-534
13	0000000013	Resp # 13	1-381	2-895
14	0000000014	Resp # 14	1-468	2-168
15	0000000015	Resp # 15	2-631	1-123
16	0000000016	Resp # 16	2-512	1-781
17	0000000017	Resp # 17	2-149	1-256
18	0000000018	Resp # 18	1-821	2-361
19	0000000019	Resp # 19	2-518	1-164
20	0000000020	Resp # 20	2-654	1-396
21	0000000021	Resp # 21	2-137	1-716
22	0000000022	Resp # 22	1-462	2-581
23	0000000023	Resp # 23	1-321	2-142
24	0000000024	Resp # 24	1-497	2-796
25	0000000025	Resp # 25	2-329	1-975
26	0000000026	Resp # 26	2-645	1-514
27	0000000027	Resp # 27	1-358	2-524
28	0000000028	Resp # 28	1-251	2-794
29	0000000029	Resp # 29	2-465	1-857
30	0000000030	Resp # 30	2-634	1-184

31	0000000031	Resp # 31	1-375	2-529
32	0000000032	Resp # 32	2-394	1-987
33	0000000033	Resp # 33	2-956	1-782
34	0000000034	Resp # 34	1-357	2-285
35	0000000035	Resp # 35	1-621	2-362
36	0000000036	Resp # 36	1-364	2-159
37	0000000037	Resp # 37	1-836	2-391
38	0000000038	Resp # 38	2-853	1-412
39	0000000039	Resp # 39	2-675	1-125
40	0000000040	Resp # 40	2-765	1-437
41	0000000041	Resp # 41	1-217	2-843
42	0000000042	Resp # 42	1-563	2-783
43	0000000043	Resp # 43	2-317	1-179
44	0000000044	Resp # 44	2-489	1-682
45	0000000045	Resp # 45	2-278	1-365
46	0000000046	Resp # 46	1-254	2-356
47	0000000047	Resp # 47	2-463	1-182
48	0000000048	Resp # 48	1-492	2-615
49	0000000049	Resp # 49	2-582	1-758
50	0000000050	Resp # 50	1-459	2-635
51	0000000051	Resp # 51	2-596	1-973
52	0000000052	Resp # 52	1-289	2-461
53	0000000053	Resp # 53	2-856	1-318
54	0000000054	Resp # 54	1-486	2-156
55	0000000055	Resp # 55	1-597	2-914
56	0000000056	Resp # 56	1-957	2-436
57	0000000057	Resp # 57	2-572	1-493
58	0000000058	Resp # 58	2-641	1-813
59	0000000059	Resp # 59	1-542	2-851
60	0000000060	Resp # 60	2-189	1-852
61	0000000061	Resp # 61	2-854	1-592
62	0000000062	Resp # 62	1-387	2-965
63	0000000063	Resp # 63	1-751	2-589
64	0000000064	Resp # 64	2-214	1-931
65	0000000065	Resp # 65	1-491	2-798
66	0000000066	Resp # 66	1-237	2-453
67	0000000067	Resp # 67	1-723	2-279
68	0000000068	Resp # 68	1-398	2-487
69	0000000069	Resp # 69	2-872	1-478
70	0000000070	Resp # 70	2-258	1-893

71	0000000071	Resp # 71	2-195	1-673
72	0000000072	Resp # 72	1-831	2-754
73	0000000073	Resp # 73	2-653	1-537
74	0000000074	Resp # 74	1-925	2-763
75	0000000075	Resp # 75	1-247	2-674
76	0000000076	Resp # 76	1-481	2-719
77	0000000077	Resp # 77	2-432	1-218
78	0000000078	Resp # 78	1-736	2-579
79	0000000079	Resp # 79	2-427	1-671
80	0000000080	Resp # 80	1-174	2-912
81	0000000081	Resp # 81	1-784	2-298
82	0000000082	Resp # 82	2-378	1-236
83	0000000083	Resp # 83	2-475	1-786
84	0000000084	Resp # 84	1-265	2-672
85	0000000085	Resp # 85	1-568	2-946
86	0000000086	Resp # 86	2-625	1-417
87	0000000087	Resp # 87	2-386	1-526
88	0000000088	Resp # 88	2-745	1-376
89	0000000089	Resp # 89	2-165	1-921
90	0000000090	Resp # 90	1-157	2-243
91	0000000091	Resp # 91	2-426	1-748
92	0000000092	Resp # 92	1-951	2-897
93	0000000093	Resp # 93	1-649	2-213
94	0000000094	Resp # 94	1-527	2-728
95	0000000095	Resp # 95	2-941	1-498
96	0000000096	Resp # 96	1-947	2-276
97	0000000097	Resp # 97	1-612	2-598
98	0000000098	Resp # 98	1-421	2-817
99	0000000099	Resp # 99	1-241	2-746
100	0000000100	Resp # 100	2-413	1-943
101	0000000101	Resp # 101	2-549	1-687
102	0000000102	Resp # 102	1-962	2-194
103	0000000103	Resp # 103	2-927	1-749
104	0000000104	Resp # 104	1-456	2-384
105	0000000105	Resp # 105	2-235	1-345
106	0000000106	Resp # 106	1-284	2-183
107	0000000107	Resp # 107	2-632	1-847
108	0000000108	Resp # 108	1-954	2-483
109	0000000109	Resp # 109	1-642	2-267
110	0000000110	Resp # 110	2-845	1-271

