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Title: ***Rheological Properties of Low-fat Processed Cheese Spread Made with Inulin as a Fat Replacer***

The accompanying research report is submitted to the **University of Wisconsin-Stout, Graduate School** in partial completion of the requirements for the

Graduate Degree/ Major: **MS Food and Nutritional Sciences**

Research Adviser: **Karunanithy Chinnadurai, Ph.D.**

Submission Term/Year: **Fall, 2012**

Number of Pages: **53**

Style Manual Used: **American Psychological Association, 6th edition**

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Dave, Punit J. ***Rheological Properties of Low-fat Processed Cheese Spread made with Inulin as a Fat Replacer***

Abstract

Developing low-fat products with the desired textural characteristics is a prime objective of the dairy industry. Various types of fat replacers like starches, gums, and fibers, are used to achieve the desired textural characteristics in low-fat products. Many fat replacers impart some off-flavors, but inulin is a flavor-free fat replacer. It forms stable and cream-like particle gel. The use of inulin as a potential fat replacer was studied by measuring the yield stress, strain, and spreadability of low-fat processed cheese spread. Low-fat processed cheese spreads (6% fat) with three different levels (6%, 7%, and 8%) of inulin were made using a Stephan cheese cooker. The yield stress, strain, and spreadability were measured using a Brookfield roto-viscometer, and results were compared with a full-fat cheese spread (20%) control and a low-fat cheese spread (6%) control neither of which contained inulin.

The addition of inulin increased the yield stress value. Low-fat cheese spreads with 7% and 8% inulin had significantly higher yield stress values (535.76 Pa and 575.52 Pa, respectively) ($p<0.05$) than the full-fat cheese spread control. The full-fat cheese spread control had a higher strain value (1.14 Rad) ($p<0.05$) compared to other treatments. Inulin also showed a positive effect on the spreadability of the low-fat cheese spreads. Results indicated that the low-fat processed cheese spreads with 7% and 8% inulin achieved the yield stress values and spreadability similar to the full-fat processed cheese spread.

Acknowledgments

I would like to convey my deepest gratitude to my former research adviser, Dr. Hans Zoerb, for his constant guidance and help in editing the research proposal, designing the experiment, reviewing the formulation, and providing all other necessary equipment training and ingredients. I would like to express my appreciation to my committee chair, Dr. Karunanithy Chinnadurai, for reviewing my thesis and providing valuable comments and also giving needed technical guidance. I am very grateful to Dr. Carol Seaborn for serving as my committee member and her valuable inputs in my thesis. I would like to thank Dr. Bob Davies for being my committee member and reviewing my thesis. I would like to thank our past departmental chair, Dr. Carolyn Barnhart, for her help and support. I am also very thankful to Connie Galep for her support and help in purchasing the needed ingredients and instruments.

I would like to thank UW-Stout Research Services for accepting my research proposal and providing required funding to carry out my research work. I am also very thankful to UW-Stout Library for providing a wide access to various books and online articles, which was very helpful to complete my thesis.

I would like to thank the Land O' Lakes Cooperative (Arden Hills, MN) for providing cheddar cheese to conduct my research. I would also like to thank the Glanbia Nutritionals Inc. (Richfield, ID) and Main Street Ingredients (La Crosse, WI) for supplying whey protein concentrate and non-fat dry milk, respectively for my research work. Furthermore, I would like to thank Beneo Inc. (Morris Plains, NJ) for providing inulin samples for my research work. I am also thankful to B.K. Giulini Corporation (Simi Valley, CA) for providing the emulsifying salt samples.

I would like to express my best regards to my parents (Smt. Taramati Dave and Shri J. S. Dave) and family members for their moral support and blessings. I am also very fortunate that I have very supportive and helping friends, and I would like to thank them all for their valuable advice, support, and encouragement during the challenges I faced in successfully completing my thesis.

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Chapter I: Introduction

According to International Dairy Food Association (IDFA), the United States of America is one of the largest producers of cheeses in the world. In 2010, 10.4 billion pounds of various varieties of natural cheese were produced in the United States of America (IDFA, 2011). Processed cheese/processed cheese food is the second largest variety of cheese produce that is consumed in the U.S.A with 1.2 billion pounds produced in 2010 (IDFA, 2011). Although processed cheese was invented in 1911 in Switzerland by Walter Gerber, this product was further developed in 1916 in the U.S.A. by Kraft Foods (Kim, Hong, Ahn, & Kwak, 2009). The primary objective of making processed cheese and processed cheese spread is to extend the shelf life of the natural cheese at normal room temperature.

As per the Code of Federal Regulation (CRF Title 21 section 133.179), processed cheese spread should be made from one or more varieties of natural cheese that may include young or aged cheddar cheese, Swiss cheese, blue cheese, and mozzarella cheese. Processed cheese spread is produced by blending the different grated natural cheeses, most commonly aged and young cheddar cheeses, at high temperatures and shearing it with the presence of emulsifying salts.

As per the World Health Organization (WHO) (2011), cardiovascular disease (CVD) is the number one cause of death, and about 17.1 million people died due to CVD in 2004. These heart-related problems are mainly caused by obesity and the consumption of high fat (high cholesterol) foods. A study reported by WHO showed that 33.8% of the total population in the United States of America was obese in 2007-2008 (WHO, 2011). Many health organizations believe that the present level of dietary fat intake is very high. According to the United States Department of Agriculture (USDA), the level of total fat intake should be 20% to 35% of the total energy, but in actuality, the fat intake is far more than the recommended daily value (USDA, 2010).

Statement of the Problem

The production of low-fat or reduced-fat foods are become an ongoing interest of researchers and industry because of the desire to reduce dietary fat intake by a large portion of population (Zalazar et al., 2002). However, making low-fat or reduced-fat dairy food is not a very easy task. The presence of fat in dairy products plays an important role in the physical, rheological, and textural properties. In addition, fat also affects other characteristics like appearance, flavor, and mouthfeel, which affect product acceptability (Barclay, Ginic-Markovic, Cooper, & Petrovsky, 2010; Brennan & Tudorica, 2008).

Hydrocolloids are high molecular weight carbohydrate- and protein-based compounds. These compounds are frequently used in dairy and food products to perform a variety of functions like thickening, gelling, stabilizing, and water-binding (Phillips & Williams, 2000). Preliminary trials were conducted to observe the water-binding and gel-forming capacity of different hydrocolloids such as pectin, inulin, and β-glucan at the Food Science and Nutrition Department of University of Wisconsin-Stout. The results showed that inulin forms a good particle gel and gives a creamier mouthfeel without imparting any off-flavor. These preliminary results prompted the following research objectives to further test the effects of inulin.

Purpose of the Study

The primary objectives of this research were to identify the optimum level of inulin (a carbohydrate-based hydrocolloid) which could be added to a low-fat processed cheese spread and to characterize the effects of inulin on the textural properties.

Definition of Terms

The following list of terms are provided to assist the reader with the terminology encountered in this experimental study.

Emulsifying salt. The citrate, phosphate, and polyphosphate based salts, which are added during the manufacturing of processed cheese foods to bind calcium ions and release casein micelles (milk protein). These casein micelles hold the water-oil interface and prevent fat separation (Fox, 1987).

Fat replacer. Food additives used to replace all or a part of fat in a food system without significantly affecting the texture, taste, flavor, and shelf-life (Akin, 2007; Lucca, 1994).

Hydrocolloids. Protein or carbohydrate based compounds widely used in food products to perform various functions; like binding, coating, thickening, gelling, and heat stability (Akin, 2007; Lucca, 1994; Phillips & Williams, 2000).

Low-fat food. Food products having 3 grams or less fat per serving or per 50 grams of the product (CFR Title 21 section 101.62).

Processed cheese spread. Processed cheese spread is a continuous homogeneous mass, mainly produced by blending different natural cheeses, especially aged and young cheddar cheese, at a high temperature and shearing it in the presence of emulsifying salts (CFR Title 21 section 133.179).

Proximate analysis. "Perform various chemical testing on any foodstuff to know its composition. Proximate analysis gives the information about moisture, fat, protein, carbohydrates, minerals, and fiber content" (Owusu-Apenten, 2005, p. 18).

Rheology. Detailed study of the flow behavior and textural changes of any material when subjected to any external forces (Gunasekaran & Ak, 2003).

Limitation of the Study

In this study, sensory evaluations of the low-fat processed cheese spreads were not conducted. Therefore, the effect of inulin on the sensory characteristics of the low-fat cheese spreads was not studied.

