ABSTRACT

SHEPARD, LAKENDRA. Relating Sensory and Chemical Properties to Consumer Acceptance of Sour Cream. (Under the direction of Dr. MaryAnne Drake.)

Sour cream is a widely popular acidified dairy product. Volatile compounds and organic acids and their specific contributions to flavor or acceptance have not been established nor has a comprehensive study been conducted to characterize drivers of liking for sour cream. The objective of this study was to determine the drivers of liking for sour cream. Descriptive and instrumental analyses followed by consumer testing were conducted. Flavor and texture attributes of 32 (22 full fat, 6 reduced fat, and 4 fat free) commercial sour creams were evaluated by a trained descriptive sensory panel. Percent solids, percent fat, pH, titratable acidity, and colorimetric measurements were conducted to characterize chemical and physical properties of sour creams. Sour creams were analyzed for organic acids by high performance liquid chromatography (HPLC) and volatile aroma active compounds were evaluated by gas chromatography/mass spectrometry with gas chromatography/olfactometry. Consumer acceptance testing (n=200) was conducted on selected sour creams. Univariate and multivariate statistical analyses including penalty analysis and external preference mapping were conducted. Full fat sour creams were characterized by the lack of surface gloss and chalky textural attributes, while reduced and fat free samples displayed high intensities of these attributes. Full fat sour creams were higher ($p<0.05$) in cooked/milky flavor than the reduced and fat free samples. Reduced and fat free sour creams were characterized by cardboard, acetaldehyde/green and potato flavors, bitter taste, and astringency. Lactic acid was the prominent organic acid in all samples followed by acetic and citric acids. High aroma impact volatile compounds in sour creams were 2,3-butanedione, acetic acid, butyric acid, octanal, 2-methyl-3-furanthiol, 1-octene-3-one, and acetaldehyde. Positive drivers of liking for sour cream were milkfat, cooked/milky, sweet aromatic flavor, opacity, color intensity, and adhesiveness. This comprehensive study established sensory and instrumental properties of sour creams and their relationship to consumer acceptance.

Key words: sour cream, organic acids, aroma active compounds, preference mapping

Relating Sensory and Chemical Properties to Consumer Acceptance of Sour Cream

by
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A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the degree of
Master of Science

Food Science

Raleigh, North Carolina

2012

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DEDICATION

To my mom and dad, thanks for always supporting me and keeping me encouraged throughout my school journey. I love you!

BIOGRAPHY

LaKendra Shepard was born to Patricia and Charles Shepard on August 16th, 1984. LaKendra graduated from Pender High School in May of 2002. In August of 2002 she went to North Carolina State University to earn her Bachelor of Science degree in Food Science. Upon completing her degree she went onto intern at Archer Daniel Midland company in Decatur, Illinois. Upon completing her internship she realized she needed to gain more knowledge before entering into the food industry. LaKendra then began her Master of Science degree with a focus on Sensory and Flavor Chemistry under the direction of Dr. MaryAnne Drake.

ACKNOWLEDGMENTS

I would like to first thank GOD for giving me the strength to complete and obtain this degree!!! This has been a great experience!!!

Thanks to my father, mother and sisters for supporting my idea to continue my education, believing in me when I doubted myself and for the many prayers. Thanks to my mom and dad for the morning chats which brightened many of my days! Thanks to my sisters for supplying me with endless laughs when I needed them! Thanks to Jahmad, Naima and all of my nieces and nephews for making me smile my way through the hard times! I'd like to thank all of my aunts and uncles and my grandmother for their continuous prayers and words of encouragement, this would not have been possible without your support and prayers! I would also like to thank my close friends/cousins for understanding that I could not attend special events and for supporting me throughout my school journey. I would also like to thank the Avery and Shiver family for their prayers support! Thanks to my church family for their support and prayers. Thanks to everyone who provided me with a word of encouragement!

I am very grateful for Penny Amato who introduced me to Dr. Drake. I would like to thank Dr. Leon Boyd who kept me encouraged along the way! I am so appreciative to Dr. MaryAnne Drake for providing me with the opportunity to join her lab and for many things that she has done for me. I am forever grateful for the knowledge that she has shared with me about academia and life. I would like to thank Dr. Brian Farkas and Dr. Timothy Sanders for their leadership, guidance and support while on this journey. I would also like to thank Dr. Stephenie Drake for her support. To Evan Miracle and Michele Yates thanks for helping me and answering all my questions. I would not have been able to graduate if it was not for your continuous help and explaining things to me over and over again.

To MAD lab thanks for all of your help and support along the way. The laughs that were supplied by many of you, along with thoughts and ideas on how to prepare for numerous experiments, sensory panels and presentations were and still are greatly appreciated!

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CHAPTER 1: LITERATURE REVIEW

Importance of Taste, Flavor, Texture, and Volatiles

The acceptance of food depends on many sensory properties. Taste, smell, touch, sight, and hearing are five senses that are a part of the human physiology. These senses are used on a daily basis and play an enormous role in the determination of foods that are pleasant (Nursten, 1997). Taste is defined as sensations developed from specialized taste receptor cells located in the mouth (Reineccius, 2006). Taste has an important role in the acceptance of food products. In order for a food product to present a basic taste (sweet, sour, salty, bitter, umami), it must come in contact with taste buds which are located mainly on the tongue. Likewise for a food product to present an aroma, it must interact with receptors located in the olfactory epithelium, which is in the higher region of the nasal cavity (Nursten, 1997). The trigeminal nerve branches are also located in the nasal cavity. These nerves are stimulated by direct interaction of chemicals that diffuse into the epithelium, touch, and or changes in temperatures (Bell and Watson, 1999).

Voilley and Etievant (2006) described flavor as a chemical sensation induced by a large number of molecules that are released when a food product is broken down during consumption. The perception of flavor is the key factor in determining rejection or acceptance of a food product. As previously mentioned, taste has a role in flavor perception, however, aroma plays the major role in flavors perceived since there are a myriad of aromas perceived by the olfactory epithelium. In many incidences when flavors are perceived by the consumer there are numerous sensory systems involved (Voilley and Etievant, 2006). Flavors perceived at any point during consumption are dependent on the means of stimulation for the taste or volatile elicited such as volatility, lipid versus water solubility, and the receptive properties of different detectors present in the nose and oral cavity (Voilley and Etievant, 2006).

One of the most important factors in determining the acceptance of fermented dairy products are sensory properties (Jaworska and others, 2005). Sensory properties of food include flavor and texture (Jaworska and others, 2005). Textural attributes in a semisolid or solid food are determined by the interactions that occur between fat, protein, and water present within the food matrix (Jaworska and others, 2005). There are many factors that affect the texture of yogurts and other similar dairy products, which include milk type, fermentation conditions and time, starter culture used, and the presence or absence of hydrocolloids applied to the matrix (Cooper, 1987). All sensory attributes play off of each other. For example, if the flavor is not appealing then the texture becomes magnified and if the texture is not appealing then the flavor is magnified. Either situation could lead to rejection of that particular food product.

Flavor is an extremely difficult sensory attribute to define and identify. Flavor perception is based upon the combination of basic tastes and aromas. Therefore volatiles are an important aspect of defining and understanding dairy flavors. In addition, understanding dairy flavors includes the identification of chemical compounds responsible for specific sensory perceived flavors (Drake, 2004). In previous years, identifying flavors perceived were based primarily on the identification and isolation of volatiles (Drake, 2004). Today, flavor identification is based on linking volatile compounds to sensory perception and there is much interest in instrumental techniques to reproduce flavor release as food is consumed in the mouth (Deibler and others, 2001). Being able to identify compounds that are responsible for a particular flavor imparted in a specific food is important in the identification of food spoilage and off flavors. If the volatile for a specific off flavor is correctly identified, it may then be possible to eliminate or control the source of the volatile.

Determining the Importance of Flavor and Texture through the use of Sensory Science

Sensory analysis is comprised of many tests or tools that measure human responses to external stimuli (Drake, 2007). Measuring consumer acceptance is one aspect of sensory science. Many studies have been conducted to gain a better understanding of the complex topic of food acceptance by consumers. A study was conducted by McEwan and Thomson (1988) to better understand the concept of food acceptability. In this study, it was revealed that psychological behavior was responsible for determining acceptability toward food products. A Stimulus-Organism-Response paradigm was proposed. The stimulus is the food product, the organism is the consumer and the response is the behavior that the consumer elicits (McEwan and Thomson, 1988).

The importance of flavor and texture are measured through means of consumer acceptance panels, descriptive panels, focus groups, and conjoint analysis. There are two basic groups of test used to analyze sensory responses to products including analytical tests and affective (consumer) tests. Analytical tests are a group of tests that use trained panelists or are designed to evaluate differences or concentrations in a food or product. Analytical tests treat panelists as instruments or detectors and analyses are usually done in duplicate or triplicate. This method of testing usually uses trained or screened panelists (Drake, 2007). Difference or discrimination test are one type of analytical test. The most commonly used discrimination tests are the duo trio and the triangle tests.

Discrimination Tests

Difference tests are used only to determine a difference among products (Drake, 2007). Often times a difference test is misused to infer consumer preference, degree of difference, and/or the nature of difference, which are not accomplished through the use of difference tests (Drake, 2007). These types of tests can also give direction for companies to move toward. In seeking direction from a test of this type the set up corresponds to that of the duo-trio and triangle tests (Drake, 2007). This test is known as a paired comparison test. In paired comparison tests panelists are asked if a particular attribute has a higher intensity within the samples given (Drake, 2007). Duo Trio, also known as alternative forced choice, consists of 1 reference and 2 coded samples. One of the coded samples is the same as the reference. The panelist is asked to pick the sample that is the same as the reference. The triangle test is a test where a panelist is given three coded samples and asked to identify the sample that is different.

Another category of analytical test is threshold testing. The main purpose is to determine the sensory threshold of a compound, flavor, or taste (Drake, 2007). A threshold is generally the lowest concentration at which a sensory response is detected. Threshold testing can be conducted by orthonasal (aroma) or retronasal (tasting). There are many different types of threshold tests including recognition, difference, and terminal thresholds. These tests are frequently used with off flavor analysis.

Descriptive Analysis

Descriptive analysis (DA) is another category of analytical test. Descriptive analysis consists of a group of individuals (usually 6 to 12) who have been trained to identify and quantify attributes that exist in a food product (Drake, 2007). The training required for this test can be time consuming, the training time depends profoundly on the attributes profiled (Drake, 2007). A lexicon with adequate references and clear definitions must be presented to panelists for proper and adequate training. Flavor profiling of food products, the earliest form of descriptive analysis (DA) was invented by Art D. Little in the 1950's. There are now different approaches used for DA, which include Quantitative Descriptive Analysis (QDA™) invented by Stone and others (1974), and the Spectrum™ method invented by Gail Civille of Sensory Spectrum (New Providence, NJ) (Lawless & Heymann 1999). QDA™ uses 8 to 12 panelists and a line scale is used to score products. In this approach, definitions are used and references are not required. The QDA™ method has a panel leader that moderates the panel discussion. The QDA™ approach allows panelists to use the scale differently. The Spectrum™ method uses the same number of panelists, however, a universal (0 to 15pt) scale is used to evaluate the attributes. The Spectrum method™ also has a leader that leads the panel. Panelists using the Spectrum method™ do not use the scale differently as with the QDA™ approach. Generic DA uses a combination of the two methods previously mentioned.

Affective or Consumer Testing

Affective or consumer testing is the other group of sensory tests. These types of tests involve the consumer and their perception of the product being evaluated. Affective tests, unlike analytical tests do not used trained panelists (Drake, 2007). Affective tests generally require large numbers of consumers to participate to account for variation among consumer responses (Drake, 2007). There are two different types of affective testing, quantitative and qualitative tests. Quantitative consumer tests include acceptance, preference, conjoint analysis, and surveys. Qualitative tests investigate the thoughts and beliefs that a consumer may have about a specific product. The tests used to obtain qualitative information about a product by consumers are focus groups and interviews.

Preference testing is conducted when a consumer is presented with 2 or more samples and asked which sample they prefer (Drake, 2007; Meilgaard and others, 2007). However, if more than two samples are presented the consumer can then be asked to rank the samples in the order of their preference (Drake, 2007; Meilgaard and others, 2007). This is ultimately a quick and easy test, however, it has the disadvantage of not determining the degree of liking for each sample (Drake, 2007; Meilgaard and others, 2007). While preference tests and acceptance tests are very similar, there is a distinct difference between the two tests. In acceptance testing, the consumer is presented with samples and asked to specify the degree of liking on a scale, which is typically a 9 point hedonic scale (Drake, 2007; Meilgaard and others, 2007). A 9-point hedonic scale is a scale anchored on each end by like and dislike. Another scale that is used with acceptance testing is the just about right (JAR) scale (Lawless and Heymann, 1999e). The JAR scale combines the intensity and hedonic scores of a consumer (Rothman and Parker, 2009). This scale is used to measure a consumer response to a particular attribute and is anchored by the words “Too little” and “Too much” on opposites ends, with “Just About Right” in the center of the scale (Lawless and Heymann, 2010). The usage of JAR scales allows product developers to optimize product formulation (Lawless and Heymann, 2010). JAR scales are used if penalty analysis is being conducted. Penalty analysis enables developers to gain insight on specific attributes that may or may not need be adjusted to improve the product. In penalty analysis the overall liking score is penalized for not being categorized as just about right (Lawless and Heymann, 2010).

Another form of quantitative testing is conjoint analysis. Conjoint analysis is conducted to gain knowledge of what type of attributes are considered important to consumer purchase intent (Drake, 2007; Lawless and Heymann, 2010; Deliza and others, 2010). A test of this type does not require the actual product to be present (Drake, 2007; Lawless and Heymann, 2010; Orme, 2006). Conjoint analysis has become more widely used in recent years with the trend in market research in new product planning, improvement of current products, and pricing policies (Gustafsson and others, 2003, 2007).

Qualitative tests are used to understand consumer beliefs, perceptions, and expectations and involve focus groups and interviews. Focus groups usually consist of 8 to 12 consumers and a moderator which leads the discussion of the product being examined (Drake, 2007; Meilgaard and others, 1999). This discussion usually last 2 to 3 hours and is generally recorded using both audio and video (Drake, 2007; Meilgaard and others, 1999). Interviews with individuals are carried out in the same manner (Drake, 2007; Meilgaard and others, 1999). The disadvantage associated with this form of testing is the fact that it will not provide representative data about the consumer population in which the moderator is attempting to capture (Hui, 2006). The advantage of this style of testing is the opportunity to gain detailed insight about a specific product (Hui, 2006). It can also be the basis for a hypothesis to be formed and tested in a large scale quantitative test (Hui, 2006).

Preference Mapping

Another tool used in sensory science is preference mapping. Preference mapping is a collection of multivariate techniques that are used to establish relationships between instrumental or descriptive data and consumer acceptance (Meilgaard and others, 2007). There are 2 types of preference mapping: external and internal. Internal preference mapping uses consumer acceptance scores to characterize product groupings and drivers of liking (Meilgaard and others, 2007; Lawless and Heymann, 2010). External preference mapping uses quantitative measurements (usually DA) to predict consumer responses to products (Meilgaard et al, 2007; Lawless and Heymann, 2010). Partial least squares (PLS) regression is one type of external preference mapping approach (Meilgaard et al, 2007). Multivariate statistics are used to analyze data for preference mapping.

Instrumental Analysis

Chromatography has been used in research since the 19th century and is known to many researchers as a set of laboratory techniques used to separate specific compounds out of solutions. This separation method involves the partitioning of analytes in a sample between two different phases. These phases are the stationary phase and the mobile phase. While there are several different types of chromatography, column is the most common type of chromatography used in food science research. There are 2 different types of column chromatography used to explore food products. One type is gas chromatography. Gas chromatography has several types of detectors; however, only two different types of detectors will be discussed including gas chromatography – mass spectrometry (GC/MS) and gas chromatography –olfactometry (GC/O). The other type of chromatography is high pressure liquid chromatography (HPLC). These instruments all have major components in common including stationary phase, mobile phase, analyte (compound of interest), and detectors.

Gas Chromatography

Gas chromatography was developed in the early 1900's as a simple, fast, and applicable means of separation for various volatile compounds (McNair and Miller, 2009). Gas chromatography is used to separate and identify volatile compounds. This instrument works by separating the volatile compounds based upon the polarity of the stationary phase, and the polarity along with the molecular weight/volatility of the compound(s) of interest. In gas chromatography the mobile phase is a gas that carries the analytes through the stationary phase (liquid column). Once the sample is vaporized it is then carried off by the mobile phase through the column. The sample is then partitioned into the stationary phase based on the solubility of the analyte at a specific temperature (McNair and Miller, 2009). The process of an analyte being removed from the column is known as elution. All compounds have a specific retention time (RT) for specific columns (Croissant and others , 2010). Each compound's retention time is normalized by comparing the retention times against an alkane series (van den Dool and Kratz 1963; Croissant and others, 2010). Normalization of the RT provides a retention index which has more stability than the RT and also allows comparison across time, machine, and location (Croissant and others, 2010). Once compounds elute off the column they are passed through a detector which translates the chemical information into a signal response which is recorded by a software program. There are many advantages of using gas chromatography including fast analysis, efficiency, sensitivity, high accuracy, small sample amounts, reliable, and inexpensive (McNair and Miller, 2009).

Gas Chromatography/Mass Spectrometery

There are many different types of detectors that can be coupled with the GC, however, mass spectrometry (MS) is often used. The MS ionizes the molecule as it enters the detector and the compound ions are then separated in the mass spectrophotometer by their mass-to-charge ratio and then detected according to their abundance (Hoffmann and Stroobant, 2007). This process produces a mass spectrum. Compound identities are confirmed by injection of a pure standard followed by comparison of retention index (RI) and mass spectra to an unknown. The MS is connected to a computer that has a database with several different compound spectras. The unknown spectra can be matched with the database spectra for a tentative identification. The GC/MS allows operation in two different modes; scan and selective ion mode (SIM). The scan mode monitors a range of mass to charge ratios (ions), while SIM monitors specific ions. Scan mode is usually completed first to gain insight on the type of compounds present with in a sample. Below is a schematic of the GC/MS.

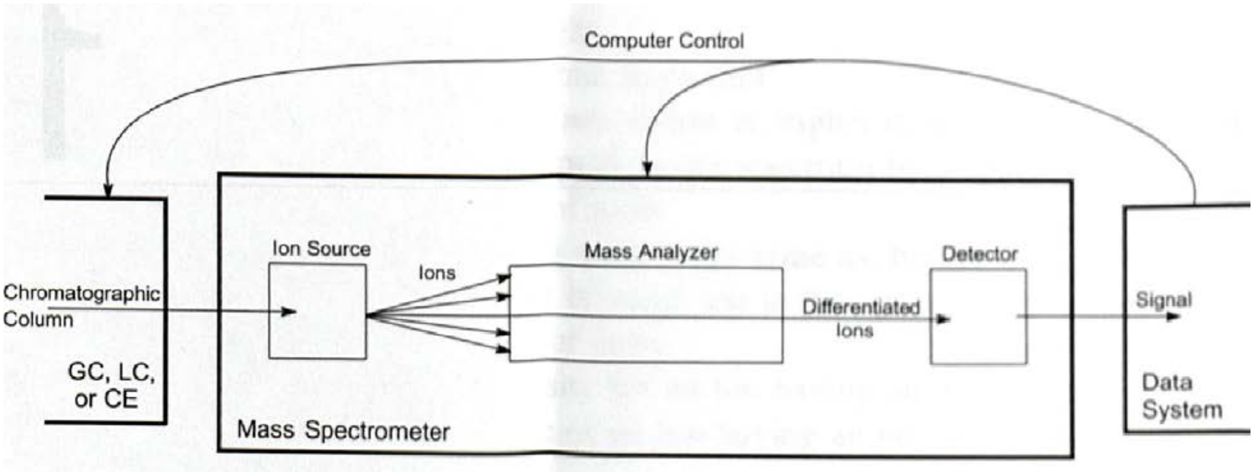

Figure 1. Block Diagram of GC/MS (Smith, 2004).

Gas Chromatography-Olfactometry

Another detector that is often coupled with GC is the human nose. During GC/O analysis, as compounds elute from the GC column, a human detector sniffs the eluant and records the aroma present. GC/O allows for detection of aroma active compounds (Friedrich and Acree, 2000). This method is used to confirm the identity of a compound and it also allows researchers to determine the aroma activity of compounds and their contribution to the flavor of the food product (Croissant and others, 2010). Below is a schematic of the GC/O.

