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MICROSTRUCTURE, SENSORY AND TEXTURAL CHARACTERISTICS OF CHEDDAR CHEESE AS INFLUENCED BY MILKFAT

By

Anita Corinne Bryant

A THESIS

Submitted to
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ABSTRACT

MICROSTRUCTURE, SENSORY AND TEXTURAL CHARACTERISTICS OF CHEDDAR CHEESE AS INFLUENCED BY MILKFAT

By

Anita Corinne Bryant

Cheddar cheese was manufactured with varying fat levels (34, 31.5, 26.8, 20.5, 12.6, and <0.1%) and allowed to ripen 16 weeks at 7°C. Microstructure of the cheeses was studied using Scanning Electron Microscopy (SEM). Textural parameters (adhesiveness, cohesiveness, hardness, springiness) were evaluated using the Instron Universal Testing Machine and a trained sensory panel. Overall texture acceptance of the cheeses was evaluated by an untrained sensory panel. SEM micrographs indicated that the open, intricate microstructure of the cheese was lost with a decrease in fat. In the low fat cheeses (20.5, 12.6, <0.1%) the casein matrix was more compact. Hardness, springiness and cohesiveness of the cheeses increased ($p<0.5$) as determined by the trained sensory panel. However, adhesiveness and cohesiveness decreased ($p<0.5$) as determined by this panel. Overall texture acceptance of the cheese decreased with a decrease in fat content. At 12.6% fat, the cheese was no longer acceptable to the untrained sensory panel.

This thesis is dedicated to my mother, Helen D. Bryant

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TABLE OF CONTENTS

LIST OF TABLES

Table	Page

Table **Page**

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Consumption of lowfat products is increasing due to recommendations from the American Heart Association that consumers decrease their intake of dietary fat and cholesterol [Dexheimer (1992)]. Dairy products, particularly cheeses, have been specifically targeted as a potential area for reduction of fat intake due to their typically high fat content. In response to consumer demand for low fat products, manufacturers have increased development and production of dairy products that are fat-free and lower in fat compared to the conventional dairy products.

Cheddar cheese is the most popular hard type cheese in the United States. It is consumed in a variety of ways, such as eaten alone as a snack, used as a topping on vegetables and other foods, and being used as an ingredient in cooking. Presently there are reduced fat Cheddar cheese products available in the market, but many tend to disappoint the consumer. These products contain about a 33% reduction in fat. Reduced fat cheeses are typically associated with quality problems such as flavor and texture defects as well as the presence of off flavors. Such cheeses tend to lack flavor and are hard and rubbery.

The main purpose of this research was to investigate the role of milkfat in the textural and microstructural characteristics of Cheddar cheese, to gain further insight to the function of fat in Cheddar cheese.

CHAPTER II

LITERATURE REVIEW

DIETARY HEALTH CONCERNS

The American Heart Association has recommended that Americans reduce their consumption of dietary fat and cholesterol. These recommendations stem from research that shows that diet influences serum levels of cholesterol and lipoproteins, VLDL (very low density lipoprotein), LDL (low density lipoprotein) and HDL (high density lipoprotein) [Grundy and Denke (1990)]. Cholesterol, saturated fatty acids and excess calories are main factors in increasing serum LDL levels. Serum LDL levels have been positively correlated with the development of coronary heart disease (CHD). Cholesterol is generally recognized as a possible risk factor in the development of atherosclerosis and other heart diseases [Kumar and Singhal (1992)]. Recently, much attention has focused on the role of fat and specific fatty acids and their contribution to increased serum cholesterol and LDL levels [Grundy and Denke (1990)]. Reports on the role of dairy products in increasing serum cholesterol and LDL levels is conflicting. There is evidence that indicates that butterfat (milkfat) significantly contributes to increased serum cholesterol levels [Grundy and Denke (1990)]. Butterfat is high in palmitic (23-48%) and myristic acid (8-

17.7%) [Grundy and Denke (1990); Banks (1991)]. Palmitic acid, which is the major saturated fatty acid in animal fats and the principal fatty acid in most U.S. diets, is reported to be the main serum cholesterol raising saturated fatty acid [Grundy and Denke (1990)]. Kumar and Singhal (1992), report however that attacks on the dairy industry are unwarranted because there is no direct evidence proving the involvement of dairy products in the development of heart disease.

Dairy foods over the years have been perceived as being healthy and nutritious. Cheeses, in particular, are a dense source of nutrients. They contain fat soluble vitamins, and high quality protein. Most cheeses are suitable for lactose intolerant individuals, because the major milk sugar, lactose, is converted to lactic acid, and/or removed in the whey. Cheeses are also a source of minerals, such as calcium and phosphorous. More recently, there are increasing reports that cheese may also have a role in dental health by inhibition of demineralization of the tooth enamel, and clearance of sugar from the oral cavity [National Dairy Council (1989)]. Thus, dairy products, including cheeses should be part of a balanced diet.

A study done by the United Dairy Industry Association (UDIA) in 1988, which surveyed 3700 persons, showed that the healthy image of dairy foods is in jeopardy. Compared with results from a survey done in 1980, the 1988 study showed consumer's attitudes towards dairy foods such as sour cream, butter and cheese have changed. Fewer people felt these foods were healthy, 50% linked heart disease with cheese and 66% with butter [Berner and Lofgren (1991)]. As a result of the current research and information out concerning dietary fat and cholesterol and heart diseases, and changing attitudes of consumers, it is imperative to the dairy industry that quality dairy products are developed that are lower in fat, in addition to the traditional dairy products currently available.

Consumption of lowfat foods in general has grown tremendously [Dexheimer (1992)]. A projection of lowfat food sales into the year 1995 is $41.4 billion. Dairy products make up the largest category (74%) of lowfat, low cholesterol products in the market. In 1991, cheese represented 23% of the total new nonfat/lowfat dairy products introduced [Dexheimer (1992)]. In 1992, this figure grew to 36% of new nonfat/lowfat dairy products [O'Donnell (1993)]. Per capita consumption of cheese has increased 41%, and cheese consumption is expected to increase 2-3% annually through the next decade, equalling 1/2 billion pounds in 3 years. The volume of light cheeses increased 60% from April, 1991 to April, 1992 [Levitt (1992)]. Consumers may be more likely to accept a low fat product if provided with the necessary nutrition information [Light *et al.* (1992)].

According to Hise (1991) and Levitt (1992), "healthy" (reduced and non-fat) cheeses represent 5-10% of the cheese marklet. This figure is believed to remain stable until reduced fat cheeses have been introduced that are similar in flavor and texture to their full fat counterparts [Levitt

(1992)]. Fat has a direct influence on the acceptance of cheeses. A test conducted by Madsen *et al.* (1970) showed that consumer preference decreased as the fat content of the cheese decreased. Cheddar cheese with 35.5% fat on a dry basis (FDB) was preferred the least and cheese with 54.3% FDB was preferred the most.

REDUCED FAT CHEESES

Research has been conducted on the development of reduced fat cheese for many years. Early research showed that cheese produced from skimmilk resulted in a hard, tough, inedible mass of casein [LeRoux and Abbott (1962); Hargrove *et al.* (1966)]. Fat is one of the major components of cheese, and serves many functions. Milkfat adds to the creaminess, lubricity and opaqueness of cheese [Lindsay (1991)]. Milkfat affects cheese yield and contributes to flavor and texture of the cheese [Olson and Johnson (1990)]. Therefore, cheeses produced with reduced fat content exhibit several problems. Problems typically associated with reduced fat cheeses are lack of flavor, presence of off flavors, body defects, reduced cheese yield and reduced shelf life.

Fat is very important for flavor development in cheese. Fat may act as a flavor resevoir for fat soluble compounds [Lindsay (1991)]. However, there are other compounds, in addition to fat that may be important in flavor development in cheese such as sulphur, present as hydrogen sulfide

(H_2S), lactic acid, butanone, water soluble nitrogen and acetic acid. Barlow ***et al.*** (1989) isolated these compounds from Cheddar cheese and found that they were strongly correlated to a sensory panel's flavor score. Banks ***et al.*** (1989) evaluated the effect of fat on the flavor of Cheddar cheese. They concluded that Cheddar cheeses with low levels of fat (16.8%) lacked flavor and cheeses with intermediate levels of fat (26.7%) possessed a very mild Cheddar flavor. Off flavors in cheese include bitterness, meaty/brothy flavors and unclean flavors. These flavors are more pronounced in reduced fat cheeses due to lack of the flavor masking effect of fat and its contribution to flavor. Bitterness is usuallly caused by the presence of hydrophobic bitter peptides. These peptides result from the breakdown of proteins by proteases. Bitterness is caused by poor starter culture performance. To reduce bitterness in cheese, it is important to choose starter cultures that have high peptidolytic activity to breakdown the peptides to amino acids [Lindsay (1991)]. Meaty/brothy flavors result from a browning type reaction in which α-dicarbonyls react with amino acids producing the flavor precursors furanones and pyrazines, which produce the off flavors. Unclean flavors in cheese are unpleasant lingering aftertastes that may be associated with hydrolytic rancidity. Unclean type off flavors are caused by the presence of Strecker-type reactions that produce aldehydes and alcohols [Lindsay (1991)].

Texture defects are also commonly associated with reduced fat cheeses. Production of low-fat cheese with low moisture (43-44%) yields a cheese with a corky and rubbery body. However if the moisture is high (>47%), a soft pasty body is obtained [Johnson and Chen (1991)]. Fat occupies the interstitial spaces within the protein network of the cheese. Removal of the fat causes the protein network to be more compact and rigid, yielding a hard cheese. The increased moisture occupies some of the space previously occupied by fat and loosens the protein network, thus it is thought to improve texture.

Production of a Cheddar-type cheese with 33% fat reduction yields cheeses that are acceptable, but reductions in fat of 50% or greater produce cheeses that are of lower flavor quality and physical properties [Olson and Johnson (1990)]. In general, quality reduced fat cheeses cannot be made using conventional manufacturing procedures. Methods for improving quality of reduced fat cheeses have been suggested. These include, alteration of typical make schedules [Chen *et al.* (1992a); Chen (1991); Banks *et al.* (1989)], processing of the cheese milk prior to cheese manufacture by ultrafiltration or homogenization [McGregor and White (1990a; 1990b); Metzger and Mistry (1993)], suitable starter culture selection [Chen *et al.* (1992b); Simard (1991)], and the use of fat substitutes [El-Newshawy *et al.* (1986)].

One of the main goals of altering the cheese make schedule is to improve texture by increasing moisture retention. Chen (1991) reported on increasing moisture of reduced fat Cheddar cheeses by cooking the curd at lower temperatures, and cutting the curd using larger knives, 3/8" as opposed to 1/4", and milling at pH 5.9. These changes in manufacturing procedures, produced a Cheddar cheese with about a 44-45% moisture [Chen (1991)]. Banks *et al.* (1989) increased moisture retention in Cheddar cheese by decreasing cook temperature and reducing cheddaring and stirring time. They produced a low fat cheese (16.8%) with 47.2% moisture and an intermediate fat cheese (25.6%) with 42.9% moisture. The curd of the low fat cheese was cooked at 35°C and the curd of the intermediate fat cheese was cooked at 37°C. Both cheeses were cooked for 30 minutes and cheddared for 60 minutes. The curd of the control cheese (33.1% fat, 37.9% moisture) was cooked at 39°C for 60 minutes and cheddared for 90 minutes. The intermediate fat cheese (25.6%) had a flavor and texture quality comparable to the full fat cheese. The low fat cheese (16.8%) lacked Cheddar flavor and was judged to be over firm. Chen *et al.* (1992a) studied the effects of altering various manufacturing parameters on the quality of a 33% reduced fat Cheddar cheese. The parameters studied were milk pasteurization temperatures, starter culture levels, rennet levels, drain pH and mill pH. Higher pasteurization temperatures (77.7°C) produced a higher moisture cheese, and higher starter culture levels (2.0%) produced higher flavor intensity in young cheeses. However the quality of these cheeses deteriorated with age. They concluded that a higher curd pH at drain and mill pH, 6.37 drain pH as opposed to 6.13, produced cheeses of higher flavor and texture quality. They concluded pH control was a critical factor in producing a quality reduced fat Cheddar cheese. Washing the cheese curd, or diluting the whey with water will help control pH. High pH values at drainage will assist in water retention. Washing the curd also reduces lactose and lactic acid concentration in the cheese maintaining a higher pH, thus aiding in moisture retention [Simard (1991)]. Tunick *et al.* (1991) showed that moisture retention improves the texture of reduced fat Mozzarella cheese. Moisture of Mozzarella cheese was increased by eliminating a cooking step (45.9°C for 15 min.) in the procedure. Cheeses produced with a higher moisture, 57.4% vs. 51.8%, were softer. Moisture retention improved texture by resulting in a softer Mozzarella cheese.

Processing of the milk or cream for cheese manufacturing is another method for improving the quality of reduced fat cheeses. Emmons *et al.* (1980) produced a reduced fat Cheddar cheese using homogenized milk. The cheese was slightly softer, less elastic and had a slightly higher moisture content than cheese made from non-homogenized milk. Tunick *et al.* (1992) produced reduced fat Mozzarella cheese, 22% fat on dry basis (FDB), using milk homogenized at 10300 and 17200kPa. At the higher homogenization pressure, adverse affects were noticed in the rheological and melting properties of the cheese. At the lower pressure, the textural and melting properties were improved. Metzger and Mistry (1993) improved the texture of reduced fat Cheddar cheese by homogenization of the cream. Homogenization of the milk caused shattering of the curd. Therefore, they separated the milk into cream and skim. When skim milk was standardized to 1.9% fat with cream homogenized at 176/35 kg/cm^2, curd shattering did not occur. The cheese had an improved texture when compared to the non-homogenized control.

Ultrafiltration(UF) has been used as a method for improving quality of reduced fat cheeses [Dao and Renner (1988); Green (1990); McGregor and White (1990a; 1990b)]. The UF process increases the retention of whey proteins and enhances the removal of calcium. Increasing whey proteins may improve texture by increasing the water holding capacity of the cheese. Reduction of calcium may reduce firmness [McGregor and White (1990a)]. UF milk gels rapidly, forming a coarse protein network, which tends to lose fat and water. Heating the UF milk above pasteurization temperatures will cause it to gel more slowly and form a finer protein network which retains fat and water [Green (1990)]. Dao and Renner (1988) increased Cheddar cheese yield by 22% using heated UF milk. The cheese made from heated UF milk had an improved flavor over cheese made from non-heated UF milk. McGregor and White (1990a; 1990b) improved the texture of reduced fat Cheddar cheese using UF milk. The cheeses made from UF milk had an improved body and texture over the reduced fat cheese made from non-UF milk. However, ultrafiltration of the milk did not improve the flavor of the cheeses. Anderson ***et al.*** (1992) suggested that condensing cheese milk will improve quality of reduced fat Cheddar cheese. Condensing cheese milk to 15.4% and 18.3% total solids (TS) improved the body, texture and flavor of the cheeses. Condensation of milk by evaporation may increase fat retention and reduce the amount of fat loss in the whey [Foster ***et al.*** (1990)].

Starter selection is important for production of a quality reduced fat cheese. In manufacture of reduced fat cheeses, cultures that are less proteolytic and slow acid producers are desirable. Starters that are used for full fat cheeses produce meaty/brothy flavors in reduced fat cheeses [Johnson and Chen (1991)]. Chen ***et al.*** (1992b) studied the effects of four different starter cultures on ripening of reduced fat Cheddar cheese. ***Streptococcus salivarius*** susp. ***thermophilus*** produced acceptable Cheddar cheeses, but the cheese developed less flavor and exhibited less protein and body breakdown. ***Lactococcus*** strains produced more typical Cheddar cheeses. The strains used were ***Lactococcus lactis*** subsp. ***lactis*** and ***cremoris.*** The use of adjunct cultures may improve the texture and flavor of reduced fat cheeses. The use of ***Lactobacillus casei casei*** as an adjunct culture to increase protein and peptide breakdown improved the texture and flavor of low fat cheese [Simard (1991)]. Johnson ***et al.*** (1993) improved the texture and flavor of reduced fat cheeses using attenuated bacterial cultures. Adjunct cultures, ***Lactobacillus helveticus*** CNR232 were attenuated by freeze drying or freeze shocking. The addition of the cells accelerated body development without causing bitterness and excessive softening.

The use of fat replacers is a method for improving the texture of reduced fat cheese, specifically processed cheeses. Fat mimetics mimic the mouthfeel of fat and fat substitutes have some chemical and physical properties related to fat. Fat replacers do not contribute to flavor [Olson (1991)]. El-Neshawy ***et al.*** (1986) produced a low fat Cephalotyre (Ras) cheese using stabilizers as fat replacers. Low fat Ras, a hard Egyptian type cheese was produced from milk standardized to 1%, 1.5% and 2% fat. Carboxymethylcellulose (CMC) and carrageenan were added after addition of the culture and prior to renneting. The fat levels of the cheeses were 13%, 19% and 23% FDB, made from milk containing 1%, 1.5% and 2% fat, respectively. Addition of the stabilizers increased the softness and smoothness of the cheese. The cheese with 23% FDB had a mild flavor. The flavor of the two remaining cheeses (13% and 19%) was described as being flat. Low fat Ras cheeses made with the same fat content, without the addition of the stabilizers were hard, tough and lacked flavor. CMC and carrageenan react with milk proteins forming complexes that have high water binding capacity and enhances moisture retention of the curd.