Chapter II: Literature Review

In this chapter, literature relevant to production of the various cheeses such as processed cheese spread, cheddar cheese, mild cheddar cheese, and aged cheddar cheese as well as the role of non-fat dry milk, whey protein concentrate, and emulsifying salt in production of the processed cheese spread were reviewed. Hydrocolloids used in the dairy industry and the unique properties imparted by inulin were discussed. The Brookfield Vane-rheometer used in this study to test the textural properties of processed cheese spread was also discussed.

Processed Cheese Spread

The main objective of making processed cheese and processed cheese foods has been to increase the shelf life of the natural cheese. Processed cheese was first made in Switzerland about a century ago, but it was developed and commercialized by Kraft in the United States of America in 1916 (Kim et al., 2009). Processed cheese and processed cheese spreads have a variety of food applications like sliced cheese, cheese dips, sauces, and a variety of spreads. Because of its wide range of food applications, processed cheese spreads have become a popular variety of processed cheese products.

The Code of Federal Regulation (CFR) defines processed cheese spread as the standardized category of process cheese. As per the CFR (Title 21 Section 133.179) definition; processed cheese spread is the food prepared by comminuting and mixing, with the aid of heat, one or more varieties of natural cheeses or cheese ingredients, with or without one or more of the dairy ingredients, with one or more emulsifying salts, and with or without one or more of the optional ingredients into a homogeneous plastic mass that should be spreadable at 70˚F. During its preparation, processed cheese spread is heated for a minimum of 30 seconds at a minimum of

150˚F. Applying a high heat (>150˚F) treatment during its production gives the processed cheese spread a longer shelf life at room temperature.

The main ingredients of processed cheese and processed cheese spread are natural cheeses (Kapoor & Metzger, 2008). Appropriate selection of the natural cheeses is the most important factor to produce the best quality processed cheese and processed cheese spreads. Some parts of the world use a single variety of natural cheese with different degrees of aging to make processed cheese and processed cheese spreads. More often, processed cheese and processed cheese spreads are manufactured from a variety of selected natural cheeses and selection criteria depends on the desired qualities of the final products. The most commonly used selection criteria include: the type of cheese, the flavor and maturity of the cheese, the texture, and the consistency of the cheese. However, natural cheeses having microbial defects should not be used to make processed cheese because spore-forming, gas-producing, and pathogenic bacteria are particularly hazardous (Caric & Kalab, 1987).

By changing the raw materials (especially the variety and the proportion of the natural cheeses), different kinds of flavor and texture can be achieved in processed cheese spreads. This feature of the production of processed cheese spreads has led to the various food applications. According to Kapoor and Metzger (2008), the popularity of processed cheese has grown due to its numerous applications. The large number of applications utilizing processed cheese spreads has resulted from numerous studies. There are a number of studies that have been conducted with regards to improving the textural properties; examining various ingredients effects on flavor or sensory properties; improving nutritional value by reducing fat or cholesterol; incorporating fibers; and conducting spreadability trials (Brickley, Auty, Piraino, & McSweeney, 2007; Brummel & Lee, 1990; Cunha & Viotto, 2010; Daubert, Tkachuk, & Truong, 1998; Kim et al., 2009; Macků, Buňka, Pavlínek, Leciánov, & Hrabě, 2008; Swenson, Wendorff, & Lindsay, 2000).

Cheddar Cheese

Since 6000-7000 BC, cheese making has been the classic example of preserving the most important constituents of milk (i.e., fat and protein). The basic principles of preserving these milk constituents involve lactic acid production and reduction of water activity by removing water and adding salt (Lawrence & Gilles, 1987). There are more than 800 varieties of cheese produced all over the world and out of these, 400 varieties are officially recognized (Upadhyay, 2003).

According to International Dairy Foods Association (IDFA) (2011), the United States of America is one of the largest producers of cheese in the world with 10.4 billion pounds of cheese in 2010. Out of 300 varieties of cheese found on the U.S.A. market shelves, mozzarella and cheddar cheeses are the two most popular varieties of cheese consumed.

Cheddar cheese is used as a main ingredient in the production of processed cheese spread and other processed cheese foods. Therefore, the quality of cheddar cheese directly affects the final quality of the processed cheese spread. As per Fox (1987), cheese making basically consists of expelling moisture from the rennet coagulum and increasing the required acidity in a given amount of time. The traditional cheddar cheese manufacturing process is described in Appendix A. Cheddar cheese making is a very lengthy process because it involves a long ripening period to develop the required flavor maturity and texture.

The general formulation for making processed cheese spread is 70-75% of mild cheddar cheese and 25-30% of aged cheddar cheese (Brummel & Lee, 1990; Kapoor & Metzger, 2008).

Changing the proportion of mild and aged cheddar cheese significantly affects the flavor and textural properties of the processed cheese spread (Caric & Kalab, 1987).

Mild Cheddar Cheese

Mild cheddar contributes more than 50% of the total cheddar cheese sales in the United States of America. The Code of Federal Regulation (CFR) has not set any legal standards for the ripening period or textural and flavor profile to label any cheddar cheese as mild, medium, sharp, or extra sharp (Drake, Gerard, & Drake, 2008). In general, mild cheddar cheese is not ripened after the salting and pressing step. Therefore, mild cheddar cheese contains more moisture, a firmer texture, and a poorer flavor profile (Caric & Kalab, 1987).

The reasons for using a greater amount of mild cheddar cheese in the formulation of processed cheese spread are reduction of the cost of ingredients, a firmer body, and production of a uniform and stable emulsion with a higher water-holding capacity than the spread with greater amount of aged cheddar cheese. However, there are certain disadvantages of utilizing only mild cheddar cheese. Mild cheddar cheese might contribute an odd flavor, exhibit excessive swelling, form air bubbles, and may become hard during storage. To overcome these problems, a small proportion of aged cheddar cheese is added to the mild cheddar cheese (Caric & Kalab, 1987).

Aged Cheddar Cheese

Cheddar cheese with more than six months of aging is generally considered an "aged/ripened" cheese. Remarkable changes in flavor and texture have been observed during the aging of the cheese. Cheese ripening is a controlled and slow decomposition of rennet coagulum by various proteolytic and lipolytic enzymes produced by a starter culture over a period of time (Lawrence & Gilles, 1987). Many researchers have reported that the intensity of aged flavor, described as "sulfur," "brothy," and "nutty," developed as the cheese aged (Whetstine et al., 2007; Drake, Yates, Gerard, & Barbano, 2008). Lawrence and Gilles (1987) reported that cheddar cheeses became harder and less elastic over time. This is due to the binding of free water by the cleaved ionic group of the polypeptide chains (protein) during proteolysis.

Addition of aged cheddar cheese in the preparation of processed cheese spread shows a helpful effect in the development of a cheesy flavor, good flow ability, and a high melting index. However, a very high content of aged cheese might give a very sharp flavor, a low stability of the emulsion, and a soft body (Caric & Kalab, 1987).

Whey Protein Concentrate

Whey is a clear, green-tinted, liquid by-product produced during the manufacturing of cheese or casein. Whey proteins are rich sources of functional and nutritious proteins. Some products made by the processing of liquid whey include: whey protein fractions, whey protein concentrate, whey protein isolate, lactose, and lactalbumin (Evans, Zulewska, Newbold, Drake, & Barbano, 2009). Many researchers (Abd El-Salam, El-Shibiny, & Salem, 2009; Resch & Daubert, 2002) have investigated the incorporation of whey protein concentrate in production of soft cheese and low-fat cheese to maximize the yield and improve the texture and flavor. In the production of the soft and reduced-fat cheeses, incorporation of whey proteins shows positive results in terms of replacing fat and increasing water-binding ability (Jooyandeh, 2009).

Non-fat Dry Milk

Non-fat dry milk powder is produced by spray drying skim milk to increase the shelf life (Sert, Yilmaz, Karakaya, & Bayrak, 2009). The solubility of milk powder depends on various factors like the composition of the milk powder, the temperature during the drying process, and the temperature of water used to hydrate the milk powder. It has been reported that low heat-treated powder is more soluble than high-heat powder (Baldwin & Truong, 2007). Addition of non-fat milk powder to different dairy products gives a more viscous and stable body (Khan & Abrahem, 2010). Caric and Kalab (1987) also reported that skim milk powder improves the spreadability and uniformity of processed cheese products.

Hydrocolloids

The growth of food ingredients over the past decade has been quite noticeable. There are thousands of companies involved in the production of healthy foods with a desirable texture, flavor, shape, appearance, and taste to satisfy the millions of consumers. The platform of this revolution in food innovation and fabrication are the hydrocolloids. The name “hydrocolloids” refers to a range of polysaccharides and protein-based compounds that are widely applied in various food industries to perform a number of tasks (Phillips & Williams, 2000). In general, hydrocolloids have various chemical and physical properties including: thickening, gelling, emulsion stabilization, heat stability, salt tolerance, binding, coating, and suspension ability.