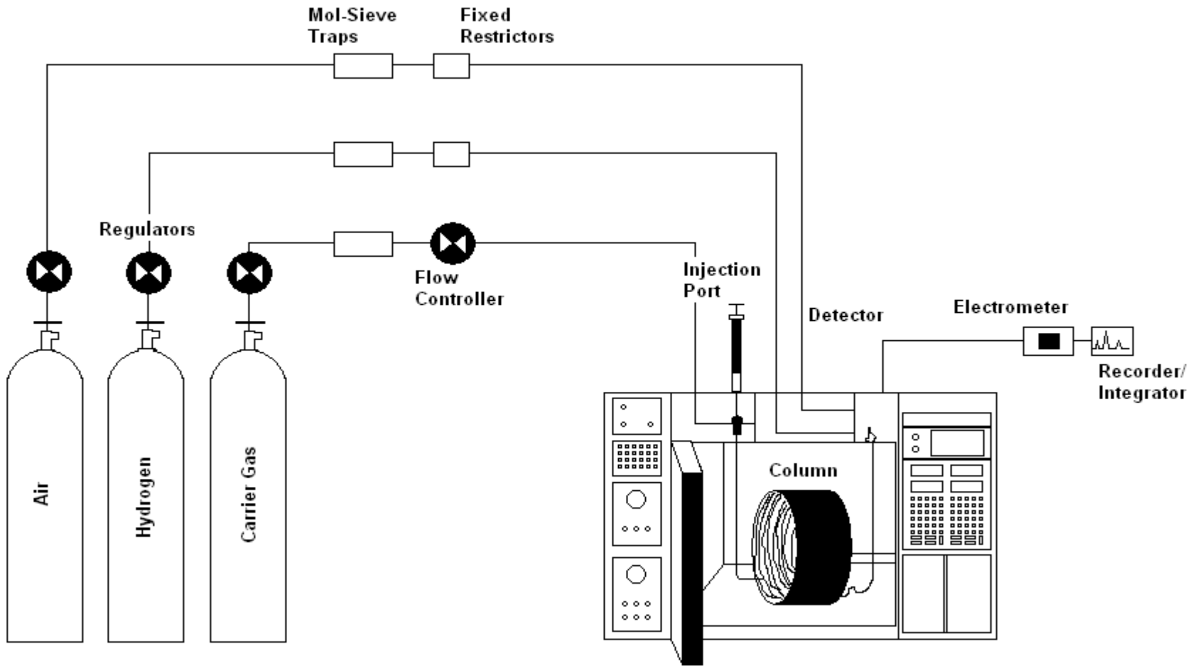

Figure 2. Components of a GC system. (Courtesy of Hewlett Packard Co., Analytical Customer Training, Atlanta, GA)

High Pressure Liquid Chromatography

HPLC is a form of liquid chromatography that separates nonvolatile compounds. HPLC has several components including the mobile phase, analyte, stationary phase, pump, column, and computer system. The most important part of the HPLC is the column, which is where separation occurs. The mobile phase is the liquid portion of the system that introduces the analyte (compound of interest) to the stationary phase which is the solid packing located inside of the column. The analyte will either remain in the mobile phase or retain to the stationary phase based on the polarity of both the column and analyte. Retention times are calculated based on the time in which the analyte is eluted from the stationary phase. Below is a schematic of an HPLC.

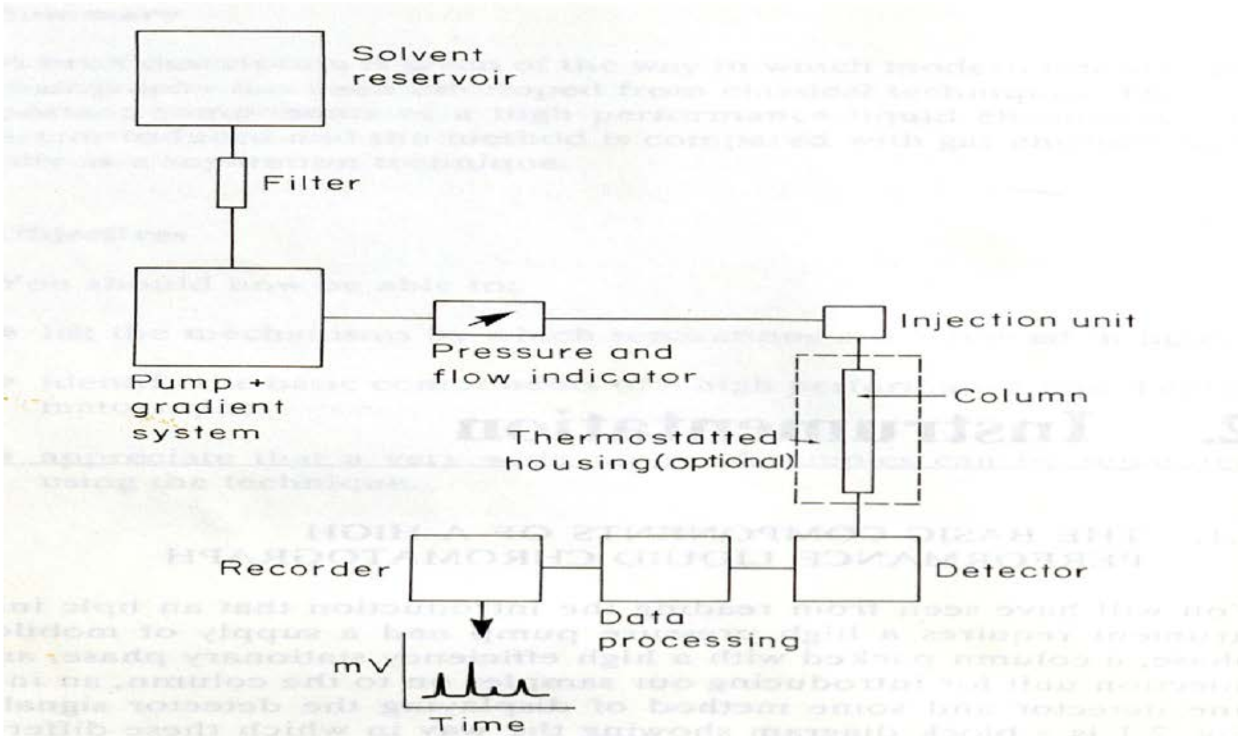

Figure 3 Components of the HPLC (Lindsay, 1987)

HPLC Detectors

Detectors used for HPLC can be categorized into 2 groups, universal and selective. The selective detector only responds to a specific physicohechemical property of the eluted analyte (Ahuja and Dong, 2005). Some examples are: electrochemical detectors, single wavelength ultra violet-visible (UV-VIS) absorption and fluorescene detectors. The universal detector has no specific physiochemical property of the eluted analyte it responds to, it simply responds to all solutes that pass through it (Ahuja and Dong, 2005). Some examples are: evaporative light scattering (ELSD) and refractive index (RI). There are several different detectors that can be used with the HPLC. Ultra violet/Visible detector is a detection method that records the absorption of UV or visible light of the analyte that elutes

(Ahuja and Dong, 2005). The UV or visible light is typically measured by a deuterium source and a monochromator (Ahuja and Dong, 2005). Another type of HPLC detector is the photodiode array (PDA). The PDA allows a UV spectra of the peaks eluted to be produced (Ahuja and Dong, 2005). The PDA not only provides the spectra, it also performs like the UV/VIS and monitors the absorbance of compounds that are eluted off the column (Ahuja and Dong, 2005). The light source for this detection method is the same as the UV/VIS. However, it is different due to having a diode array element which allows measurement of light to be taken at each wavelengh (Ahuja and Dong, 2005). UV detection is often the preferred method of detection, however, it is limited to detecting compounds that have chromophore groups, such as aromatic rings, and is not applicable to compounds that do not absorb within the UV range (Snyder and others, 2010). Refractive Index is another type of HPLC detector. This detection method is different from the previous detectors mentioned. The RI responds by recognition of difference in the refractive index of the mobile phase as it passes through the detector flow cell (Snyder and others, 2010). The RI is a universal detector in that it responds to all solutes passing through. The light source for this detector is typically a tungsten lamp (Snyder and others, 2010). There is usually a small portion of the mobile phase that is trapped in a cell, which is used as a reference cell (Snyder and others, 2010). This reference cell is compared to all solutes that pass through the cell containing the solute (Snyder and others, 2010). The difference in the refraction is measured by a pair of photodiodes (Snyder and others, 2010). The RI has several limitations, such as sensitivity to changes in pressure, ambient temperatures, and flow rate changes (Snyder and others, 2010).

Application of Sensory Tools to Dairy Products

Sensory analysis has been conducted on dairy products from the milk of cows with high polyunsaturated fatty acids intake. Chen and others (2004) investigated whether or not the flavor and texture of dairy products made with cow's milk that contained higher or lower unsaturated fatty acids differed from dairy products made with bulk-tank milk. Specific dairy products investigated for possible texture and flavor differences due to fatty acid differences were butter, vanilla ice cream, yogurt, and Cheddar and Provolone cheeses. Texture analysis was conducted by rheology instruments. The sensory tool used to evaluate the flavors perceived was descriptive analysis. Chen and others (2004) found that fatty acid content did have an effect on the texture of the butter, ice cream, yogurt, or Provolone cheeses. Dairy products displayed a softer texture when manufactured from milk of high polyunsaturated fatty acids fed cows (Chen and others, 2004). There were not flavor differences associated with the content of fatty acids present (Chen and others, 2004).

Allgeyer and others (2010) determined the drivers of liking for yogurt drinks that contained prebiotics and probiotics. To complete this study, 110 consumers evaluated the overall acceptance and purchase intent of 10 different drinkable yogurts. A demographic survey was also given to the consumers for the purpose of understanding or gaining insight on how much consumers knew about prebiotics and probiotics (Allgeyer and others, 2010). This study revealed that consumers would be most likely to purchase yogurt drinks that were characteristic of a medium level of sweetness and high viscosity (Allgeyer and others, 2010).

The content of diacetyl as a flavor component in full fat cottage cheese was researched by Antinone and others (1994). Diacetyl is an aroma active compound responsible for a buttery aroma and flavor in cultured dairy products (Antionone and others, 1994). Antinone and others (1994) conducted a consumer test to gain better insight on how consumers responded to different concentrations of added diacetyl in cottage cheese. In addition to the consumer acceptance test, threshold testing was conducted to determine relevant concentrations. Consumer testing revealed that consumers preferred cottage cheese with 1ppm diacetyl (Antinone and others, 1994).

A study conducted by Drake and other (2009) examined the variability in flavor profiles for sharp or aged U.S. Cheddar cheese. This study examined whether or not location played a role in the overall liking of aged or sharp Cheddar cheeses. The cheeses (n=29) were evaluated by a descriptive panel. Descriptive panel results suggested that 9 samples be included in the consumer panel. Consumers (n=110) then evaluated the cheeses for overall liking, color liking, sharp cheese flavor liking, sharp cheese flavor intensity, salty taste liking, and texture liking using a 9-point hedonic scale (Drake and others, 2009). Preference mapping revealed the term aged or sharp Cheddar cheese means different things to different consumers and that liking of specific cheese flavor attributes was not dependent or defined by consumer location (Drake and others 2009).

Conjoint analysis was conducted to assess consumer responses to reduced fat cheese. A conjoint survey was created based upon focus groups that included both users and non-users of reduced fat cheese (Childs and Drake, 2009). The attributes investigated were fat content, flavor, texture, and price of reduced fat cheese. Two different kinds of cheeses were examined including Cheddar and Mozzarella cheese. The results of the conjoint analysis survey revealed that consumers preferred a 2% reduced fat Cheddar cheese and a part-skimmed milk Mozzarella cheese (Childs and Drake, 2009).

Bruhn and others (2002) used focus groups to explore consumer perception of probiotic products. This study revealed that some people rejected potential health claims because of negative connotations associated with food borne illnesses related to diarrhea while purchasing food items (Bruhn and others, 2002). Bruhn and others (2002) found that some participants were more receptive of statements that did not convey absolute certainty such as "May reduce cancer risk" versus "Reduces cancer risk." This study also revealed that consumers do read the nutrition labels of the food products that they purchase and expect them to be accurate. It also revealed that consumers rely heavily on researchers and news media to inform them of health benefits that are food related (Bruhn and others, 2002).

Wright and others (2008) conducted a focus group on alcoholic beverages. The objective of their research was to evaluate how consumers were influenced on a daily basis in their decisions of what type of food or drink they consumed. The influential factors included TV/entertainment, environmental factors, and moral/religious reasons or any other fact that played a role in influencing consumer perception of a food product. This study revealed that many consumers viewed red wine as a healthy alcoholic beverage and that males viewed alcoholic beverages to be healthy while women did not view alcoholic beverages to be as healthy (Wright and others, 2008).

In Australia, obesity is on the rise among kids (Ip and others, 2007). Researchers are led to believe that this rise is due to television commercials and reduced physical activities. To address this issue, Ip and others (2007) conducted focus groups with parents to gain their perception of television food advertising directed toward kids. Many parents reported that commercials played on the child's emotions and that it heavily influenced the child's food preferences (Ip and others, 2007).

Instrumental Analysis of Texture

Food rheology is conducted to better understand the flow of various types of foods. White (1970) defined food rheology as the study of deformation and flow of the raw, the intermediate products, and the final products of the food industry. White (1970) also defines psycho-rheology as the relationship between consumer preferences and rheological properties. Szczesniak (2002) defined texture as a combination of sensory and apparent function of structural, mechanical and surface properties of foods detected through the senses of vision, hearing, touch, and kinesthetics. Studies have been conducted to gain a better understanding of the texture of foods. Instrumental tests to quantify texture are not the same as having a consumer analyze the texture; however it is still very useful to understand physical properties. In the food industry, many companies use rheological instruments to evaluate the texture of wheat flour dough (Bloksma 1971), cereal snack bars (Kim and others, 2009), mayonnaise (Terpstra and others, 2008), canned peaches (Apostolopoulos and Brennan, 1993), gelatin gels (Surowka, 1997), cheese analogs (Lobato-Calleros and others, 1999), Cheddar cheese (Hort and Le Grys, 1999), meat (Chen and Trout, 1991), and custards (Jellema and others, 2005).

Measurements on rheological instruments can imitate different stages of human consumption (Jellema and others, 2005). Jellema and others (2005) conducted a study to investigate different creaminess levels in custards using both rheological equipment and sensory analysis. A Paar Physica MCR 300 rheometer was used to evaluate the textural properties of the custard (Jellema and others, 2005). In addition to using rheological equipment to assess the creaminess of custard, a descriptive panel was also used to assess the difference in creaminess levels for the custards. The instrumental data was similar to that of the sensory data for some of the textural attributes, however, not for all. Therefore it was concluded that instrumental analysis of texture may aid in relieving the use of sensory panels. However, instrumental analysis of texture could not be a replacement for sensory analysis due to an inability lack of instruments to measure some sensory textural attributes (Jellema and others, 2005).

Hort and Le Grys (1999) conducted a study with a descriptive panel and rheological equipment to evaluate the texture of Cheddar cheeses. Seventeen different types of Cheddar cheeses and an English cheese were compressed and a cutting test was conducted using an Instron Universal Testing Machine. The results of the Instron equipment were reported in terms of the true stress and Henky strain (Hort and Le Grys 1999). Among the different rheological equipments used by Hort and Le Grys (1999), the instruments that mimicked the action of humans were most accurate and successful at predicting all textural attributes except creaminess at all stages except for the earliest stages during maturation.

Instrumental Analysis of Volatile and Non-Volatile Compounds

The nature of milk, heterogeneous, makes it difficult to analyze the aroma of dairy products (Friedrich and Acree, 1998). Friedrich and Acree (1998) focused on the use of GC/O and Retronasal Aroma Simulation (RAS) to analyze various cheeses, milks, and fermented milk products. Retronasal Aroma Simulation (RAS) is another instrument that has been used to characterize the odor active compounds in different food matrices. Friedrich and Acree (1998) defined retronasal aroma as the odor sensation experienced during food consumption when flavor molecules travel from the mouth to the olfactory epithelium. The volatiles of food change as it is consumed due to mixing with saliva, which modifies the polarity, pH and temperature of the volatiles (Friedrich and Acree, 1998). However the RAS device considers all of the factors previously mentioned and is able to properly simulate human breakdown of food. This is achieved by the use of synthetic saliva, temperature regulation, and blending at shear rates that mimic the chewing that occurs during food consumption (Friedrich and Acree, 1998). In this study Friedrich and Acree (1998) were able to identify the aroma profile of dairy products such as milk and cheese with the use of GC/O, however, they found that it would be advantageous to couple RAS with GC/O in order to produce a similar retronasal product.

Neta and others (2008) investigated Farmstead Cheddar cheeses to identify the compounds responsible for earthy bell pepper (EBP) flavor. Farmstead Cheddar cheeses have a distinctive flavor. These cheeses are in a natural bandage (Lieberman, 2007). Earthy/bell pepper (EBP) flavor was characteristic of bandage-wrapped Cheddar cheeses, frequently observed in International Cheddar cheeses (Neta and others, 2008). A trained sensory panel evaluated cheeses to document the flavors in each cheese. Four out of 8 cheeses were characterized by EBP flavors. Each cheese was then evaluated by GC/MS and GC/O. The combined results of GC/MS, GC/O, and descriptive panel data indicated that 2-sec-butyl-e-methoxypyrazine and 2-isopropyl-3-methoxypyrazine were the main sources of EBP flavor characteristics in Farmstead Cheeses (Neta and others, 2008).

High pressure liquid chromatography can aid in identifying non-volatile compounds. In the cheese industry it is important to develop a well aged cheese that is not bitter (Dunn and Lindsay, 1985). The bitterness that is present in some aged Cheddar cheeses is due to the existence of bitter peptides (Visser, 1997a). Lemieux and others (1989) investigated the possibility of eliminating the bitter taste that can occur in aged Cheddar cheeses. Their study included adding strains of lactobacillus to the lactic starter of Cheddar cheese to accelerate ripening and potentially eliminate bitter taste (Lemieux and others, 1989). Lemieux and others (1989) found that adding lactobacillus strains allowed free amino acids to be released. The use of size exclusion HPLC chromatography allowed accurate molecular weights of proteinase and peptidase activities to be examined and ultimately provided an understanding of the cause of bitter taste (Lemieux and others, 1989).

High pressure liquid chromatography and GCO was used in a study conducted by Laye and others (1993) to examine the non-volatile and volatile compounds that characterized several commercial yogurt products. The main purpose of their study was to compare the composition of experimental yogurt product to that of commercial yogurt products. Laye and others (1993) were able to identify volatile compounds, through the use of GCO, that were responsible for a desirable aroma of plain yogurt. In this experiment they identified numerous compounds by HPLC that were present including lactic acid and acetone (Laye and others, 1993). Laye and others (1993) also identified compounds such as diacetyl and acetaldehyde by use of GC/O. However, Rash (1990), stated that the main flavor of cultured yogurt was lactic acid, an organic acid.

History of Sour Cream

Fermented food products date back to ancient times. The first occurrence of fermentation of food was most likely accidental; however, many found the taste and texture pleasant. Once found that a pleasant food item was made from this incidence, people began to purposely ferment foods. Fermentation is most commonly known as the process by which a microorganism feeds on carbohydrates and acid is then secreted. In dairy products the microorganism used for fermentation include numerous forms of lactic acid bacteria starter culture, such as *Lactococcus lactis* subsp*. lactis*, *Lactococcus lactis* subsp*. cremoris, Cit +L. lactis subsp. lactis and Leuconostoc citrovorum)* (Hui and others, 2004). The process of fermentation not only preserves food, it also enhances the taste, aroma, texture, and nutritional value of the food product. The acids produced are believed to contribute to the flavor profile of dairy products, fruits and vegetables, and other food products (Marsili and others, 1981; Lamikanra, 2002).

Sour cream, a relatively heavy, viscous product with a gloss, has a delicate lactic acid taste with a balanced, pleasant, buttery-like (diacetyl) aroma (Hui and others, 2004) . Sour cream is defined by the U.S. Food and Drug Administration (21CRF 131.160) as "Sour cream results from the souring, by lactic acid producing bacteria, of pasteurized cream. Sour cream contains not less than 18 percent milkfat; sour cream has a titratable acidity of not less than 0.5 percent, calculated as lactic acid." Sour cream is a product that is high in fat. In recent years the desire to consume less fat has created a market for reduced fat sour cream.

Production of Sour Cream

Sour cream manufacture is initiated by acquiring grade raw milk into a vertical holding tank at 4^{o}C with some agitation to ensure no separation occurs (Hui and other, 2004). Separation of skim and cream is then conducted in approved equipment (Hui and others, 2004). During separation undesired particles are removed for final production. Once separated the cream is mixed with skim milk to the desired fat level (Hui and others, 2004). The product is pasteurized after separation and then homogenized. Homogenization is the next step, this ensures that the milk fat globules are evenly dispersed and in an extremely small diameter. After homogenization the product is cooled to 20-22^{o}C and a mesophilic strand of lactic acid bacteria the starter culture is added (Hui and others, 2004). The incubation temperature is usually 22.2 – 23.9^{o}C and the incubation time is typically 14 -18 hours. The product is then incubated to a titratable acidity (TA) of 0.7-0.9% and a pH of 4.50-4.55 is obtained, cooled to 4-10^{o}C, packaged and stored.

Previous Research Conducted on Sour Cream

There has been a limited amount of research conducted on sour cream from both a sensory and instrumental aspect. Most sour cream research involves the microbiological views on sour cream and or studies on the affect of packaging for sour cream. Larsen and others (2009) investigated the photooxidation of sour cream which was packaged in cups with varying light barrier properties. Sour cream was evaluated in three different cups (a white cup, a cup with medium light barrier (LB), and a cup with high LB) under standard fluorescent light tubes for 36 hours (Larsen and others, 2009). Sensory analysis and front face fluorescence spectroscopy were used to analyze the quality of the stored sour creams

(Larsen and others, 2009). Larsen and others (2009) discovered that cups with high LB gave the best protection against light oxidation.

Folkenberg and Skriver (2001) investigated the role of fermentation culture and storage time played on the sensory properties of sour cream. This study provided evidence that both storage time and fermentation culture significantly affected the sensory properties of the sour cream. Folkenberg and Skriver (2001) found that the following attributes were controlled by the fermentation culture: margarine-fatty flavor, diacetyl odour, acetic flavor, and sour taste. While prickling mouthfeel, diacetyl flavor, acetaldehyde flavor sour odour, rancid flavor, cheesey flavor and bitter taste were correlated to the storage time of the sour cream (Folkenberg and Skriver, 2001).