CHEESE TEXTURE AND RHEOLOGY

Texture of cheese may be one of the most important characteristics in determination of quality and type of cheese. Rheology is the science of the deformation of matter. Texture and rheology are related because the texture of a product affects the rheological properties of that product. Rheological and fracture properties affect the eating quality, usage (ease of cutting, melting etc.) and handling of cheese [Walstra and Peleg (1991)]. Rheological characterization of cheese is important as an index for determining body, texture, quality and identity. Determination of the rheological properties of cheese provides a means of studying the structure of a product as a function of its composition. [Konstance and Holsinger (1992)].

The final texture of a Cheddar cheese is determined by its pH and ratio of intact casein to moisture. The breakdown products of casein are water soluble and are not able to contribute significantly to texture [Lawrence *et al.* (1983)]. After the cheese is manufacured, texture development of the cheese takes place mainly during the ripening process. Conditions during cheese manufacture and ripening promote the necessary microbial and enzymatic activity for degradation of proteins, which is required for proper development of the textural characteristics. Proteolysis is influenced by pH, salt to moisture ratio, moisture to casein ratio, and ripening temperature [Cooper (1987)]. Two phases of texture development occur during ripening; (1) Transformation of the rubbery curd into a smooth, homogeneous product, occurs 1-2 weeks after manufacture and about 20% of the α_{s1}-casein is hydrolyzed to yield α_{s1}-I casein; (2) Breakdown of remainder of the α_{s1}-casein causes a more gradual change in texture, which may continue for months [Creamer and Olson (1982)].

Cheese is considered a viscoelastic material, exhibiting both fluid and solid like properties. During short time spans of deformation, with low strain levels, its behavior is elastic. The sample almost regains its original shape once the applied stress is removed. During long time spans of deformation, its behavior is viscous. The cheese remains deformed after the deforming stress is removed. Cheese shows very little yield stress. Even a small amount of stress can cause a permanent deformation [Walstra and Peleg (1991)]. The three main components of cheese, casein, fat and moisture, all contribute to the rheological properties of cheese. The rheological role of casein is to provide a continuous elastic frame-work for the individual fat globules and moisture. The properties of the fat are determined by the ratio of solid to liquid (protein : moisture). Water acts as a low viscosity lubricant between the surface of the fat and protein. Deformation of the protein, causes deformation of the fat. The movement of the protein relative to the fat is lubricated by the presence of the moisture. The whole complex system and the interaction of the major components gives cheese its viscoelastic properties [Lee *et al.* (1992)].

Texture measurement of cheese involves measurement of its fundamental rheological properties. These properties are characteristic of the material and independent of the test instrument. Some fundamental properties are elastic modulus (E), shear modulus (G^*), Poisson's ratio (μ), bulk modulus (K) and viscosity (σ/δ) [Bourne (1982)]. Fundamental tests typically used to evaluate cheese include force-compression, creep and stress relaxation tests [Tunick and Nolan (1992); Prentice (1992)]. Fundamental tests can be performed using the Instron Universal Testing Machine. The Instron is a multiple measuring instrument that can also be used to measure multiple textural parameters. These parameters are hardness, fracturability, adhesiveness, cohesiveness, springiness, gumminess and chewiness [Tunick and Nolan (1992)]. There are many factors to be considered when evaluating the rheological properties of cheese. These factors include, sample shape and size, ratio of deformation, surface friction and sample lubrication [Sherman (1989)]. All of these factors will affect the measurement of its rheological properties. Ak and Gunasekaran (1992) evaluated the effect of sample lubrication and deformation rate on the rheological properties of Cheddar cheese. In this study, cheeses were subjected to six different deformation rates and were either lubricated or not lubricated. Lubrication did not affect the parameters studied. However the data from the non lubricated samples had a higher coefficient of variation. This suggests that lubrication of the cheeses produced more reproducible results.

Tunick *et al.* (1990) determined the viscoelastic properties of Cheddar and Cheshire cheeses as a method for distinguishing these two cheeses. The properties determined were the two components of shear modulus(G^*), elastic or storage modulus (G'), and viscous or loss modulus(G''), complex viscosity (η^*) and frequency (ω). The Cheshire showed G', G'' and η^* values almost half those of the Cheddar cheese after 60 weeks of ripening. The inflection point, which is the point at which the cheese begins to fracture, was also lower for the Cheshire cheese. The Cheddar cheese did not break down under the same conditions. This was expected because, Cheshire cheese has a more crumbly texture than Cheddar.

Lee *et al.* (1992) evaluated the rheological properties of cheese using an ultrasonic technique. Storage and loss modulus were measured by propagation of an ultrasonic wave through the material. The results were compared with those obtained from a Rheometer. Good qualitative agreement was found between the two measurements. This suggests that there is potential for developing this technique as a method for an on-line, non-destructive method for rheological evaluation of foods.

Creamer and Olson (1982) evaluated the effect of proteolysis on texture using rheological measurements. The force at yield point of the cheeses was measured and they found that the yield strain decreased linearly with the logarithm of days aged. This suggests that the texture of the cheese softens during aging. Bertola ***et al.*** (1992) analyzed the changes in rheological behavior of Tybo Argentino cheese during ripening. Tybo Argentino is a semi-hard cheese with 40% FDB. Uniaxial compression tests were performed using the Instron, to obtain values for hardness, adhesiveness and cohesiveness. Viscoelastic parameters, elastic moduli and relaxation times, were also obtained. Hardness decreased, adhesiveness increased and cohesiveness remained unchanged during ripening. The rheological changes correlated with water soluble nitrogen and trichloroacetic acid (TCA) soluble nitrogen. Hardness was highly correlated with viscosity.

Green ***et al.*** (1981) analyzed textural characteristics of Cheddar cheese made from concentrated milk, using the Instron. Instrumental firmness, cohesiveness, force required for fracture and adhesiveness increased as the concentration factor of the milk increased. Elasticity did not change. Metzger and Mistry (1993) analyzed the rheological characteristics of reduced fat Cheddar cheese made with skim milk standardized with homogenized cream (176/35 kg/cm^2). The cheese made with the homogenized cream (47.7% moisture) was significantly harder than cheese made with non-homogenized cream (46% moisture). The hardness values, determined by the Instron, were 9.02 kg and 11.59 kg respectively. Stampanoni and Noble (1991a & 1991b) used the Instron to evaluate the effect of fat, acid and salt on textural attributes of cheese analogs. The fat levels used were 10, 17.5 and 25 %, acid levels, 0.1 and 1.2% citric acid and salt levels, 0.5 and 2.0% sodium chloride. Cheese analogs containing higher amounts of fat were softer, less springy, more cohesive and adhesive. Increasing acid or salt increased firmness, but decreased cohesiveness and springiness as determined by the Instron. Adhikari ***et al.*** (1992) analyzed the relationship between the textural properties of Chhana and Rasogolla. These are two Indian-style cheeses. Chhana is similar to Cottage cheese and Rasogolla is a sweetened product made from Chhana. Analysis of the texture of the cheeses using the Instron showed that as Chhana was transformed to Rasogolla, hardness, gumminess and chewiness of the cheese decreased, while springiness increased.

One of the main goals of analyzing the textural properties of cheese is to determine the relationship between instrumental and sensory properties. This relationship is usually determined by observing the correlation between instrumental and sensory parameters [Zoon (1991)]. Lee ***et al.*** (1978) evaluated the texture of several cheeses including Cheddar, Cream, Mozzarella and Swiss using the Instron and a sensory panel. The panelists ranked the various samples for each of the following characteristics, hardness, brittleness, chewiness, springiness, adhesiveness and lumpiness. Hardness, chewiness, springiness and adhesiveness all correlated highly with Instron measurements. Chen ***et al.*** (1979) analyzed six textural characteristics of eleven different cheese varieties. The characteristics measured were, hardness, cohesiveness, adhesiveness, elasticity, gumminess and chewiness. Hardness, cohesiveness, chewiness and adhesiveness were correlated with measurements from a trained sensory panel, composition and pH of the cheese samples. The panel did not evaluate gumminess and elasticity. Stampanoni and Noble (1991a) observed a positive correlation between sensory and instrumental measurements as determined by a trained sensory and the Instron, of cheese analogs with varying fat, salt and acid contents. Correlations were observed between firmness and a 55% compression force, sensory and instrumental adhesiveness and springiness with modulus of elasticity. Lakhani *et al.* (1991) were not able to correlate instrumental and sensory characteristics of Cheddar cheese made from ultrafiltered milk. A trained sensory panel judged the UF cheese to be harder, more rubbery and chewy than the control cheese. The Instron was not able to distinguish among the cheeses. To obtain a correlation between instrumental and sensory measurements testing conditions must be as close as possible.

CHEESE MICROSTRUCTURE

Microstructure is the microscopic structure of a material. It is a result of the combination of chemical components and physical forces of the food [Stanley and Tung (1976)]. Microstructure is determined by the composition and processing of the product. Microstructure in turn, affects the sensory and mechanical properties of the food [Heertje (1993)]. Microstructure of dairy products may be based on fat such as in ice cream, cream cheese, butter, or on protein such as in buttermilk, yogurt, cottage cheese, or on both, as in most cheeses [Kaláb (1979)]. Lawrence *et al.* (1983) stated that the basic structure of cheese largely may be determined by the acidity at draining. This controls the mineral content of the cheese and the proportions of rennet and plasmin that remain in the curd. The structure of cheese develops as the casein micelles come together to form chains, and then a protein network which entraps fat globules and moisture. As the network forms, the curd clusters together and forms an amorphous mass [Glaser *et al.* (1980); Green *et al.* (1981)]. The basic structure of the protein network is formed during the curd firming process and does not change significantly throughout the remainder of the cheesemaking process [Green *et al.* (1981)].

The microstructure of cheese has been studied extensively using Scanning Electron Microscopy [Emmons *et al.* (1980); Green *et al.* (1981); Tunick *et al.* (1990); Adhikari *et al.* (1992)] and Transmission Electron Microscopy [Kimber *et al.* (1974); Green *et al.* (1981); Kaláb *et al.* (1991)]. The resolving power of electron microscopes enables the visualization of minute particles in dairy products, such as casein micelles and fat globule membranes [Kaláb (1993)]. The research in this area has studied the changes in the milk and curd throughout the cheesemaking process, as well as throughout the ripening stage.

Electron microscopy is a method of imaging and magnifying specimens using electrons to carry the necessary information, because electrons have greater resolving power than visible light. The Scanning Electron Microscope (SEM) has a resolving power of 3-6 nm and magnification range of 20X-150,000X [Klomparens ***et al.*** (1992)]. The SEM also had a great depth of focus which enables one to visualize three dimensional objects, including the protein networks of cheese [Kaláb (1993)].

Evaluation of cheese structure using SEM shows an open irregular protein matrix in which the lipid has been intermeshed. Young Cheddar cheeses exhibit an open irregular network, with spherical shaped openings. Initially, the structure of the cheese has a fibrous appearance. During ripening, there is a loss of the fibrous appearance and the development of a more compact, amorphous structure, as if the proteins contracted or pulled together [Stanley and Emmons (1977)]. The fat globules separate initially, but are forced together by the compacting of the casein network to form clumps. Starter cultures are typically trapped at the fat-protein interface, areas high in moisture [Kimber ***et al.*** (1974)].

Emmons ***et al.*** (1980) observed the microstructure of full and reduced fat cheeses made from homogenized milk. The fat globules in the homogenized cheeses were drastically reduced in size. In the full fat cheese, the fat globules were clustered together and associated with the protein network forming a "lace-like" structure [Emmons *et al.* (1980)]. The structure of the cheese made from reduced fat homogenized milk was not as compact as the structure of the cheese made from whole non-homogenized milk. Metzger and Mistry (1993) observed the microstructure of reduced fat Cheddar cheese made from skim milk standardized with homogenized cream. In these cheeses the microstructure showed a large number of small, evenly dispersed fat globules. In the cheeses made with non-homogenized cream, there was a small number of large, unevenly dispersed fat globules.

Green *et al.* (1981) observed microstructural changes in Cheddar cheese made from concentrated milk. In the cheeses made from the more concentrated milk, the protein was packed in larger, more compact areas and the fat was more segregated. Mistry and Anderson (1993) observed a reduction in fat globule distribution with a reduction in fat content. The microstructure of full and reduced fat, natural and processed cheeses was compared. Full fat cheese had a smooth protein matrix, with large fat globules. In the reduced fat cheeses, the protein matrix became more dense and rougher.

Kiely *et al.* (1993) observed large cavities of irregular dimensions in the microstucture of Mozzarella cheese. The cavities were dispersed randomly throughout the paracasein matrix. These observations were made

3 days after cheese manufacture. After 50 days of ripening, the porosity of the paracasein matrix decreased. The microcavities were larger in diameter. The growth of the cavities was attributed to proteolytic destruction of the protein. Taneya *et al.* (1992) observed the structure of string cheese. Stringiness, an important characteristic in string cheese, was found to be associated with a uniform, longitudinal orientation of the protein matrix. Fat, also in a longitudinal direction, was dispersed between the protein strands. The diameter of the subunits in the casein matrix were equivalent to the diameter of casein submicelles. Adhikari *et al.* (1992) compared the relationship between the microstructure in Chhana and Rasogolla, two Indian style cheeses. SEM showed that the structure of Chhana consisted of a compact, conglomerated matrix with embedded fat globules. Rasogolla, a sweetened product made from Chhana, had a ragged, porous protein matrix with collapsed and ruptured fat globules embedded in the matrix.

Ideally, a correlation between microstructure and rheological measurement is desirable. This will allow the prediction of the functional properties of a product from its microstructure. Quantitative correlation of textural and structural properties has been attempted recently and is an area of much interest to food scientists. Preliminary research has been conducted using image analysis as a method for establishing correlation [Holcomb *et al.* (1992)]. Rosenberg *et al.* (1991) used magnetic resonance imaging (MRI) as a method for viewing cheese structure. MRI is a non-destructive method which provides images of the inner structure of cheeses. This allows one the ability to determine cheese quality at any stage in the ripening process.

There are many factors involved in the development of the textural and microstructural properties of cheese. These properties are related and are important for quality determination of cheese. This research further investigates the effect fat has on the microstructural, textural and sensory properties of Cheddar cheese.

CHAPTER III

EXPERIMENTAL PROCEDURES

MILK STANDARDIZATION

Raw skim milk (0.03% milkfat) and cream (40.0% milkfat) were obtained from Michigan Milk Producers Association (Ovid, Michigan). The skim milk was pasteurized at 74°C for 18 sec. and the cream was pasteurized at 63°C for 30 min. The skim milk and cream were stored at 2°C until use. The milk for cheese manufacture was standardized to, 4.0%, 3.2%, 2.4%, 1.6%, 0.8%, and 0.03% fat. The final fat content of the milk was determined using the Babcock method for fat determination [Marshall (1992)]. Table 1 shows the composition of the milk used for cheese manufacture.

MANUFACTURE OF CHEDDAR CHEESE

Cheddar cheese was manufactured according to the procedure outlined by Kosikowski (1982) using pilot plant equipment. The milk was warmed to 31°C and ripened for one hour using Redi Set DVS (Direct Vat Set) cheese culture (DVS #980, Chr. Hansens Laboratory, Milwaukee,WI). The milk was set in 30 minutes using Chymax-Double Strength (Pfizer, Milwaukee,WI). The curd was salted at a 2.3% level, (weight of the curd), hooped and pressed for 18 hours. The cheeses were vacuum sealed and allowed to ripen for four months (16 weeks) at 7°C.

Table 1. Composition of milk for cheese manufacture.

TREATMENT	% MILKFAT	% MILK PROTEIN	TOTAL SOLIDS
1	4.0	3.00[a]	12.30[a]
2	3.2	2.91[a]	11.60[b]
3	2.4	2.93[a]	10.91[c]
4	1.6	2.92[a]	10.19[d]
5	0.8	2.82[a]	9.31[e]
6	<O.1	2.96[a]	8.76[f]

[a-f] Means with the same superscript within a column do not differ significantly. ($p<0.05$) n=4 for all treatments.

ANALYTICAL PROCEDURES

Babcock Fat Test

The fat content of the milk, cream and cheeses was determined using the Babcock method outlined by Marshall (1992).

Kjeldahl Protein Determination

The protein was estimated by determining the total nitrogen content of the samples using the Kjeldahl nitrogen determination method [Marshall (1992)]. The nitrogen determination system used consisted of the Buchi 342 control unit, the Tecator 40/1016 digester, the Buchi 322 digestion unit, the Metrohm 614 impulsomat, the Metrohm 623 pH meter and the Metrohm 655 Multi-Dosimat unit [Buchi Laboratories, Flawil, Switzerland]. The % total nitrogen was determined from the volume of HCl used to titrate the sample to an endpoint using the following equation:

$$\%\ TN = \frac{(HCl_s - HCl_b)}{\text{Sample weight}} \times A \times \text{Normality } HCl \times 6.38 \times 100$$

where:
HCl_s = volume HCl used to titrate sample to the endpoint(ml)
HCl_b = volume HCl used to titrate blank to the endpoint(ml)
Sample weight = weight of sample (g)
A = 1.4007 (g/mol)
6.38= nitrogen conversion factor for dairy products

Atmospheric Oven Moisture Determination

The total solids of the milk and moisture of the cheese was determined using an atmospheric oven method outlined by Marshall (1992).