The food industry has seen a large increase in using these materials in recent years. The global hydrocolloid market is growing at 2.8% per annum (Phillips, 2007). The forecasted value of hydrocolloid consumption is $3.9 billion for 2012 (Phillips, 2007). Although the hydrocolloids are often present only in very small (< 1%) concentrations, the additions have significant influence on the textural and organoleptic properties (Phillips & Williams, 2000). The changing lifestyle and increasing awareness about the relationship between diet and health have been linked to the remarkable rise in the consumption of ready-to-eat foods, novelty foods, reduced or low-fat foods, and fiber-rich foods (Brummel & Lee, 1990; Phillips & Williams, 2000). Various hydrocolloids were developed, specifically, to be fat replacers in food (Lucca & Tepper, 1994). Selection of hydrocolloids depends on the characteristics desired in the final product. Table 1 lists known hydrocolloids, which have different functions including gelling, thickening, and emulsifying.

Table 1. Principal Functions of Various hydrocolloids

Hydrocolloid	Principal function
Agar	Gelling agent
Alginate	Gelling agent
Carrageenan	Gelling agent
Carboxymethyl cellulose	Thickener
Hydroxymethyl cellulose	Thickener and emulsifier
Methyl cellulose	Thickener, emulsifier, and gelling agent
Microcrystalline cellulose	Thickener and gelling agent
Gelatin	Gelling agent
Guar gum	Thickener
Karaya	Thickener
Locust bean gum	Thickener
Pectin	Gelling agent
Inulin	Gelling agent
Propylene glycol alginate	Emulsifier and foam stabilizer
Starch	Thickener and gelling agent
Tragacanth	Thickener
Xanthan gum	Thickener

There is a growing belief that foods with lower fat and enhanced dietary fiber contents are an essential part of a healthy lifestyle. Dietary fiber is generally defined as the portion of the plant cell walls that are not digestible by human digestive enzymes; this includes all non-starch polysaccharides and lignin. More recently, oligosaccharides, such as inulin and resistant starches were also included in this category (Anderson et al., 2009; Phillips & Williams, 2000). Increasing fiber consumption reduces the risk of CHD (coronary heart disease), stroke, hypertension, obesity, and diabetes. Moreover, fiber also improves serum lipid concentration, controls blood pressure, and improves digestibility (Anderson et al., 2009). Fermentation of dietary fiber produces short-chain fatty acids and also reduces the population of pathogenic bacteria, such as *Clostridia,* which can prevent diarrhea (Larsson et al., 2009; Phillips & Williams, 2000).

Inulin. The hydrocolloid inulin is a naturally available carbohydrate-based dietary fiber, extracted from chicory root. Inulin is a polymer of fructose units (2-60 fructose units) with one terminal glucose molecule. Inulin is a white, odorless, and tasteless powder that is easily dissolved in water (Modzelewska-Kapituła & Kłębukowska, 2009; Phillips & Williams, 2000). Inulin is considered a food ingredient and has achieved the dietary fiber definition in almost every country. After passing through the mouth, stomach, and small intestine, the fiber arrives in the large intestine unchanged. Upon anaerobic fermentation by gut microflora, inulin produces short-chain fatty acids and gases, while increasing bacterial mass (Blaut, 2002; Losada & Olleros, 2002). Consumption of inulin offers health benefits that include: protection against colon cancer, improved resistance against pathogens, increased calcium absorption, and reduction of blood lipid level (Blaut, 2002; Larsson et al., 2009; Losada & Olleros, 2002).

Compared to other hydrocolloids, the inulin molecule is smaller, so it has a lower water-binding capacity at low concentration level. As the concentration of inulin increases to more than 15%, it can form a stable gel or cream. This inulin gel or cream mimics a fat-like texture (Phillips & Williams, 2000). With application of shear force, inulin particles will absorb the water and form a perfect gel with creamy texture and good flow properties. These ideal textural and sensory properties of the inulin gel enable the use of the fiber as an outstanding fat replacer in a wide range of foods such as yogurt, cheese spread, sauces, etc. A creamier mouth feel is also achieved when inulin is used as a fat replacer in dairy products due to its interactions with whey protein and caseinate. Therefore, inulin has been successfully used as a fat replacer in a variety of dairy products (Barclay et al., 2010; Bot, Erle, Vreeker, & Agterof, 2004; Brennan & Tudorica, 2008; Karaca, Güven, Yasar, Kaya, & Kahyaoglu, 2009; Modzelewska-Kapituła & Kłębukowska, 2009).

Emulsifying Salts

Processed cheese spread (the water-in-oil type of emulsion) is very hydrophobic in nature. To achieve the self-stable mass of the processed cheese spread, emulsifying salts play a major role during the melting process of cheese spread production (Caric & Kalab, 1987). Various physico-chemical changes occur during the manufacturing process of cheese spread, and these changes facilitate the conversion of the natural cheese matrix into a shelf-stable mass with a softer body and a variety of textural characteristics such as slice-ability and spreadability (Lu, Shirashoji, & Lucey, 2008).

Citrate, phosphate, and polyphosphate are the three major categories of emulsifying salts widely used in the manufacturing of processed cheese and other processed cheese foods (Cunha & Viotto, 2010). Each category of emulsifying salts provides end products with different flow and textural properties. The behavior of each emulsifying salt can be determined by its capability to hydrate and disperse proteins, especially casein (Dimitreli & Thomareis, 2009). However, in the strict chemical sense, these compounds are not emulsifiers or surface active compounds. Since emulsification is not their only ability, these melting salts are conditionally called "emulsifying agents" (Caric & Kalab, 1987).

Emulsifying salts do not directly contribute to the process of fat emulsification, but the salts improve the emulsifying capability of aggregated para-caseinate in the cheese matrix, with the aid of shear and heat (Awad, Abdel-Hamid, El-Shabrawy, & Singh, 2004; Cunha & Viotto, 2010; Dimitreli & Thomareis, 2009). The primary caseins in the cheese matrix (β, $\alpha_{s1,}$ α_{s2}) have a non-polar, lipophilic C-terminal; a polar, hydrophilic N-terminal; and contain calcium phosphate. The similar structures of casein molecules enable them to act as an emulsifier. The water solubility and emulsifying capacity of casein are improved by decreasing the calcium phosphate content (Caric & Kalab, 1987).

In the presence of heat and shear, natural cheese melts but the presence of calcium in the cross-linking maintains the micellar structure of casein and does not allow casein to disperse in the system. Emulsifying salts chelate or bind the calcium ions from calcium para-caseinate and form sodium caseinate, which is soluble and has a dispersing effect on the protein system (Awad et al., 2004; Cunha & Viotto, 2010; Dimitreli & Thomareis, 2009). During this dispersing effect on the protein system, the casein networks composed of casein micelles dissolve and break into small particles roughly the size of casein sub-micelles. This incident, also termed as casein peptization, increases the water-binding capacity of protein, and opens the polar hydrophilic N-terminal and the non-polar, lipophilic C-terminal of the protein, and permits the casein to act as an emulsifier in the oil-water interface (Zehren & Nusbaum, 1992).

Casein peptization during the cooking of processed cheese spread is reliant on the type and concentration of the emulsifying salt added in the formulation of the processed cheese spread. Swenson et al. (2000) reported that trisodium citrate and disodium phosphate produced significantly softer cheese spreads with a better meltability than those spreads made with concentrated phosphate-based Joha-brand salts. Increasing the concentration of trisodium citrate or disodium phosphate from 0.5% to 3% increased the firmness and decreased the spreadability and melting property of fat-free processed cheese spreads (Swenson et al., 2000).

Caric and Kalab (1987) described that polyvalent anions (e.g., phosphates and citrates) provide a negative charge to protein molecules by chelating the calcium ions from protein molecules and also increase the pH of cheese. These changes lead to higher water sorption by the proteins. Emulsifying salts containing a monovalent cation and a polyvalent anion have the best emulsifying properties. It is necessary to maintain an appropriate pH value of processed cheese. The pH value affects protein configuration, solubility, and calcium sequestering ability of emulsifying salts. The pH of processed cheese varies from 5.0 to 6.5. At a lower pH (pH~5.0), which is near the isoelectric point of casein (pH= 4.6), processed cheese becomes crumbly due to the weakening of the protein-protein linkages. At a higher pH (pH~6.5), the cheese becomes very soft due to the higher moisture-binding ability of casein, which lowers the shelf life due to increased microbial growth (Caric & Kalab, 1987; Lu et al., 2008).