111	0000000111	Resp # 111	1-743	2-539
112	0000000112	Resp # 112	1-316	2-726
113	0000000113	Resp # 113	2-892	1-739
114	0000000114	Resp # 114	2-548	1-263
115	0000000115	Resp # 115	2-712	1-647
116	0000000116	Resp # 116	2-685	1-451
117	0000000117	Resp # 117	2-185	1-392
118	0000000118	Resp # 118	2-816	1-734
119	0000000119	Resp # 119	2-628	1-176
120	0000000120	Resp # 120	1-678	2-915

Appendix C: SAS Code for ANOVA Analysis

```
options ls=80 nodate pageno=1 formdlim='~';
goptions ftext=swiss ftitle=swissb htitle=3 htext=3 vorigin=1 in
hsize=8 in vsize=8 in device=win rotate=portrait;
run;
/* Enter data */
data compression;
input temp fat $ force @@;
datalines;
G1
5 w 1734000    5 wo 4155000
5 w 1693000    5 wo 506700
25 w 36350    25 wo 72.43
25 w 54510    25 wo 142.1
run;
proc glm data=compression;
      class fat temp;
      model force = fat|temp;
      output out = residuals p=pred r=resid;
      lsmeans fat|temp / pdiff adjust=Tukey;
      ods output lsmeans=lsmeans;
run;
proc means data=compression;
          class fat temp;
          var force;
run;
proc plot data=residuals;
plot resid*(resin pred);
run;
title1 "Summary Statistics and Plots for the Residuals";
title2 ;
proc univariate normal plots data=residuals;
var resid;
histogram resid / normal noframe;
probplot resid / noframe;
run;
/* graphical diagnostics*/
Proc glot data=compression;
Plot resid*(resin pred) / vaxis=axis1;
Symbol v=dot;
Axisl label=(angle=90);
```

```
Title1 'check heteroscedasticity';
Run;
Proc univariate data=out1 normal plots;
Var resid;
Histogram resid / normal(color=blue) cfill=yellow;
Probplot resid / normal(mu=est sigma=est color=red w=3 L=2);
Title1 'check normality';
```

Appendix D ANOVA data I

Cake

Cake batter density

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	5	0.21080866	0.04216173	20.40	<.0001
Error	39	0.08062112	0.00206721		
Corrected Total	44	0.29142978			

Cake density

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	5	0.29788025	0.05957605	4.45	0.0025
Error	41	0.54839119	0.01337539		
Corrected Total	46	0.84627145			

Cake moisture content

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	11	495.5015921	45.0455993	14.94	<.0001
Error	110	331.6233981	3.0147582		
Corrected Total	121	827.1249902			

Cake water activity

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	11	0.01158429	0.00105312	23.12	<.0001
Error	144	0.00655924	0.00004555		
Corrected Total	155	0.01814353			

Cookie

Cookie dough density

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	5	1.45367056	0.29073411	4.69	0.0015
Error	47	2.91565397	0.06203519		
Corrected Total	52	4.36932453			

Cookie height

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	5	126.2117152	25.2423430	21.00	<.0001
Error	198	237.9531436	1.2017836		
Corrected Total	203	364.1648588			

Cookie spread

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	5	67.4521972	13.4904394	11.88	<.0001
Error	237	269.2329880	1.1360042		
Corrected Total	242	336.6851852			

Cookie moisture content

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	11	52.7775837	4.7979622	16.01	<.0001
Error	210	62.9148311	0.2995944		
Corrected Total	221	115.6924149			

Cookie water activity

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	11	0.51926479	0.04720589	28.95	<.0001
Error	218	0.35546427	0.00163057		
Corrected Total	229	0.87472906			

Pie crust

Pie crust breaking strength

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	5	15.03500470	3.00700094	55.24	<.0001
Error	51	2.77595886	0.05443057		
Corrected Total	56	17.81096356			

Pie crust height

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	5	65.3005224	13.0601045	66.41	<.0001
Error	508	99.9014559	0.1966564		
Corrected Total	513	165.2019783			

Pie crust highest point

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	14	382.8224896	27.3444635	13.34	<.0001
Error	66	135.3088906	2.0501347		
Corrected Total	80	518.1313802			

Pie crust moisture content

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	11	222.2519433	20.2047221	55.85	<.0001
Error	143	51.7350654	0.3617837		
Corrected Total	154	273.9870086			