Marsili and others (1981) identified the presence of organic acids in various dairy products by HPLC. The dairy products included in this study was whole milk, skim powder, cultured buttermilk, sour cream, cottage cheese, yogurt, sharp Cheddar cheese, and blue cheese. HPLC with an ultraviolet/visible detector was used (Marsili and others, 1981). Their research revealed that a substantial amount of orotic, citric, and lactic acid was present in all the dairy products. Yogurt, sour cream, and cultured buttermilk had the highest amounts of lactic acids. Hippuric was not found in large amounts in many of the dairy products except for whole milk and cottage cheese and this could have been due to hippuric present below the instrumental limit of detection which was less than 1 parts per million (ppm). Uric acid was found in substantial amounts in all of the dairy products along with citric and orotic acids.

Organic Acids

Organic acids are very important to dairy food products. This importance is due to their ability to contribute to the flavor, texture, and stability or microbial protection to many dairy food products. Organic acids also contribute to the nutritional factors of dairy products (Izco and others, 2002). Organic acids are also used as an index of maturity of dairy products that ripen or are associated with microbial deterioration of some foods as well as an indicator of fermentation stages. Organic acids are the products of normal metabolic processes in animals, hydrolysis of butterfat, desired action of bacterial cultures or microbial deterioration, as well as a direct addition of acids when required by a particular process. Starter cultures can determine the amount of lactic acid that is present, production of volatile flavor compounds, proteolytic or lipolytic activity, along with production of other products, and prevention of growth and many spoilage organisms (Tamine, 1981). The acids that are of main importance to identify in fermented dairy products are orotic, citric, pyruvic, lactic, uric, formic, acetic, propionic, butyric, and hippuric (Garcia and McGregor, 1994: Marsili and others, 1981; Zeppa and others, 2001; Akalin and others, 2002; Izco and others, 2002; and Tormo and Izco, 2004).

Organic acids appear in many dairy products as a result of the hydrolysis of milk fat, direct addition of acidulants, normal bovine biochemical metabolism, or bacterial growth (Izco and others, 2002). Organic acids are also a major product of carbohydrate catabolism of lactic acid bacteria (Izco and others, 2002). One of the major factors of milk fermentation is the ability for acids to be produced along with pH reduction (Izco and others, 2002). Izco and others (2002) reported that the acidity aids in preventing the development of spoilage and pathogenic microorganisms, improving the hygienic quality of dairy products.

Organic acids are found in many dairy products but they are also found in non dairy food products including tomato (Thorne and Efiuvwevwere, 1998), oranges/orange juice (Shaw and Wilson, 1983), cherry juice (Shaw and Wilson, 1993), grapefruit juice (Shaw and Wilson, 1983), mangoes, pickles (McFeeters and others, 1982), cocoa (Holm and Aston, 1993), and other acidified foods (Helms and others, 1993). The main organic acids responsible for the antimicrobial effects in fermented dairy products, such as Kefir and sour cream, are lactic acid and acetic acid. These two organic acids are what initiated the belief that organic acids could potentially allow kefir to be a probiotic product (Garrote and others, 2000). The inhibitory power of these acids over growth of bacteria is related to the undissociated form of both lactic acid and acetic acid (Garrote and others, 2000).

It is important to identify and quantify organic acids in dairy products, since they directly affect the flavor of the product (Marsili and others, 1981). As previously mentioned several lactic acid bacterial cultures are used for sour cream fermentation. The lactic acid bacteria are used for the purposes of breaking down lactose, generating flavor, providing texture, and serving as a preservative (Urbach, 1995). Some organic acids are produced during fermentation as a result of butter fat lipolysis (Urbach, 1995). Organic acids that could potentially form during fermentation of sour cream are orotic, citric, pyruvic, lactic, uric, formic, acetic, propionic, butyric, formic, and hippuric (Marsili and others, 1981). The structures of each are shown below.

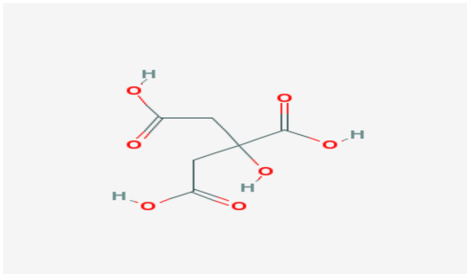

Figure 4. Structure for citric Acid (National Center for Biotechnology Information, 2010).

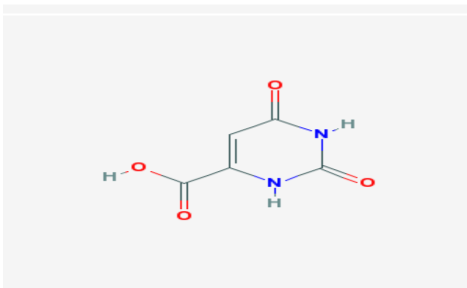

Figure 5. Structure for orotic acid (National Center for Biotechnology Information, 2010).

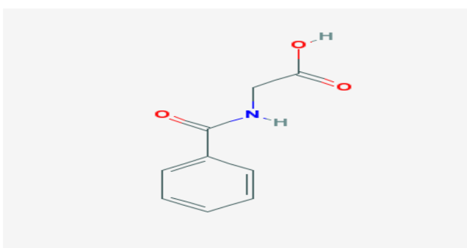

Figure 6. Structure for hippuric acid (National Center for Biotechnology Information, 2010).

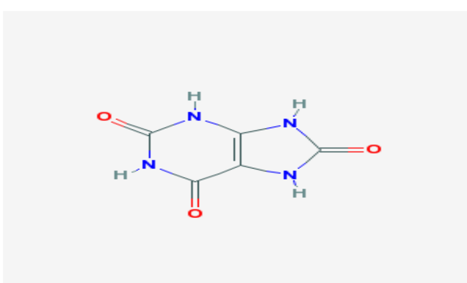

Figure 7. Structure for uric acid (National Center for Biotechnology Information, 2010).

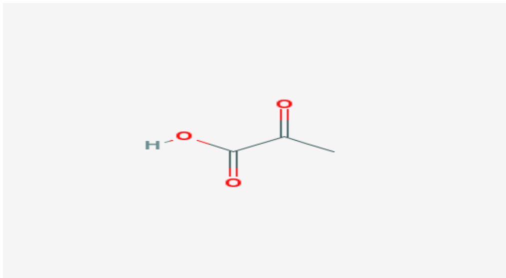

Figure 8. Structure for pyruvic acid (National Center for Biotechnology Information, 2010).

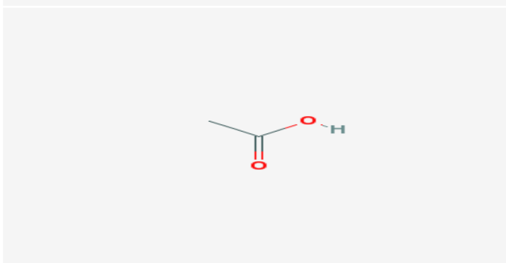

Figure 9. Structure for acetic acid (National Center for Biotechnology Information, 2010).

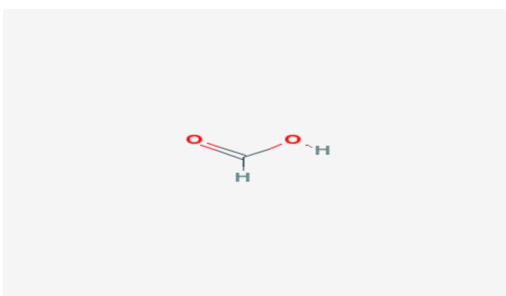

Figure 10. Structure for formic acid (National Center for Biotechnology Information, 2010).

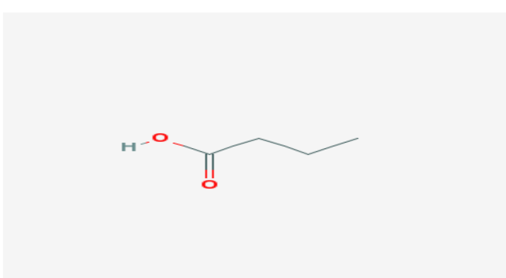

Figure 11. Structure for butyric acid (National Center for Biotechnology Information, 2010).

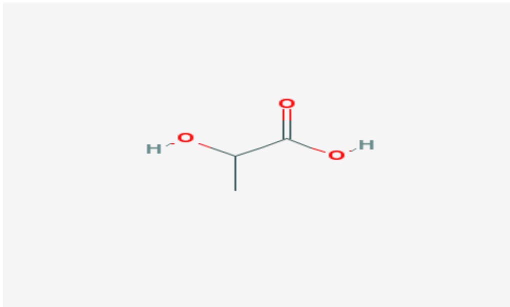

Figure 12. Structure for lactic acid (National Center for Biotechnology Information, 2010).

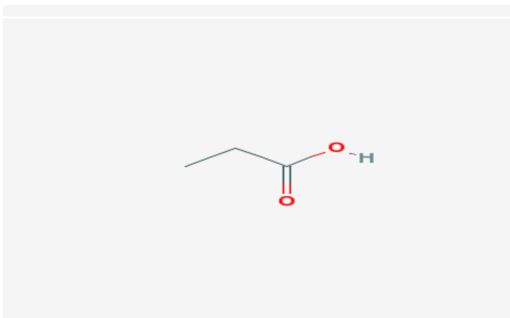

Figure 13. Structure for propionic acid (National Center for Biotechnology Information, 2010).

Organic acids exist in two different forms which include buffered acids or a pure (naturally occurring state) acid (Theron and Lues, 2007). The pure organic acids include lactic, propionic, acetic, citric, and benzoic acids (Theron and Lues, 2007). The buffered acids are calcium and sodium salts of propionic, acetic, citric, and benzoic acids (Theron and Lues, 2007). Buffered organic acids are either protonated or non protonated. The non-protonated forms have a negative charge and are polar where as the protonated acids have no charge and are not polar (Madras and others, 2006). Buffered acids have an advantage over pure acids in product development because they are safer to handle and less caustic to machinery (Theron and Lues, 2007). Organic acids are now used in many sectors of the food industry to slow microbial growth. Not only have some of these organic acids been approved by the FDA to aid in slowing microbial growth, they have also been approved to be used as acidulants, antioxidants, flavouring agents, pH adjusters, and even nutrients (Food Safety and Inspection Service, 1999).

Identification of Organic Acids in Foods

The organic acids found in food are identified by the same equipment that identifies other flavor volatile and non-volatile compounds. This includes HPLC, GC-O, and GC. However there are advantages to using the HPLC due to its ability to identify organic acids with higher speed, simultaneously analyze several acids, and the ease of sample preparation (Fernandez-Garcia and McGregor, 1994). The HPLC has been used by a number of researchers to characterize organic acids in a variety of dairy products (Marsili, 1985; Panari, 1986; Bevilacqua and Callifano, 1989; Lombardi and others, 1994: Lues and Botha, 1998; Califano and Bevilacqua, 1999). When organic acids are identified by HPLC, several steps are carried out. For example, Fernandez-Garcia and McGregor (1994) examined the existence of 10 organic acids present in the fermentation and cold storage of yogurt. The organic acids included in their research included orotic, citric, pyruvic, lactic, uric, formic, acetic, propionic, butyric, and hippuric. Two methods of extraction were used. The methods included acetonitrile and water extraction and the other method used was .01N H_2SO_4 extraction. The extracts were then filtered and injected (Fernandez-Garcia and McGregor, 1994). The peaks were identified by retention times.

Although the identification of organic acids using the GC is similar in that the organic acids are identified by retention times just as with the HPLC, but it is a bit more difficult. This is difficult for several reasons with one of the most important being that not all organic acids are volatile. Another difference is the manner in which the samples are prepared for analysis. In GC analysis, sample extractions are sometimes conducted using HS-SPME, which was previously mentioned.

Akalin and others (2002) investigated the variation in organic acid content during the ripening of pickled white cheese. In this study, they identified 9 organic acids including formic, pyruvic, lactic, acetic, orotic, citric, uric, propionic, and butyric. HPLC with a reverse phase C18 (120x5-mm) column and UV detector was used (Akalin and others, 2002). Akalin and others (2002) found that fresh cheeses (0-1months) were characterized by a decrease in pyruvic, lactic, and citric acid contents in comparison to older cheeses. There was an increase in concentrations of propionic, butyric, and formic acids in comparison to the previous acids mentioned. Cheeses aged 2 to 3 months were characterized by increased concentrations of pyruvic, lactic, citric, propionic, and butyric acids, and decreased acetic, formic, orotic, and uric acids compared to the concentration levels of the 6 month old cheese (Akalin and others, 2002). Older cheeses (>6 month) were characterized by high concentrations of lactic, propionic, butyric, formic, acetic, orotic, and extremely low concentrations of citric acids (Akalin and others, 2002).

Many experiments have been conducted to analyze the organic acids and flavor active compounds that are present in dairy products. Guzel-Seydim and others (2000) conducted an experiment to determine the content of organic acids and volatile flavor compounds in Kefir during fermentation. Organic acids were determined by HPLC. The method used for the HPLC was similar to Marsili and others (1981) and Fernandez-Garcia and McGregor (1994). GC/O was used to identify the flavor volatile compounds. After 15 hours of fermentation the concentration of orotic acid decreased significantly (Guzel-Seydim and others, 2000). Orotic acid is an intermediate product that is generally characterized as being involved in the synthesis of nucleotides (Gottschalk, 1986). Hippuric and uric acid decreased in concentration during fermentation, however, it was in a shorter time frame than that of orotic acid. The concentration of hippuric and uric acid decreased after 5 hours of fermentation and was not able to be detected once the fermentation was completed (Guzel-Seydim and others, 1998). Guzel-Seydim and others (1998) hypothesized that the disappearance of hippuric acid was a result of the growth of lactic acid bacteria. Acetic, propionic, and butyric acids were not detected at all during kefir fermentation (Guzel-Seydim and others, 1998).

The effects of frozen and refrigerated storage on organic acid profiles of goat milk plain soft and monterey jack cheese was examined by Park and others (2006). The purpose of this experiment was to determine the organic acid profiles of PS, MJ, and to evaluate the effects of 6 months of freezing and 4weeks of refridgeration storage on organic acid contents of the 2 types of goat cheeses in comparison with those of nonfrozen control groups. A HPLC was used to identify and quantify the amount of organic acids present. The results of the HPLC showed that the lactic acid for the PS cheese drop initially and increased through out the freezing process, however the lactic acid content was not as consistent in the MJ (Park and others, 2006). The formation of lactic acid is critical to the development of cheese due to flavor development, proper aging, and achieving a desirable product with good quality (Wong, 1974). The amount of butyric acid observed in the PS cheese was low compared to lactic acid, however, the butyric content for the MJ cheese increased. Butyric and propionic acids concentrations did increase in PS cheeses over the storage period, however, they were less and not as consistent for the propionic acid (Park and others, 2006). Acetic acid concentrations were higher for the PS cheeses than the MJ cheeses. Significant differences in levels of other organic acids (isotartaric, citric, formic, and uric) were detected between different storage groups for the PS cheese but not for the MJ cheese (Park and others, 2006).

Application of Preference Mapping to Dairy Products

Valuable consumer information is obtained through the application of preference mapping (MacFie and Thomson, 1994). The information gained is often used to aid in further optimization of various different products in an attempt to satisfy consumers. A study conducted by Lovely and Meullenet (2009) compared different preference mapping techniques for the optimization of strawberry yogurt. Preference mapping has been used on a variety of different liquid dairy products (Richardson-Harman and others, 1999), powdered chocolate milk (Hough and Sanchez, 1998), Cheddar cheese (Caspia and others, 2006; Drake and others, 2008; Drake and others, 2009), Mozzarella cheese (Pagliarini and others, 1997), dulce de leche (Ares and others, 2006; Hough and others, 2007), ice cream (Bower and Baxter, 2007), and chocolate milk dessert (Ares and others, 2010).

Drivers of liking for yogurt drinks containing prebiotics and probiotics were investigated by Allegery and others (2010). Drivers of liking for yogurt beverages were determined through the use of internal and external preference mapping (Allegery and others, 2010). A quantitative consumer panel was conducted and panelist evaluated the following sensory attributes overall acceptance, acceptance of aroma, appearance, and taste. This study found yogurt beverages that contained higher levels of prebiotics in the presence probiotics were one of the major factors of consumer acceptance (Allegery and others, 2010).

Consumers also preferred yogurt beverages with a medium level of sweetness and a high level of viscosity (Allegery and others, 2010). Another study conducted by Elmore and others (1999) used preference mapping to relate sensory characteristics of vanilla pudding to consumer responses. Elmore and others (1999) found that consistency, smoothness, and dairy flavor were the attributes that were closely related to liking of creaminess for instant vanilla pudding.

Thompson and others (2004) conducted a study to gain insight on the drivers of consumer liking for chocolate milk. Both internal and external preference mapping was used to identify the sensory characteristics that were responsible for liking of chocolate milk. Thompson and others (2004) found that the major driver of acceptance for chocolate milk was cocoa aroma. Young and others (2004) conducted a study to examine the flavor profile and the consumer acceptability of 7 Cheddar cheeses at different maturity levels. External and internal preference mapping revealed 6 different segmentations among consumers. Therefore, Young and others (2004) concluded that the acceptance of Cheddar cheese varied among consumers and preference was based on the consumer preferences for Cheddar Cheese.

Thompson and others (2007) conducted a study to identify sensory drivers for drinkable yogurts in the US. This study first involved descriptive analysis of drinkable yogurts. Following the descriptive panel, a focus group and quantitative consumer panel were held with three different ethnic groups (African American, Caucasian, and Hispanic) (Thompson and others, 2007). Thompson and others (2007) found that ethnicity did not define liking profiles of commercially available strawberry drinkable yogurts. However, three clusters were identified, including drinkable yogurt likers, drinkable yogurt lovers, and drinkable yogurt hard sells. These results were obtained through the use of preference mapping.

A study was conducted by Drake and others (2009) to identify and define sensory characteristics of commercial cottage cheese and to compare different approaches for characterizing consumer preferences including qualitative multivariate analysis (QMA). The first step was the development of a sensory language to properly and correctly identify the sensory properties present in cottage cheese (Drake and others, 2009). The attributes examined were appearance, flavor, and texture. The descriptive panel evaluated 26 samples and 8 samples were selected for consumer tests (Drake and others, 2009). Drake and others (2009) found that cottage cheeses were differentiated by cooked, milkfat, diacetyl and acetaldehyde flavors and salty taste, along with texture parameters (firmness, smoothness, tackiness, curd size, and adhesiveness). The two consumer testing approaches identified similar liking factors including diacetyl and milkfat flavors, smooth texture, and mouthcoating (Drake and others, 2009).

Conclusion

It is very important to have an understanding of the consumer perception of a food product. Understanding sensory and physical properties of sour creams and how consumers perceive the product would be advantageous to the manufacturers of sour cream since there has not been many recent studies conducted on sour cream. The objective of this study was to determine the drivers of liking for sour cream through descriptive analysis and consumer testing and to identify the compounds that contribute to flavor by use of descriptive analysis and instrumental analysis.

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CHAPTER 2. RELATING SENSORY AND CHEMICAL PROPERTIES TO CONSUMER ACCEPTANCE OF SOUR CREAM

Relating Sensory and Chemical Properties to Consumer Acceptance of Sour Cream

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Abstract

Sour cream is a widely popular acidified dairy product. Volatile compounds and organic acids and their specific contributions to flavor or acceptance have not been established nor has a comprehensive study been conducted to characterize drivers of liking for sour cream. The objective of this study was to determine the drivers of liking for sour cream. Descriptive and instrumental analyses followed by consumer testing were conducted. Flavor and texture attributes of 32 (22 full fat, 6 reduced fat, and 4 fat free) commercial sour creams were evaluated by a trained descriptive sensory panel. Percent solids, percent fat, pH, titratable acidity, and colorimetric measurements were conducted to characterize physical properties of sour creams. Sour creams were analyzed for organic acids by high performance liquid chromatography (HPLC) and volatile aroma active compounds were evaluated by gas chromatography/mass spectrometry with gas chromatography/olfactometry. Consumer acceptance testing (n=200) was conducted on selected sour creams. Univariate and multivariate statistical analyses including penalty analysis and external preference mapping were conducted. Full fat sour creams were characterized by the lack of surface gloss and chalky textural attributes, while reduced and fat free samples displayed high intensities of these attributes. Full fat sour creams were higher ($p<0.05$) in cooked/milky flavor than the reduced and fat free samples. Reduced and fat free sour creams were characterized by cardboard, acetaldehyde/green and potato flavors, bitter taste, and astringency. Lactic acid was the prominent organic acid in all samples followed by acetic and citric. High aroma impact volatile compounds in sour creams were 2,3-butanedione, acetic acid, butyric acid, octanal, 2-methyl-3-furanthiol, 1-octene-3-one, and acetaldehyde. Positive drivers of liking

for sour cream were milkfat, cooked/milky, sweet aromatic flavor, opacity, color intensity, and adhesiveness. This comprehensive study established sensory and instrumental properties of sour creams and their relationship to consumer acceptance.