TEXTURAL EVALUATION

The texture of the Cheddar cheese manufactured was evaluated after 16 weeks of ripening using the Instron Universal Testing Machine Model 4202,#537 (Livonia, MI) (Figure 1). Cylindrical samples of 20x20 mm size at 9°C were used for analysis. The cheeses were cut the day before testing and stored at 9°C. The cheeses were held at this temperature until the test was performed. A two-bite compression test was performed at 80% compression, 10KN load cell, crosshead speed of 100mm/min and chart speed of 20 cm/min. Adhesiveness, cohesiveness and hardness was determined from the Texture Profile Analysis curve (Figure 2).

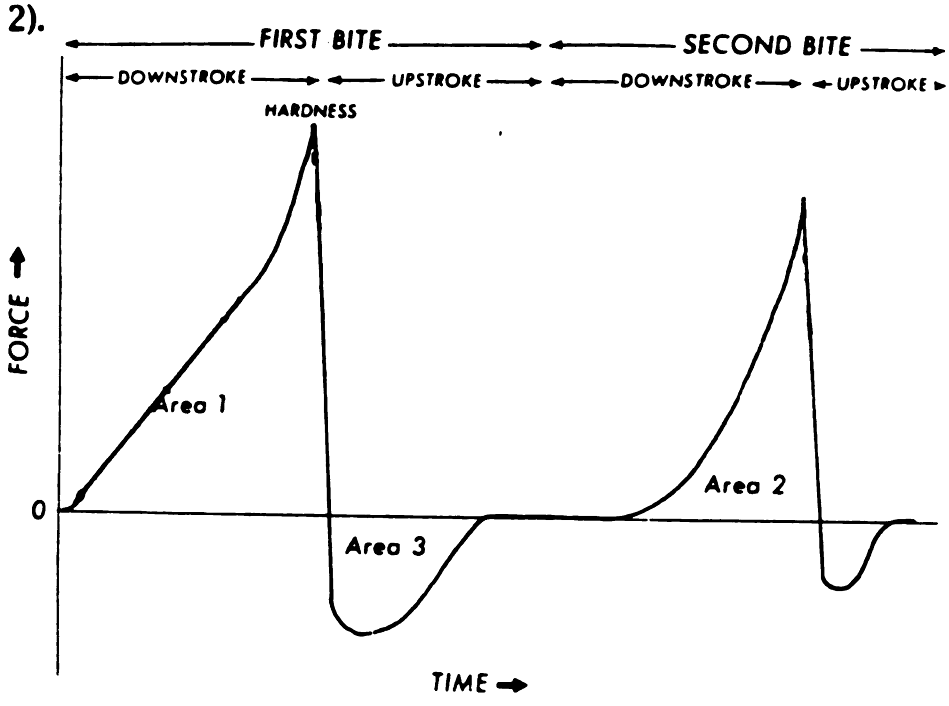

Figure 2. Texture Profile Analysis curve from Instron Universal Testing Machine.

Figure 1. Instron Universal Testing Machine

The samples were lubricated by placing one drop of vegetable oil on the top and bottom surfaces of the sample. The compression plate and surface of the Instron was cleaned with a paper towel after measuring each individual sample.

Hardness was determined from the height of the force peak from the first compression. A is the beginning of the first compression and B is the beginning of the second compression (Figure 2). Cohesiveness was determined by taking the ratio of the areas A_2 and A_1 (A_2/A_1). Adhesiveness was determined from the area A_3. The Instron gives a force-time curve as well as a force-distance curve, which enables the parameters obtained from it to have the dimensions listed in Table 2.

Table 2. Dimensional Analysis of TPA parameters[a].

Mechanical parameter	Measured variable	Dimensions of measured variable
Hardness	Force	mlt^{-2}
Cohesiveness	Ratio	Dimensionless
Springiness	Distance	l
Adhesiveness	Work	ml^2t^{-2}

[a] Reprinted from Bourne(1967) *J. Food Sci.* 32, 154. Copyright by Institute of Food Technologists.
m=mass, l=length, t=time

Springiness was determined using a 55% compression test similar to Stampanoni and Noble (1991a). The height of the sample was measured before and after compression and springiness was expressed as percent the sample returned to its original height, using the following eqation (Figure 3).

$$\textit{Springiness} = \frac{L - \Delta L}{L}$$

where:
L = height of sample before compression (mm)
ΔL = change in height of sample after compression (mm)

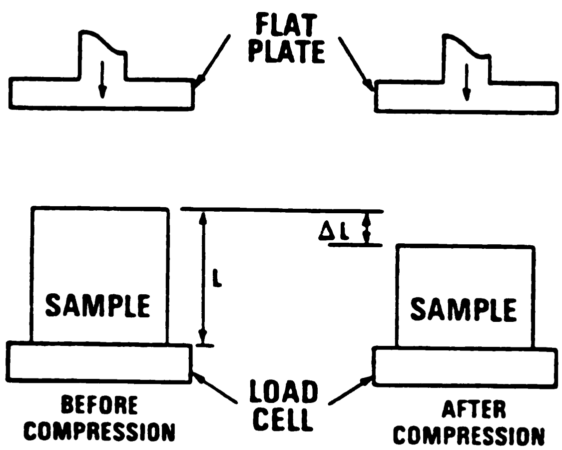

Figure 3. Textural definition of springiness (elasticity). (Reprinted from Chen *et al.* (1979) *J. Dairy Sci.* 62(6), 903. Copyright by Journal of Dairy Science)

MICROSTRUCTURAL EVALUATION

The microstructure of the cheeses manufactured was evaluated using the Scanning Electron Microscope (SEM) following the method outlined by Tunick ***et al.*** (1990) with modifications. Small samples of each cheese were cut and primary fixed in 4% buffered glutaraldehyde for 1 ½ hours, washed in 0.1M phosphate buffer for 30 minutes, post fixed in buffered Osmium tetroxide for 2 hours and washed for 30 minutes in 0.2 M phosphate buffer. The samples were dehydrated in increasing ethanol and water solutions, 25%, 50%, 75% and 100% for 30 minutes in each solution. The samples were quick frozen and fractured in liquid nitrogen to expose an uncut surface and placed in fresh 100 % ethanol. The samples were critical point dried in a Balzers Critical Point Dryer (Figure 4) and coated with a thin layer of gold in an Emscope Sputter Coater EM 500 (Figure 5). The samples were viewed on a JEOL Scanning Electron Microscope (Figure 6) at 15 KV accelerating voltage.

SENSORY EVALUATION

The texture of the six cheeses manufactured was evaluated at 16 weeks of ripening using a trained sensory panel. The panel consisted of faculty and graduate students at Michigan State University, East Lansing, MI. The panel evaluated four textural characteristics, adhesiveness, cohesiveness, hardness and springiness. A trained panel was used

Figure 4. Balzers Critical Point Dryer

Figure 5. Emscope Sputter Coater EM500

Figure 6. JEOL Scanning Electron Microscope

because most individuals are not familiar with the specific characteristics measured and would perceive each characteristic in a different manner. Training provides a sensory panel that is familiar with the attributes tested and have similar perceptions of each attribute. Panel members were selected first by participating in a primary screening process. Approximately 20 people participated in the screening. Each participant was screened for his or her ability to distinguish the four desired characteristics, adhesiveness, cohesiveness, hardness, and springiness. The panelists initially attended a brief orientation in which the goal and purpose of the experiment was explained as well as the definitions and procedure for evaluating each characteristic [Civille and Szczesniak (1973)]. Before evaluating the samples, the panelists signed a consent form (Appendix A, Table A.2) and completed a questionnaire to assist the panel selection process (Appendix A, Table A.1). The tests were conducted in a sensory room, room temperature (25°C) under fluorescent lighting. Testing took place in individual testing booths. The panelists were presented a tray, containing three cheese samples that ranged in their degree of each characteristic (adhesiveness, cohesiveness, hardness, springiness), crackers, a pencil for scoring, a score sheet and a cup of water at room temperature. The panelists were asked to rank the samples from least to most for each characteristic (Appendix A, Table A.3) [Larmond (1987)].

The cheeses were cut into 20x20 mm cylinders the day before testing and refrigerated. The temperature of the samples during the testing was 9°C. The samples used for training were commercial Cheddar and Colby cheeses purchased from the local grocery store. Panelists who were able to correctly determine the order of the samples were selected to be a part of the trained sensory panel. Fifteen panelists were selected to undergo panel training.

The fifteen selected members participated in four panel training sessions. In each session, the panelists were given a tray containing five cheese samples and instructed to assign a specific value to the sample based on which characteristic was being judged (Appendix A, Table A.4-A.7). Each of the five samples corresponded to a specific value on a 9 point scale, either 1,3,5,7 or 9, 1 being least, 5, being moderate and 9 being most of each characteristic e.g. least adhesive, moderately adhesive etc. The panelists were also instructed as to how to evaluate each sample. To determine adhesiveness, the panelists were asked to place sample between molars; chew sample five times; press sample to the roof of mouth with tongue; evaluate the force required to remove the sample from the roof of the mouth with tongue. To determine cohesiveness, the panelists were asked to place sample between molars; compress fully; evaluate the degree to which the sample deforms rather than crumbles, breaks or falls apart. To determine hardness, the panelists were asked to place sample between molars; bite through once; evaluate for hardness, and to determine springiness, the panelists were asked to place the sample between the molars; compress partially without breaking the sample structure [Civille and Szczesniak (1973)]. This portion of the training session took place in panel booths, the panelists judged the samples individually and no discussion took place.

After evaluating the samples, the panelists were seated around a table and given the same samples. The panelists were told the correct responses, allowed to taste the samples again and compare the correct response to their original response. During this portion of the panel training, panelists were allowed to discuss their responses as well as give suggestions to the panel leader.

After 16 weeks of ripening the trained panelists evaluated all six cheeses manufactured for this study for the four characteristics: adhesiveness, cohesiveness, hardness and springiness. The samples were cut into 20x20 mm cylinders the day before testing and stored at 9°C until testing. The samples were coded with three digit numbers (Appendix C, Table C.1). The panelists were presented with a tray containing four cheeses of same treatment (one sample to evaluate each characteristic), four score sheets, one for each characteristic, a pencil for scoring, crackers and a cup of water. The samples were presented to the panelists in a random order (Appendix B). The panelists evaluated each cheese for each characteristic using a nine point intensity scale (Appendix A, Table A.3). The panelists were allowed to evaluate 3 treatments, a total of 12 samples per session to reduce fatigue.

Overall texture acceptance was also determined. This was investigated using an untrained sensory panel, consisting of faculty, staff, graduate and undergraduate students at Michigan State University. The untrained panel evaluated treatments 1-5 (34%, 31.5%, 26.8%, 20.5%, 12.6% fat cheeses) after 36 weeks of ripening. The panelists completed a short questionnaire to obtain information about their dietary habits (Appendix A, Table A.8). The panelists were presented a tray containing all five cheeses labeled with a 3-digit code in a random order (Appendix C, Table C.2) and instructed to taste each sample and indicate their degree of likeness of the texture of the cheese using a nine point hedonic scale ranging from 1=dislike extremely to 9=like extremely (Appendix A, Table A.9) [Meilgaard *et al.*(1987)]. The panelists were also given crackers and water and instructed to rinse their mouths between samples. Twenty-five panelists evaluated each replicate of all five cheeses, giving a total of 100 panelists for the entire experiment.

STATISTICAL ANALYSIS

A randomized block design was used consisting of six treatments, with four replicates of each treatment. The data was analyzed using the

Microcomputer statistical program (MSTAT) (Crop & Soil Sciences, Michigan State University). A one-way Analysis of Variance (ANOVA) and Student-Neuman-Keul's test was conducted to determine the treatment means and differences between the treatment means at the 0.05 probability level.

CHAPTER IV

RESULTS AND DISCUSSION

CHEESE COMPOSITION

The composition (fat, protein and moisture) of the cheeses are listed in Table 3. Composition was determined to evaluate the effect of changing the milkfat content on final cheese composition. As expected, reduction in milk fat, resulted in a reduction in fat content ($p<0.05$) and thus an

Table 3. Cheese composition

TREATMENT	% MILKFAT	% FAT	%MOISTURE	%PROTEIN
1	4.0	34.0[1a] (2.94)	38.5[a] (1.34)	22.3[a] (1.74)
2	3.2	31.50[b] (2.35)	39.7[a] (1.89)	24.3[a] (1.06)
3	2.4	26.8[c] (1.44)	40.8[a] (1.35)	27.9[b] (1.53)
4	1.6	20.50[d] (1.96)	40.8[a] (1.81)	32.7[c] (1.26)
5	0.8	12.6[e] (1.93)	44.7[b] (2.16)	36.4[d] (1.06)
6	<0.01	<0.1[f] (--)[2]	49.6[c] (1.29)	42.3[e] (1.69)

[1] Means with standard deviations in parentheses, n=4 for all treatments
[2] % Fat not detectable
[a-f] Means with the same superscript within a column do not differ significantly ($p<0.05$).

increase in moisture and protein content of the cheeses. The fat contents of the cheeses were 34.0%, 31.5%, 26.8%, 20.5%, 12.6% and <0.1%, when manufactured from milk containing 4.0%, 3.2%, 2.6%, 1.8%, 0.8% and 0.03% fat, respectively. The moisture content of these cheeses ranged from 38.5% - 49.6%, and the protein ranged from 22.3% - 42.3%. It was also noted that removal of fat from Cheddar cheese affected the overall appearance of the cheeses. Fat reflects light. When fat was removed, the cheeses became more translucent and darker in color (Figure 7).

MICROSTRUCTURE EVALUATION

The effect of fat content on the microstructure of the Cheddar cheeses was studied using Scanning Electron Microscopy (Figures 8-13). Scanning Electron micrographs show the basic protein network of the cheese. The fat, which was removed during the fixation process, occupied the open regions within the protein network. The effect of fat on the microstructure of Cheddar cheese is apparent when examining the micrographs. Figures 8 & 9 show the microstructure of cheeses containing 34.5% and 31.5% fat. As observed by the SEM, these cheeses had an open, lacy, irregular network, suggesting that the fat is distributed in an uneven pattern throughout the matrix. The fat appeared to have been present as clusters or aggregates of fat globules. The gradual decrease in fat is

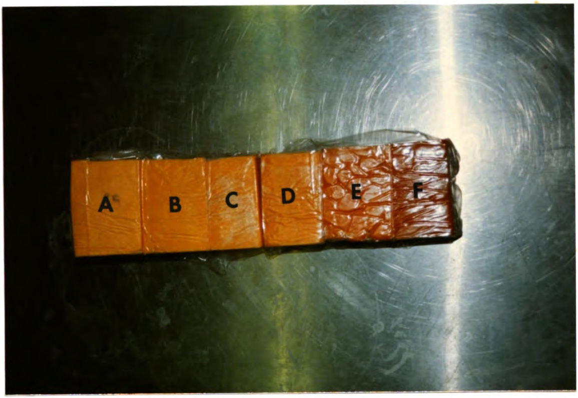

Figure 7. Cheddar cheese manufactured with varying fat contents. Fat content (%): A=34% B=31.5% C=26.8% D=20.5% E=12.6% F=<0.1%

evident when comparing the micrographs of the different cheeses. The microstructure of treatment 3, containing 26.8% fat, (Figure 10) still has the open microstructure, but not as open as that of the higher fat Cheddar cheeses (34.0 and 31.5%). The openings observed were more spherical in shape and more defined. Areas existed in the protein matrix that weren't broken up by fat, resulting in strong protein bridges. The structure became more dense and compact. The Cheddar cheese containing 20.5% fat cheese was similar in its microstructure to the cheese containing 26.8% fat (Figure 11). However, the fat was distributed in a more regular pattern giving the microstructure a sponge like, but more defined appearance.

The lower fat Cheddar cheese containing 12.6% fat had very few openings (Figure 12). The openings were spherical in shape and scattered evenly throughout the protein matrix. The majority of the microstructure appeared to be dense, compact protein. The skim milk cheese, with <0.1% fat contains no openings in its structure (Figure 13). The structure has a almost flat, rock like appearance. This cheese is essentially a solid block of protein. Without the fat present to disrupt the protein network, the protein formed a compact, very rigid microstructure.

Tunick *et al.* (1991) used Scanning Electron Microscopy as a method to distinguish differences between Cheddar and Cheshire cheeses. The two cheeses were purchased locally and analyzed at 60 weeks and 20 weeks

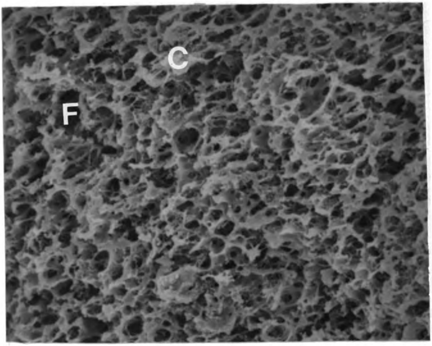

Figure 8. Scanning Electron micrograph of Cheddar cheese with 34% fat. Magnification 800X C=casein F= area previously occupied by fat globule.