The type of emulsifying salts influences the melting property, color, texture, and sensory acceptance of processed cheese spreads. These characteristics can essentially be attributed to various mechanisms of the salts on the protein structure during the manufacturing process (Cunha & Viotto, 2010).

Rheology

Professor E.C. Bingham used the term rheology to characterize a novel branch of engineering, related to the study of flow pattern and deformation of a material subjected to external force. This was the basic definition of rheology that was accepted by the Society of Rheology (then, the American Society of Rheology) in 1929. At present, rheology is a well-defined field with various applications in different industries (Gunasekaran & Ak, 2003).

Rheology primarily measures those characteristics, which are responsible for deformation and flow properties of materials. Thus, rheology is mainly concerned with the correlation between stress, strain, and time. Strain accounts for the change on material deformation due to the difference in length or height, while stress accounts for the change in applied force due to the difference in the cross-sectional area of specimens (Gunasekaran & Ak, 2003).

Foods can be classified into different categories: solids, gels, emulsions, suspensions of solids within liquids, and homogeneous liquids. Semi-solid or fluid foods are described as those foods which do not retain their shape but can be pourable (or flowable) and take the shape of containers. These foods demonstrate both viscous and elastic properties and are also termed as viscoelastic foods (Rao, 1999). These viscoelastic foods are soft and spreadable. Textural characteristics of these foods, such as spreadability, play an important role in consumer acceptance. Spreadability is described as the measure of how easily and uniformly a product breaks and spreads at the end use temperature (Sun & Gunasekaran, 2009).

Various methods have been used to measure the spreadability of products. Many researchers used the vane method to evaluate the spreadability and textural properties of spreadable foods like, cream cheese, peanut butter, and cheese spread (Breidinger & Steffe, 2001; Daubert et al., 1998). Daubert et al. (1998) used the vane method to measure the spreadability of various spreadable foods and reported that the vane method is a simple method to quantify the spreadability.

Brookfield Vane Rheometer

The Brookfield programmable rheometer measures fluid parameters, such as shear stress and viscosity at a given shear rate. A four-bladed vane spindle is driven into the fluid sample through a calibrated spring and the fluid causes drag against the spindle. This drag is measured by the spring deflection (Brookfield Engineering Laboratories). Spreadable or semi-solid foods need a certain amount of force (stress) for adequate spreading and deformation. However, the material shows irreversible deformation after this stress is achieved and this stress value is known as yield stress (Daubert et al., 1998).

The vane geometry shows many advantages over conventional rotational techniques. Some of these advantages include: elimination of the wall slip, simple sample preparation, and the ability to measure weak materials with little disturbance to the gel. Vane geometry is a simple yet effective means of measuring yield stress (Gunasekaran & Ak, 2003).

When a four-bladed vane is immersed in the sample and the yield test is run, a typical torque-time response of the sample would be measured and expressed in a graphical form. The Brookfield vane rheometer finds the torque value by measuring the deflection of the calibrated spiral spring. The maximum torque (peak torque) is the only parameter used to calculate the yield stress value (Gunasekaran & Ak, 2003; Nguyen & Boger, 1985).

When the vane spindle is immersed up to the primary mark, the Brookfield rheometer uses the following equation to calculate the yield stress (τ) value.

$$\tau = [2T_{max}/\pi D^3] \text{ x } [(H/D) + (1/3)]^{-1}$$

Where, T_{max} is maximum torque, D is vane diameter, and H is height of vane.

When the vane spindle is immersed up to its secondary mark, the following equation is used to find the yield stress (τ) value.

$$\tau = [2T_{max}/\pi D^3] \text{ x } [(H/D) + (1/6)]^{-1}.$$

Primary and secondary immersion mark of vane spindle is shown in Figure 1.

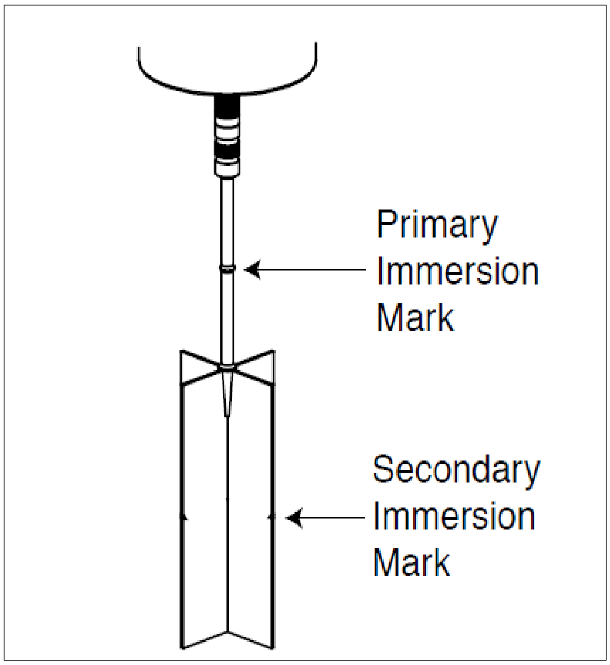

Figure 1. Primary and secondary immersion mark of vane spindle.

The Brookfield vane rheometer was an important instrument in conducting the testing of the low-fat processed cheese in this research. The purpose of the research, selection of fat replacer, production of the low-fat processed cheese spread, and the chemical and rheological testing of the low-fat processed cheese spread are described in Chapter 3.

Chapter III: Methodology

The purpose of this research was to observe the rheological changes in low-fat processed cheese spread supplemented with three different concentrations of inulin. The research was carried out in two steps; selection of a fat replacer (pectin, β-glucan or inulin) and production of the low-fat processed cheese spread with the selected fat replacer, inulin.

Selection of Fat Replacer

In order to select a suitable fat replacer, three different fat replacers namely pectin, β-glucan, and inulin were evaluated for their solubility, stability, water binding capacity, texture, and sensory attributes. These characteristics were evaluated by visual observation of gels and some bench-top testing like mixing the gel with a spoon to measure the firmness, tasting the gel for flavor and testing the gel for an odor. Pectin, β-glucan, and inulin were dispersed in water as recommended by the suppliers. Many researchers have reported the positive effects of these fat replacers on textural and sensory properties of various dairy products (Brennan & Tudorica, 2008; Hennelly, Dunne, O'Sullivan, & O'Riordan, 2006; Liu, Xue, & Shi, 2008).

As per May (2000), pectin is a charged hydrocolloid and therefore the gelling strength of pectin depends on the calcium content of the system. Since milk is a good source of calcium, pectin can gel the milk by interacting with calcium. It has been also suggested by May (2000) that pectin can work better at a lower pH (3 to 4.1) and a higher sugar concentration. Since the processed cheese spread does not contain any sugar and has a higher pH (5.5 to 6), pectin is not a suitable fat replacer. Moreover, Macků et al. (2008) reported that processed cheese made with pectin has less spreadability and more rigidity compared to processed cheese without pectin.

Brennan and Tudorica (2008) reported that low-fat yogurt made with inulin has a creamier and smoother texture compared to β-glucan. It has also been observed that inulin gel does not give an off flavor like β-glucan. Furthermore, inulin has demonstrated the ability to form a stable and soft particle gel. These characteristics of inulin gel make it a suitable fat replacer in processed cheese spread to get a good spreadability. As we discussed earlier that at or above 15% concentration of inulin forms stable and cream-like gel, therefore the experiment reported herein utilized inulin at a composition of 6%, 7%, and 8%. These addition rates were calculated based on the moisture content of the processed cheese spread formulation. Each inulin percentage rate, 6%, 7%, and 8%, is representing approximately 10%, 11%, and 12% of the total moisture content of the formulation, respectively.

Production of Low-fat Processed Cheese Spread

Materials. Natural cheeses are the basic ingredients for making processed cheese spreads. The processed cheese spread was produced by mixing natural cheddar cheeses of different ages in different proportions. Three different varieties of cheddar cheese were used to manufacture the processed cheese spread. The Land O'Lakes Cooperative (Arden Hills, MN) provided the full-fat mild and aged cheddar cheeses. Reduced-fat cheddar cheese was purchased from the local Wal-Mart store (Menomonie, WI). Whey protein concentrate, Avonlac 180, was supplied by Glanbia Nutritionals Inc. (Richfield, ID). Main Street Ingredients (La Crosse, WI), provided the low-heat, non-fat, dry milk powder. Emulsifying salt, JOHA S9, was supplied by B. K. Giulini Corporation (Simi Valley, CA) and inulin, Orafti HP, was provided by BENEO Inc. (Morris Plains, NJ). Pectin, TIC Pretested Pectin 1400, was provided by TIC GUM Inc. (Belcamp, MD) and β-glucan, Glucagel, sample was supplied by PolyCell Technologies LLC. (Crookston, MN). Cheddar cheese flavor was obtained from Jeneil Biotech Inc. (Saukville, WI).