Introduction

In 2010, over five hundred million kilograms of sour cream were produced in the United States (USDA, 2010). Sour cream is a fermented dairy product that is defined as the souring of pasteurized cream by lactic acid producing bacteria (21CFR 131.160; Code of Federations, 2011). In sour cream, the microorganisms used are *Lactococcus lactis* subsp. *lactis*, *Lactococcus lactis* subsp. *cremoris*, *Cit +L. lactis* subsp. *lactis and Leuconostoc citrovorum* (Hui and others, 2004). There are different types of sour creams which are defined based on fat content. Full fat sour creams must have at least 18 percent milkfat and not less than 14.4 percent milkfat (USDA Specification for Sour Cream and Acidified Sour Cream, 2005). Reduced fat sour cream has a minimum fat reduction of 25 percent (USDA Specification for Sour Cream and Acidified Sour Cream, 2005). Light or lite and low fat sour creams fall under the labeling category of reduced fat. Light or lite sour cream has a minimum of 50 percent fat reduction (USDA Specification for Sour Cream and Acidified Sour Cream, 2005). Low fat sour cream must contain 3 grams or less fat per 50 grams and 6 percent or less total fat (USDA Specification for Sour Cream and Acidified Sour Cream, 2005). Nonfat sour cream must have less than 0.5 grams of fat per 50 grams of product and less than 1 percent total fat (USDA Specification for Sour Cream and Acidified Sour Cream, 2005).

Lactic acid is an organic acid present in many fermented dairy products including cheese (Tormo and Izco, 2004; Izco and others, 2002), yogurt (Marsili and others, 1981; Fernandez-Garcia and McGregor), sour cream (Marsili and others, 1981), and Kefir (Marsili and others, 1981; Bevilacqua and Califano, 1989; Tormo and Izco, 2004). Lactic acid and organic acids found in fermented dairy products are usually produced by one of the following: direct addition of an acidulant, normal bovine biochemical metabolism, hydrolysis of milk fat, or bacterial growth (Tormo and Izco, 2003). Acetic, butyric, citric, formic, hippuric, lactic, orotic, propionic, pyruvic, and uric are the most common organic acids in fermented dairy products. Many studies have been conducted to examine the concentrations of these organic acids in fermented dairy products including cheese (Tormo and Izco, 2004; Izco and others, 2002), yogurt, (Marsili and others, 1981; Fernandez-Garcia and McGregor, 1994; Bevilacqua and Califano, 1989), kefir (Marsili and others, 1980) and sour cream (Marsili and others, 1981). Most of these organic acids are not volatile and as such are not aroma active, but they do display distinct taste profiles (Urbach, 1995; Marsili and others, 1981). Their specific contributions to sour cream flavor or acceptance are not known.

Flavor plays a critical role in the acceptance of any product. Therefore flavor is often investigated by descriptive analysis and consumer acceptance testing. Preference mapping is a collection of multivariate techniques used to establish relationships between instrumental and descriptive results and consumer acceptance data (Meilgaard and others, 2007). Preference mapping has been applied to examine the drivers of liking for many dairy products including strawberry yogurt (Thompson and others, 2007), Cheddar cheese (Drake and others, 2008; Yates and Drake, 2007; and Drake and others, 2009), and cottage cheese

(Drake and others, 2009). Hui and others (2004) described sour cream as a heavy, viscous glossy product that has a delicate lactic acid taste with a balanced, pleasant, buttery-like (diacetyl) aroma, but a complete sensory understanding of this important cultured dairy product has not been established. Previous research with sour cream has examined sensory properties of sour cream following light exposure or as influenced by different starter cultures (Larsen and others, 2009; Folkenberg and Skriver, 2001). Volatile compounds and organic acids and their specific contributions to flavor or acceptance have not been established nor has a comprehensive study been conducted to characterize drivers of liking. The objective of this study was to determine the drivers of liking for sour cream. Descriptive analysis and instrumental analyses followed by consumer testing were conducted.

Materials and Methods

Sour Cream

Commercial sour creams (n=32) were collected from across the United States. Sour creams were collected based on market share as well as fat content (full fat= 22, light= 6, and fat free=4). National, regional, and store brands were included. Samples were received overnight on ice packs and were examined for damage and discarded if necessary. Products were stored in the dark at 4^{o}C. Each product was analyzed no later than 21 days before expiration date. Duplicate lots of each brand were obtained approximately 1mo apart.

Descriptive Analysis

Sensory testing was conducted in compliance with the NCSU Institutional Review Board for Human Subjects approval. Sour creams (30 grams) were scooped (30 gram, Sheboygan, W.I., USA) into lidded 60 gram soufflé cups with 3-digit codes. Sour creams were tempered to 15^{o}C for tasting. Each sample was served monadically with room temperature deionized water and unsalted crackers. Panelists expectorated samples.

A trained descriptive sensory panel (n=8, 8 females, ages 23-47y) evaluated the samples using a 0-15 point universal intensity scale with the Spectrum^{TM} method (Meilgaard and others, 1999; Drake and Civille, 2003). Each panelist had more than 200 h of experience with descriptive analysis of flavor and approximately 100 h of experience with descriptive analysis of texture with various dairy products including cheese and yogurt. Sour cream attributes were generated across 3 2-hour sessions where panelists tasted an array of sour creams as well as other cultured dairy products (yogurt, buttermilk) and discussed and generated terms and definitions. The lexicon generated for sour cream included 11 flavor, 2 chemical feeling factors, 4 taste, 4 appearance, and 6 texture attributes. Following lexicon generation, seven 3 hour sessions were held to refine the lexicon and to allow the panel to calibrate and consistently identify and score the attributes. Each sample from each lot (32 samples from duplicate lots) was evaluated in duplicate by each panelist. Compusense Five^{TM} (Compusense, Guelph, ON, Canada) or paper ballots were used for data collection.

Consumer Acceptance Testing

Representative sour creams (n=12) were selected for consumer acceptance testing based on examination of principle component biplots, product mean attributes and market share. All sour creams were commercial products. Samples were prepared in the same manner as for descriptive analysis with the exception that samples were served at 4^{o}C. Consumer acceptance testing (n=201) was conducted over four days. Both heavy (n=101) and light sour cream users (n=100) were recruited from an online database maintained by the

Sensory Service Center, NCSU. The database consisted of 3500 individuals from the Raleigh, NC area recruited by newspaper and magazine advertisements. Light users consumed sour cream occasionally (twice a year) to at least once a month and purchased 227 to 452 g containers of sour cream at least once a month. Heavy users were those that purchased 452 to 1361 g tubs of sour cream and consumed sour cream once a week. All consumers were the primary shoppers in their households and purchased as well as consumed sour cream. Consumers who participated were compensated with a $30 Target gift card. Six sour creams were tasted in two sessions on two consecutive days by each consumer (n=12 sour creams evaluated by each consumer).

For each session, consumers were provided with consent forms consistent with human subjects approval followed by a ballot. Each treatment was scooped as each consumer arrived using a 40 gram scoop and placed in a 118 mL soufflé cup with a 3-digit code. Spoons and napkins were provided. Compusense five ™ or paper ballots were used for data collection.

Consumers were first asked to evaluate overall appearance. The appearance of each sample was scaled using a 9 point hedonic scale where 1 = dislike extremely and 9 = like extremely. They were then asked to taste the sample and evaluate their overall impression of the sample using the 9 pt hedonic scale. Consumers were then asked to evaluate their liking of flavor on a 9 pt hedonic scale and their perception of product freshness, with 1= not fresh at all and 9= extremely fresh. Consumers were then asked to evaluate sourness, texture, and thickness liking using a hedonic 9 pt scale. This was followed by Just About Right (JAR) questions on sourness, texture, creaminess, and smoothness, where 1 and 2 = not sour enough, 3 = just about right, and 4 and 5 = too sour; 1 and 2 = too thin, 3 = just about right, and 4 and 5 =too thin ; 1 and 2 = not creamy enough, 3 = just about right, 4 and 5 = too creamy; and 1 and 2 = not smooth enough, 3 = just about right, 4 and 5 = too smooth, respectively. Consumers were then asked how likely they would be to purchase this product. They responded to this question using a 5 pt scale where 1 and 2 = definitely would not buy, 3 = neither, and 4 and 5 = definitely would buy.

Composition Analysis

Proximate analysis and color measurements were conducted on all sour creams. Sour creams were analyzed for total solids and fat using the SMART Trac system (CEM Microwave Technology, Matthews, N.C., U.S.A.). Hunter l*a*b* was conducted using the Minolta Chroma meter (CR-410, Ramsey, NJ). Ten grams of sour cream was placed into a 60 mm x 15 mm polystyrene petri dish (Beckton Dickinson, Franklin Lakes, NJ), each petri dish was measured in duplicate. A method from Wehr and Frank (2004) was used to measure titratable acidity. Measurements for pH were conducted with a Mettler-Toledo GmbH (Schewezenbach, Switzerland), probe (Comination Electrode, BNC, Corning, NY, USA) at 4^{o}C. All compositional analyses were conducted in duplicate.

Organic acid extraction and separation

A modified method from Marsili and others (1981) and McGregor and Fernandez (1994) was utilized for organic acid extraction of sour creams. Four grams was weighed into a 25 mL volumetric flask. The sample was diluted with 0.01N sulfuric acid (2.0 N, Mallincrkrodt Baker Inc., Phillipsburg, N.J.) and shaken for 1 min by hand. The sample was also vortexed for 20 sec to insure proper mixing. The sample was then centrifuged at 24,150 x g (Sorvall Model RC-B5,Thermo Scientific) for 10 min and filtered using a .22um (Nylon membrane, VWR, West Chester, P.A.) and injected onto the HPLC (Waters 2996, Milford, M.A.). All sour creams were extracted in duplicate.

The HPLC was equipped with a manual 10uL loop injector, Waters 2996 Photodiode Array detector, Waters 515 Pump, Waters Inline Degasser AF, and an insulated column oven. The Software system used was Empower (Waters Inc., Milford, MA.). The amount of sample injected was 10 ul. The mobile phase used was 0.01N sulfuric acid (Mallinckrodt Chemicals, INC, Phillipsburg, NJ (2N sulfuric acid)). The flow rate was 0.7ml/min and the temperature of the column and guard column was 65^{o}C. Organic acids were identified by injecting authentic standards and comparing the retention times of the authentic standard. The column used was an Aminex HPX-87 H cation exchange column, 300x7.8 mm, 9um particle size (Bio-Rad Laboratories INC, USA). The guard column used was a Cation H Cartridge (Bio-Rad Laboratories INC, USA). All sour cream samples were injected in duplicate.

Solid Phase Microextraction: Gas Chromatography /Olfactometry (SPME GC-O)

Solid Phase Microextraction was conducted on all samples followed by GC/O for characterization of aroma active compounds. Ten grams of each sample along with 10% sodium chloride (w/w) were dispersed into six 40 ml amber vials (28 x 98 mm, Supelco, Bellefonte, PA) with a PTFE/Silicone Septum (Supelco, Bellefonte, PA) and a stir bar. The vials were heated at 40^{o}C for 20 min with constant stirring. A SPME fiber (DVB/CAR/PDMS) (Supelco, Bellefonte, PA) was exposed in each sample at 1cm for 30 min. The fiber was then injected on an Agilent 6850 gas chromatography-flame ionization detector (GC-FID) equipped with an olfactometer port (Agilent Technologies, Santa Clara, CA) at 3 cm. The GC method used an initial temperature of 40^oC for 3 min. The temperature was then increased at a rate of 10^oC/min to 150^oC followed by 30^oC/min to 200^oC, and held for 5 min. Samples were evaluated in duplicate on two different columns: polar ZB-WAX (30-m length x 0.25mm i.d. x 0.25-um df) and a nonpolar ZB-5 ms (30-m length x 0.25-mm i.d. x 0.25-um df) (Phenomenex Zebron, Torrance, CA). Effluent was split 1:1 between the FID and sniffing port using deactivated fused silica capillaries (1m length x 0.25-mm i.d.) (Phenomenex Zebron, Torrance, C.A.). The FID sniffing port was held at a temperature of 300^oC with a helium carrier gas flow of 1018.6 cm s^{-1}, and the port was supplied with humidified air at 30 mL/min. Each sample was evaluated by two highly experienced sniffers who recorded aroma character and perceived intensity (van Ruth, 2001).

Solid Phase Microextraction: Gas Chromatography /Mass Spectrometry (SPME GC/MS)

All sour cream samples were evaluated by SPME-GC/MS for extraction and identification of volatile compounds. Each sour cream was evaluated in scan mode followed by selective ion monitoring (SIM) mode. Five mL of each sour cream along with 10% sodium chloride (w/w) were dispensed into three 20 mL auto sampler vials with steel screw tops containing silicon septa face in Teflon (Microliter Analytical, Suwannee, GA). An internal standard of 2-methyl-3-heptanone in methanol at 81ppm (Sigma Aldrich, St. Louis, MO) was added to the samples. The samples were then injected using a CTC Analytics CombiPal auto sampler (Leap Technologies, Carrboro, NC) attached to an Agilent 6890N GC-MS with inert 5973 MSD (AgilentTechnologies, Santa Clara, CA). The SPME fiber contained three different phases (DVB/CAR/PDMS) (Supelco, Bellefonte, PA). The column used was a nonpolar ZB-5 ms (30-m length x 0.25-mm i.d. x 0.25-um df) (Phenomenex Zebron, Torrance, CA). The GC method used an initial temperature of 40^{o}C for 3 min. The temperature was then increased at a rate of 10^{o}C/min to 90^{o}C, increased by 5^{o}C/min to 200^{o}C and held for 10 min. The temperature was then increased at a rate of 20^{o}C/min to 250^{o}C and held for 5 min. The SPME fiber was introduced into the split/splitless injector at 250^{o}C at a pressure of 7.06 psi with helium as the carrier gas with a purge flow of 1697 cm s^{-1}. A constant flow rate of 34 cm s^{-1} was maintained. Purge time was 1 min. The MS transfer line was maintained at 250^{o}C with the quad at 150^{o}C and the source at 250^{o}C.

Identification of Odorants

Positive identification of aroma active compounds was achieved retention indices (RI) on both GC columns, comparison of odor properties, and mass spectra of the unknowns against authentic standards or an evaluation of the literature. An n-alkane series (Fluka, Buchs, Switzerland) was used for the calculation of RI (Van den Dool and Kratz, 1963).

Compound Relative Abundance with Selective Ion Monitoring Mode (SIM)

All samples were subsequently evaluated by SPME-GC-MS using selective ion monitoring (SIM) mode. SIM mode allowed for improved detection levels by focusing on unique ion(s) at a certain retention time of a compound of interest, ignoring other ions present within the sample. Compounds were selected for evaluation in SIM based on aroma activity from GC-O results. The unique ions for each compound were selected using the NIST Mass Spectral Search Program 2.0 (Hoboken, N.J) and injection of authentic standards. The data was analyzed using MS ChemStation software (Agilent Technologies, Durham, NC). Relative abundance was calculated for each sour cream.

Statistical Analysis

All statistical analyses were conducted with XLSTAT (Addinsoft, New York, NY). Liking scores were evaluated by analysis of variance ANOVA with Fisher's post hoc test using. Just About Right scores were evaluated using Penalty Analysis and Chi-Square. Purchase intent was evaluated using Kruskal-Wallis with Dunn's post hoc test. All statistics were calculated to 95% confidence. Descriptive analysis, volatile compound relative abundance, and organic acid concentrations were analyzed using (ANOVA) with Fisher's least significant difference test at $p \leq 0.05$ significance level. Consumer clusters were evaluated using K-means. Clusters were validated using discriminant analysis. Three-way ANOVA was conducted on sample, user status, and clusters for main effects and 2-way and 3-way interactions. External preference mapping with consumer clusters was conducted using partial least squares regression on descriptive and consumer data. Correlation analysis was also conducted to determine individual relationships between sensory attributes and instrumental data.

Results and Discussion

Descriptive Analysis

Twenty-seven sensory attributes were identified for sour creams. The language included 4 basic tastes, 2 chemical feeling factors, 11 aromatics, and 10 textural and visual attributes (Tables 1 and 2). All sour creams had the following attributes: overall aroma impact, sour aromatic, cooked/milky, cooked/sulfurous/beefy, astringency, and sweet taste and sour taste. Milkfat flavor was present in all samples with the exception of fat free products (Table 3). Full fat sour creams collectively had the highest intensities of cooked/milky flavor with the exception of fat free sample 445. Sweet aromatic was present in all treatments with the exception of treatment 123, a full fat sample. Treatments 665 and 654 were the only samples which had perceivable salty taste (Table 3). Sour taste was the predominant sensory attribute among the sour creams ranging from 1.1-5.2 on a 0 to 15 point universal scale, which is characteristic of fermented dairy products. Full fat treatment 357 had the highest intensities of sour taste and green/acetaldehyde flavor 5.2 and 4.7, respectively (Table 3). Treatment 775, a fat free sample, had the highest intensity of bitterness (Table 3). Full fat treatment 335 was higher in milkfat flavor than other samples and it also had a higher fat content than the other samples (Table 3). The reduced fat and fat free sour creams contained higher intensities of sweet taste than the full fat samples (Table 3).

Principle component analysis explained 61% of the variability on 4 PC's (Figure 1). Principle component 1 was comprised of milkfat, sour aromatic, diacetyl, sweet aromatic, and potato (Figure 1). Principle component 2 was comprised of cooked/milky, overall aroma, sour taste, astringent, cardboard, bitter, and green/acetaldehyde (Figure 1). All full fat samples were characterized by milkfat, diacetyl, sour aromatic, cooked/milky, and cooked/sulfurous/beefy flavor attributes (Figure 1). Principle component 3 was comprised of the following attributes diacetyl, free fatty acid, and cardboard flavors, bitter taste and fizzy (Figure 2). Principle component 4 was comprised of astringency (Figure 2). Reduced fat and fat free samples were characterized by cardboard, sweet taste, potato, and green/acetaldehyde flavors (Figure 1 and 2), while full fat sour creams were characterized by a lack of these flavors.

Textural and visual appearance principle component analysis explained 62% of the variability among the treatments (Figure 3). Principle component 1 was comprised of mouthcoating, color intensity, and opacity (Figure 3). Principle component 2 was comprised of surface grain, adhesiveness, surface gloss, slipperiness, and chalky (Figure 3). Full fat samples were characterized by mouthcoating, opacity, adhesiveness, color intensity, firmness, and denseness (Figure 3) while reduced fat and fat free samples were characterized by chalkiness and surface gloss (Figure 3). Treatment 665, a full fat sour cream, was extremely opaque and had the highest intensity (13.5) of opacity (Table 4). Treatment a 222, reduced fat sour cream, had the highest intensity of surface grain followed by treatment 753 and 321 which were full fat samples (Table 3). Treatment 123, a full fat sour cream, also had higher surface gloss intensity than other sour creams (Table 4). The organic sour creams (951, 987, and 885) had higher color intensities than the non-organic samples, possibly due to carotenoids present from grass feeding (Nozière and others, 2006) (Table 4). Treatment 123 had higher slipperiness than the other sour creams (Table 4).

Full fat sour creams had higher firmness scores than reduced fat and fat free sour creams (Table 4). The majority of the full fat treatments had high denseness intensities, possibly due to the presence of more milkfat (Table 4). However, there was no consistent trend in the attribute of denseness in relation to fat content. Denseness could also be contributed by the presence of stabilizers and thickeners used in the reduced fat and fat free treatments. Treatments 106, 119, 123, 881, and 999 were full fat all natural treatments. All natural treatments contained no stabilizers or thickeners and also had the lowest chalky intensities of the full fat samples. No chalkiness was detected in treatment 335, an all natural reduced fat treatment with no stabilizers or thickeners present. Treatments 885 and 969 were reduced fat all natural sour creams which contained no thickeners or stabilizers. These treatments also had lower chalky intensities. Chalkiness was possibly due to the presence of stabilizers and thickeners.

Consumer Acceptance

All consumers purchased sour cream at least once a month. Seventy percent of the consumers (n=140) purchased sour cream at least a few times a month. As previously mentioned, 50 percent were light users of sour cream (consumed sour cream at least once a month and purchased 227 to 452 g containers of sour cream at least once a month) and the remaining 50 percent were heavy users of sour cream (purchased 452 to 1361 g tubs of sour cream and consumed sour cream at least once a week). Full fat sour creams were most frequently purchased by heavy users, followed by reduced fat and then fat free sour creams ($p<0.05$). Reduced fat sour creams were most frequently purchased by light users followed by full fat and then fat free sour creams ($p<0.05$).

Consumers were asked to rank the importance of the factors that influenced their purchase of sour cream. Flavor was the top factor for both light and heavy users, followed by price, availability and brand. Sour cream was most used as a topping, then, an ingredient, and then as a dip by both heavy and light users of sour cream. User status had no effect on overall liking scores ($p>0.05$) and these data were combined. Treatments 996, 106, 363, 357, 888, and 753 had the highest overall appearance liking scores. Sample 888 had the highest color liking score. Treatments 106, 363, and 888 received the highest flavor liking scores. Consumers scored sample 106 the highest in freshness and sour taste intensities. Treatments

363 and 888 were scored the highest in both texture and thickness attributes. Sample 363 was the only treatment to receive 50% or more for all categories of JAR questions.

Consumer segmentation was used to investigate specific consumer preferences and drivers of liking for sour cream. Three clusters were identified (Table 12). Cluster 1 were consumers that liked firm and dense textures and milkfat flavor and disliked sweet taste in sour cream. Cluster 2 was very similar to C1 consumers as far as drivers of liking. The only difference was that C2 consumers liked firmness, denseness, and milkfat as long as it was not over powering or too strong. Cluster 3 (C3) consumers liked sour creams with sweet aromatic and disliked sour creams high in diacetyl, milkfat, and cooked flavors. Cluster analyses were confirmed by assessing product attributes and liking of each product by clusters.