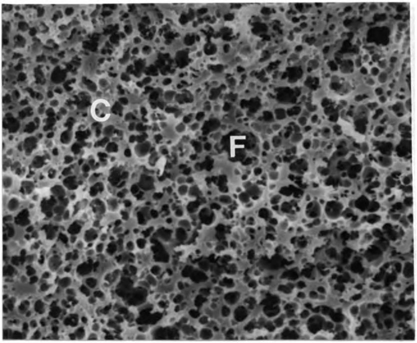

Figure 9. Scanning Electron micrograph of Cheddar cheese with 31.5% fat. Magnification 800X C=casein F= area previously occupied by fat globule.

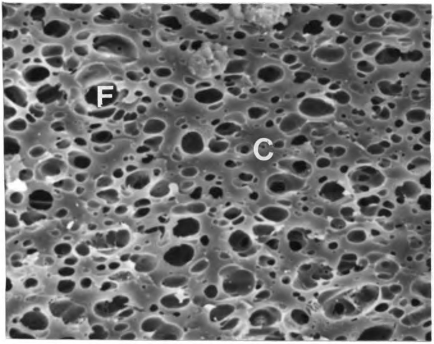

Figure 10. Scanning electron micrograph of Cheddar cheese with 26.8% fat. Magnification 800X C=casein F= area previously occupied by fat globule.

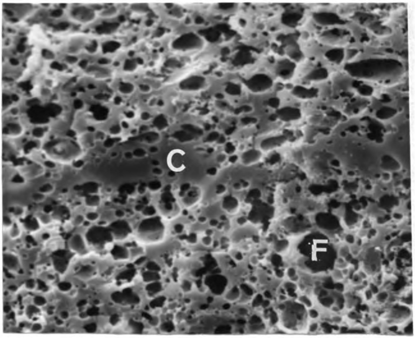

Figure 11. Scanning electron micrograph of Cheddar cheese with 20.5% fat. Magnification 800X C=casein F=area previously occupied by fat globule.

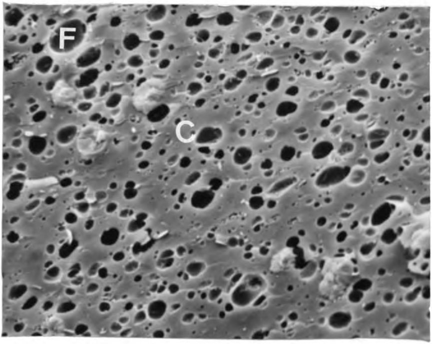

Figure 12. Scanning electron micrograph of Cheddar cheese with 12.6% fat. Magnification 800X C=casein F= area previously occupied by fat globule.

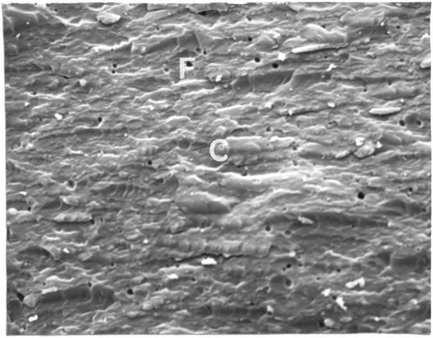

Figure 13. Scanning electron micrograph of Cheddar cheese with <0.1% fat. Magnification 800X C=casein F=area previously occupied by fat globule.

respectively. The Cheddar and Cheshire cheeses, containing between 30-33% fat were described as having a smooth, continuous network surrounding irregular lipid inclusions, similar to observations in this study. The microstructure of the Cheddar cheese was similar, however the protein matrix in the Cheddar cheese was more dense, than that observed in Cheshire cheese. The size of the lipid inclusions in Cheddar cheese ranged from 1-5μ in diameter and the lipid inclusions in the Cheshire cheese ranged from 2-30μ in diameter. The microstructure of the two cheeses were different, however the microstructure of the Cheddar was similar to the microstructure observed in Mozzarella cheese. The microstructure of Mozzarella cheese has been described as a dense, homogenous paracasein matrix, with a large number of microcavities of irregular dimensions [Kiely *et al.* (1993)]. Mistry and Anderson (1993) compared the microstructure of commercial full and reduced fat, processed and natural cheeses. Similar to the results observed in this experiment, the protein matrix became more dense and compact as the fat content of the cheese decreased. In the reduced fat cheeses, the protein dominated the structure. The full fat cheeses had a smooth protein matrix interlaced with aggregated fat globules.

TEXTURAL EVALUATION

Adhesiveness is defined as the work necessary to overcome the attraction forces between the surface of the sample and the surface of the other materials with which the food comes in contact, in this case the compression plate [Civille and Szczesniak (1973)]. The adhesiveness from the Texture Profile Analysis is a measure of the negative force or curve A_3 on the TPA (Figure 2). This is a measure of how much the sample sticks to the plunger plate, as the plunger begins its upstroke. The adhesiveness of the cheese increased as the fat in the cheese increased (Figure 14). The higher fat cheeses (34%, 31.5%), with scores of 1.15 and 1.13 N.mm, were more adhesive than the lower fat cheeses(20.5%, 12.6%) with scores of 0.53 and 0.49 N.mm respectively (Table 4). However these differences were not significant. There was no curve produced with the skimmilk cheese (Table 4). The adhesiveness results obtained from the Instron were not very conclusive. A high variation was observed. One factor that may have affected the adhesiveness results and contributed to the variation, was lubrication of the compression plates. With samples containing fat, the cheese sample stuck to the plunger without lubrication, and prevented the production of an accurate TPA curve. Once the plate was lubricated, the cheeses did not produce very high adhesiveness scores. The fat in the cheese also contributed to lubrication of the plate. As the sample is compressed, fat is exuded contributing to lubrication. Similar to the results

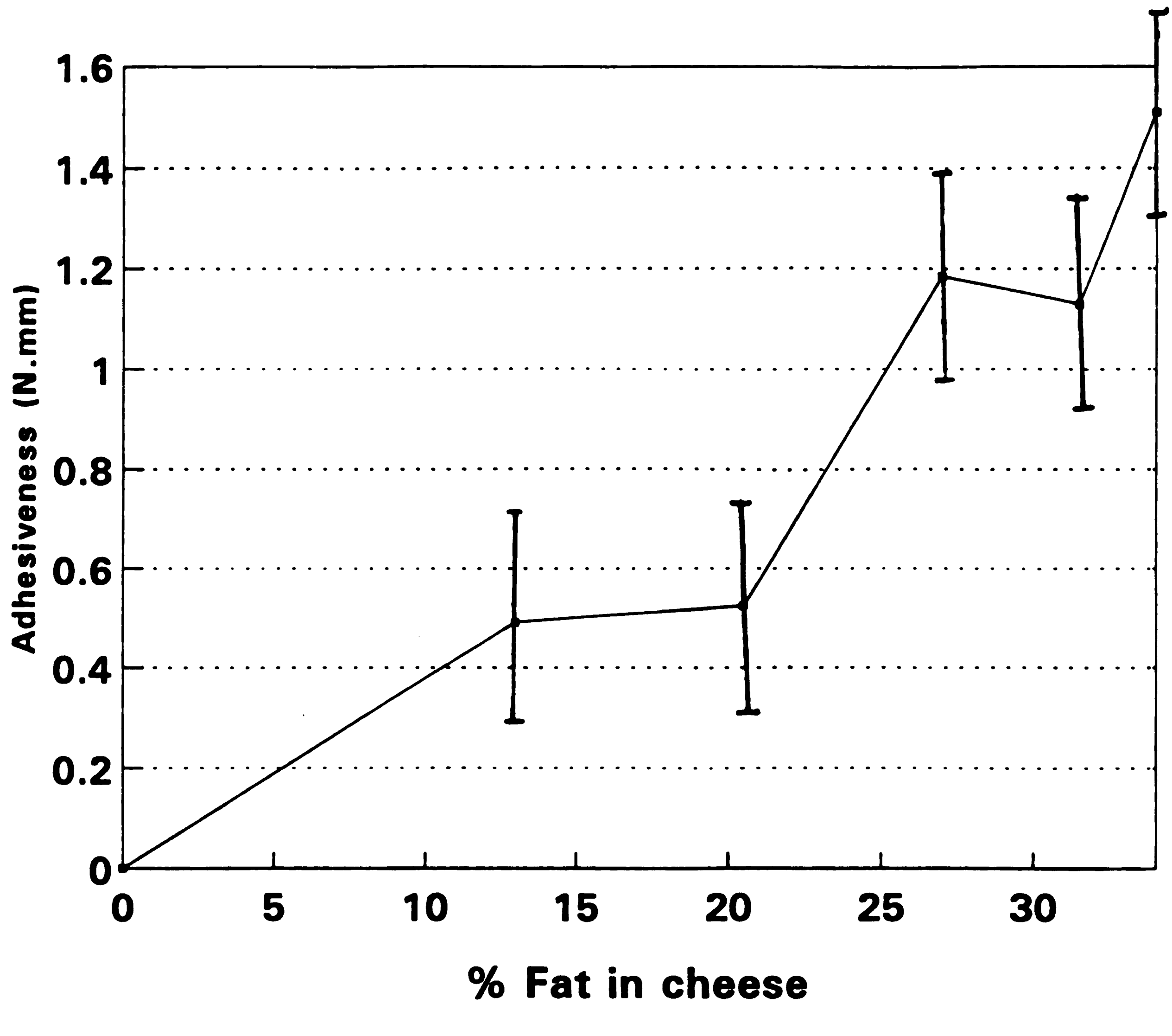

Figure 14. Influence of fat on adhesiveness of Cheddar cheese as determined by the Instron Universal Testing Machine.

obtained in this experiment, Adhikari *et al.* (1992) failed to obtain a curve for adhesiveness when evaluating the texture of Chhana and Rasogolla, two Indian style cheeses. However the fat content of the Chhana was 22.4% and the fat content of the Rasogolla was 7.8%. Therefore other factors such as manufacturing procedures or components of the cheese other than fat affected the lack of adhesiveness of these cheeses. Chhana is manufactured by direct acidification of cow's milk and is similar to cottage

Table 4. Textural characterization of Cheddar cheese as influenced by fat content: Results from Texture Profile Analysis

TREATMENT (% fat)[1]	ADHESIVENESS N.mm	COHESIVENESS (Ratio)	HARDNESS (N)	SPRINGINESS (%)
34.0	1.15[a] (0.62)[2]	0.135[a] (0.03)	193.7[a] (66.55)	58.1[a] (13.26)
31.5	1.13[a] (0.80)	0.131[a] (0.03)	260.7[a] (105.37)	57.8[a] (7.25)
26.8	1.18[a] (0.36)	0.154[a] (0.02)	280.0[a] (60.25)	71.5[b] (6.04)
20.5	0.525[ab] (1.44)	0.192[b] (0.03)	468.7[b] (129.96)	78.9[c] (8.19)
12.6	0.492[ab] (0.82)	0.216[b] (0.04)	762.3[c] (186.36)	88.1[d] (6.52)
<0.1	0.0[c] (--)[3]	0.271[c] (0.06)	960.3[d] (168.97)	94.6[d] (2.52)

[1] % Fat in cheese
[2] Standard deviations in parentheses n=4 for all treatments
[3] Adhesiveness not detectable
[a-e] Means with the same superscript within a column do not differ significantly ($p<0.05$).

cheese. Rasogolla is produced from Chhana by cooking kneaded Chhana in concentrated syrup.

The physical description of cohesiveness is the extent to which a material can be deformed before it ruptures [Civille and Szczesniak (1973)]. The cohesiveness results are strongly due to the way cohesiveness is measured on the Instron. Cohesiveness is related to the hardness and springiness of the cheese when measured by the Instron since it is determined as a ratio of curve A_2 to A_1 of the TPA curve (Figure 2). If an extremely hard, springy cheese is being measured then the ratio of A_2/A_1 will be large, because the height of both peaks will be high. The sample has a tendency to recover, generating a high A_2 peak. If the cheese is relatively soft, the recovery of the sample is not as great and the height of peak A_2 will be shorter, relative to peak A_1 decreasing the overall ratio. Cohesiveness of Cheddar cheese decreased as the fat content of the cheese increased (Figure 15). In this evaluation, the higher fat cheeses with 34, 31.5, and 26.8% fat were similar in their cohesiveness, with cohesiveness values of 0.135, 0.131 and 0.154 respectively (Table 4). At 20.5% fat, a significant increase ($p<0.05$) in cohesiveness was detected among the cheeses. The intermediate (20.5%) and low fat (12.6%) cheeses were similar in their cohesiveness, with scores of 0.192 and 0.216. The skim milk cheese (<0.1%) with a value of 0.271 was the most cohesive cheese ($p<0.05$) as determined by the Instron.

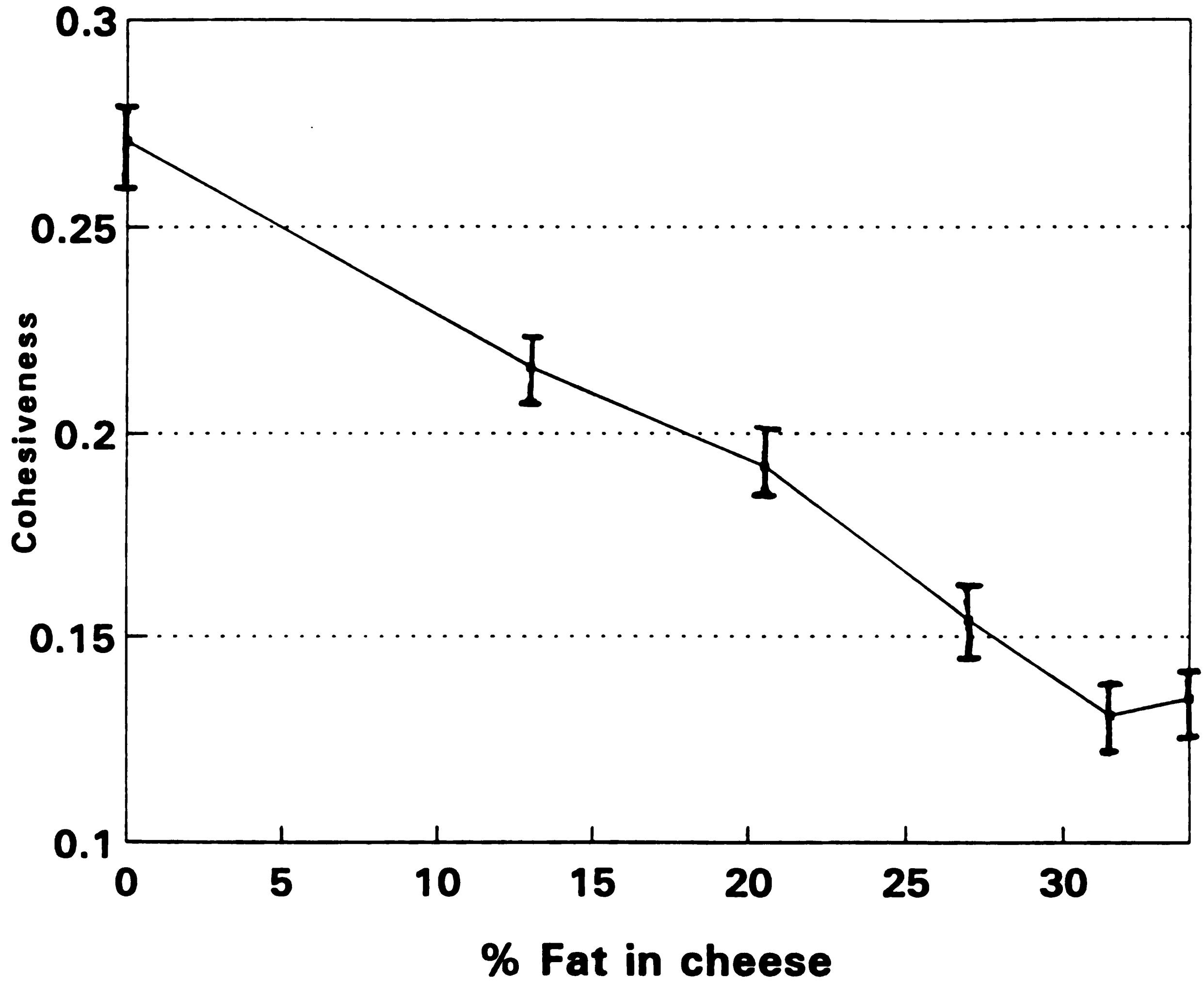

Figure 15. Influence of fat on cohesiveness of Cheddar cheese as determined by the Instron Universal Testing Machine.

These results are consistent with those obtained by Stampanoni and Noble (1991a). Cheese analogs made from rennet casein, deionized water and melted vegetable fat, became more cohesive as the fat content of the analog was decreased. The cheese analogs were cut into 13x10 mm cylinders and evaluated with the Instron at 9°C. The objective of the experiment was to determine the effect of fat, acid or salt levels on the texture of cheese analogs. Cohesiveness was also related to the salt and acid levels in the analog. Cheese analogs containing higher levels of acid or salt were less cohesive. These results suggest that fat alone does not effect the cohesiveness of cheese, the composition and interaction of the other components contribute to cheese cohesiveness as well.