Manufacture of processed cheese spread. For the full-fat processed cheese spread, 55% cheddar cheese (34% mild cheddar cheese, 10% aged cheddar cheese, and 11% reduced-fat cheddar cheese) was used in the formulation to achieve the minimum fat requirement (20%). The mild cheddar cheese was not used in the formulation of the low-fat cheese spread due to the lower fat percentage (not more than 6%) requirement for low-fat cheese. Reduced-fat cheddar cheese and aged cheddar cheese were used to make the low-fat processed cheese spread. Aged cheddar cheese was added to get the desired cheddar flavor in the final product. As the proportion of aged cheddar cheese was much less in the low-fat cheese spread, natural cheddar cheese flavor was added in the low-fat cheese spread formulation.

The processed cheese spread was made in 2 Kg batches using a jacketted Stephen cheese cooker by mixing cheddar cheese with emulsifying salts (sodium polyphosphate salt converts proteins into a dispersed form and uniformly distributes fat and other components), whey protein concentrate, non-fat dry milk, salt, and inulin. Cheddar cheese was grated and tempered at room temperature (21˚C) for an hour prior to use. A detailed flow chart for the manufacturing of the processed cheese spread is described below. Two control samples (full-fat and low-fat without inulin) and three low-fat samples were produced in duplicate. After making the cheese spread, it was poured into plastic containers. These containers were stored in refrigerator (at 4 ˚C) until further analysis.

Flow Chart for Manufacturing of Low-fat Process Cheese Spread

1. Equipment Cleaning and Set up:

Stephen cooker was properly washed and dried.

↓

Stephan cooker was firmly fixed on spindle and the hot water inlet and outlet tubes were attached to the cooker's jacket from a preset water bath.

↓

The temperature probe was attached to the Stephan cooker.

↓

The shear blade was properly assembled and set on the rotary spindle, inside the cooker.

↓

After filling the cooker with about one liter of clean water, the lid was closed.

↓

The air vent (located on the lid) was kept partially open to release the pressure.

↓

The shear blade was rotated at 300 rpm (revolution per minute) and the water bath temperature was set at 95˚C.

↓

The Stephan cooker was sterilized at 85˚C for 15 minutes.

↓

After sterilization, the cooker was emptied out.

2. Weighing of raw material and pretreatment:

All the ingredients were weighed as per the formulation.

↓

The weighed cheese was grated and thawed at room temperature (21˚C) for one hour.

↓

All of the dry ingredients (non-fat dry milk, salt, inulin, whey protein concentrate, and cheese flavor) except the emulsifying salt were mixed together.

↓

The emulsifying salt was dissolved in 25% of the total water required at 60˚C.

3. Making of Process Cheese Spread:

The Stephen cooker was filled with 75% of the total water required and heated to 60˚C.

↓

The dry ingredient mix was slowly added into the Stephen cooker and mixed at 300 rpm for 8-10 minutes at 60-65˚C.

↓

The grated cheddar cheese (mild and aged) was added to the uniform slurry of water and dry ingredients and mixed at 300 rpm for 2-3 minutes.

↓

The emulsifying salt solution was added into the cooker. The agitation was raised and held at 900 rpm until the temperature of product reached 85˚C. The spread was held at this temperature for two minutes.

↓

The shear blade was stopped and the spread was poured into plastic containers. The product was stored at 4˚C.

Chemical Analysis of Low-fat Processed Cheese Spread

The processed cheese spreads with 6%, 7%, and 8% inulin and the full-fat and low-fat controls with no inulin were analyzed for moisture, fat, protein, and pH. Fat, protein, and moisture content of the spreads were determined using the standard methods for the examination of dairy products (Marshall, 1992). For fat, the Mojonnier method (Standard Methods for The Examination of Dairy Products, 16th Edition 1992 15.8-F) was used, and protein analysis was carried out using the Kjeldahl method (Standard Methods for The Examination of Dairy Products, 16th Edition 1992 15.12-B). Commercial Testing Laboratory, Inc. (Colfax, WI) conducted fat and protein analyses. The Atmospheric Oven Draft Method (Standard Methods for The Examination of Dairy Products, 16th Edition 1992 15.10-A) was used to determine moisture and a pH meter (Accumet AB15+ Basic, Fischer Scientific, Pittsburgh, PA) was used to measure the pH of the processed cheese spread (Food Science Department, UW-Stout). All the tests were conducted in duplicate.

Rheological Test of Low-fat Processed Cheese Spreads

A programmable Brookfield roto-viscometer was used to determine the rheological properties (yield stress and strain) of the processed cheese spreads with 6%, 7%, and 8% inulin and the full-fat and low-fat controls with no inulin. The Brookfield spindle no. 75 was used to calculate the percent torque. The samples were thawed at room temperature (21˚C) prior to running the test. After attaching the spindle, the Brookfield roto-viscometer was calibrated to zero prior to spindle immersion. The primary immersion mark was located on the shaft of the spindle. The spindle was inserted into the sample cup so that the sample reached the primary immersion mark of the spindle. The viscometer calculated the percent torque value by measuring the deflection of the calibrated spiral spring. Maximum torque (peak torque) was the only parameter used to calculate the yield stress value. The stress and strain values were calculated from the percent torque and time values by EZ Yield V1.4 software (Brookfield Engineering Laboratory). The following formula was used to determine the yield stress (τ) value;

$$\tau = [2T_{max}/\pi D^3] \times [(H/D) + (1/3)]^{-1}$$

Where, T_{max} is maximum torque, D is vane diameter, and H is height of vane.

The spreadability of the samples was determined by plotting the yield stress values against the respective strain values of all the samples.

Statistical Analysis

The experiment was carried out in duplicate. The compositional and textural data were analyzed using one-way ANOVA (analysis of variance). Fisher's least significance difference (LSD) test at a 95% confidence interval was used to determine the differences between the means. All the chemical and rheological tests were replicated two times. Fisher's LSD test was used to determine whether statistically significant differences occurred between the mean values using XLSTAT software (Addinsoft, 2010).

Appropriate graphs of the data were created. The results of adding inulin at 6%, 7%, and 8% to the low-fat processed cheese spreads are reported in Chapter 4.

Chapter IV: Results and Discussion

The effects of adding inulin at different levels in the low-fat processed cheese spread were studied in this experiment. Rheological properties, yield stress and yield strain, were determined using the Brookfield roto-viscometer (Brookfield Engineering Laboratory Inc. Middleboro, MA). Since cheese spread requires easy deformation of a gel at low temperature, spreadability was also determined. In general, spreadable foods require a certain amount of stress (force) to deform and be able to be spread. The value of stress required is called yield stress and once the stress value passes this point, the material will flow or spread. However, Daubert et al. (1998) observed that spreadability may not only associate with yield stress but also with yield strain. The material's strain value at the yield stress point gives information about the maximum deformation a sample can withstand before flow or spread. Therefore, spreadability may be considered as a function of yield stress and yield strain. It is measured by using the stress vs. strain graph. To correlate the rheological properties with the composition of cheese spread, chemical analyses (fat, protein, moisture, and pH) of the samples were also carried out.

Proximate Analysis

All the compositional analyses were conducted in duplicate following AOAC methods. As shown in Table 2, the percentages of fat and protein of all of the low-fat processed cheese spreads were held constant to minimize the effects that fat and protein might exert on the texture of the product and to better characterize the effects of inulin. The full-fat product contained 20.6% fat. As per the CFR regulation for low-fat products, the fat content of the product must be less than or equal to 6% and that was achieved in all the low-fat samples. The fat and protein content did not differ between the low-fat samples. The moisture content of the low-fat cheese spread control (0% inulin) was higher (71.22%) than the experimental low-fat spreads with inulin, 66.2%, 65.8% and 64.75 for 6%, 7%, and 8% inulin, respectively. As the inulin content was increased, the inulin replaced part of the product's moisture. As compared to the lower moisture content of the full-fat cheese spread (56.1%), the higher moisture content of the low-fat cheese spread was associated with a more alkaline pH value, 6.1 versus 5.6 for the full-fat control, but this pH difference was not significantly different.