There was no significant user status*cluster interaction ($F=1.80$, $p>0.05$) which suggests that user status had no affect on cluster membership and was consistent with the lack of user status impact on overall liking. Sample main effects and sample * cluster interaction ($F =21.25$, $p<0.05$) were observed. The interaction of sample*cluster suggests that all clusters liked samples differently. Treatments 106 and 363 were ranked highly among clusters 1 and 2 and were not ranked as high by cluster 3 (Figure 5) ($p>0.05$). Treatments 106 and 363 were characterized by adhesiveness, milkfat, and diacetyl (Figure 4). Treatment 753 and 888 received higher liking scores from cluster 3 compared to clusters 1 and 2. Treatment 753 received lower scores from clusters 1 and 2. The lower scores from consumers in cluster 1 and 2 for samples 885 and 969 were possibly due to the combination of textural attributes of this sour cream (adhesiveness, firmness, and mouth coating) (Figure

4 and 5). Treatment 888 was liked by all clusters, this may be due to this product having a moderate amount of sweet aromatic, sweet taste, sour taste, and the absence of green/acetaldehyde flavor (Figure 3 and Table 2). Treatment 357 was liked by cluster 1 and not liked as much by cluster 3 (Table 6). Treatment 357 was characterized by sour taste, sour aromatic, denseness, firmness, and mouth coating (Figure 4). This difference displays that cluster 1 consumers liked sour taste and sour aromatic more than cluster 2 and 3 consumers.

Partial least squares was conducted to determine the drivers of liking for each consumer cluster. The variable importance projection (VIP) scores were used to identify drivers of liking (Wold and others 2001). Drivers of liking for cluster 1 were cooked/milky, diacetyl, opacity, and milkfat. These drivers explain why Cluster 1 scored samples 106 and 363 as their top choices for sour cream. These samples had the highest amounts of diacetyl and cooked/milky flavor attributes. Drivers of liking for cluster 2 were sweet aromatic, cooked/milky, diacetyl, milkfat, and denseness. Sample 363 and 106 was also the top choices for cluster 2 as well. Drivers of liking for cluster 3 were milkfat, potato, sweet aromatic, and cooked sulfurous, these findings confirm the top sour cream choices for cluster 3. Both samples 753 and 888 contained relatively high intensities of cooked/sulfurous attributes.

Drives of dislike can also be determined from PLS. Drivers of dislike for cluster 1 were green/acetaldehyde, cooked/sulfurous, potato, astringent, sweet taste, sour taste, surface gloss, color intensity, adhesiveness, mouthcoating, and chalkiness. Samples 969 and 885 had a combination of the dislike drivers present at higher concentrations and these samples did not contain a perceivable intensity of diacetyl, thus, liking scores for these samples were lower for cluster 1. Drivers of dislike for cluster 2 were sour aromatic, green/acetaldehyde, potato, astringent, sour taste, color intensity, adhesiveness, and chalkiness. Sample 357 had the highest amount of green/acetaldehyde of all sour creams and this sample also did not have a perceivable amount of diacetyl, therefore, this sample received lower liking scores for cluster 2. Drivers of dislike for cluster 3 were diacetyl, sour aromatic, sweet taste, and sour taste. This suggest that the reason for cluster 3 ranking samples 888 and 753 the highest may be due to no perceivable diacetyl flavor in either sample. Samples 357 and 222 had the lowest scores for cluster 3. Sample 357 had the highest amount of sour taste among all samples, while sample 222 had the highest amount of sweet taste among all samples. Therefore, these samples had lower liking scores for clusters 1, 2 and 3.

Compositional Results

The amount of fat present in each sour cream was consistent with labels as expected (Table 8). Treatment 335, a reduced fat sample, had a higher fat content than the other reduced fat products (Table 8). This product had a 25% fat reduction while the others had a fat reduction of 50% or higher. Full fat samples had higher fat content, while low fat and fat free samples had lower fat contents (Table 8). Total solids were also measured for each sour cream. Treatment 335 and 951 had the highest amounts of solids (Table 8). These treatments were all natural and contained no thickeners or stabilizers. Total solids for reduced and fat free treatments were not different from full fat treatments (Table 8). Reduced and fat free treatments may have high total solids due to fat replacers which are added to help mimic the texture of a full fat product. Ingredients such as hydrocolloids are added to improve the texture in reduced fat and fat free products (Alting and others, 2009).

Reduced and fat free samples in this study contained one or more of the following ingredients: guar gum, carrageenan, locust bean gum, carob guar gum, and/or cornstarch. These ingredients aided in mimicking the texture of full fat products. Ingredients previously mentioned were observed in reduced fat and fat free sour creams that were not all natural.

Treatments 789, 885 and 951 were organic sour creams that had the highest color intensities and concurrently the highest b* values (Table 8). Treatment 515, a full fat sour cream, had the lowest pH (3.81) of all sour creams (Table 8). All natural sour creams (106, 119, 123, 881, 999, and 951) had the lowest percentage of lactic acid present. Treatment 357 had one of the highest percentages of lactic acid present. This treatment also had the highest intensities for sour aromatic and sour taste. Sour creams 357, 464, 555, and 775 had the highest percentage of lactic acid present. Sour taste is characteristic of dairy products (Neta and others, 2009). Previous literature has established that sour taste is produced by organic acids present with one or more protonated carboxyl groups (Neta and others, 2007). Neta and others (2009) revealed that the sour taste of organic acids is related to both pH and titratable acidity. Samples 357 had the highest intensities of sour taste and lowest pH, higher titratable acidity, and higher amounts of lactic and acetic acids, which were predominant acids present in all sour creams. These results suggest that organic acid, pH and titratable acidity affect the perception of sour taste.

Organic Acid Results

Full fat samples 753 and 999 had the lowest amounts of citric acid present, 10.6 ppm and 11.2 ppm respectively (Table 9). Fat free sample 552 had the highest amount of citric acid (Table 9). No apparent trend was observed with the amount of citric acid present and fat content. Full fat sample 357 had the highest amount of lactic acid present, which corresponded to its high titratable acidity. Full fat sample 951 had the lowest amount of lactic acid, and this result also corresponded with titratable acidity. Sample 552 had the highest amount of formic acid present among all of the samples. Fat free sample 333 had the lowest amount of formic acid present. Fat free samples with the exception of sample 445 had the highest amount of uric acid present. Full fat sample 464 had the highest amount of orotic acid present and full fat sample 779 had the highest amount of pyruvic acid present. Pyruvic acid was not detected in samples 951 and 885. Full fat sample 357 had the highest amount of butyric acid present. Samples 363, 654, 999, 666, and 333 contained no detectable levels of butyric acid. Full fat sample 464 had the highest amount of acetic acid present while sample 357 had no detectable levels of acetic acid present. Only samples 665, 888, 885, 666, 464 had detectable levels of propionic acid. Full fat sample 115 was the only sample with hippuric acid detected.

Citric acid occurs naturally in milk and is the most prevalent acid in raw milk (Urbienė and Leskauskaitė, 2006). However, citric acid is also consumed by lactic acid bacteria during the fermentation process of dairy products (Urbienė and Leskauskaitė, 2006). Fermentation times for each sour cream may contribute to the amount and type of organic acids present. The end result of consumption of lactose by LAB is acetic and lactic acids (Urbienė and Leskauskaitė, 2006). As milk ferments, the concentrations of some acids such as lactic, propionic, and acetic acids increase and hippuric, orotic, and citric acids decrease (Dellaglio, 1988; Driessen and Puhan, 1988). Hippuric acid is naturally present in milk (Hatanaka and Kaneda, 1986). Lactic acid bacteria can convert hippuric acid into benzoic acid during fermentation (Hatanaka and Kaneda, 1986). Previous research has demonstrated that hippuric acid disappeared 4 h into the fermentation process of kefir (McGregor and Fernandez, 1994), which may explain this acid being detected in only one sample and at a low level. Pyruvic acid is an intermediate compound that occurs in different metabolic pathways (Ryssad and Abrahamsen, 1987). McGregor and Fernandez (1994) also found that pyruvic acid was present at its highest concentration in the 6^{th} hour of fermentation of kefir and from there it continued to decrease.

Acetic and butyric acids, in addition to contributing sour taste, are also flavor-active compounds. Like acetic acid, butyric acid is also a product of lactose fermentation (Zhang and others, 2009). Acetic was present in the majority of the sour creams and likely contributed to some degree, the intensities of sour aromatic present within sour creams. While butyric acid was detected by instrumental analysis in the majority of the sour creams, free fatty acid flavor was only detected by sensory analysis in a few sour creams. This may be due to the low amount of butyric acid present within the sour creams or that butyric acid was not solely responsible for this flavor.

Gas Chromatography Olfactometry/Mass Spectrometry Results

Forty aroma active compounds were detected in sour creams SPME GCO (Table 11). Thirty-four compounds were positively identified by GC/MS, RI, and aroma compared to authentic standards. Seven compounds were tentatively identified by RI and odor compared to authentic standards or RI and odor compared with published literature. All aroma compounds detected by SPME GCO were not detected by GC/MS. The following aroma active compounds were not detected by GC/MS, but were detected by GC/O: methyl ethyl sulfide, 2-isobutyl-3-methoxypyrazine, estragole, methyl-2-methyl-3-furyl disulfide, 2-octyl-furan, benzolthiazole, and o-aminoactephenone.

Seven of the 34 aroma compounds detected by GC/MS (dimethyl trisulfide (DMTS), 2 methyl-3-furanthiol, 1-hexen-3-one, nonanal, dimethyl sulfide,1-octene-3-one, and acetaldehyde) were present in all samples. Five of the 34 aroma compounds detected by GC/MS (2,3-butanedione, methional, acetoin, octanal, 3-methylbutanal, acetic acid) were present in all except 1 sour cream. All aroma active compounds detected were derived through chemical conversion of the components present within the milk or heat treatment of the milk. The conversion of fat (lipoylsis), lactose (glycolysis), and caseins (proteolysis) are the major metabolic pathways involved in the formation of aroma active compounds in dairy products (Cadwallader and Singh, 2009; Cadwallader and Drake, 2007). Previous research has identified all of these compounds in fermented dairy products including buttermilk (Heiler and Schieberle, 1996), yogurt (Mar Serra and others, 2009), goat cheese (Carunchia-Whetstine and others, 2003), Munster cheese (Cadwallader and Baek, 1998; Singh and others, 2003b) and Cheddar cheese (Singh and others, 2003; Carunchia-Whetstine and others, 2006).

Reduced fat and fat free samples were characterized by concentrations of EZ-2,6 nonadienal, EE-2,4-nonadienal, methional, E-nonanal, 1-octene-3-one, nonanal, 2-hexanol (Table 10). Previous research has demonstrated that some aldehydes and sulfur compounds contribute to cardboard flavor (Whitson and others, 2010) and potato and brothy flavors in dairy products (Wright and others; 2006, Carunchia Whetstine and others, 2005). While full fat samples have some of these compounds present they were collectively present at lower levels compared to lower fat and fat free samples. Sensory profiles were consistent with the GC/MS and GC/O results. Higher intensities of potato and cardboard flavors were collectively reported for reduced fat and fat free sour creams.

Fat content has a role in flavor release and this is dependent on the aromatic compound being investigated (Cadwallader and Singh, 2009). Brauss and others (1999) found that low fat yogurts released volatiles quicker and at higher concentrations than full fat yogurts. This difference was demonstrated by higher sensory thresholds in oil versus water (Relkin and others, 2004). The presence of fat allows hydrophobic flavor compounds to bind to the fat molecule (Plug and Haring, 1993) and therefore only a small amount of hydrophobic flavor compounds are allowed into the headspace thus increasing the sensory threshold (Carunchia and others, 2006). Flavor molecules in low fat foods are not as soluble as they are in full fat products which allows for higher flavor release (Carunchia and others, 2006). Roberts and others (2003) conducted a research with varying fat levels in water and milk and found that the release of volatile flavor compounds was greater when less fat was present. This further explains why off flavors are more prevalent in lower fat foods and may also explain why off flavors were more prevalent in reduced and fat free sour creams compared to full fat products.

Aroma active compounds 2,3-butanedione and acetoin, detected by GC/MS, were present in most of the samples. However, there was a higher amount of acetoin than 2,3-butanedione. The presence of these compounds corresponds with previous literature, in that 2,3-butanedione is produced by LAB in lower quantities than acetoin (Cadwallader and Singh, 2009). These compounds are produced by metabolism of citrate by LAB, which is present at low levels in bovine milk (Cadwallader and Singh, 2009). Acetaldehyde is an aroma active volatile that is prevalent in sour cream and yogurt and is produced by lactic acid bacteria (Cadwallader and Singh, 2009). Acetaldehyde is formed from an intermediate, pyruvate, by glycolysis (Smit and others, 2005). Acetaldehyde plays a role in the sour aromatic present in sour cream, so as expected, the sour cream with the highest amount of acetaldehyde had the highest intensity of sour aromatic (Table 3, 10, 11).

Correlation analysis and principle component analysis of instrumental and descriptive data confirmed relationships between flavor-active compounds and sensory flavor attributes (Table 11 and Figure 7 and 8). Acetaldehyde was correlated to green/acetaldehyde, sour taste, and sour aromatic. Sample 357 has the highest concentration of acetaldehyde and also had the highest intensities of sour aromatic and green/acetaldehyde. The flavor active compound, methional, was correlated with potato flavor (Table 11). Previous research demonstrated that cardboard flavor was due to the presence of aldehydes and some sulfur-containing compounds (Whitson and others, 2010). The sensory attribute cardboard was correlated with flavor active aldehyde compound E,E-2,4 nonadienal and dimethyl trisulfide. Butyric acid was correlated with free fatty acid (FFA) flavor. Diacetyl was associated with 2,3-butanedione. Gamma-decalactone was correlated with cooked/milky flavor.

Conclusion

Reduced fat and fat free sour creams were characterized by cardboard, sweet taste, potato, and green/acetaldehyde flavors, while full fat sour creams were characterized by a lack of these flavors. Sour creams with the lowest pH, higher titratable acidity, and higher amounts of acetic and lactic organic acids also had higher intensities of sour taste. Acetic and lactic acid were present in majority of the sour creams and contributed to sour taste and sour aromatic flavor. Sour creams that had the highest consumer liking scores were characteristic of the flavor active compounds: diacetyl, acetoin, delta-decalactone, and 2-methyl-3-furanthiol. Lower fat and fat free sour creams differed in flavor active compound concentrations and in the release of flavor active compounds than that of full fat sour creams. Consumers generally rated full fat sour creams higher than fat-reduced sour creams. Milkfat was a consistent driver of liking across all clusters, but differences were observed in intensities of milkfat flavor, diacetyl flavor, cooked flavor, sweet taste, firmness and denseness.

Acknowledgement

Funding provided in part by the Dairy Research Institute (Rosemont, IL). The use of tradenames does not imply endorsement nor a lack of endorsement by those not mentioned.

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Tables and Figures

Table 1. Flavor attributes for sour creams

Descriptor	Definition	Reference	Preparation
Overall Aroma	The overall orthonasal aroma impact	N/A	Evaluated as the lid is removed from the cupped sample
Sour Aromatic	Sour aromatics associated with fermented dairy products	Plain yogurt	A 225-mL amber sniff jar with 100 ppm of acetaldehyde
Sweet Aromatic	Sweet aromatic associated with sweet smelling foods	Ricotta cheese	A table spoon of ricotta cheese in a 58-mL lidded soufflé cup
Acetaldehyde/green	Aromatics reminiscent of green apples	Acetaldehyde at 100ppm or plain yogurt	A 225-mL amber sniff jar with 100 ppm of acetaldehyde
Cooked/Milky	Aromatics associated cooked milk	Cooked milk	1 ounce of heated milk in a 60-mL soufflé cup.
Cooked/sulfur/beefy	Aromatics associated with sulfurous compounds and or beef stock	Boiled mashed egg or struck match, 2-methyl-3-furanthiol	Eggs were boiled and mashed and 10 g placed in a 58 mL soufflé cup. A 225-mL amber sniff jar with 100 ppm of 2-methl-3-furanthiol
Diacetyl	Aromatics reminiscent of butter	Diacetyl	A 225-mL amber sniff jar with 100 ppm of diacetyl
Milkfat	Aromatics associated with milk fat	Fresh coconut meat, heavy cream, or δ–decalactone	A 225-mL amber sniff jar with 500 ppm of δ–decalactone
Potato	Aromatics associated with canned potato	Methional at 100 ppm	A 225-mL amber sniff jar with 100 ppm of methional
Cardboard	Aromatics associated with cardboard	Wet cardboard	Soak 2 cm square of cardboard in water for 30 min

Flavor attributes were scored using 0- to 15-Point Spectrum^{TM} Intensity Scale (Meligaard and others, 1999; Drake and Civille, 2003; Drake and others, 2010). Most dairy product flavor attributes fall between 0 to 5 on this scale (Drake and others 2008; Drake and others, 2009, 2010; Wright and others, 2009).

Table 1 continued. Flavor attributes for sour creams

Descriptor	**Definition**	**Reference**	**Preparation**
Free fatty acid	Aromatic associated with short chain fatty acids	Feta cheese, butyric acid	A 225-mL amber sniff jar with 100 ppm of butyric acid
Sweet taste	Basic taste associated with sugars	Sucrose	5% sucrose solution
Salty	Basic taste associated with salts	NaCl	2% NaCl solution
Bitter	Basic taste associated with various compounds	Caffeine	0.5% caffeine solution
Sour	Basic taste associated with acids	Citric Acid	0.08% citric acid solution
Astringent	Drying or puckering of oral tissues	Black tea	Soak 6 tea bags in hot water for 10 min
Fizzy	Burning/stinging sensation on the tongue	Carbonated Soda Water	1 ounce of Carbonated soda water in a 60-mL soufflé cup

Flavor attributes were scored using 0- to 15-Point Universal Spectrum™ Intensity Scale (Meligaard and others, 1999; Drake and Civille, 2003; Drake and others, 2010). Most dairy product flavor attributes fall between 0 to 5 on this scale (Drake and others 2008; Drake and others, 2009,2010; Wright and others, 2009). Terms were adapted from Drake and others, 2010, Drake and others 2008).

Table 2. Textural and visual attributes for sour creams

Descriptor	Definition	Reference	Preparation
Color Intensity	Degree to which the sample is light, where light (white) = 0 and dark (yellow) = 15	Kroger Original Sour Cream 5.0	2 ounces of sour cream in a 118mL lidded soufflé cup
Opacity	Degree to which the sample is transparent, where clear = 0 and white = 15	Kroger Original Sour Cream 12	2 ounces of sour cream in a 118mL lidded soufflé cup
Adhesiveness	Degree to which the sample sticks to any mouth surface, where not sticky = 0 and very sticky = 15	Kroger Original Sour Cream 1.0	2 ounces of sour cream in a 118mL lidded soufflé cup
Chalky	Degree to which sample exhibits a powdery mouthfeel	Kroger Original Sour Cream 0.0	2 ounces of sour cream in a 118mL lidded soufflé cup
Denseness	Compactness of the cross-section; absence of air as tongue is moved through the sample	Kroger Original Sour Cream 7.0	2 ounces of sour cream in a 118mL lidded soufflé cup
Firmness	Force required to compress the sample to the roof of the mouth using the tongue	Kroger Original Sour Cream 7.0	2 ounces of sour cream in a 118mL lidded soufflé cup
Surface Gloss	Degree to which the sample reflects light	Kroger Original Sour Cream 11	2 ounces of sour cream in a 118mL lidded soufflé cup
Surface Grain	Degree to which	Kroger Original Sour Cream 0	2 ounces of sour cream in a 118mL lidded soufflé cup
Slipperiness	Degree to which the tongue slides over the sample	Kroger Original Sour Cream 8.0	2 ounces of sour cream in a 118mL lidded soufflé cup
Mouthcoating	Degree to which any sample residue remains over the sample	Kroger Original Sour Cream 2.0	2 ounces of sour cream in a 118mL lidded soufflé cup

Texture attributes were scored using 0- to 15-Point product specific scale (Meligaard and others, 1999; Drake and Civille, 2003; Drake and others, 2010). Terms were adapted from (Foegeding and Drake, 2007;Yates and Drake, 2007).

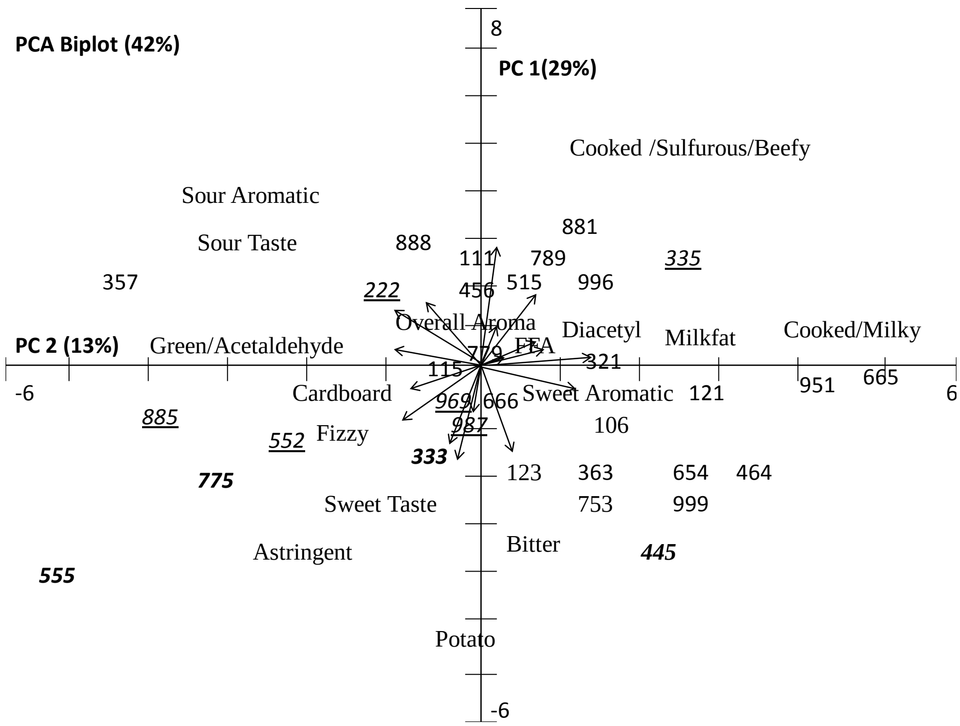

Figure 1. Principle Component Analysis biplot (PC 1 and 2) of flavor attributes of sour creams. Full fat treatments are numbers, underlined numbers, reduced fat treatments are underlined and italic numbers, and fat free treatments are bold numbers.