Hardness is defined as the force necessary to obtain a given deformation [Civille and Szczesniak (1973)]. Hardness on the Instron is measure of the force in Newtons required to compress the samples to 80% of their original height with a flat plate plunger. Hardness of the Cheddar cheese decreased ($p<0.05$) as the fat content if the cheese increased (Figure 16). The higher fat cheeses (34%, 31.5% and 26.8%) were softer ($p<0.05$) than the lower fat cheeses. These cheeses were similar in their hardness with scores of 193.7, 260.7 and 280 N respectively (Table 4). Differences in hardness became apparent when fat was reduced to 20.5% in Cheddar cheese. The cheese containing 12.6% fat was harder ($p<0.05$)

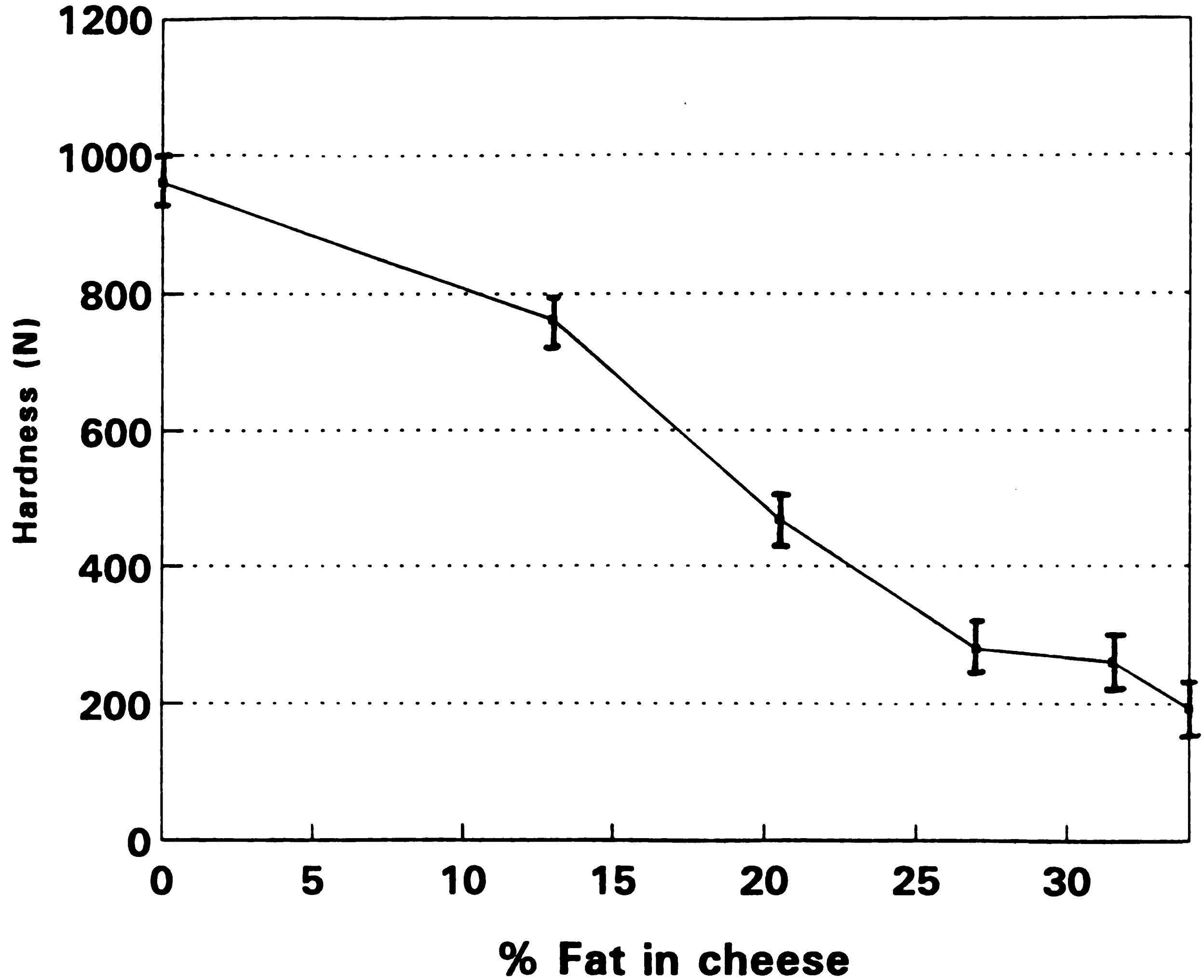

Figure 16. Influence of fat on the hardness of Cheddar cheese as determined by the Instron Universal Testing Machine.

than the cheese containing 20.5% fat with a value of 762.3 N. The skim milk cheese (<0.1% fat) was the hardest, requiring 960.3 N for compression. When the fat is removed from cheese, the protein becomes more compact and rigid as observed in the scanning electron micrograph discussed previously (Figure 13). The skim milk cheese with <0.1% fat was essentially a rigid block of casein and very firm and rigid in its microstructure since there wasn't enough fat present to loosen the protein network. This cheese was very compact and dense, therefore very hard as observed with Instron values. High variation in the data among the replicates was observed when measuring hardness. The textural evaluation of the hardness or firmness of cheese is very complex. Hardness is affected by the composition of the cheese as well as the conditions of the experiment. Hardness is also affected by the size of the sample, % deformation, and the amount of surface friction [Sherman (1989)]. The variation in this experiment most likely arose from surface friction. When cylindrical shapes are deformed, they assume a barrel shape. This results from the surface friction between the compressing plate and the surface of the sample and hinders lateral movement of the upper and lower surfaces of the cheese. Some of the compressing force is used to overcome the surface friction and not all the force is used to compress the food. Barrel deformation can be eliminated by lubrication of the sample with oil, or bonding the sample to the compression plates [Sherman (1989)]. The cheeses in this study were lubricated, however, lack of uniform lubrication among samples may have caused the variation observed in this experiment. Another factor that may have contributed to the variation is the presence of openings within the cylindrical cheese samples. If there were openings in the sample, this would have resulted in a lower force required for deformation.

These results are consistent with those obtained by Stampanoni and Noble (1991a & 1991b). Cheese analogs manufactured with rennet casein, deionized water and melted vegetable fat, became more firm as the fat content of the analog was decreased. Firmness was measured with a 80% flat plate compression force as well as a 80% puncture force using a U-shaped probe. In contrast to the results obtained in this experiment, Tunick *et al.* (1991) observed little change in the hardness of Mozzarella cheese when fat content was decreased. Low fat, high moisture (22.3% FDB, 57.4% moisture) Mozzarella cheeses had hardness values comparable to high fat, low moisture (47.6% FDB, 47.3% moisture) Mozzarella cheeses.

Springiness is the rate at which a deformed material goes back to its undeformed condition after the deforming force is removed. Springiness of the cheeses decreased as the % fat in the cheese increased (Figure 17). Cheddar cheese containing 34 and 31.5% fat had similar springiness with scores of 58.1% and 57.8%, respectively. When fat was reduced to 26.8%, significant differences ($p<0.05$) in springiness were detected. This cheese

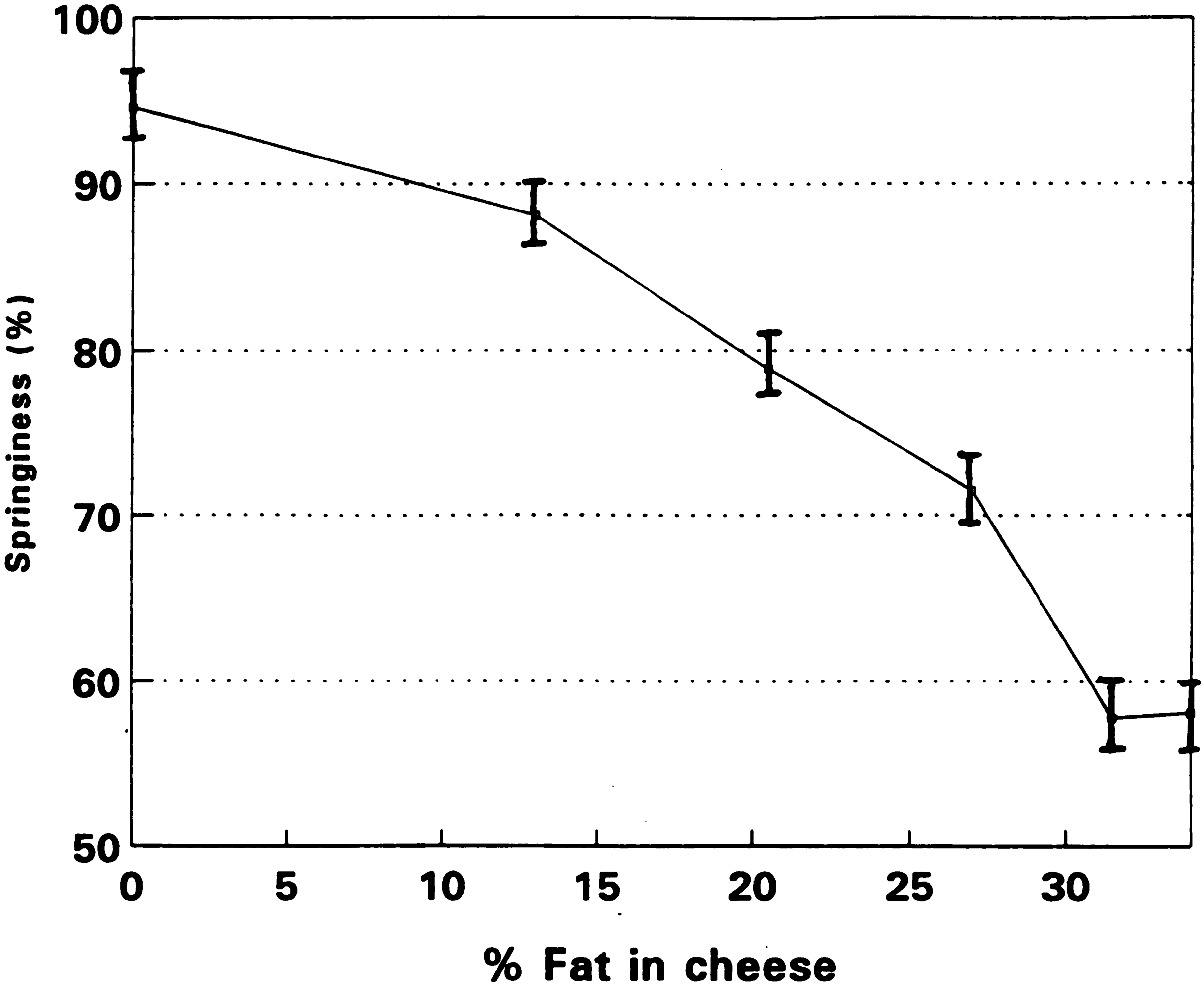

Figure 17. Influence of fat on springiness of Cheddar cheese as determined by the Instron Universal Testing Machine.

exhibited 71.5% recovery. The Cheddar cheese became more springy ($p<0.05$) with 20.5% fat exhibiting 78.9% recovery. The lower fat cheeses, 12.6% and <0.01% fat, exhibiting 88.1 and 94.6% recovery, these values were statistically similar. As with the hardness, the high variation observed when measuring springiness is most likely due to surface friction.

Consistent with the springiness results obtained in this experiment, Stampanoni and Noble (1991a) observed an increase in the springiness of cheese analogs manufactured with rennet casein, deionized water, and melted vegetable fat, with increased levels of fat. In contrast to the results obtained in this experiment, Tunick *et al.* (1991) did not observe a change in the springiness of Mozzarella cheese when the fat content was reduced.

SENSORY EVALUATION

Trained sensory panelists evaluated the six Cheddar cheeses of varying fat contents for four textural characteristics (adhesiveness, cohesiveness, hardness, springiness) (Table 5). The results from the trained panel texture evaluation followed a distinct pattern. Generally adhesiveness and cohesiveness increased as the % fat content of the cheese increased and hardness and springiness decreased as the % fat in the cheese increased (Figure 18). Adhesiveness in sensory applications refers to the force required to remove the material that adheres to the mouth (generally the palate) during the normal eating process. The method used in the

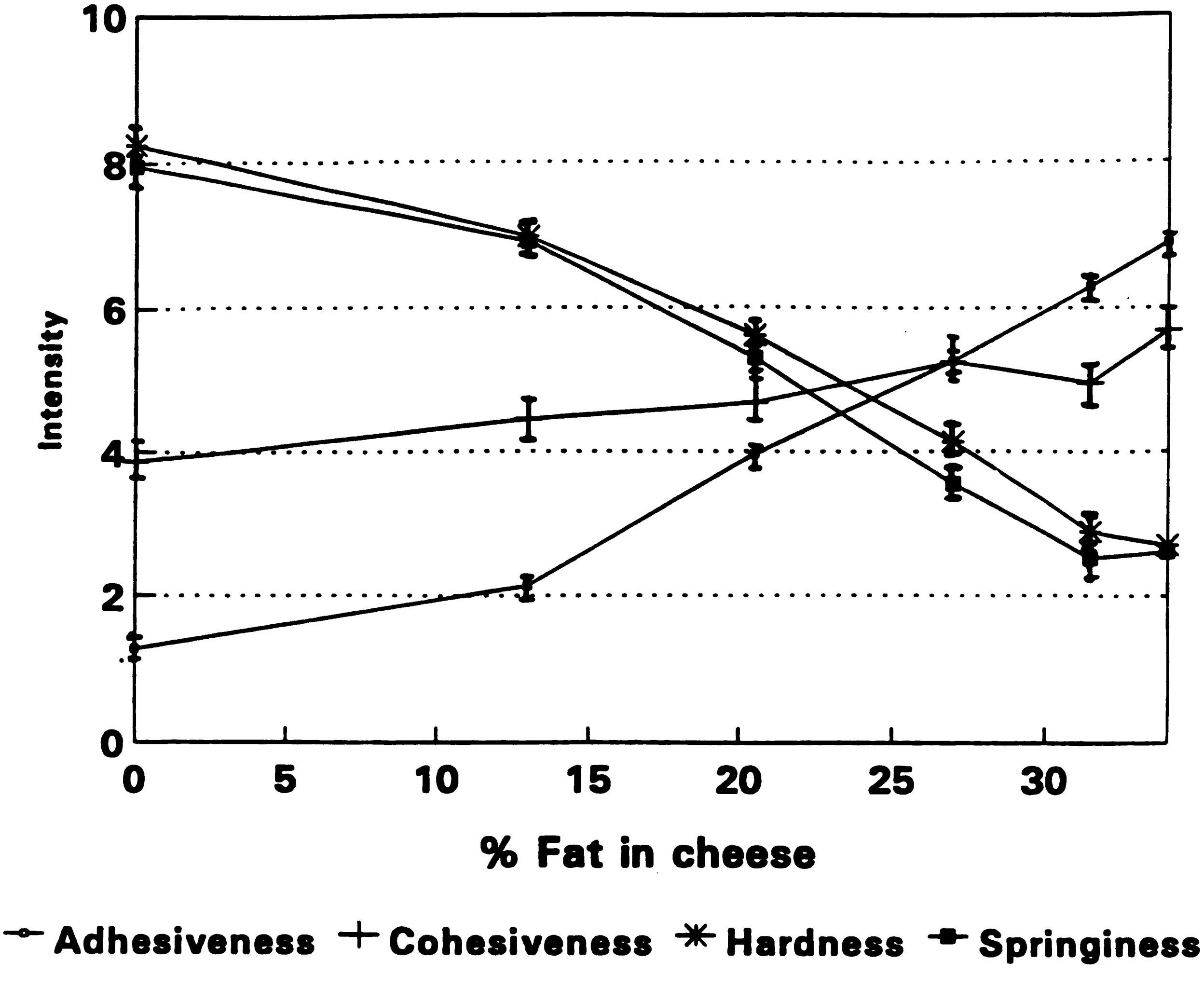

Figure 18. Influence of fat content on the textural characteristics of Cheddar cheese as determined by a trained sensory panel.

adhesiveness evaluation involved the panelists physically forcing the cheese sample to the roof of their mouth with the tongue and evaluating the force required to remove the sample from the roof of the mouth [Civille and Szczesniak (1973)]. Adhesiveness scores increased as the fat content of the cheese increased. Adhesiveness scores were significantly different ($p<0.05$) for all cheeses with the exception of the two higher fat cheeses containing 34 and 31.5% fat. The score for these cheeses were 6.89 and 6.29 respectively and were similar in their adhesiveness as determined by the

Table 5. Adhesiveness, cohesiveness, hardness and springiness of Cheddar cheese as influenced by fat content, determined by a trained sensory panel.