Pie crust water activity

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	11	1.45824127	0.13256739	90.64	<.0001
Error	167	0.24424138	0.00146252		
Corrected Total	178	1.70248265			

Appendix E: ANOVA data II

Cake

Cake batter density

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	3	0.05329278	0.01776426	6.32	0.0023
Error	26	0.07312099	0.00281235		
Corrected Total	29	0.12641378			

Cake density

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	3	0.05329278	0.01776426	6.32	0.0023
Error	26	0.07312099	0.00281235		
Corrected Total	29	0.12641378			

Cake compression force

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	3	699357072	233119024	55.96	<.0001
Error	118	491564961	4165805		
Corrected Total	121	1190922033			

Cake moisture content

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	7	887.8802307	126.8400330	146.76	<.0001
Error	116	100.2534298	0.8642537		
Corrected Total	123	988.1336605			

Cake water activity

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	7	0.03164145	0.00452021	72.14	<.0001
Error	120	0.00751909	0.00006266		
Corrected Total	127	0.03916054			

Cookies

Cookie dough density

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	3	1.13138889	0.37712963	11.74	<.0001
Error	32	1.02811111	0.03212847		
Corrected Total	35	2.15950000			

Cookie height

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	3	69.7204130	23.2401377	83.02	<.0001
Error	146	40.8686030	0.2799219		
Corrected Total	149	110.5890160			

Cookie moisture content

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	7	6.73614528	0.96230647	9.20	<.0001
Error	122	12.76076549	0.10459644		
Corrected Total	129	19.49691077			

Cookie spread

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	3	85.5045260	28.5015087	141.67	<.0001
Error	320	64.3774802	0.2011796		
Corrected Total	323	149.8820062			

Cookie water activity

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	7	0.13427349	0.01918193	31.45	<.0001
Error	117	0.07136971	0.00061000		
Corrected Total	124	0.20564321			

Pie crust

Pie crust breaking strength

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	3	1661493.607	553831.202	3.84	0.0161
Error	43	6209661.883	144410.741		
Corrected Total	46	7871155.489			

Pie crust height

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	3	13.44818291	4.48272764	21.78	<.0001
Error	360	74.09303028	0.20581397		
Corrected Total	363	87.54121319			

Pie crust water activity

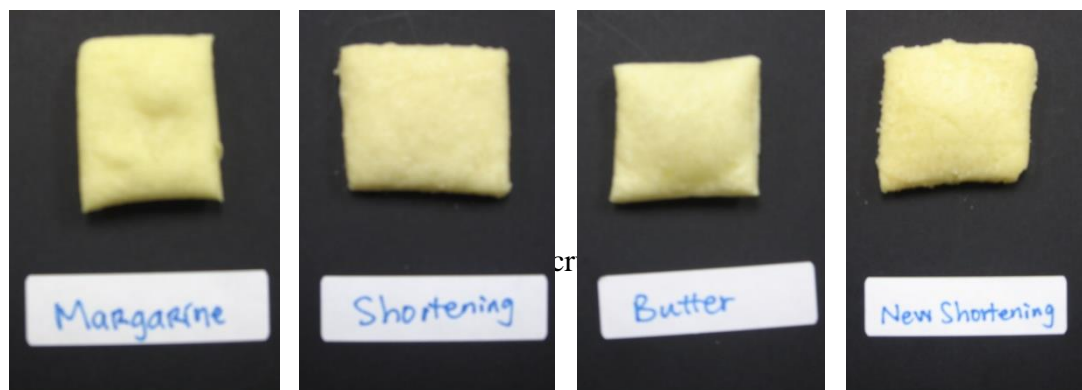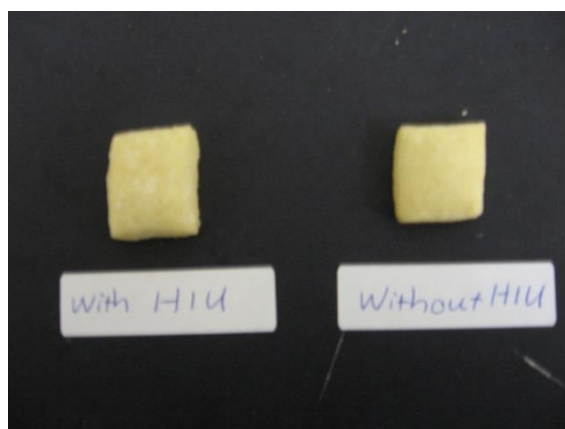| Source	DF	Squares	Mean Square	F Value	Pr > F
Model	7	0.54500645	0.07785806	252.15	<.0001
Error	120	0.03705320	0.00030878		
Corrected Total	127	0.58205965			

Appendix F: Pictures of baked products

Cake

Cookies

5 °C

25 °C

5 °C

25 °C

5 °C

25 °C