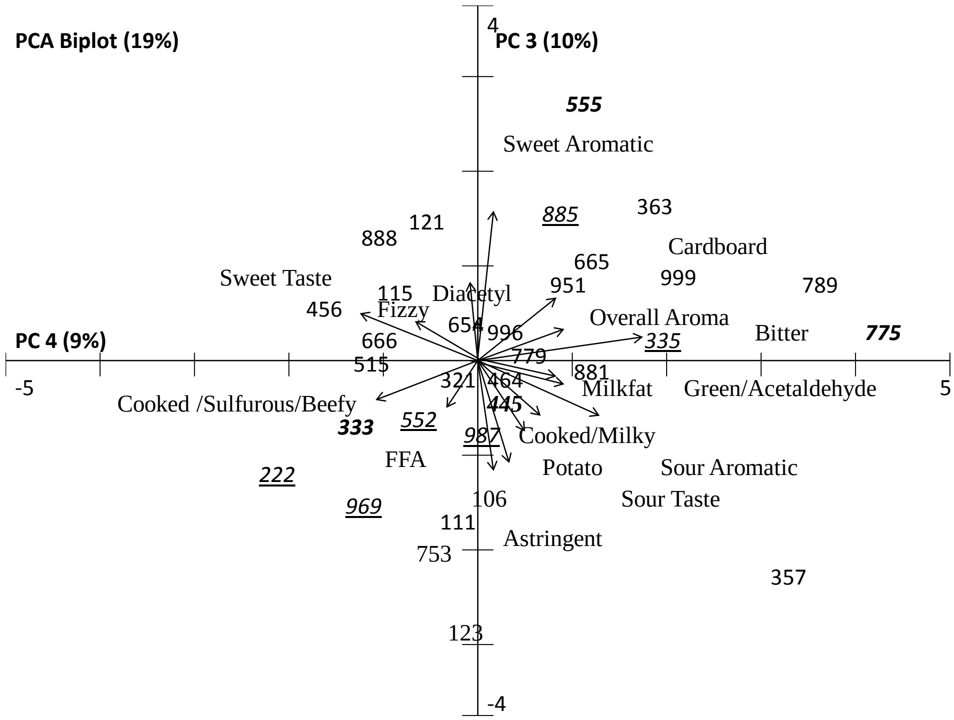

Figure 2. Principle Component Analysis biplot (PC 3 and 4) of flavor attributes of sour creams. Full fat treatments are numbers, underlined numbers, reduced fat treatments are underlined and italic numbers, and fat free treatments are bold numbers.

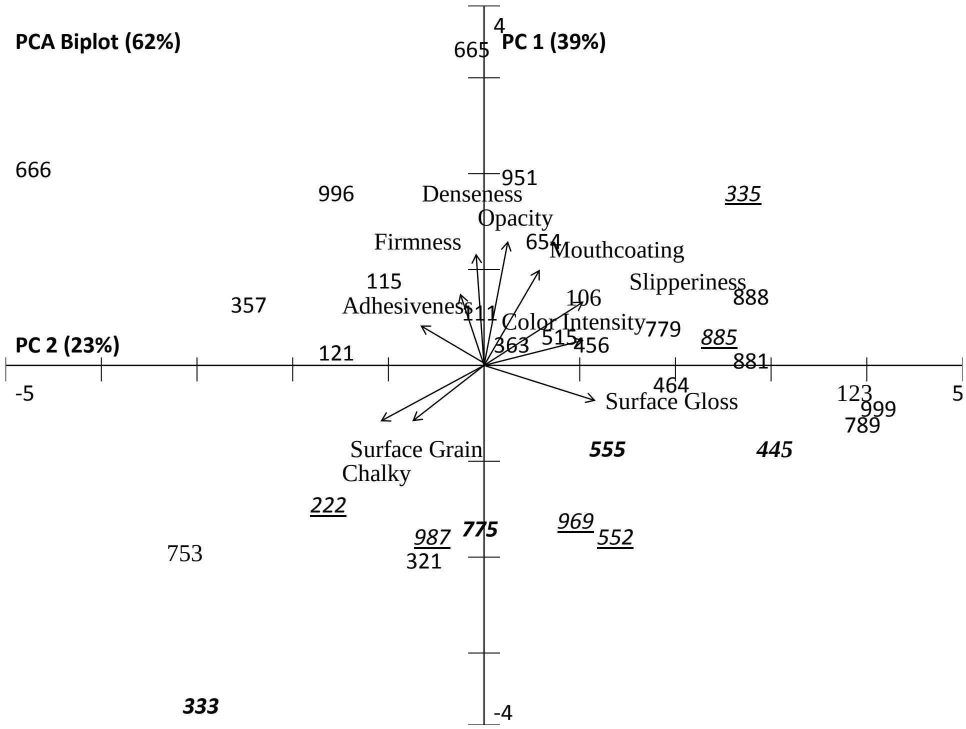

Figure 3. Principle Component Analysis biplot (PC 1 and 2) of texture and visual appearance attributes of sour creams. Full fat treatments are numbers, pourable treatments are bold, underlined numbers, reduced fat treatments are underlined and italic numbers, and fat free treatments are bold numbers.

Table 3. Descriptive flavor attribute means for sour creams[1]

Treatment	Overall aroma	Sour aromatic	Sweet Aromatic	Potato	Green /acetaldehyde	Cooked /milky	Cooked /sulfurous/beefy	FFA
106[4]	1.3	1.6	1.2	1.4	ND	3.2	1.8	ND
779[4]	2.8	2.0	1.5	1.8	ND	2.5	2.0	1.0
121[4]	1.5	1.2	2.9	ND	0.5	3.0	1.7	ND
111[4]	2.9	2.8	1.3	0.5	1.0	2.2	3.2	1.7
515[4]	1.5	3.0	1.8	0.5	ND	2.3	3.3	ND
115[4]	2.0	1.8	2.0	1.0	1.3	2.7	1.9	ND
464[4]	3.0	0.5	1.0	1.7	ND	3.5	1.3	ND
881[4]	3.8	4.5	1.3	ND	ND	2.3	3.0	ND
363[4]	2.8	1.6	2.8	0.8	1.6	3.3	1.8	ND
357[4]	4.3	5.5	1.0	1.3	4.7	1.5	1.8	ND
321[4]	1.3	2.0	2.1	ND	1.3	2.8	3.0	0.8
654[4]	2.2	1.5	2.2	1.5	ND	3.2	2.1	ND
123[4]	1.5	1.5	ND[2]	2.4	1.3	2.3	2.5	ND
888[4]	3.5	3.8	2.8	ND	ND	2.0	4.3	ND
999[4]	1.8	2.0	2.7	0.7	1.4	3.3	0.5	ND
456[4]	2.5	3.0	1.3	1.4	1.0	2.8	3.7	0.5
951[4]	1.8	0.5	2.0	ND	ND	3.5	1.5	ND
996[4]	2.4	3.4	2.0	0.5	0.8	3.0	3.5	ND
666[4]	1.3	2.4	1.8	1.0	1.0	2.3	1.8	ND
789[4]	3.0	2.8	1.5	ND	0.5	2.8	2.0	ND
753[4]	2.0	1.0	1.0	ND	ND	2.3	3.3	ND
665[4]	2.2	1.3	1.8	ND	ND	3.7	1.0	ND
335[5]	2.7	2.2	1.4	1.0	ND	3.0	1.8	0.5
222[5]	2.5	2.8	1.0	0.8	ND	2.4	3.3	1.5
969[6]	1.8	2.0	1.6	2.0	1.0	2.5	3.7	ND
552[6]	1.8	3.0	1.8	2.3	1.8	2.5	2.5	0.5
987[6]	2.8	1.8	2.0	1.3	1.3	2.2	1.8	ND
885[6]	4.8	2.0	1.5	1.7	3.8	1.8	2.3	0.5
445[7]	1.8	0.8	2.0	1.0	1.0	3.5	1.3	ND
333[7]	3.0	1.8	1.8	1.3	ND	1.5	1.3	ND
555[7]	5.3	1.8	1.5	1.8	3.5	1.8	3.5	ND
775[7]	2.3	3.5	2.0	1.5	2.7	2.0	1.8	ND
LSD[3]	0.99	0.99	0.82	0.96	0.72	0.81	1.09	0.38

[1]Flavor intensities were scored using a 0 to 15-point Spectrum™ intensity scale where 15 = high intensity of an attribute and 0 = absence of attribute (Meilgaard and others, 1999; Drake and Civille, 2003). ND[2] = Not detected. LSD[3]=Least significant difference value. Means in a row that differ by LSD are different ($P<0.05$). 4=full fat sample, 5=reduced fat samples, 6=light samples, 7=fat free samples.

Table 3 (Continued). Descriptive flavor attribute means for sour creams[1]

Treatment	Diacetyl	Milkfat	Cardboard	Fizzy	Astringent	Salty taste	Sweet taste	Sour taste	Bitter
106[4]	0.50	3.4	0.50	ND	2.9	ND	2.9	2.7	ND
779[4]	1.00	3.0	1.0	ND	2.8	ND	2.4	2.4	1.5
121[4]	ND	4.3	ND	ND	2.3	ND	3.2	2.2	ND
111[4]	0.75	3.2	ND	0.5	3.0	ND	2.3	3.0	0.75
515[4]	1.1	4.0	ND	1.3	3.2	ND	3.3	2.9	ND
115[4]	0.50	3.3	ND	2.0	3.3	ND	2.8	3.7	ND
464[4]	ND	3.5	0.50	ND	2.0	ND	2.3	1.4	0.50
881[4]	2.2	4.2	ND	ND	2.5	ND	2.4	2.8	ND
363[4]	0.50	3.0	1.3	ND	2.9	ND	2.8	2.5	1.4
357[4]	ND	2.8	0.50	ND	3.9	ND	1.8	5.2	ND
321[4]	ND	3.5	ND	1.0	2.9	ND	2.2	1.5	1.9
654[4]	0.50	3.5	ND	ND	2.8	0.50	3.1	1.8	0.50
123[4]	ND	2.7	ND	ND	3.0	ND	2.1	2.1	0.75
888[4]	ND	3.9	ND	ND	2.5	ND	3.0	3.0	ND
999[4]	ND	2.9	ND	ND	2.7	ND	2.5	2.0	1.0
456[4]	0.75	3.3	ND	1.0	2.0	ND	3.0	2.5	0.50
951[4]	1.5	4.0	ND	ND	2.5	ND	2.0	1.5	1.0
996[4]	1.0	4.0	ND	ND	2.8	ND	1.9	2.2	0.50
666[4]	ND	3.3	ND	0.5	3.0	ND	2.9	2.4	0.50
789[4]	2.3	2.9	1.8	ND	2.5	ND	2.0	3.6	2.2
753[4]	ND	ND	ND	ND	4.2	ND	2.0	1.5	1.0
665[4]	1.3	4.5	ND	ND	3.0	4.8	2.0	1.1	ND
335[5]	2.3	4.7	ND	0.5	2.4	ND	2.3	2.6	ND
222[5]	0.50	2.0	ND	1.3	3.6	ND	3.8	3.7	ND
969[6]	ND	2.5	ND	ND	3.8	ND	2.9	3.0	0.50
552[6]	ND	1.3	0.75	1.0	3.4	ND	3.7	3.3	0.50
987[6]	ND	2.8	ND	ND	4.0	ND	3.2	2.9	ND
885[6]	ND	1.8	1.8	0.5	3.0	ND	3.3	3.4	0.75
445[7]	ND	ND	ND	ND	3.5	ND	2.1	1.3	ND
333[7]	ND	0.50	ND	ND	2.5	ND	4.0	2.5	0.50
555[7]	ND	ND	2.8	2.3	3.7	ND	4.4	3.4	ND
775[7]	0.75	ND	2.0	1.0	3.8	ND	3.1	3.8	5.3
LSD[3]	0.53	0.66	0.49	0.68	0.55	0.25	0.66	0.77	2.3

[1]Flavor intensities were scored using a 0 to 15-point Spectrum™ intensity scale where 15 = high intensity of an attribute and 0 = absence of attribute (Meilgaard and others, 1999; Drake and Civille, 2003). ND[2] = Not detected. LSD[3]=Least significant difference value. Means in a row that differ by LSD are different ($P<0.05$).). 4=full fat sample, 5=reduced fat samples, 6=light samples, 7=fat free samples.

Table 4. Descriptive texture attribute means for sour creams[1]

Treatment	Surface Gloss	Color Intensity	Slipperiness	Firm-ness	Dense-ness	Adhesiveness	Chalky	Opacity	Surface Grain	Mouthing-coating
106[4]	9.9	3.3	6.2	8.8	8.8	2.3	0.8	12.3	3.8	2.3
779[4]	10.8	4.3	8.0	6.4	7.0	2.5	1.3	13.0	1.8	2.5
121[4]	3.7	5.8	5.5	7.9	7.5	2.0	4.5	13.0	3.8	2.0
111[4]	8.3	3.0	6.8	8.3	8.8	1.3	2.4	13.3	5.5	2.3
515[4]	10.3	4.0	6.8	7.8	7.5	2.8	1.8	13.0	3.3	2.0
115[4]	7.0	5.7	5.5	9.0	8.3	3.3	4.5	12.3	2.3	2.8
464[4]	9.8	4.8	7.3	5.8	7.0	2.0	2.0	12.5	2.0	2.0
881[4]	12.0	5.0	7.6	6.5	7.6	0.5	0.8	12.3	1.3	2.3
363[4]	9.3	5.2	7.7	8.0	7.8	1.5	2.7	13.3	4.3	1.5
357[4]	6.5	4.3	2.3	10.3	9.0	1.0	3.3	13.3	7.5	2.0
321[4]	9.0	6.4	3.5	6.0	5.3	2.0	4.3	11.0	6.3	2.0
654[4]	9.5	4.8	6.2	8.0	8.0	3.0	1.3	13.0	1.8	2.7
123[4]	13.3	3.0	8.9	5.5	6.0	1.0	0.5	12.3	0.9	2.3
888[4]	11.0	5.0	8.0	7.0	7.0	1.0	ND	12.3	0.5	2.0
999[4]	13.0	3.8	8.0	3.5	6.5	ND[2]	0.7	12.8	1.7	2.3
456[4]	8.5	4.3	5.5	7.5	6.7	1.3	1.8	13.0	1.4	2.5
951[4]	10.0	8.5	7.3	7.0	9.0	2.5	2.0	12.8	5.3	3.8
996[4]	4.5	5.5	5.8	9.0	9.0	2.3	2.5	12.9	5.0	3.5
666[4]	2.9	6.7	1.3	11.0	10.0	4.8	5.3	13.2	7.0	2.2
789[4]	13.0	5.8	7.8	4.0	4.9	0.5	1.3	13.0	0.7	1.8
753[4]	7.1	2.5	4.5	8.4	6.0	3.7	7.5	13.3	7.8	ND
665[4]	7.5	5.4	7.9	10.5	9.6	3.8	1.8	13.5	0.8	3.9
335[5]	12.2	5.9	7.7	7.8	8.5	1.0	ND	11.0	2.5	4.8
222[5]	6.5	4.8	3.3	5.8	7.8	1.3	3.8	10.3	10.3	2.5
969[6]	10.0	3.0	5.8	7.0	7.0	1.8	2.5	9.3	4.0	2.0
552[6]	10.0	6.0	6.3	5.0	4.8	3.0	2.9	10.5	3.8	2.5
987[6]	8.0	7.3	4.8	5.8	5.8	2.0	4.0	10.5	6.0	2.3
885[6]	10.5	7.3	7.5	5.5	7.0	1.3	1.2	11.5	0.5	3.2
445[7]	11.0	4.0	8.3	5.3	5.0	2.8	1.3	10.5	0.9	3.3
333[7]	5.3	3.8	2.5	6.8	5.0	2.5	4.5	8.5	7.5	1.0
555[7]	8.0	3.3	7.0	5.8	6.8	2.5	3.8	8.9	1.8	4.0
775[7]	8.5	5.8	5.8	5.8	5.5	3.3	4.8	10.8	2.5	2.3
LSD[3]	1.4	1.1	0.9	1.3	1.5	1.0	1.3	1.5	1.8	0.9

[1]Texture intensities were scored using a 0 to 15-point Product specific scale where 15 = high intensity of an attribute and 0 = absence of attribute (Meilgaard and others, 1999; Drake and Civille, 2003). ND[2] = Not detected. LSD[3]=Least significant difference value. Means in a row that differ by LSD are different (P<0.05) 4=full fat sample, 5=reduced fat samples, 6=light samples, 7=fat free samples.

Table 5: Overall liking attribute means from consumer acceptance testing of sour cream.

	996[1]	222[3]	111[1]	969[2]	106[1]	115[1]	363[1]	357[1]	885[2]	888[1]	789[1]	753[1]
Appearance	6.9 a	5.5 c	7.1 a	5.8 c	7.2 a	6.3 b	7.2 a	7.1 a	4.9 d	7.2 a	6.5 b	7.1 a
Color	7.3 bc	6.6 e	7.5 ab	7.1 d	7.5 ab	7.1 cd	7.5 ab	7.4 ab	6.0 f	7.6 a	7.1 d	7.5 ab
Overall Impression	6.4 bc	4.6 e	5.5 d	5.27 d	6.57 ab	5.33 d	6.79 a	4.22 e	4.33 e	6.65 ab	6.18 c	5.39 d
Flavor	6.3 ab	4.5 d	5.3 c	5.39 c	6.54 a	5.33 c	6.62 a	3.81 e	4.34 d	6.50 a	6.08 b	5.04 c
Fresh	7.0 ab	5.8 f	6.6 cd	6.49 de	7.26 a	6.53 de	7.11 ab	5.93 f	5.79 f	7.20 ab	6.91 bc	6.28 e
Sourness	6.0 ab	4.4 d	5.2 c	5..29 c	6.24 a	5.11 c	6.07 ab	3.58 e	4.32 d	6.10 ab	5.79 b	4.95 c
Texture	6.4 c	5.4 de	6.7 bc	5.27 e	6.92 ab	5.68 d	7.12 a	5.59 de	4.66 f	7.21 a	6.44 c	6.62 bc
Thickness	6.1 c	5.3 e	6.79 ab	5.72 d	6.77 ab	5.83 cd	6.99 a	4.87 f	4.19 g	7.04 a	6.13 c	6.54 b
	31.3%a	7.46%de	20.9%abc	10.9%cd	15.4%bc	18.3%bc	4.97%e	3.97%e	25.9%ab	19.3%abc	14.9%c	31.3%a
Sour JAR	48.7%bc	28.3%d	42.2%bc	46.7%bc	61.6%a	35.3%cd	56.7%ab	17.9%e	29.8%d	54.2%ab	52.2%ab	26.8%d
	19.9e%	64.2%b	36.8%d	42.3%c	22.9%e	46.3%c	38.3%d	78.1%a	44.3%c	26.4%e	32.9%d	41.8%c
	1.5%e	45.8%b	10.4%cd	17.4%c	3.5%e	18.4%c	3.5%e	1.5%e	73.6%a	12.4%cd	36.8%b	12.0%cd
Texture JAR	57.7%cd	46.3%de	81.6%a	51.7%cd	64.7%bc	58.7%cd	78.1%a	34.3%ef	24.4%f	82.1%a	58.2%cd	73.1%a
	40.8%b	8.00%f	8.00%f	30.8%bc	31.8%bc	22.9%cd	18.4%de	64.2%a	2.00%fg	5.50%f	5.00%f	14.9%e
	16.4%c	31.8%b	12.0%cd	43.3%a	12.9%cd	27.9%b	8.50%d	28.3%b	41.8%a	6.50%d	18.4%c	14.4%cd
Smooth JAR	72.6%ab	56.2%de	80.1%a	45.3%f	76.1%ab	59.6cd%	83.6%a	54.7de%	36.8%g	81.1%a	69.6%bc	74.1%ab
	11.0%b	11.9%b	7.95%bc	11.4%b	10.9%b	12.5%b	7.94%bc	16.9%b	21.4%a	12.4%b	11.9%b	11.4%b
	17.9%c	23.9%c	8.00%d	48.7%a	8.00%c	32.3%b	8.00%d	26.3%c	23.4%c	5.50%de	10.4%d	9.00%d
Creamy JAR	78.1%ab	60.67%c	85.6%a	46.8%d	85.6%a	60.7%c	85.6%a	64.2%c	43.3%d	84.6%a	75.1ab%	79.1%ab
	4.00%d	15.4%b	6.47%cd	4.48%d	6.46%cd	6.97%cd	6.46%cd	9.5%bc	33.4%a	10.0%bc	14.4%b	11.9%bc
Purchase Intent	3.43a	2.35bc	3.09ab	2.78ab	3.71a	2.86ab	3.73a	2.04d	2.18d	3.70a	3.34a	2.57ab

Data represents 201 consumers
Liking attributes were scored on a 9-point hedonic scale where dislike extremely=1 and like extremely=9
JAR scales were scored on a 5-point scale where too little= 1 or 2, just about right=3 and too much= 4 or 5; percentage of consumers that selected these options is presented.
Purchase Intent was scored on a 5-point scale where definitely would not buy=1, probably would not buy=2, may or may not buy=3, probably would buy=4, definitely would buy=5.
Different letters in rows following means signify significant differences ($p<0.05$)
All samples were spoonable, 1= Full fat, 2= Reduced fat, 3= Light

Table 6. Overall liking means for each cluster

Sample	Cluster1 (n=47)	Cluster2 (n=94)	Cluster3 (n=57)
106[2]	6.9a	6.9a	5.8e
111[2]	6.0e	6.2d	4.4g
115[2]	5.1fg	5.3e	5.7e
888[2]	6.6bc	6.4bc	6.9a
969[4]	3.9i	5.0e	6.8ab
885[4]	4.4h	3.4g	5.1ef
222[3]	5.4f	4.6f	3.6gh
996[2]	6.6bc	6.6b	6.0d
363[2]	6.7ab	7.1a	6.4c
789[2]	6.0e	6.4bc	6.1d
753[2]	6.1d	3.2g	6.9a
357[2]	6.2d	2.6h	3.9gh

[1]Means in a column with a different letter are statistically different ($p<0.05$)
2=full fat samples, 3=reduced fat samples, 4=light samples. Liking attributes were scored on a 9-point hedonic scale where dislike extremely=1 and like extremely=9.