TREATMENT (% fat)[1]	ADHESIVENESS	COHESIVENESS	HARDNESS	SPRINGINESS
34.0	6.89^{a} (1.63)[2]	5.68^{a} (2.68)	2.70^{a} (1.29)	2.61^{a} (1.49)
31.5	6.29^{a} (1.68)	4.96^{abc} (2.22)	2.89^{a} (1.60)	2.52^{a} (1.49)
26.8	5.26^{b} (1.87)	5.25^{ab} (2.03)	4.14^{b} (1.70)	3.55^{b} (1.84)
20.5	3.96^{c} (2.12)	4.68^{abc} (1.63)	5.61^{c} (1.47)	5.30^{c} (1.93)
12.6	2.14^{d} (1.27)	4.45^{bc} (2.15)	6.98^{d} (1.39)	6.91^{d} (1.72)
<0.1	1.27^{e} (0.62)	3.86^{c} (2.67)	8.25^{e} (1.12)	7.96^{e} (1.74)

[1] % Fat in cheese
[2] Means with standard deviations in parentheses n=4 replicates x 14 judges
[a-e] Means with the same superscript within a column do not differ significantly ($p<0.05$).

trained sensory panel. The values for these cheeses (34 and 31.5% fat) fall between 5-moderately adhesive and 9-very adhesive. Both of these cheese were perceived as adhesive, in that their scores were higher than 5 which is the midpoint of the scale. The remaining cheeses (26.8%, 20.5%, 12.6%, <0.1% fat) were all different from each other in their adhesiveness ($p<0.05$). Cheddar cheese with 26.8% fat with a score of 5.29 was perceived as moderately adhesive. The intermediate (20.5%) and low fat (12.6%) cheeses received scores of 3.96 and 2.14, respectively, which fall between moderately and not adhesive. The skim milk cheese (<0.1%) was not perceived as adhesive by the sensory panel, receiving a low score of 1.27.

The above results suggest that the amount of fat in the cheese affected the cheese adhesiveness. However, this data also suggests that human perception of adhesiveness does not change up to a certain level fat. In this study, it was observed that trained panelists could not detect differences in adhesiveness of up to 4%. Only when fat levels were increased greater than 4% differences in adhesiveness were detected by the panelists. The fat in cheese adds to the lubricity and softness of the cheese, making the cheese easier to compress to the roof of the mouth, but more difficult to remove with tongue. Panelists commented that the higher fat cheeses were very difficult to remove, and once the sample was removed, a film remained on the roof of the mouth. The cheeses containing 26.8 and 20.5% fat stuck to the roof of the mouth easily, but they were able to be removed easily, with no remaining film on the palate. The low fat cheese (12.6%) stuck to the roof of the mouth slightly and was removed easily. The skim milk cheese (<0.1%) did not stick to palate at all, therefore it was judged to be not adhesive. These results are similar to those obtained by Stampanoni and Noble (1991a). A trained sensory panel evaluated cheese analogs made with rennet casein, deionized water and vegetable fat. The trained panel detected an increase in adhesiveness in the cheese analogs with an increase in fat content. Increasing the acid concentration of the cheese analog resulted in a decrease in adhesiveness as determined by the trained sensory panel.

Cohesiveness in sensory applications refers to the degree to which a substance is compressed between the teeth before it breaks. The cohesiveness evaluation involved compressing the sample between the molars and evaluating the degree to which the sample deforms, rather than crumbles, breaks or falls apart (Appendix A, Table A.6). Cohesiveness of Cheddar cheese decreased as the fat content decreased. Table 4, column 3 lists the cohesiveness scores. The sensory panel failed to detect many differences in the cohesiveness of the Cheddar cheeses. Cheddar cheeses containing 34%, 31.5%, 26.8% and 20.5% fat were all judged to have a similar cohesiveness. Likewise, cheeses with 31.5%, 26.8%, 20.5% and 12.6% fat were also similar in their cohesiveness and cheeses with 31.5%, 20.5%, 12.6% and <0.1% were also judged to be similar by the trained sensory panel. All of the cheeses tended to fall within the mid range of the scale ranging from 3.86-5.68, corresponding to moderately cohesive. The fat in the cheese is dispersed in the protein matrix, and contributes to the cohesiveness of the cheese, or to the ability of the cheese to stick to itself. As the fat is removed, the protein matrix becomes more compact and rigid. A rigid structure crumbles and breaks more easily than a soft structure, making the cheese less cohesive as observed in this study. Cohesiveness is a difficult characteristic to evaluate, because as the fat is removed from the cheese, the cheese becomes more springy. A springy cheese resists deformation. Since a springy cheese does not break as easily, panelists may tend to judge this characteristic as cohesive, therefore, extremely springy cheeses may be given a higher cohesiveness score. These results are consistent with those obtained by Stampanoni and Noble (1991a). A trained sensory panel evaluated cheese analogs made with rennet casein, deionized water and vegetable fat. The trained panel detected an increase in cohesiveness of the cheese analogs with an increase in fat content.

Hardness in sensory applications is defined as the force required to compress a substance between the molar teeth. The hardness evaluation involved compressing the sample through the molar teeth once, and evaluating the force required to achieve this. No significant differences in hardness existed between the higher fat cheeses containing 34 and 31.5% fat (Table 4). However all four remaining treatments were different in their hardness ($p<0.05$). The higher fat samples, treatments 1 (34.5%) and treatment 2 (31.5%), received scores of 2.70 and 2.89 for hardness (Table 5). A score of 1 represents not hard. The 3% difference in fat did not result in a significant difference in the hardness of the cheese as perceived by the trained sensory panel. The cheese with 26.8% fat received a score of 4.14, which is one point below moderately hard, and the cheese with 20.5% fat received a score of 5.61, which is slightly above moderately hard. The low fat cheese (12.6%) fell between moderately hard and very hard with a score of 6.98, and skim milk cheese was perceived as very hard with a score of 8.25, less than the one point below the maximum of 9 on the scale. These data further support, the statement that fat level affects the hardness of the cheese consistent with the Instron data. These results are consistent with those obtained by Stampanoni and Noble (1991a). A trained panel detected an increase in the hardness of the cheese analogs with a decrease in fat content. Also consistent with the results obtained in this study, Banks *et al.* (1989) observed an increase in the hardness of Cheddar cheese when the fat content of the cheese was reduced and moisture content was increased. Reduced fat Cheddar cheeses were manufactured with 25% and 16% fat. The moisture of the cheeses were 42.9% and 47.2%, respectively.

Springiness in sensory applications refers to the degree to which a product returns to its original shape after it has been compressed between the teeth. The evaluation involved compressing the sample partially between the teeth without breaking the sample structure and evaluating the degree to which the sample returned to its original height.

Significant differences did not exist between the springiness of the two higher fat cheeses (34, 31.5%). The scores were 2.61 and 2.52, for the cheeses containing 34% and 31.5% fat, respectively (Table 5). The remaining cheeses (26.8%, 20.5%, 21.6%,<0.1%) were all different ($p<0.05$) in their springiness. The 26.8% fat cheese, with a score of 3.55, fell between not springy and moderately springy, and the 20.5% fat cheese was moderately springy with a score of 5.30. The low fat cheese (12.6% fat) was springier with a score of 6.91 and the skim milk cheese (<0.1% fat) was the springiest ($p<0.05$) among the cheeses with a score of 7.96, as perceived by the trained sensory panel. The rigid structure of cheese without fat or a reduced amount of fat prevents the sample from breaking easily. The sample resists deformation and a higher force is required to break the sample structure.

These results are consistent with those obtained by Stampanoni and Noble (1991a). In their study, a trained sensory panel evaluated cheese analogs manufactured from rennet casein, deionized water and vegetable fat. Springiness of the cheese analogs increased with an increase in the fat content of the cheese analog as determined by the trained panel.

Fat is very important to the texture of Cheddar cheese. As fat is removed from the cheese, it losses its adhesiveness, and cohesiveness and becomes more springy and hard. The data presented from the Instron and sensory study supports this statement. An ideal Cheddar cheese would receive a moderate score for each of these characteristics. An ideal Cheddar cheese should have moderate adhesiveness. A very adhesive cheese would be sticky and pasty and a cheese with no adhesiveness would be very dry [Olson and Johnson (1990)]. Cheddar cheese should be moderately cohesive, a low cohesive cheese would have crumbly texture like that of a Cheshire cheese and a very cohesive cheese like a Havarti would have a texture too soft for Cheddar cheese. Cheddar cheese is considered a hard cheese, however the hardness of the cheese with <0.1% fat in this experiment was similar to that found in Parmesan cheese, an unacceptable texture for Cheddar cheese. Springy or rubbery cheese is not a desirable characteristic for Cheddar cheese. This characteristic is typically found in reduced fat cheeses. The hardness and springiness scores for each treatment were very similar, for example, the cheese with 34% fat received a hardness score of 2.70 and a springiness score of 2.61. These results suggest that the hardness or firmness of cheese is related to, or affects the springiness or elasticity of cheese. A harder cheese is more likely to be more springy, and exhibit higher elastic recovery.

Fat is not solely responsible for the alteration of these characteristics. Cheese texture is affected by many parameters, such as protein and water interactions and interactions of fat, water and protein. However removal of the fat significantly alters cheese composition and the textural characteristics of cheese. The removal of the fat affected adhesiveness, hardness and springiness after differences of 4% or greater. Treatments 1 and 2, 34% and 31.5% fat cheeses were only different in their fat content by 3% and there were no perceived differences in these characteristics as observed in this study.

The differences in the textural characteristics of the cheeses can be explained by their microstructure. The higher fat cheeses which were softer, less springy and more cohesive and adhesive than the other cheeses, had a very open irregular protein matrix (Figures 8 and 9). The protein network was not very rigid due to disruption of the matrix by the fat present. As the sample was deformed, the fat was present to act as a lubricant, allowing the structure to move freely. As the fat content of the cheese was decreased, the structure became more compact, dense and rigid with fewer openings in the protein matrix. The microstructure of the intermediate fat cheeses (26.8% and 20.5%) was not as open as that of the higher fat cheeses. This closed compact structure resulted in harder, more springy cheeses. The adhesiveness and cohesiveness of these cheeses decreased due to a decrease in the amount of fat present to act as an adhesive force. In the lower fat cheese (12.6%) the structure was even more compact and the bridges connecting proteins were thicker, resulting in the rigid texture of this cheese. The skim milk cheese with <0.1% fat, and an almost completely closed structure resulted in a very hard, springy cheese, with very little cohesiveness and adhesiveness. The rigid structure required a very high force for deformation and would regain much of its original height when compressed at low forces. This cheese had no fat present to act as an adhesive force. Once the sample structure was broken, it fell apart very easily without the fat present to contribute to the cohesiveness of the cheese.

Adhikari ***et al.*** (1992) explained the characteristics of Chhana and Rasogolla, two Indian cheeses using SEM. The Chhana, the more firm of the two cheeses, had a conglomerated matrix, with small numerous uniformly distributed pores. The structure contained thick protein bridges which reduce the mean free path of the casein micelles, limiting movement of the fat phase relative to the protein phase. Likewise in this study, the lower fat samples with strong protein bridges (20.5% and 12.6% fat) were more firm than the higher fat cheeses (26.8%, 31.5% and 34% fat) that lacked the strong thick protein bridges. The Rasogolla had a ragged, porous, loose protein matrix. Large voids were present between the proteins allowing the protein bodies to move freely, resulting in a lower firmness than the Chhana. Also consistent with the results observed in this study, Mistry and Anderson (1993) observed that reduced fat cheeses with a firm, rubbery texture had a dense, rough microstructure, dominated by protein as determined by SEM.

CORRELATION BETWEEN INSTRON AND SENSORY MEASUREMENTS

The results from the sensory and Instron measurements were correlated. The Instron and sensory measurements show a linear relationship for all textural parameters studied (Figure 19 and 20). A strong correlation existed for determination of hardness (r=0.95) and springiness (r=0.94) as measured by the Instron and a trained sensory panel.

Table 6. Regression statistics for relationship between Instron and sensory measurements.

Characteristic	r[1]	a	b
Adhesiveness	0.73*	-0.25	0.21
Cohesiveness	-0.41**	0.27	-0.02
Hardness	0.95*	-192.55	132.66
Springiness	0.94*	42.87	6.56

[1]r= correlation coefficient a= line intercept b= line slope
* significant at p<0.001.
** significant at p<0.05.

A positive correlation (r=0.73) also existed between adhesiveness determined by the Instron and the trained sensory panel. Overall, the sensory panel was better able to detect the differences in adhesiveness of the cheese with a change in fat content compared to the Instron. However the trend of instrumental and sensory adhesiveness, was an increase in

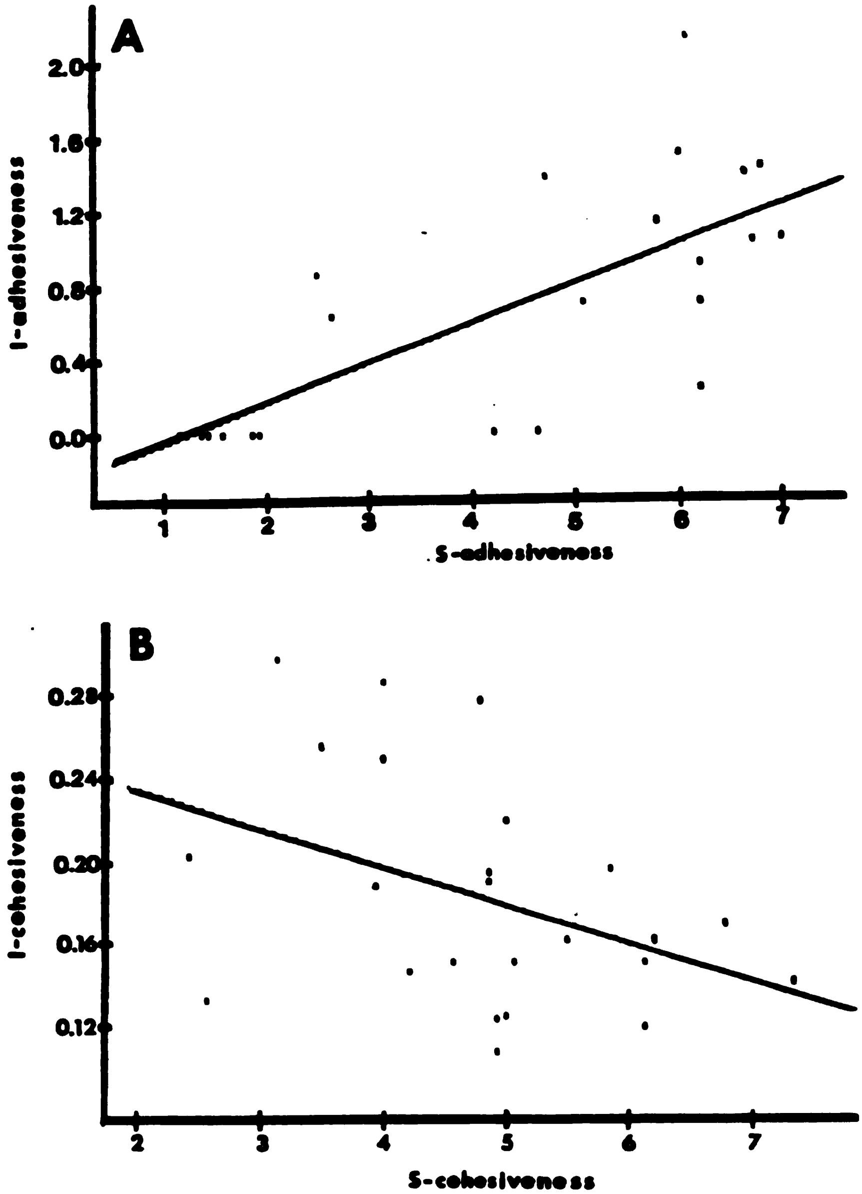

Figure 19. Relationship between textural characteristics (adhesiveness and cohesiveness) as determined by the Instron Universal Testing Machine and a trained sensory panel. I=Instron S=Sensory

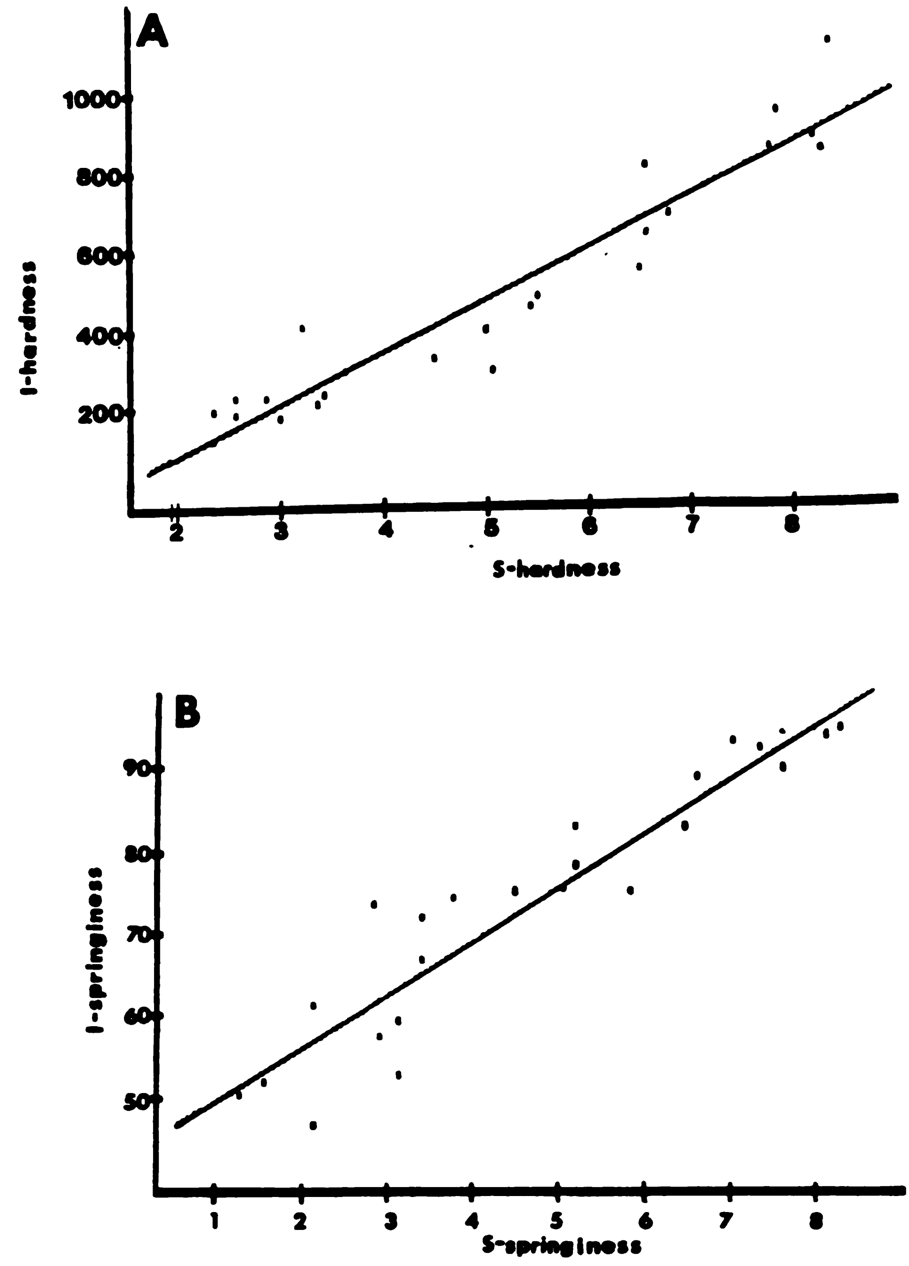

Figure 20. Relationship between textural characteristics (hardness and springiness) as determined by the Instron Universal testing Machine and a trained sensory panel. I=Instron S=Sensory.

adhesiveness with an increase in fat content.