Table 2. Chemical Composition of Low-fat and Full-fat Processed Cheese Spreads

	Control		Treatment		
Parameter	FFC[1]	LFC[2]	LF 6%[3]	LF 7%[4]	LF8%[5]
Fat (%)	20.60 [a]	6.00 [b]	5.94 [b]	5.61 [b]	5.60 [b]
Protein (%)	16.70 [a]	12.10 [b]	12.00 [b]	12.00 [b]	11.90 [b]
Moisture (%)	56.06 [d]	71.23 [a]	66.17 [b]	65.80 [b]	64.74 [c]
pH	5.60 [a]	6.10 [a]	6.10 [a]	6.10 [a]	6.10 [a]

Note. [a-d]Means within a row with different letters differ significantly ($p<0.05$) using Fisher method.
[1]FFC – Full-fat control with no inulin added
[2]LFC – Low-fat control with no inulin added
[3]LF6% - Low-fat processed cheese spread with 6% inulin added
[4]LF7% - Low-fat processed cheese spread with 7% inulin added
[5]LF8% - Low-fat processed cheese spread with 8% inulin added

Rheological Analysis

Food rheology is important in the manufacturing of food products such as cheese. Food rheology is the study of the consistency and flow of food under tightly specified conditions and is important in determining food texture. Consumer acceptability of food products is often determined by food texture, such as how spreadable and creamy a food product is. The rheological properties reported in this research are stress, strain, and spreadability.

Stress and strain. Stress and strain values were measured using a Brookfield roto-viscometer. When an external force (stress) is applied to a gel structure, the stress causes deformation of the gel matrix and at some point the stress causes the breaking of the gel structure and the product begins to flow. This maximum stress value is also known as the yield stress value.

As shown in Table 3, the low-fat cheese spread without added inulin had the least yield stress value (253.6 Pa). As the inulin level in low-fat cheese spreads increased, yield stress values also increased; 6%, 7%, and 8% inulin low-fat spreads had yield stress values of 304, 535, and 575 Pa, respectively. This high value of stress may have been achieved due to the binding of additional moisture by the added inulin. The hydroscopic nature of inulin facilitates the water-binding and gel-forming activity within the cheese spread matrix. It has been observed that viscosity of the products increased with increasing levels of inulin (Akin et al., 2007). The low-fat processed cheese spread with 7% inulin showed no significant difference in the yield stress value compared to the full-fat control sample (522 Pa). The product with the highest level of inulin gave a firmer texture (575 Pa) compared to the full-fat control. Hennelly et al. (2006) reported that reduced-fat imitation cheese containing inulin can achieve the similar hardness as a full-fat control. A similar pattern was observed in this study, in terms of yield stress value, between low-fat processed cheese spreads with varying amount of inulin. Figure 2 shows the effect of inulin content on the yield stress value.

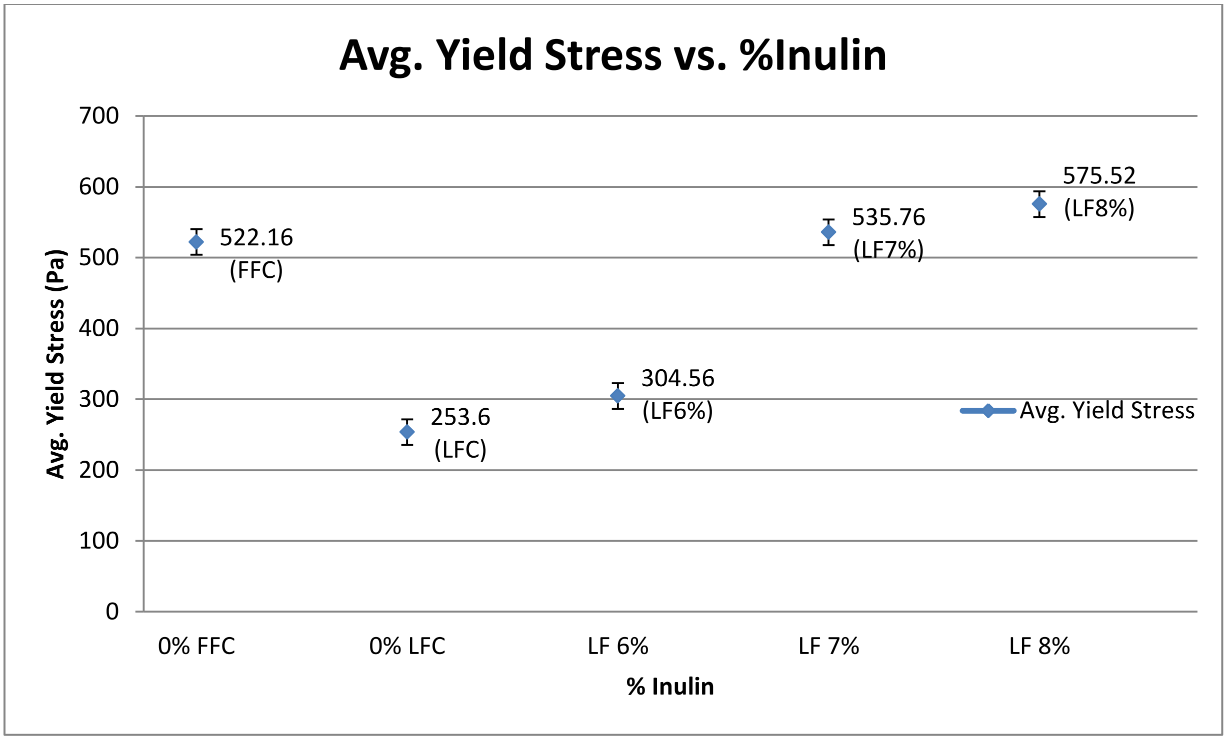

Figure 2. Average yield stress vs. % inulin content graph of full-fat and low-fat processed cheese spreads with different levels of inulin added.
Where, 0%FFC – Full-fat control with no inulin added
0%LFC – Low-fat control with no inulin added
LF6% - Low-fat processed cheese spread with 6% inulin added
LF7% - Low-fat processed cheese spread with 7% inulin added
LF8% - Low-fat processed cheese spread with 8% inulin added

The strain values of low-fat cheese spreads with different amount of inulin were significantly lower (0.589, 0.484, 0.606, and 0.48 rad for low-fat cheese spread with 0%, 6%, 7%, and 8% inulin, respectively) than the full-fat control (1.141 rad), which indicates that the low-fat cheese takes a shorter time to break and has a smoother texture than the full-fat control. Lower strain values of low-fat cheese spreads also represent that the gel structure of a low-fat spread requires a lower force (stress) to break or flow (Gunasekaran & Ak, 2003). This can be observed in Figure 3.