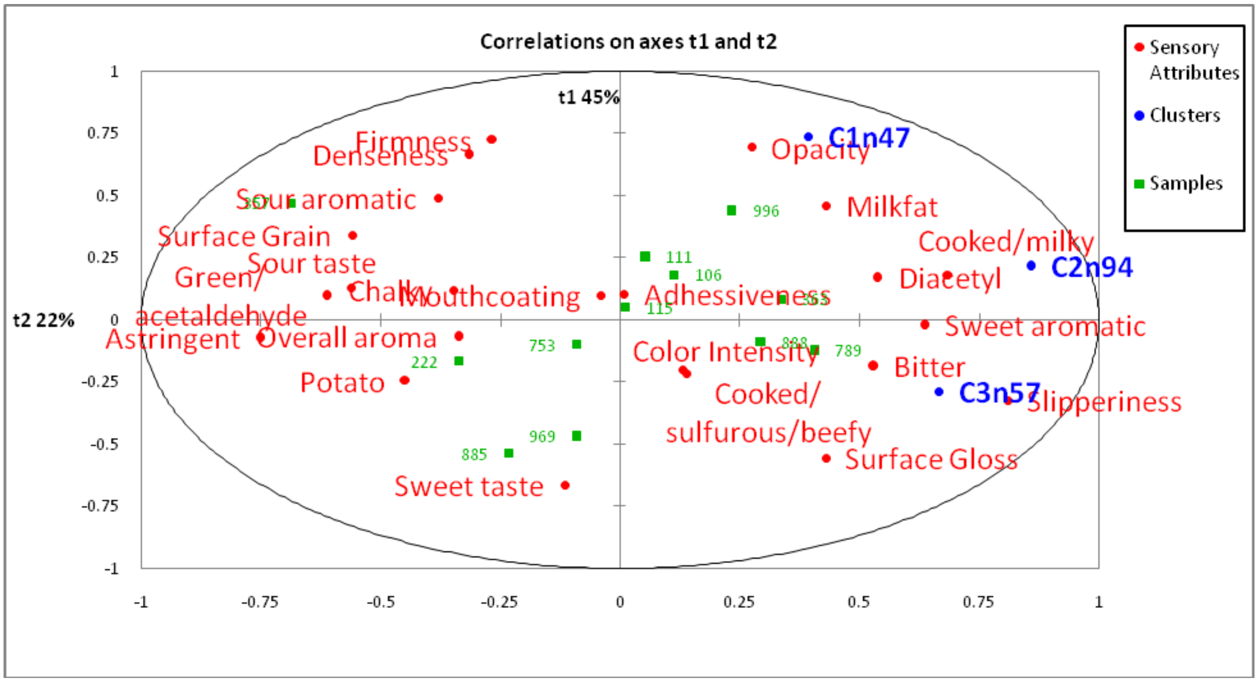

Figure 4. Partial least squares correlation biplot of clusters for sour cream. Numbers represent the sour cream treatments that were included in consumer acceptance tasting. C1 represents cluster 1 (n=47). C2 represents cluster 2 (n=94). C3 represents cluster 3 (n=57). Flavor, texture and visual attributes are included in this biplot. Sample 222 is reduced fat. Samples 885 and 969 are light sour cream. All other sour creams are full fat.

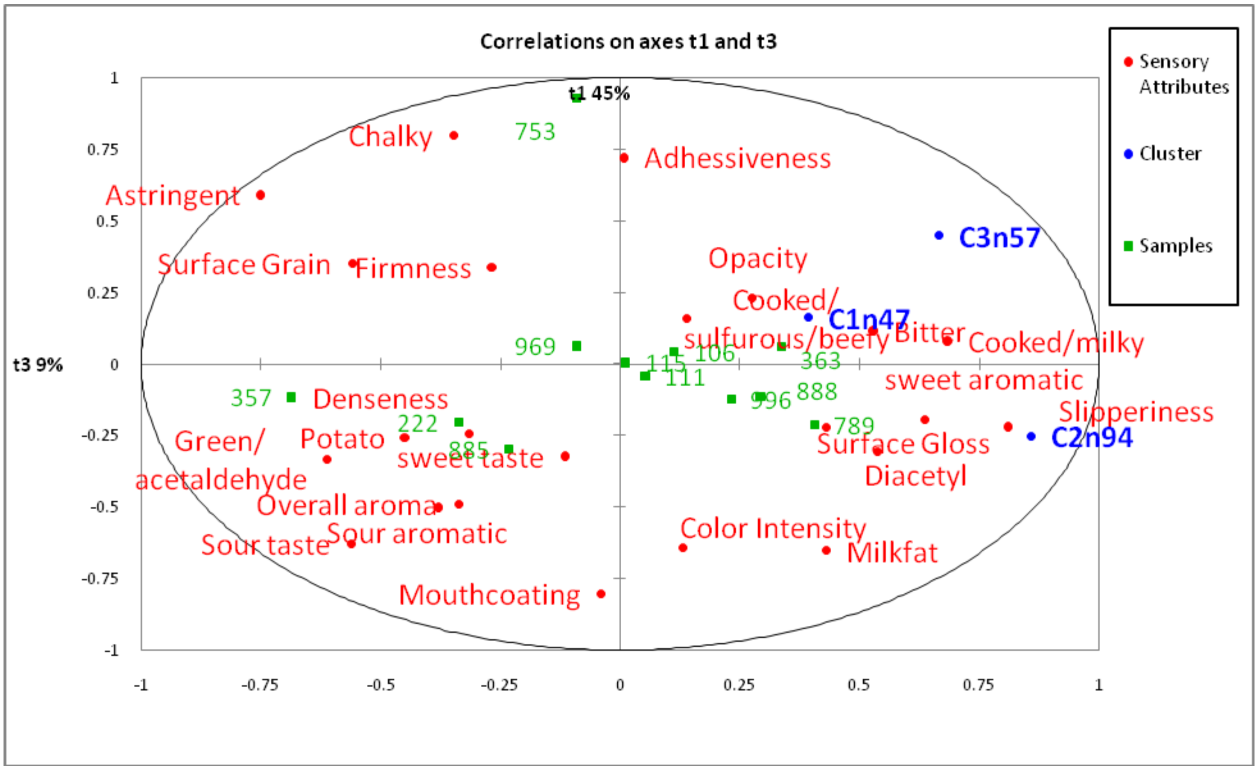

Figure 5. Partial least squares correlation biplot of clusters for sour creams. Numbers represent the sour cream treatments that were included in consumer acceptance tasting. C1 represents cluster 1 (n=47). C2 represents cluster 2 (n=94). C3 represents cluster 3 (n=57). Flavor, texture and visual attributes are included in this biplot. Sample 222 is reduced fat. Samples 885 and 969 are light sour cream. All other sour creams are full fat.

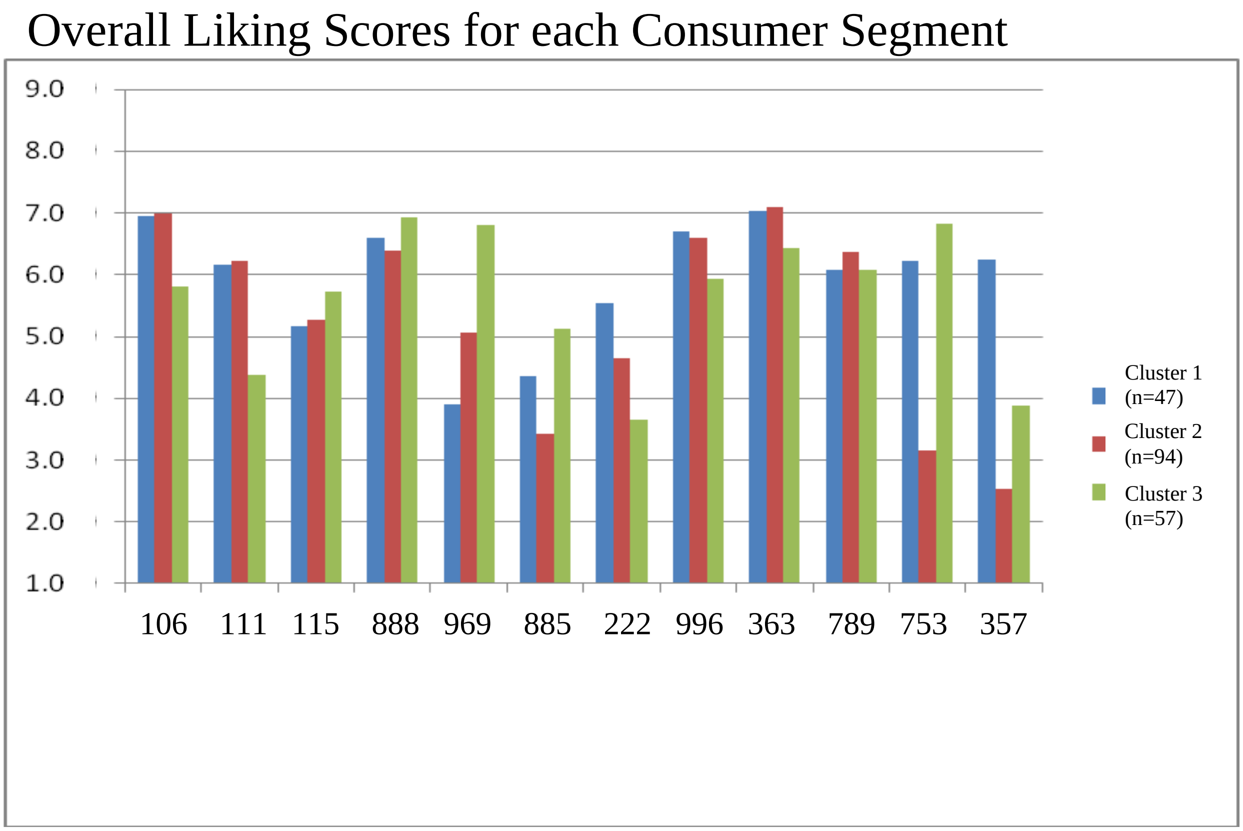

Figure 6. Mean overall scores for each consumer segment. 3-digit codes refer to treatments. Clusters were acquired by K-means clustering and validated using discriminant analysis (DA) and received 93% from validation. Sample 222 is reduced fat. Samples 885 and 969 are light sour cream. All other sour creams are full fat.

Table 7. pH, total fat, total solids, L*a*b* Hunter values, and percent lactic acid of sour creams

Treatments	pH	Total Fat	Total Solids	L*	a*	b*	Percent Lactic Acid
106[2]	4.53	18.2	25.3	84.8	-1.63	8.76	0.07
111[2]	4.55	17.7	25.1	83.3	-1.69	8.73	0.08
115[2]	4.34	18.0	29.2	83.5	-1.72	10.2	0.10
121[2]	4.67	18.6	27.6	84.5	-2.09	9.41	0.09
123[2]	4.56	18.7	26.2	85.0	-1.54	7.93	0.07
222[3]	4.51	9.86	22.2	82.8	-2.33	9.95	0.11
321[2]	4.67	17.7	26.0	84.9	-1.65	9.89	0.08
333[5]	4.67	1.41	22.3	82.9	-2.72	8.83	0.10
335[3]	4.38	25.5	32.2	83.9	-1.65	10.5	0.10
357[2]	4.21	18.1	26.9	82.1	-1.41	9.44	0.17
363[2]	4.47	17.9	26.6	84.8	-2.10	9.92	0.09
445[5]	4.69	1.45	16.8	82.6	-1.76	7.91	0.10
456[2]	4.78	20.1	29.4	82.4	-1.62	9.71	0.09
464[2]	4.82	18.0	26.9	83.6	-1.64	9.06	0.17
515[2]	3.81	17.8	27.4	85.4	-1.93	8.76	0.09
552[4]	4.74	7.69	21.8	82.8	-2.02	10.1	0.14
555[5]	4.74	0.83	19.5	81.2	-2.07	9.50	0.17
654[2]	4.77	17.8	26.7	82.7	-1.5	9.65	0.09
665[2]	4.67	22.2	29.6	84.4	-1.87	10.0	0.10
666[2]	4.34	19.6	29.5	85.3	-2.02	10.7	0.10
753[2]	4.71	22.1	33.0	84.6	-1.2	7.68	0.09
775[5]	4.57	1.62	22.9	82.7	-1.84	9.05	0.17
779[2]	4.74	16.8	26.3	84.7	-2.16	10.0	0.09
789[2]	4.44	17.8	25.3	83.8	-1.66	10.7	0.08
881[2]	4.54	18.0	26.4	83.4	-1.62	9.81	0.08
885[4]	4.61	5.98	21.1	82.1	-1.86	11.0	0.12
888[2]	4.83	17.7	27.2	83.5	-1.69	8.73	0.09
951[2]	4.74	33.1	39.5	85.0	-2.35	15.0	0.05
969[4]	4.59	8.84	22.2	83.9	-1.74	7.96	0.11
987[4]	4.65	6.72	20.3	83.9	-2.65	12.3	0.10
996[2]	4.46	18.4	26.4	83.9	-1.66	9.60	0.08
999[2]	4.56	17.4	24.5	83.1	-1.71	9.06	0.08
LSD[1]	0.030	1.82	0.24	0.94	0.14	0.22	0.0024

LSD[1]=Least Significant Difference value. Means in a row that differ by LSD are different ($P<0.05$). Total solids were based on a w/w and total fat were based on w/v. 2=full fat samples, 3=reduced fat samples, 4=light samples, 5=fat free samples.

Table 8. Organic Acid Concentrations (ppm) of Commercial Sour Creams (n=32)[1]

Sample	Citric	Lactic (ppt)	Formic	**Uric	*Orotic	Pyruvic	Butyric	Acetic
106[3]	26.5	2.09	46.0	4.00	9.00	10.0	43.0	145
779[3]	76.3	2.44	57.6	5.42	10.9	5.82	127	174
121[3]	16.8	2.47	48.2	4.42	16.4	1.99	41.6	177
111[3]	16.8	2.02	48.2	3.97	9.91	2.12	115	148
515[3]	212	2.52	56.6	5.74	10.7	7.11	116	168
115[3]	31.8	2.93	61.2	5.08	11.9	2.11	144	220
464[3]	167	2.16	50.6	3.80	40.5	7.35	50.8	253
881[3]	19.7	2.26	47.6	5.09	9.57	3.76	105	178
363[3]	23.0	2.29	46.2	4.78	10.2	2.58	ND[2]	164
357[3]	86.7	4.32	38.6	6.55	4.30	9.47	810	ND
321[3]	26.2	2.10	55.0	4.30	7.74	4.68	106	169
654[3]	146	2.39	63.0	5.53	6.94	6.83	ND	134
123[3]	20.4	2.14	54.5	3.95	8.00	4.80	63.1	114
888[3]	22.5	2.55	58.1	4.27	9.67	5.65	73.0	231
999[3]	11.2	1.84	57.7	4.15	7.30	3.68	ND	153
456[3]	37.6	2.20	47.1	4.00	9.81	3.61	50.8	147
951[3]	22.7	1.52	76.8	0.57	8.45	ND	59.6	110
996[3]	22.2	2.14	56.4	4.08	8.35	5.79	131	189
666[3]	15.1	2.60	48.0	5.15	10.1	9.14	ND	174
665[3]	24.7	2.89	73.2	5.17	11.6	3.40	432	187
789[3]	43.3	2.12	50.1	3.67	7.11	3.50	90.9	120
753[3]	10.6	2.67	62.4	4.86	11.0	3.96	121	241
222[4]	44.0	3.55	89.6	6.31	12.4	6.07	114	224
335[4]	43.6	2.37	60.2	4.13	7.69	4.78	121	159
969[5]	23.8	2.70	59.8	4.77	8.50	2.02	109	168
552[5]	815	3.36	190	6.26	13.1	4.59	167	232
987[5]	186	2.46	83.6	5.10	10.2	3.29	81.3	167
885[5]	24.3	2.91	67.2	7.86	17.0	ND	97.5	39.8
445[6]	58.0	2.78	69.5	5.65	12.1	3.49	94.7	201
333[6]	21.4	2.39	16.8	11.6	14.2	2.60	ND	66.2
555[6]	41.4	3.77	73.5	9.36	19.8	5.36	146	419
775[6]	364	3.82	89.5	7.95	12.9	9.70	119	320
LSD	93.1	0.326	161	3.07	16.4	2.06	30.4	31.4

[1]Organic acid concentration of commercial sour cream (n=32) by HPLC peak absorbance. Measurements were taken at a wavelength of 220nm. *Measurements taken at a wavelength of 275nm. **Measurments taken at a wavelength of 290nm. There were only a few samples that contained hippuric and propionic acids. The samples that contained hippuric acid included 115b (1ppm). The samples that contained propionic acid included 665 (18ppm), 888 (24ppm), 885 (64ppm), 666 (76ppm), and 464 (16ppm). The LSD values for hippuric=1.33 and propionic=8.31. [2]ND=not detected. 3=full fat samples, 4=reduced fat samples, 5=light samples, and 6=fat free samples

Table 9. Relative abundance of compounds in sour cream (ppb).

Compounds	111[3]	115[3]	121[3]	123[3]	222[4]	321[3]	333[6]	335[4]	357[3]	363[3]	445[6]	456[3]	464[3]	515[3]	552[5]	555[6]	654[3]	LSD[2]
2-pentyl furan	2.8	0.7	3.3	6.0	4.3	4.1	6.3	1.6	2.5	1.7	1.8	ND	0.7	1.6	1.0	3.1	ND	2.37
E,E-2,4-Nonadienal	ND	ND	0.1	ND	ND	ND	0.1	ND	ND	ND	0.2	ND	ND	ND	ND	1.3	ND	0.16
Acetaldehyde	833	155	414	90.3	137	562	96.2	370	1021	174.9	192.5	54.7	127	80.6	45.9	47.9	155	435
o cresol	ND	0.8	1.5	0.6	ND	ND	ND	ND	ND	ND	0.5	ND	0.1	ND	0.1	0.1	ND	5.32
dimethyl heptenal	ND	ND	3.7	10	ND	ND	0.6	ND	ND	ND	ND	ND	ND	ND	ND	0.7	ND	17.4
2-ethyl-5-methylpyrazine	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
sotolone	0.6	26.3	1.2	0.8	0.9	0.7	2.0	0.1	ND	ND	47.6	ND	82.5	ND	8.4	12.7	117.9	83.2
Butyl-2methylbutyrate	2.9	1.8	4.5	1.9	ND	ND	2.0	0.6	ND	ND	4.4	ND	2.7	1.0	1.3	4.5	3.8	2.26
isopropyl butanoate	0.9	1.3	2.4	0.5	ND	ND	2.2	0.6	ND	ND	0.7	ND	1.1	2.4	1.8	4.7	ND	4.80
Gamma-decalactone	ND	ND	ND	ND	0.3	ND	6.8	ND	1.3	ND	0.7	ND	ND	ND	ND	ND	ND	0.41
2,3-Butanedione	14.8	0.1	31.5	43.2	2.6	0.5	53.2	296.1	1.8	608	47.2	ND	21.9	4.6	2.3	68.0	9.2	115
Acetoin	46.4	0.2	382.1	513.4	420	3.6	58.2	27.7	28.4	11.1	137.6	ND	0.2	15.6	1.4	20	9.0	228
ethyl isohexanoate	1.5	1.1	0.8	0.5	1.1	1.5	1.7	ND	ND	1.2	1.6	ND	ND	ND	1.2	0.2	ND	1.25
delta decalactone	3.0	2.0	0.8	0.1	2.2	2.0	1.2	ND	4.3	1.4	0.2	1.2	0.4	0.2	0.7	ND	2.4	1.98
methional	1.9	3.9	1.0	1.1	1.7	0.8	7.3	ND	7.0	3.6	2.7	2.8	3.0	0.6	2.0	5.0	4.4	1.94
Guaiacol	ND	ND	0.2	0.1	ND	0.7	0.5	ND	0.2	ND	ND	ND	ND	ND	ND	0.2	ND	1.32
2-methyl-3-furanthiol	2.5	0.6	0.7	2.9	0.4	4.6	0.8	2.1	3.1	2.3	0.6	2.5	0.5	0.3	0.4	3.2	1.1	4.69
dimethyl trisulfide	0.1	0.3	1.0	0.8	1.3	2.3	1.3	0.2	0.9	0.4	1.3	0.4	0.3	0.1	05	10.9	0.4	2.09
1-hexen-3-one	2.6	1.5	4.0	3.8	4.2	1.6	0.7	0.7	16.7	1.7	5.7	0.6	5.6	2.6	1.7	3.3	4.0	5.05
E-2-nonenal	15.4	4.2	0.6	ND	7.6	20	43.7	ND	106	0.3	ND	ND	6.3	ND	8.9	40.9	9.6	13.2
hexanal	9.2	1.3	41.2	126.1	ND	ND	16.2	3.2	6.5	ND	1.9	ND	2.5	0.8	1.7	11.2	ND	37.5
octanal	17.5	20	106	11.3	697.3	944.5	16.2	0.6	ND	6.2	3.6	2.5	20.5	7.9	2.9	19.5	7.9	521
2-hexanol	0.4	ND	1.3	0.6	ND	ND	1.3	0.4	ND	ND	0.3	ND	13.5	0.7	ND	2.4	ND	6.81
nonanal	4.7	1.8	11.7	5.7	8.2	8.9	15.2	1.7	107	1.5	4.6	1.1	11.2	10	3.6	102	13.6	8.65
3-methyl butanal	38.0	9.4	0.2	0.5	1.2	28.2	46.0	24.3	62.2	ND	8.7	0.8	ND	0.7	0.4	1.3	3.3	29.1
acetic acid	9210	1224.4	1668.2	322.2	5408	1159.1	341.2	739.6	2340	652.2	926.3	ND	ND	124.5	0.5	ND	ND	1422

Concentrations in parts per billion (ppb). ND[1]=not detected. LSD[2]= Least significant difference value. Means in a row that differ by LSD are different ($P<0.05$).
3=full fat sour creams, 4=reduced fat samples, 5=light samples, 6=fat free samples

Table 9 continued. Relative abundance of compounds in sour cream (ppb).