The negative correlation for cohesiveness (r=-0.41) was not significant. Correlation between instrumental and sensory cohesiveness was not significant. Cohesiveness determined by the Instron increased with a decrease in fat content and decreased with a decrease in fat content as determined by the trained sensory panel. This is most likely the result of differences in measurement. Instron cohesiveness is a ratio of the height of two peaks. Sensory determination of cohesiveness is a measure of how much the sample deforms or falls apart. To obtain a good correlation, the types of measurements must be similar or measuring the same type of property. The Instron was able to distinguish differences in the cohesiveness of the cheeses whereas the scores from the trained panel tended to overlap.

The relationship between sensory and instrumental measurements is typically linear, however some characteristics such as firmness may exhibit a curvilinear relationship, with the instrumental firmness increasing more than the sensory firmness. However, this relationship for cheese is typically non-linear unless the parameters are not too wide [Zoon (1991)]. In this study, a high positive linear correlation was observed between the two measurements for adhesiveness, hardness, and springiness (Figure 19A and 20 A&B). A low negative correlation was observed between sensory and Instron cohesiveness. Chen *et al.* (1979) obtained a positive correlation coefficient between instrumental and sensory determination for hardness (r=.845), consistent with these results. They observed a high negative correlation between instrumental and sensory adhesiveness(r=-.837), and in contrast to these results, a high positive correlation (r=.849) for cohesiveness. The experiment evaluated rectangular cheese samples of various varieties including Cheddar cheese at 12.6°C. Hardness, cohesiveness and adhesiveness were evaluated using a plunger probe as opposed to a flat plate. Springiness or elasticity was determined using a flat plate. A trained sensory panel evaluated the samples using a 15-point scale.

Stampanoni and Noble (1991) observed a negative correlation (r=-.66) between springiness and modulus of elasticity for cheese analogs as determined by the Instron in contrast to these results. Firmness as determined by a trained sensory panel correlated (r=.89) with 80% puncture force and 55% compression force (r=.93), consistent with these results. Adhesiveness as determined by a trained sensory panel correlated (r=.72) with adhesiveness as determined by the Instron. A trained sensory panel evaluated 13x10 mm cylindrical cheese analogs using an unstructured 100 mm scale.

TEXTURE ACCEPTANCE TESTS

An untrained sensory panel evaluated the five cheeses with 34%, 31.5%, 26.8%, 20.5% and 12.6% fat, for overall texture acceptance. The skim milk cheese (<0.1%) was an inedible mass of casein and was not evaluated by the untrained sensory panel. Before the evaluation of the cheeses the panelists were instructed to fill out a brief questionnaire to obtain information regarding their concern for dietary fat intake, to determine whether or not the panelists were consumers of reduced fat cheeses, and what their expectations of a reduced fat cheeses were as compared to full fat cheeses (Appendix A, Table A.8).

Table 7 lists the results from the questionnaire regarding the dietary fat concerns of the panelists. Forty four percent of the panelists were moderately concerned about their dietary fat intake. Six percent of panelists were extremely concerned about their intake of dietary fat. Seven percent of the panelists were not concerned about dietary fat consumption.

Table 7. Results from questionnaire - dietary fat concerns

EXTREMELY CONCERNED	6%
VERY CONCERNED	27%
MODERATELY CONCERNED	44%
SOMEWHAT CONCERNED	16%
NOT CONCERNED	7%

Of the panelists who have any concern (extremely, very, moderately and somewhat total 93%) regarding their fat intake, 43% percent of the panelists choose to reduce fat intake by consuming low fat cheese as recommended by the dietary guideline that suggest people reduce their dietary fat intake. Fifty-seven percent of the panelists were not reduced fat cheese consumers.

Table 8 lists the results from the final question on the questionnaire. This question asked the panelists what they expected from a reduced fat cheese, did they expect it to be better than full fat, the same as a full fat of worse than full fat.

Table 8. Untrained panelists expectations of the quality of a reduced fat cheese compared to a full fat cheese.

Better than full fat	12%
Same as full fat	50%
Worse than full fat	35%
No idea	3%

Fifty percent of the panelists expected a reduced fat cheese to be the same as a full fat cheese, 12% expected it to be better and 35% expected it to be worse. These results are from a small group relative to the entire population of cheese consumers. However, they do suggest that consumers want products that are lower in fat, but they expect these products to have the same quality flavor and texture of a full fat counterpart. Reduced fat Cheddar cheese has been marketed as a Cheddar cheese, therefore consumers expect the same type of product, and are greatly disappointed when it does not perform as well as regular Cheddar [Hise (1991)]. Twelve percent of the panelists expected a better product. This suggests that the consumer expects that if any factor of the product is improved i.e. less fat is better for your health, this will improve the overall quality of the product, not taking into account the functional properties fat has in cheese and not realizing some of these functional properties may be eliminated by removal of fat. Thirty five percent of the panelists expected the product to be worse. This expectation may stem from previous experience with eating reduced fat cheeses, or other products reduced in fat that did not compare to their full fat counterparts. Three percent of the panelists did not know what to expect from a reduced fat cheese.

Table 9 lists the results from the overall texture acceptance tests. Cheeses receiving a score of 5 or higher were judged to be acceptable. A score of 5 corresponded to neither like nor dislike on the scale. As expected, the acceptance of the cheese increased as the fat in the cheese increased, suggesting that an increase in fat content makes a cheese more desirable (Figure 21). The panelists did not judge the three higher fat cheeses differently. These cheeses contained fat levels of 34.5%, 31.5% and 26.8% and were similar in their overall texture acceptance by the untrained

Table 9. Overall texture acceptance of Cheddar cheese as influenced by fat content, determined by an untrained sensory panel.

TREATMENT (% fat)[1]	RESPONSE (acceptance)
34.0	6.78[2a] (2.03)
31.5	6.70[a] (1.85)
26.8	6.79[a] (1.68)
20.5	5.67[b] (2.00)
12.6	3.72[c] (2.20)

[1] % Fat in cheese
[2] Means with standard deviations in parentheses
n= 4 replicates x 25 judges
[a-c] Means with the same superscript within a column do not differ significantly (p<0.05)

panelists. These cheeses received mean scores of 6.78, 6.70 and 6.79 respectively, indicating that their textures were liked and acceptable to the panelists. The individual scores for the cheese with 34% fat ranged from 1-9, and cheeses with 26.8% and 20.5% fat ranged from 2-9. Panelists who gave these treatments lower scores, commented that, the samples left a film on the roof of their mouth. At 20.5% fat level the acceptability of the cheeses began to decrease. This Cheddar cheese sample received a score of 5.67, which is between like slightly and neither like/dislike, was still

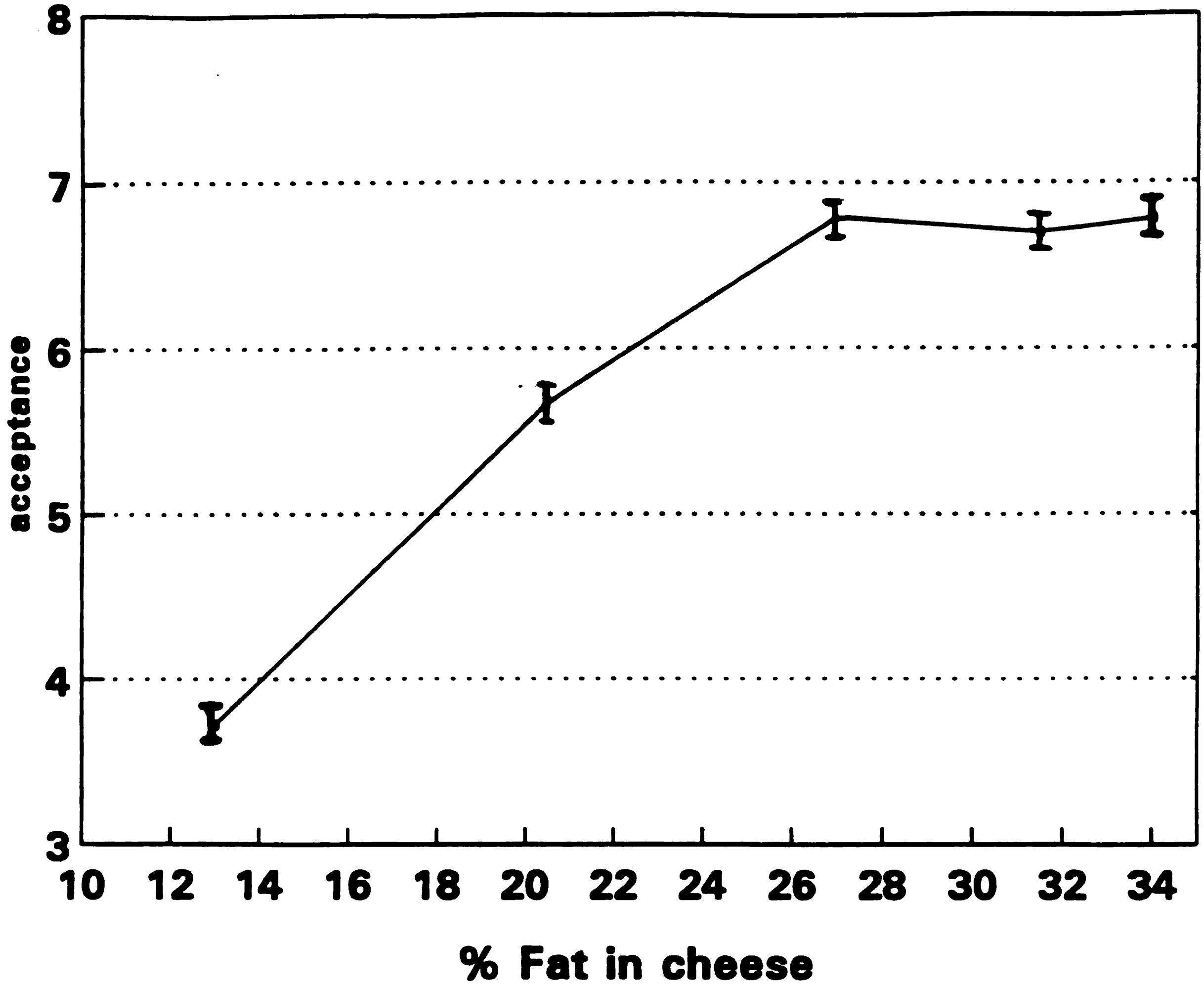

Figure 21. Influence of fat content on the overall texture acceptance of Cheddar cheese.

acceptable, suggesting that the texture was not preferred by the untrained panel, but was not necessarily unacceptable. The low fat cheese (12.6% fat) with a mean score of 3.72, was no longer acceptable. A score of 3.72 falls between dislike moderately and dislike very much. Many panelists commented that this sample was waxy and dry, and the texture was unacceptable.

A list of the panelists comments are in Appendix D. The majority of the panelists disliked the sample as the mean indicates, however there were panelists who did prefer the hard texture of this sample. Fat influences the acceptance of Cheddar cheese. Consumers enjoy dairy foods because of their sensory characteristics, specifically flavor and texture [Jameson (1990)]. The results obtained in this study are consistent with those obtained by Madsen ***et al.*** (1970). Cheddar, Swiss and Colby cheeses with reduced fat contents were evaluated by consumers to determine the effect of fat on the preference of the cheeses. Preference for Cheddar and Colby cheeses decreased with a decrease in fat content. Cheddar cheese with 35.5% FDB and Colby with 24.4 % FDB were preferred the least while Cheddar and Colby cheeses with 54.3% and 52.6% FDB, respectively were preferred the most. However, the consumer preference for Swiss cheese increased with a decrease in fat content. Swiss cheese with 36.1% FDB was preferred more than cheese with 45.9% FDB. Banks ***et al.*** (1989) produced several Cheddar cheeses with varying fat levels (33.1%, 25.6% and 16.8%).

A taste panel evaluated the texture of the cheeses. Consistent with this study, the higher fat cheeses received a more favorable texture score compared to the low fat cheese (16.8%). The lowest fat cheese was judged to be over firm and rubbery.

Cheese is one of the few dairy products that a reduced fat version has not been successfully produced with texture and flavor not comparable to its full fat counterpart [Rosenberg (1992)]. Development of a reduced fat or fat free product such as ice cream is not as challenging as developing a reduced fat cheese. Ice cream contains many ingredients including milk solids, flavors, sweeteners, stabilizers and emulsifiers [Morr and Richter (1988)]. When fat is removed, the proportions of these ingredients can be altered to a certain extent without detrimental effects. Fat replacers and mimetics can be used successfully in reduced fat or fat free ice creams to improve texture (mouthfeel), and melting properties when fat is removed. Fat replacers and mimetics are starch-based, cellulose-based or protein-based and function well in frozen desserts since these ingredients are part of the formulation and are just used in higher concentrations in reduced fat products [Olson (1991)]. Flavor can be improved by increasing or addition of flavors and sweeteners.

Cheese has a limited ingredient list, when compared to a product such as ice cream. Cheese is made from milk. Other ingredients include starter cultures, rennet and salt. Cheese is a more complex system. Texture and flavor development involve many chemical and physical reactions. The flavor and texture of cheese develops through the action of the starter cultures and rennet on the fat and protein in the milk [Johnson (1988)]. Moisture of the cheese, salt, pH, manufacturing conditions and ripening parameters all contribute to the complexity of the cheese texture and flavor system. Thus far, improvement of reduced fat cheeses has been through alteration of the manufacturing procedures and the use of various starter cultures. The use of fat replacers and mimetics in natural cheeses is a potential area for improvement of reduced fat cheese quality. Thirty-six percent of all reduced fat dairy products introduced in 1992 were cheeses, and 23% were ice cream. In 1991, only 16% of the products introduced were cheese compared to 50% being ice cream [O'Donnell (1993)]. These figures suggest that even though the quality of reduced fat cheeses is not comparable to full fat cheeses, the demand and consumption of reduced fat cheeses is increasing and perhaps the quality is constantly improving.

CHAPTER V

SUMMARY AND CONCLUSIONS

Fat is a major component of cheese. Reduction of fat in cheese significantly affects the microstructure, thus affecting the textural characteristics of Cheddar cheese.

1. Reduction of fat levels in Cheddar cheese resulted in a loss of the open, intricate microstructure of Cheddar cheese. As the fat level of the cheese decreased, the structure of the cheese became more closed and compact.

2. Reduction of cheese fat level resulted in an increase in hardness, springiness and cohesiveness, and a decrease in adhesiveness as determined by the Instron Universal Testing Machine.

3. Reduction of cheese fat level resulted in an increase in hardness and springiness and a decrease in adhesiveness and cohesiveness as determined by a trained sensory panel.

4. A positive linear correlation was observed between the textural characteristics determined by the Instron and the trained sensory panel for hardness, springiness and adhesiveness.

5. Reduction of cheese fat level resulted in a decrease in the overall texture acceptance as determined by an untrained sensory panel. At 12.6% fat, the cheese was no longer acceptable to the panel.