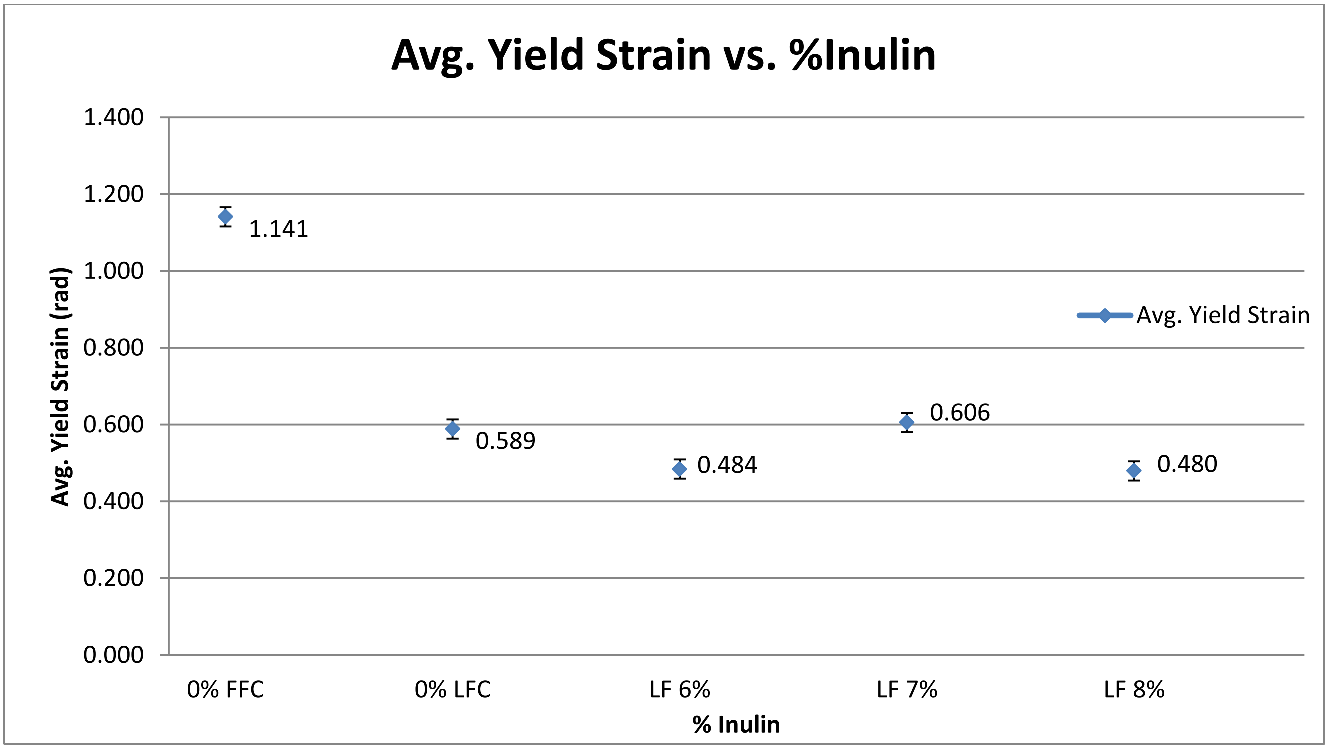

Figure 3. Average yield strain vs. % inulin content graph of full-fat and low-fat processed cheese spreads with different levels of inulin added.
Where, 0%FFC – Full-fat control with no inulin added
0%LFC – Low-fat control with no inulin added
LF6% - Low-fat processed cheese spread with 6% inulin added
LF7% - Low-fat processed cheese spread with 7% inulin added
LF8% - Low-fat processed cheese spread with 8% inulin added

The statistical analysis of yield stress and yield strain value was done according to the Fisher method by using XLSTAT software (Addinsoft, 2010). The results are shown in Table 3, which shows the effect of % fat and % inulin content on yield stress and yield strain value. The variable manipulated in this study was the level of inulin in low-fat cheese spread. The factors that affected yield stress values were the fat and inulin contents in the product. The fat content of the low-fat processed cheese spread remained constant but the stress value significantly increased as the inulin content increased.

Table 3.

Stress and Strain Values of Low-fat and Full-fat Processed Cheese Spreads.

	Control		Treatment		
Parameter	FFC[1]	LFC[2]	LF 6%[3]	LF 7%[4]	LF8%[5]
Fat (%)	20.60 [a]	6.00 [b]	5.94 [b]	5.61 [b]	5.60 [b]
Yield Stress (Pa)	522.16 [b]	253.60 [d]	304.56 [c]	535.76 [ab]	575.52 [a]
Strain (Rad)	1.141 [a]	0.589 [b]	0.484 [b]	0.606 [b]	0.480 [b]

Note. [a-d]Means within a row with different letters differ significantly (*p*<0.05) using Fisher method.
[1]FFC – Full-fat control with no inulin added
[2]LFC – Low-fat control with no inulin added
[3]LF6% - Low-fat processed cheese spread with 6% inulin added
[4]LF7% - Low-fat processed cheese spread with 7% inulin added
[5]LF8% - Low-fat processed cheese spread with 8% inulin added

The relationship between the stress and strain of a particular material is known as that material's stress-strain curve. It is unique for each material and is found by recording the amount of deformation (strain) at distinct intervals of tensile or compressive loading (stress). Figure 4 shows the stress vs. strain patterns of the full-fat and low-fat controls and low-fat treatments with different levels of inulin added.

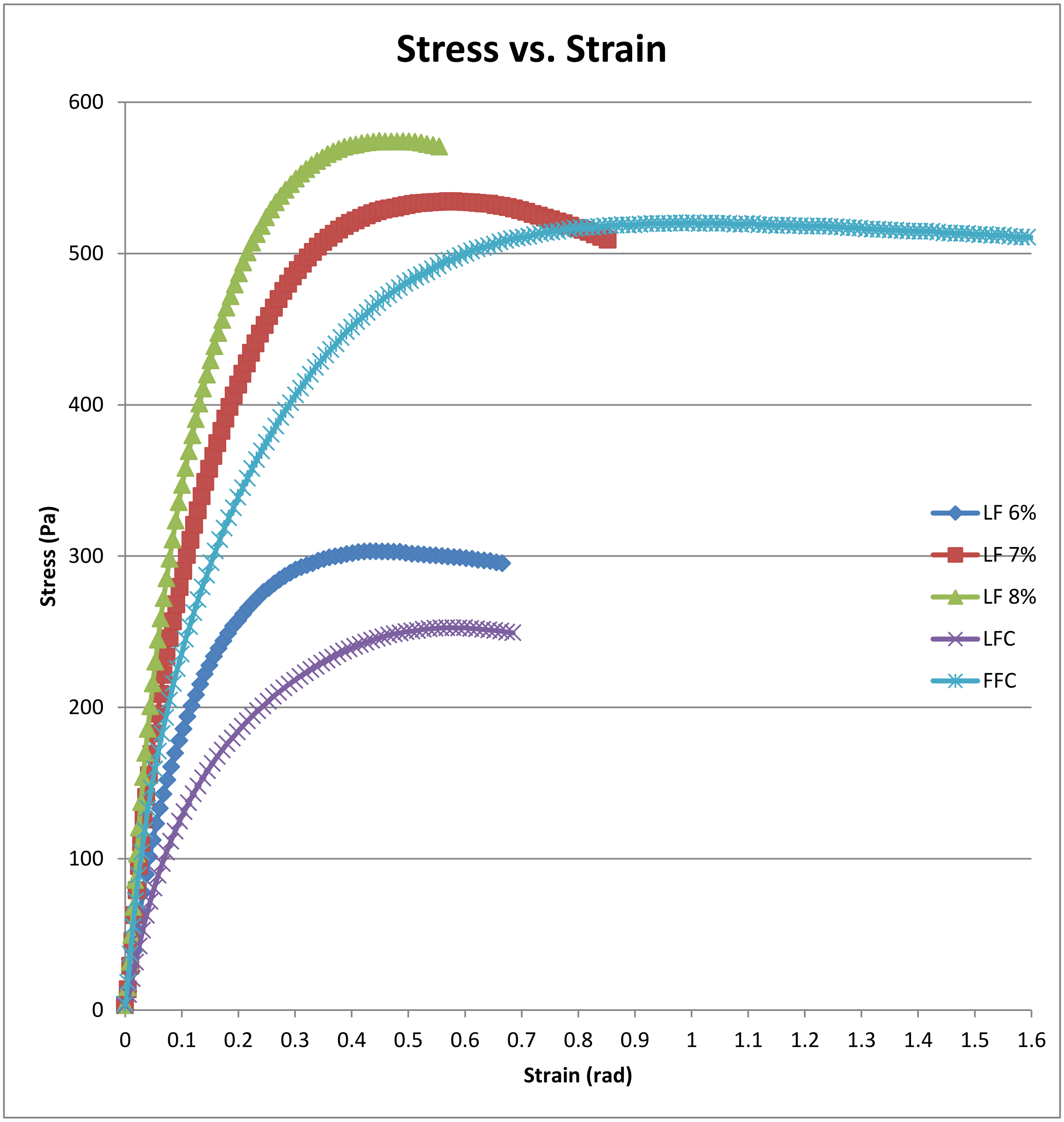

Figure 4. Stress vs. strain graph of full-fat and low-fat processed cheese spreads with different levels of inulin added.

Where, FFC – Full-fat control with no inulin added

LFC – Low-fat control with no inulin added

LF6% - Low-fat processed cheese spread with 6% inulin added

LF7% - Low-fat processed cheese spread with 7% inulin added

LF8% - Low-fat processed cheese spread with 8% inulin added

Spreadability map. Various methods have been used to measure the spreadability of products. Many researchers have used the vane method to evaluate the spreadability and textural properties of spreadable foods like cream cheese, peanut butter, and cheese spread (Breidinger & Steffe, 2001; Daubert et al., 1998). Daubert et al. (1998) used the vane method to measure the spreadability of various spreadable foods and reported that the vane method is a simple method to quantify the spreadability. In this study, the spreadability of cheese spreads was measured by plotting the stress vs. strain on a graph. The stress and strain value was measured using the Brookfield vane-rheometer.

Researchers can diagram a cheese spread's textural properties and can even predict spreadibility. Daubert et al. (1998) tested thirteen spreadable foods and created a spreadability map by plotting the relationship between the yield stress and yield strain. Three different areas were marked on this chart according to their ease of spreading. Samples in the lower-left-corner are easier to spread, progressing to the more difficult to spread region in the upper-right-corner of the map (Daubert et al., 1998). In this study, a spreadability map was constructed by plotting the relationship between the yield stress and yield strain as shown in Figure 5.

The full-fat cheese spread was found to have a moderate to hard spreadability. Low-fat cheese spreads with contents of 7% and 8% inulin content fell under the easily spreadable region. This may be due to the higher yield strain value of full-fat cheese spread compared to low-fat with 7% and 8% inulin content. A higher yield strain value means material needs more time to break the gel and begin to flow or spread. While on the other hand, product with a lower strain value requires less effort to break the gel and spread (Gunasekaran & Ak, 2003). As indicated by other researchers, the higher fat content of this sample was responsible for the firmer body and texture compared to the lower fat cheese spreads (Brighenti, Govindasamy-Lucey, Kim, Nelson, & Lucey, 2008). The higher amount of inulin (7% and 8%) in the low-fat cheese spreads formed a particle gel matrix, which might have imparted a soft body and easy spreadability to the low-fat cheese spreads. The low-fat cheese spreads with 6% and 0% inulin were also found to fall into the easily spreadable region but both have very low yield strain and yield stress value. Truong et al. (2001) studied the textural characteristics of cheddar cheese using the vane rheometer. They generated a texture map by plotting the shear stress and strain value. Four corners of the texture map represented different textural characteristics of the cheese. The top left corner of the map (higher stress and lower strain value) represented a brittle texture, while the bottom left corner (lower stress and strain value) represented a mushy texture. Similarly, the top right corner (higher stress and strain) indicated a tough texture and the bottom right corner (higher strain and lower stress) showed an elastic or rubbery texture. In this study, the low-fat control and the low-fat cheese spread with 6% inulin had lower stress and strain values. They were plotted towards the lower left corner of the spreadability map, which may indicate that they had a mushy texture.

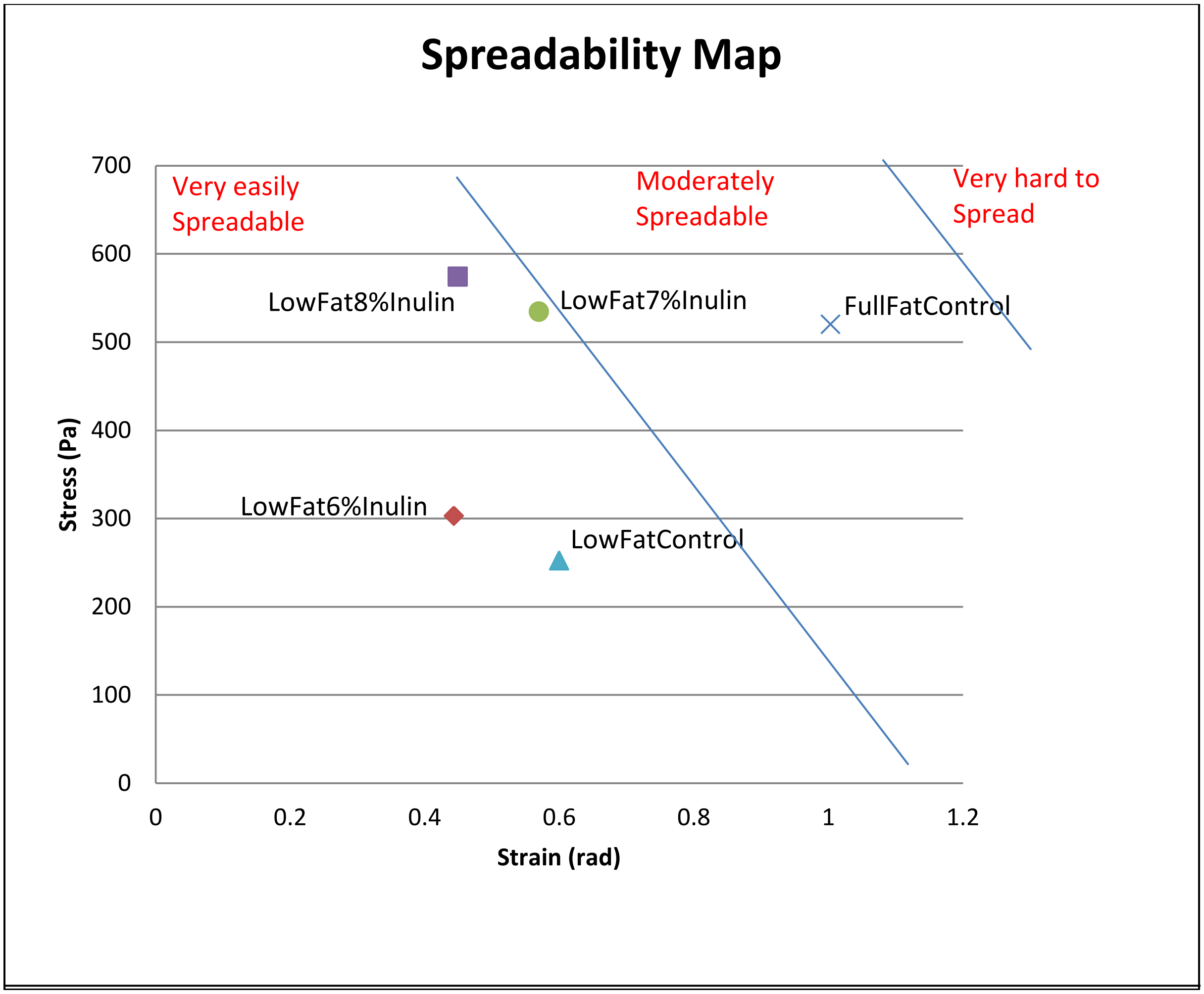

Figure 5. Spreadability map of full-fat and low-fat processed cheese spreads.

This concludes the results and discussion chapter. The conclusions of this study with limitations and recommendations are presented in Chapter 5.

Chapter V: Conclusion

This chapter will make conclusions from the results of this study and will provide limitations for the research. Recommendations for future studies are also made.

After preparing all five samples of processed cheese spread, full-fat control, low-fat control, and low-fat with 6%, 7%, and 8% inulin, the samples were analyzed for chemical and rheological properties. The results of rheological properties were compared and the positive effects of inulin content on the textural properties of the cheese spreads (yield stress and spreadability) were found.

The primary objectives of this research were to identify the optimum level of inulin (a carbohydrate-based hydrocolloid) which could be added to a low-fat processed cheese spread and to characterize the effects of inulin on textural properties. The results of the stress vs. strain graph (see Figure 4) showed that low-fat processed cheese spread with 7% and 8% inulin content demonstrated a similar and a higher yield stress value, respectively, as compared to the full-fat control. This suggests that the 7% inulin is the optimal level to achieve the same stress value as the full-fat control. The spreadability map (see Figure 5) also supported the result that inulin improved the textural properties of low-fat cheese spread with an exception of the 6% inulin level product. The low-fat cheese spread with a 6% level of inulin resulted in a mushy product. The improvement in the textural properties, indicated by a higher yield stress value and spreadability, directed that inulin could be used as a potential fat replacer in low-fat processed cheese spreads.

Limitations. Sensory analysis of food product plays an essential role to determine the sustainability of any new food product in market. In this study, sensory evaluation of the product was not conducted, so the effect of inulin on the sensory properties of the low-fat cheese spreads was not studied.

Recommendation. Fat provides a pleasant flavor and a rich taste to any food product. Fat also gives desired textural characteristics. Low-fat food products lack these sensory and textural characteristics. In this study, the desired textural characteristics were achieved by the addition of inulin. Sensory evaluation is also important to find out both the flavor and taste of products for consumers. Since sensory characteristics drive the market demand and customer preference of any food product, it is recommended that a sensory evaluation of the low-fat cheese spreads be conducted. This study focused mainly on rheological characteristics of the cheese spread. So for further study, sensory evaluation could be used as one of the testing parameters.

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Appendix A: The Manufacturing Process of Cheddar Cheese

Standardize Milk

↓

Pasteurize

↓

Cool to 30°C

↓

Add stater culture at 0.7%

↓

Curd formation (30-31°C/45-50 min)

↓

Cut curd

↓

Scald

↓

Stirring at 39-40°C/45-6- min

↓

Drain the whey

↓

Cheddaring (Packing, turning, piling, and repiling of matted curd slab)

↓

Milling and Salting of the curd slab

↓

Hooping (Fill the hoop with milled cheese curds)

↓

Pressing of cheddar cheese curds.

↓

Ripening