CHAPTER VI

FUTURE RESEARCH

Based on the results obtained in this study, areas for future for research include:

1. Correlation of microstructure data with texture data through image analysis. This will allow the prediction of textural quality by observing microstructure. Image analysis will also be a method to quantitate the information obtained from Scanning Electron Microscopy.

2. Development of a method to better measure cheese adhesiveness. Measurement of adhesiveness by the Instron Universal Testing Machine produces low results with a high amount of variation.

3. Selection of starter cultures and adjunct cultures that result in increased proteolysis, and improved flavor and texture quality.

4. Explore the use of fat mimetics and substitutes as a method to improve texture of reduced fat Cheddar cheese.

APPENDICES

APPENDIX A

APPENDIX A

QUESTIONNAIRES FOR THE SENSORY EVALUATION TESTS

A questionnaire was presented to the panelists who participated in the initial screening process to assist in panel member selection. The panelists completed a simple ranking test on cheese samples, for each of the four characteristics, adhesiveness, cohesiveness, hardness and springiness.

The trained panelists completed a 9-point hedonic test based on the degree of each characteristic.

The panelists who participated in the texture acceptance test completed a 9-point hedonic test to determine the degree of liking for treatments 1-5.

Table A.1. Prescreening questionnaire for panel selection.

PRESCREENING QUESTIONNAIRE

NAME________________________________OFFICE________________

PHONE____________

TIME

1. ARE THERE ANY WEEKDAYS THAT YOU WILL NOT BE AVAILABLE ON A REGULAR BASIS?

2. WHAT PART OF THE DAY ARE YOU NORMALLY AVAILABLE?

MORNING(8-11)	_______
EARLY AFTERNOON(11-2)	_______
AFTERNOON(2-5)	_______

3. DO YOU PLAN TO BE ON CAMPUS DURING THE SUMMER?______

HEALTH

1. DO YOU HAVE ANY OF THE FOLLOWING?

DENTURES	______
FOOD ALLERGIES	_______
ORAL DISEASE	_______

2. DO YOU TAKE ANY MEDICATIONS WHICH AFFECT YOUR SENSES?

3. ARE YOU CURRENTLY ON A RESTRICTED DIET?
IF YES, PLEASE EXPLAIN.

4. WHAT FOODS CAN YOU NOT EAT?_________________

5. WHAT FOODS DO YOU NOT LIKE TO EAT?_____________

THANK YOU ☺

Table A.2. Consent form for panel members.

CONSENT FOR TASTE PANEL MEMBERS

Food Science and Human Nutrition Department
Michigan State University

Cheddar, cheese prepared from pasteurized milk, cultures, rennet, salt and natural color.

I ____________________ have read the above list of ingredients and find none that I am allergic to. I agree to participate in the sensory panel that will take place on _____________. The panel will evaluate Cheddar cheese texture (i.e. how hard, rubbery etc.) I understand that the the panel will take approximately 15 minutes and my name will not be utilized in reporting of the results. I understand that that I am free to withdraw my consent and discontinue participation in the panel at any time without penalty.

____
Signature

____
Date

Table A.3. Ranking score sheet for panel selection.

NAME ______________________________ DATE ______________

TYPE OF SAMPLE Cheese ______________________________

CHARACTERISTIC STUDIED Adhesiveness ______________________

INSTRUCTIONS

Place sample between molars; chew five times; Press the sample to the roof of the mouth with the tongue; Evaluate the force required to remove the sample from the roof of the mouth with tongue. Rate the samples from least adhesive to most adhesive. Expectorate the sample; rinse mouth with water between samples.

925 **123** **187**

Least Adhesive ________

____

Most Adhesive ________

Table A.4. Adhesiveness evaluation score sheet.

NAME ____ **DATE** ______

TYPE OF SAMPLE CHEESE

CHARACTERISTIC STUDIED Adhesiveness

INSTRUCTIONS

Place sample between molars; chew five times: Press the sample to the roof of mouth with the tongue. Evaluate the force required to remove the sample from the roof of the mouth with tongue. Place an X next to the value which best describes the adhesiveness of the sample. Expectorate the sample; rinse mouth with water.

200

____ 1 Not Adhesive

____ 2

____ 3

____ 4

____ 5 Moderately Adhesive

____ 6

____ 7

____ 8

____ 9 Very Adhesive

COMMENTS

Table A.5. Cohesiveness evaluation score sheet.

NAME ______________________________ **DATE** __________

TYPE OF SAMPLE CHEESE ______________________________

CHARACTERISTIC STUDIED Cohesiveness ____________________

INSTRUCTIONS

Place sample between molars; compress fully; evaluate the degree to which the sample deforms rather than crumbles, breaks, or falls apart as cohesive. Place an X next to the value which best describes the cohesiveness of the sample.

200

____ 1 Not Cohesive

____ 2

____ 3

____ 4

____ 5 Moderately Cohesive

____ 6

____ 7

____ 8

____ 9 Very Cohesive

COMMENTS

Table A.6. Hardness evaluation score sheet.

NAME ______________________________ **DATE** ____________________

TYPE OF SAMPLE CHEESE

CHARACTERISTIC STUDIED Hardness

INSTRUCTIONS

Place sample between molars; bite through once; evaluate for hardness. Place an X next to the value which best describes the hardness of the sample. Expectorate sample; rinse mouth with water.

100

____ 1 Not Hard

____ 2

____ 3

____ 4

____ 5 Moderately Hard

____ 6

____ 7

____ 8

____ 9 Very Hard

COMMENTS

Table A.7. Springiness evaluation score sheet.

NAME ______________________ **DATE** ____________

TYPE OF SAMPLE CHEESE

CHARACTERISTIC STUDIED Springiness

INSTRUCTIONS

Place sample between molars; compress partially without breaking the sample structure. Place an X next to the value which best describes the springiness of the sample. Expectorate sample; rinse mouth with water.

100

____ 1 Not Springy

____ 2

____ 3

____ 4

____ 5 Moderately Springy

____ 6

____ 7

____ 8

____ 9 Very Springy

COMMENTS

Table A.8. Texture acceptance questionnaire score sheet.

QUESTIONNAIRE

NAME________________________ DATE____________

1. How are concerned are you about your intake of dietary fat and cholesterol?

___ Extremely concerned

___ Very concerned

___ Moderately concerned

___ Slightly concerned

___ Not concerned

2. Do you frequently consume dairy products, specifically Cheddar cheese? _____ __________

3. Do you frequently consume low fat dairy products, specifically Cheddar cheese ? ______________

4. What do you typically expect in a low fat cheese product as compared to a full fat cheese product, in regards to product quality, specifically texture.

___ Better than full fat

___ Same as full fat

___ Worse than full fat

Table A.9. Texture acceptance evaluation.

EVALUATION OF CHEDDAR CHEESE TEXTURE

NAME__________________________ **DATE**________

INSTRUCTIONS

Taste the following samples in the order presented. After tasting each sample place an X next to the line that best describes how you feel about the **TEXTURE** of the sample (i.e. hardness, how the sample feels in your mouth when you bite and chew it). You may expectorate the sample if desired. Rinse mouth with water between samples.

Sample	**604**	**299**	**486**	**867**	**352**
Like extremely	__	__	__	__	__
Like very much	__	__	__	__	__
Like moderately	__	__	__	__	__
Like slighty	__	__	__	__	__
Neither like/dislike	__	__	__	__	__
Dislike slightly	__	__	__	__	__
Dislike moderately	__	__	__	__	__
Dislike very much	__	__	__	__	__
Dislike extremely	__	__	__	__	__

Comments

APPENDIX B

Worksheets for the sensory evaluation.

Four replicates of each treatment were produced. The trained panelists evaluated each treatment and each replicate once. The samples were presented in such a way that the each sample as well as each type of evaluation was presented in a different order.

Twenty-five panelists evaluated each replicate once
for a total of 100 responses for the consumer acceptance test.
Treatments 1-5 were presented in five different ways so each sample was evaluated in a different order.

APPENDIX B

Table B.1. Order of presentation for replicates 1 and 3 for trained panel texture evaluation.

P/T	1	2	3	4	5	6
1	1-ACHS	4-CHSA	2-HSAC	5-SACH	6-CASH	3-SHCA
2	4-ACHS	1-CHSA	5-HSAC	2-SACH	6-CASH	3-SHCA
3	6-SHCA	3-CASH	2-SACH	4-HSAC	5-CHSA	1-ACHS
4	4-SHCA	3-CASH	2-SACH	1-HSAC	5-CHSA	6-ACHS
5	2-CHSA	5-HSAC	1-SACH	3-CASH	6-SHCA	4-ACHS
6	3-CHSA	2-HSAC	4-SACH	6-CASH	1-SHCA	5-ACHS
7	1-HSAC	6-SACH	3-CASH	5-SHCA	2-ACHS	4-CHSA
8	5-HSAC	1-SACH	6-CASH	4-SHCA	3-ACHS	2-CHSA
9	2-SACH	5-CASH	1-SHCA	3-ACHS	4-CHSA	6-HSAC
10	6-SACH	4-CASH	3-SHCA	1-ACHS	2-CHSA	5-HSAC
11	2-CASH	6-SACH	5-SHCA	4-ACHS	1-CHSA	3-HSAC
12	5-CASH	2-SACH	6-SHCA	3-ACHS	4-CHSA	1-HSAC
13	1-SHCA	3-SACH	2-CHSA	5-HSAC	4-CASH	6-SACH
14	6-SHCA	1-ACHS	4-CHSA	2-HSAC	3-CASH	5-SACH

* Number indicates order treatment was presented to panelist.
** A=adhesiveness, C=cohesiveness, H=hardness, S=springiness
***P=panelist T=Treatment

Table B.2. Order of presentation for replicates 2 and 4 for trained panel texture evaluation.

P/T	1	2	3	4	5	6
1	2*-SACH	3-CAHS	6-ASCH	4-SAHC	1-HACS	5-CSAH
2	4-ACHS	6-HCAS	2-SCHA	5-ACHS	3-ACHS	1-SAHC
3	6-CHSA	2-HSCA	3-ACSH	1-SHCA	5-SAHC	4-AHCS
4	1-HSAC	6-CHSA	4-AHSC	2-CASH	5-SHAC	3-SACH
5	3-SACH	4-CAHS	1-ASCH	6-SACH	2-HACS	5-CSAH
6	5-HSCA	6-AHSC	2-SCHA	1-ACHS	3-CASH	4-SAHC
7	1-CHSA	5-HSCA	3-HASC	4-ASCH	2-SCHA	6-AHCS
8	2-SACH	4-AHCS	1-HASC	6-HSAC	5-SHAC	3-CSAH
9	3-SACH	6-CAHS	2-ASCH	5-SACH	1-HACS	4-CSAH
10	4-ACHS	1-CHSA	5-SCHA	2-HSCA	6-ACSH	3-SAHC
11	5-CHSA	3-HSCA	6-SCHA	1-CHSA	2-SHCA	4-AHCS
12	6-HSAC	2-SCAH	4-HASC	3-HSAC	5-SHAC	1-HCSA
13	1-SACH	6-CAHS	2-ASCH	4-SACH	3-HACS	5-CSAH
14	2-ACHS	3-AHSC	1-SCHA	6-ACHS	5-ACSH	4-SAHC

* Number indicates order treatment was presented to panelist.
** A=adhesiveness, C=cohesiveness, H=hardness, S=springiness
***P=panelist T=Treatment

APPENDIX C

APPENDIX C

CODES USED FOR SAMPLES IN SENSORY EVALUATION

Table C.1. Codes used for trained panel evaluation.

TREATMENT	REP. #1	REP. #2	REP. #3	REP. #4
1	140	204	340	404
2	132	223	332	432
3	124	242	324	442
4	160	216	316	460
5	108	280	380	408
6	100	200	003	400

Table C.2. Codes used for untrained panel evaluation

TREATMENT	REP #1	REP #2	REP #3	REP #4
1	465	149	534	486
2	378	732	763	352
3	246	620	982	299
4	639	463	146	604
5	867	981	348	867

APPENDIX D

APPENDIX D

COMMENTS FROM TEXTURE ACCEPTANCE TESTS

Table D.1. Replicate #1

* 867 and 639 seemed dry and waxy
* 378 had the best texture
* Most are slightly hard.. there are some tastes in 867,465,286 I don't like
* 867 very hard to bite.. 639, I don't like color (too yellow) and texture (hard)
* 378 a little hard
* 639 harder
* 246 same as 639
* 465 perfect
* 867 to hard and chewy
* 867 is too hard to like-takes too much work to chew it
* 639 seemes too hard at first, but improves
* 246 is extremely good

Table D.2. Replicate #2

* I preferred sample # 149 out of the batch...samples 463 and 981 were rather unpalatable
* 149, 620,732 felt like they left a film on your teeth and tongue-too soft for my preference
* 981 was by far the hardest...I graded this higher because I enjoy the hardness when chewing
* 620 is a little too hard and flavor is a little different than Cheddar
* 981 is felt almost as rubber
* 463 is a little too chewy
* 620 and 149 are the best in texture
* 981 was waxy and dry
* I don't like cheese and I am not really a cheese eater, but these cheese were rather good and I enjoyed them

Table D.3. Replicate #3

* 534 and 763 were very similar in their texture, 763 was a little bit more bitter in its taste
* 348 seemed to stick in your mouth and to your teeth, the tase was different too
* 348 is very dry but tastes good
* 348 is like chewing a chunk of parafin
* 534 is the texture I like the best
* I like creamy smooth feeling cheese
* 348 was simply too hard
* 348 rubbery
* 982 I liked very much, it has a good texture
* 763 hard
* 534 not bad
* Like 982
* 348 was to hard, not something you would want to take more than one bite
* 534 was OK, but too smooth
* 348 had no flavor and texture was bad

Table D.4. Replicate #4

* 352 flavor-poor, 486 crumbly
* 352 does not really have acheese taste
* 367 seems too rigid
* 604 has very strong taste at first
* 867 is too dry
* 352 had the best texture
* 867 was hard and dry
* 867 had a hard texture and crumbled in one's mouth
* 352 and 486 seemed to "melt in one's mouth" - good mouthfeel
* I liked the solid, soft texture of 604 and 299... good mix between hardness and softness
* 867 too hard, 486 too crumbly
* 486 abd 352 are mealy-no cohesiveness
* 604,299, 867-too rubbery
* 867 is too rubbery to be likable- bounces back when you bite it

APPENDIX E

APPENDIX E

ANOVA TABLES

Table E.1. ANOVA table for cheese composition-fat

Source of variation	Degrees of freedom	Sum of squares	Mean square	F-Value
Between	5	3347.802	669.560	168.708
Within	18	71.438	3.969	
Total	23	3419.240		

Table E.2. ANOVA table for cheese composition-protein

Source of variation	Degrees of freedom	Sum of squares	Mean square	F-Value
Between	5	1160.530	232.106	115.406
Within	18	36.202	2.011	
Total	23	1196.732		

Table E.3. ANOVA table for cheese composition-moisture

Source of variation	Degrees of freedom	Sum of squares	Mean square	F-Value
Between	5	339.829	67.966	24.264
Within	18	50.420	2.801	
Total	23	390.420		

Table E.4. ANOVA table for sensory adhesiveness

Source of variation	Degrees of freedom	Sum of squares	Mean square	F-Value
Between	5	1456.265	291.253	112.731
Within	330	852.589	2.584	
Total	335	2308.854		

Table E.5. ANOVA table for sensory cohesiveness

Source of variation	Degrees of freedom	Sum of squares	Mean square	F-Value
Between	5	113.634	22.727	4.449
Within	330	1685.554	5.108	
Total	335	1799.188		

Table E.6. ANOVA table for sensory hardness

Source of variation	Degrees of freedom	Sum of squares	Mean square	F-Value
Between	5	1416.060	283.212	136.062
Within	330	686.893	2.081	
Total	335	2102.952		

Table E.7. ANOVA table for sensory springiness

Source of variation	Degrees of freedom	Sum of squares	Mean square	F-Value
Between	5	1472.310	294.462	101.063
Within	330	961.500	2.914	
Total	335	2433.810		

Table E.8. ANOVA table for Instron adhesiveness

Source of variation	Degrees of freedom	Sum of squares	Mean square	F-Value
Between	5	14.094	2.819	4.316
Within	66	43.105	0.653	
Total	71	57.199		

Table E.9. ANOVA table for Instron cohesiveness

Source of variation	Degrees of freedom	Sum of squares	Mean square	F-Value
Between	5	0.177	0.035	24.592
Within	66	0.095	0.001	
Total	71	0.272		

Table E.10. ANOVA table for Instron hardness

Source of variation	Degrees of freedom	Sum of squares	Mean square	F-Value
Between	5	5763683.78	1152736.76	69.628
Within	66	1092673.33	16555.657	
Total	71	6856357.11		

Table E.11. ANOVA table for Instron springiness

Source of variation	Degrees of freedom	Sum of squares	Mean square	F-Value
Between	5	13946.637	2789.327	43.957
Within	66	4188.103	63.456	
Total	71	18134.740		

Table E.12. ANOVA table for untrained panel evaluation

Source of variation	Degrees of freedom	Sum of squares	Mean square	F-Value
Between	4	700.66	175.167	45.611
Within	495	1901.020	3.840	
Total	499	2601.688		

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