Compounds	111[3]	115[3]	121[3]	123[3]	222[4]	321[3]	333[6]	335[4]	357[3]	363[3]	445[6]	456[3]	464[3]	515[3]	552[5]	555[6]	654[3]	LSD[2]
butyric acid	381.5	82.3	56.7	1206	356.5	2503	1701	92.8	205.2	2060	53.8	ND	105	204	45.1	161.5	40	169
2-acetyl-2-thiazoline	0.6	2.8	ND	ND	ND	ND	0.7	ND	ND	ND	ND	ND	14.9	ND	ND	0.7	ND	3.67
dimethyl sulfide	2.5	2.2	3.8	3.1	1.4	3.9	1.0	3.4	5.9	3.3	1.1	1.7	0.9	1.7	1.2	1.4	1.1	1.92
z-4-heptenal	2.5	ND	2.9	5.6	4.5	ND	3.6	0.8	7.7	1.2	0.4	2.0	9.9	2.0	6.4	4.3	26.3	4.74
1-octene-3-one	34.9	5.6	2.5	2.3	29.5	21.4	20.7	01	9.9	9.1	9.5	0.2	3.4	0.6	7.1	15.1	7.6	8.44
E,Z-2,6-Nonadienal	0.1	0.7	0.3	ND	ND	ND	0.5	ND	ND	ND	0.7	ND	ND	ND	0.3	0.4	ND	0.43
2-butanone	12.6	4.8	46.2	17.0	ND	9.8	4.5	10.5	ND	4.6	3.6	ND	13.2	10.3	11.5	14.5	ND	16.9

Concentrations in parts per billion (ppb). ND[1]=not detected. LSD[2]= Least significant difference value. Means in a row that differ by LSD are different (P<0.05).
3=full fat sour creams, 4=reduced fat samples, 5=light samples, 6=fat free samples

Table 9 (Continued). Relative abundance of compounds in sour cream (ppb).

Compounds	665[3]	666[3]	753[3]	775[6]	779[3]	789[3]	881[3]	885[5]	888[3]	954[3]	969[5]	987[3]	996[3]	999[3]	106[3]	LSD[2]
2-pentyl furan	2.8	0.3	0.8	3.9	3.1	8.3	0.8	2.8	0.4	ND	2.8	6.7	0.9	1.0	3.8	2.37
E,E-2,4-Nonadienal	0.2	ND	ND	ND	ND	0.1	ND	0.2	ND	ND	ND	0.7	ND	ND	ND	0.16
Acetaldehyde	121.4	87.3	62.8	107.7	363.6	255.3	182.6	271.2	58.9	168.5	285.1	267.8	250.6	120.4	375.3	435
o cresol	3.0	ND	0.4	ND	ND	2.3	ND	0.1	ND	ND	ND	7.5	0.3	ND	ND	5.32
dimethyl heptenal	7.6	ND	ND	ND	ND	8.8	ND	0.1	ND	ND	0.1	26.6	ND	ND	0.2	17.4
2-ethyl-5-methylpyrazine	ND	ND	ND	ND	ND	ND	ND	0.9	ND	ND	ND	0.1	ND	ND	ND	0.13
sotolone	3.2	0.2	113.8	9.3	0.5	2.0	ND	1.0	ND	ND	ND	5.4	0.4	ND	10.9	83.2
Butyl-2-methylbutyrate	4.3	0.9	1.5	3.3	1.6	4.2	1.2	1.2	2.6	ND	1.7	8.7	4.6	1.7	3.3	2.26
isopropyl butanoate	0.5	0.6	0.4	3.7	0.7	4.3	0.2	ND	1.6	1.4	1.3	1.2	0.9	1.5	6.7	4.80
Gamma-decalactone	ND	ND	ND	ND	ND	ND	ND	0.2	ND	ND	ND	ND	ND	ND	ND	0.41
2,3-Butanedione	239.6	12.9	2.9	87.4	30.7	196.0	11.0	1.7	3.4	13.6	11.5	356.6	1.9	1.1	161.5	115
Acetoin	1254.2	59.7	7.9	91.5	55.8	409.6	1.8	10.3	6.9	16.6	3.6	875.7	1.9	1.5	400.7	228
ethyl isohexanoate	0.5	ND	0.1	0.5	1.7	0.8	ND	0.6	ND	ND	ND	0.6	0.7	ND	0.4	1.25
delta decalactone	1.1	0.9	1.0	0.1	1.0	1.1	0.2	2.5	0.3	1.6	0.9	0.7	1.7	0.3	0.7	1.98
methional	0.6	4.8	0.8	1.6	5.3	1.2	0.3	7.1	1.3	4.5	7.1	0.9	0.4	1.2	3.6	1.94
Guaiacol	0.7	ND	ND	0.1	0.3	0.4	ND	ND	ND	0.1	ND	1.4	ND	ND	0.2	1.32
2-methyl-3-furanthiol	2.6	0.3	0.5	2.8	12.8	9.2	2.1	0.8	0.9	7.8	1.0	6.9	1.0	1.3	4.1	4.69
dimethyl trisulfide	1.7	0.2	0.3	1.0	0.5	1.2	0.1	2.2	0.2	0.5	1.3	3.6	0.2	0.2	0.8	2.09
1-hexen-3-one	8.3	5.7	1.5	3.4	0.8	13.7	2.1	3.2	10.5	2.4	6.4	20.4	1.4	0.8	6.4	5.05
E-2-nonenal	0.8	0.2	6.8	15.6	4.5	1.1	ND	43.7	ND	ND	3.7	2.0	1.0	0.3	1.6	13.2
hexanal	93.0	1.6	1.6	23.0	3.6	68.3	3.8	7.5	6.5	ND	5.5	91.4	2.1	1.9	76.7	37.5
octanal	23.4	1.5	9.0	22.0	8.9	15.2	1.8	14.5	19.3	2.4	2.7	40.7	1.8	14.2	8.8	521
2-hexanol	1.9	12.9	ND	1.9	2.7	4.3	0.3	30.2	0.2	ND	1.4	4.3	ND	0.6	4.4	6.81
nonanal	25.7	1.2	12.3	7.8	6.2	16.3	1.4	7.6	0.5	3.2	3.4	45.5	3.6	1.1	8.6	8.65
3-methyl butanal	1.4	4.1	1.0	4.3	24.5	ND	10.9	17.9	1.7	9.6	18.0	0.7	8.6	3.8	17.2	29.1
acetic acid	5275.5	ND	214.8	1991.8	848.6	1583.0	398.5	342.3	206.2	476.0	794.3	2802.7	716.4	503.3	2313.0	1422

Concentrations in parts per billion (ppb). ND[1]=not detected. LSD[2]= Least significant difference value. Means in a row that differ by LSD are different ($P<0.05$).
3=full fat sour creams, 4=reduced fat samples, 5=light samples, 6=fat free samples

Table 9 (Continued). Relative abundance of compounds in sour cream (ppb).

Compounds	665[3]	666[3]	753[3]	775[3]	779[3]	789[3]	881[3]	885[5]	888[3]	954[3]	969[5]	987[3]	996[3]	999[3]	106[3]	LSD
Butyric acid	190	46.6	55.1	61.7	149.8	97.6	115.9	304.2	17.0	ND	27.5	381.4	116.2	93.6	96.8	169
2-acetyl-2-thiazoline	ND	0.2	13.2	0.3	0.4	0.2	ND	0.2	ND	ND	0.2	ND	ND	ND	0.4	3.67
dimethyl sulfide	10.6	1.6	1.4	2.2	2.3	2.8	1.6	1.5	1.5	2.3	3.3	3.5	3.1	3.0	2.8	1.92
z-4-heptenal	6.5	1.5	3.1	2.1	0.5	9.2	1.4	2.1	3.8	0.7	6.9	15.4	2.0	3.0	4.2	4.74
1-octene-3-one	9.2	0.7	4.5	9.9	12.8	10	1.4	36.4	1.0	2.0	2.8	25.6	5.6	4.4	6.1	8.44
E,Z-2,6-Nonadienal	0.9	ND	0.1	ND	ND	0.5	ND	0.2	ND	ND	0.2	1.9	ND	ND	0.2	0.43
2 butanone	75.1	9.2	12.2	20.5	8.0	26.6	9.1	6.1	10.2	ND	6.6	53.1	7.5	5.7	31.1	16.9

Concentrations in parts per billion (ppb). ND[1]=not detected. LSD[2]= Least significant difference value. Means in a row that differ by LSD are different ($P<0.05$). 3=full fat sour creams, 4=reduced fat samples, 5=light samples, 6=fat free samples

Table 10. Aroma active compounds in sour creams.

Aroma	**RI (DZ-5)**	**RI (DZ-WAX)**	**Possible Compound**	**106[d]**	**111[d]**	**115[d]**	**121[d]**	**123[d]**	**222[g]**	**321[d]**	**333[g]**	**335[e]**
Sulfur	<600	680	Dimethyl Sulfide	+	+	+	+		+	+		+
Ether/solvents	<600	<600	2-Butanone	+	+		+	+		+	+	
Butter	<600	876	2,3-Butanedione	+	+	+	+	+	+	+	+	+
Acetic/vinegar	<600	1335	Acetic Acid	+	+	+	+	+		+	+	+
malty/choc.	611	614	2 or 3-Methyl Butanal	+			+		+	+		
Garlic/cabbage	615		Methylethyl sulfide									
Rubbery	680		1-hexen-3-one	+	+	+	+	+	+	+	+	+
cheesey/ffa	806	1631	Butyric acid	+	+	+	+		+		+	
Grassy	802	1011	Hexanal	+					+		+	
Fruity	859	1159	Isopropyl butanoate									
cooked/brothy	866	1262	2-methyl-3-furanthiol	+	+	+	+		+	+	+	+
Green	890		2-Hexanol	+	+							
fishy/fatty	899	1146	Z-4 Heptenal		+			+				
potato	905	1395	Methional	+	+	+	+		+	+	+	+
popcorn	921	1345	2-acetyl pyrroline									
fruity	924		Ethyl isohexanoate				+			+		
sulfur (cabbage, garlic)	969		Dimethyl Trisulfide	+			+	+			+	+
mushroom	976		1-octene-3-one				+				+	
green, metal	987	1205	2-pentyl furan	+	+		+		+		+	
Fruity	996		Ethylmethyl pyrazine	+								
citrus/fruity	1002	1263	Octanal	+			+		+		+	
Fruit, Cocoa	1051		Butyl methylbutyrate									
sweet/caramelized sugar	1064	1416	Furaneol								+	
citrus/sweet	1075		Dimethylheptenal	+								

[a]Retention indices of the aroma event on the ZB-5 column. [b]Retention indices of the aroma event on the ZB-Wax column [c]Method of identification by RI (retention indices). (+) indicates the presence of compound detected by two experienced sniffers, () blanks-indicates the absence of compound. D=full fat samples, E=reduced fat samples, F=light samples, G=fat free samples

Table 10 continued. Aroma active compounds in all sour creams.

Aroma	**RI (DZ-5)**	**RI (DZ-WAX)**	**Possible Compound**	**106[d]**	**111[d]**	**115[d]**	**121[d]**	**123[d]**	**222[g]**	**321[d]**	**333[g]**	**335[e]**
sweet/smokey	1081	1479	Guaiacol	+	+				+		+	+
sweet fatty cukes	1100	1331	Nonanal	+			+	+	+	+	+	+
popcorn	1107	1757	2-acetyl-2-thiazoline	+					+	+		
maple/curry	1129		Sotolone	+							+	
green,cukes	1151	1530	E,Z,-2,6-Nonadienal	+							+	+
carpet	1166	1493	E-2-nonenal	+	+		+			+		+
licorice	1173		Estrogole									
pasta/fatty	1175	1687	Methyl-2-methyl-3-furyl disulfide					+				
bell pepper	1182		2-Isobutyl-3-methoxypyrazine									
fatty hay	1221	1677	E,E- 2,4-Nonadienal								+	
minty hay	1220		2-octyl-furan								+	
stale/grapy/tortilla	1333		o-aminoacetophenone	+							+	
phenolic rubbery	1347		Benzolthiazole									
sweet/peach	1448		Gamma-decalactone									
coconut/soapy	1503		Delta-decalactone									
popcorn	1107	1757	2-acetyl-2-thiazoline	+								

[a]Retention indices of the aroma event on the ZB-5 column. [b]Retention indices of the aroma event on the ZB-Wax column [c]Method of identification by RI (retention indices). (+) indicates the presence of compound detected by two experienced sniffers, () blanks-indicates the absence of compound. D=full fat samples, E=reduced fat samples, F=light samples, G=fat free samples

Table 10. Aroma active compounds in sour creams.

Aroma	**RI (DZ-5)**	**RI (DZ-WAX)**	**Possible Compound**	**357[d]**	**363[d]**	**445[g]**	**456[d]**	**464[d]**	**515[d]**	**552[e]**	**555[6]**
Sulfur	<600	680	Dimethyl Sulfide	+	+	+	+	+	+	+	+
Ether/solvents	<600	<600	2-Butanone		+						+
Butter	<600	876	2,3-Butanedione	+	+	+		+	+	+	+
Acetic/vinegar	<600	1335	Acetic Acid	+	+	+		+	+	+	+
malty/choc.	611	614	2 or 3-Methyl Butanal	+				+	+	+	+
Garlic/cabbage	615		Methylethyl sulfide								+
Rubbery	680		1-hexen-3-one	+	+			+	+	+	+
cheesey/ffa	806	1631	Butyric acid		+						+
Grassy	802	1011	Hexanal	+				+			
Fruity	859	1159	Isopropyl butanoate								
cooked/brothy	866	1262	2-methyl-3-furanthiol	+		+	+	+	+	+	+
Green	890		2-Hexanol								
fishy/fatty	899	1146	Z-4 Heptenal				+	+			+
potato	905	1395	Methional	+	+	+	+	+		+	+
popcorn	921	1345	2-acetyl pyrroline								
fruity	924		Ethyl isohexanoate					+	+	+	+
sulfur (cabbage, garlic)	969		Dimethyl Trisulfide						+	+	+
mushroom	976		1-octene-3-one						+		+
green, metal	987	1205	2-pentyl furan		+			+		+	
Fruity	996		Ethylmethyl pyrazine								
citrus/fruity	1002	1263	Octanal	+				+	+		+
Fruit, Cocoa	1051		Butyl methylbutyrate								
sweet/caramelized sugar	1064	1416	Furaneol								
citrus/sweet	1075		Dimethylheptenal								

[a]Retention indices of the aroma event on the ZB-5 column. [b]Retention indices of the aroma event on the ZB-Wax column [c]Method of identification by RI (retention indices). (+) indicates the presence of compound detected by two experienced sniffers, () blanks-indicates the absence of compound. D=full fat samples, E=reduced fat samples, F=light samples, G=fat free samples

Table 10 continued. Aroma active compounds in all sour creams.

Aroma	**RI (DZ-5)**	**RI (DZ-WAX)**	**Possible Compound**	**357[d]**	**363[d]**	**445[g]**	**456[d]**	**464[d]**	**515[d]**	**552[e]**	**555[6]**
sweet/smokey	1081	1479	Guaiacol					+		+	+
sweet fatty cukes	1100	1331	Nonanal		+	+		+		+	+
popcorn	1107	1757	2-acetyl-2-thiazoline							+	+
maple/curry	1129		Sotolone								+
green,cukes	1151	1530	E,Z,-2,6-Nonadienal	+				+		+	
carpet	1166	1493	E-2-nonenal	+	+	+			+	+	
licorice	1173		Estrogole				+				+
pasta/fatty	1175	1687	Methyl-2-methyl-3-furyl disulfide								
bell pepper	1182		2-Isobutyl-3-methoxypyrazine								+
fatty hay	1221	1677	E,E- 2,4-Nonadienal								+
minty hay	1220		2-octyl-furan								+
stale/grapy/tortilla	1333		o-aminoacetophenone								
phenolic rubbery	1347		Benzolthiazole								+
sweet/peach	1448		Gamma-decalactone								
coconut/soapy	1503		Delta-decalactone					+			
popcorn	1107	1757	2-acetyl-2-thiazoline							+	+

[a]Retention indices of the aroma event on the ZB-5 column. [b]Retention indices of the aroma event on the ZB-Wax column [c]Method of identification by RI (retention indices). (+) indicates the presence of compound detected by two experienced sniffers, () blanks-indicates the absence of compound. D=full fat samples, E=reduced fat samples, F=light samples, G=fat free samples

Table 10 continued. Aroma active compounds in all sour creams.

Aroma	RI (DZ-5)	RI (DZ-WAX)	Possible Compound	654[d]	665[d]	666[d]	753[d]	775[g]	779[d]	789[d]	881[d]
sulfur	<600	680	Dimethyl Sulfide	+	+	+	+	+	+	+	+
Ether/solvents	<600	<600	2-Butanone								
Butter	<600	876	2,3-Butanedione	+	+	+	+	+	+	+	+
Acetic/vinegar	<600	1335	Acetic Acid		+	+		+	+	+	+
malty/choc.	611	614	2 or 3-Methyl Butanal	+	+	+		+	+	+	+
Garlic/cabbage	615		Methylethyl sulfide					+			
Rubbery	680		1-hexen-3-one	+	+	+	+				+
cheesey/ffa	806	1631	Butyric acid	+	+			+	+	+	
Grassy	802	1011	Hexanal							+	
Fruity	859	1159	Isopropyl butanoate							+	
cooked/brothy	866	1262	2-methyl-3-furanthiol	+	+	+	+	+	+	+	+
Green	890		2-Hexanol					+			
fishy/fatty	899	1146	Z-4 Heptenal	+		+		+			
Potato	905	1395	Methional	+	+	+	+	+	+	+	+
Popcorn	921	1345	2-acetyl pyrroline	+		+					
Fruity	924		Ethyl isohexanoate								
sulfur (cabbage, garlic)	969		Dimethyl Trisulfide		+			+	+	+	+
Mushroom	976		1-octene-3-one						+		
green, metal	987	1205	2-pentyl furan		+		+			+	
Fruity	996		Ethylmethyl pyrazine						+		
citrus/fruity	1002	1263	Octanal		+			+	+		
Fruit, Cocoa	1051		Butyl methylbutyrate		+			+			
sweet/caramelized sugar	1064	1416	Furaneol			+					

[a]Retention indices of the aroma event on the ZB-5 column. [b]Retention indices of the aroma event on the ZB-Wax column [c]Method of identification by RI (retention indices). (+) indicates the presence of compound detected by two experienced sniffers, () blanks-indicates the absence of compound. D=full fat samples, E=reduced fat samples, F=light samples, G=fat free samples

Table 10 continued. Aroma active compounds in all sour creams.

Aroma	**RI (DZ-5)**	**RI (DZ-WAX)**	**Possible Compound**	**654[d]**	**665[d]**	**666[d]**	**753[d]**	**775[g]**	**779[d]**	**789[d]**	**881[d]**
citrus/sweet	1075		Dimethylheptenal								
sweet/smokey	1081	1479	Guaiacol	+	+	+		+		+	+
sweet fatty cukes	1100	1331	Nonanal	+		+		+	+	+	
popcorn	1110	1757	Acetylthiazoline								
maple/curry	1129		Sotolone								
green,cukes	1151	1530	E,Z,-2,6-Nonadienal				+			+	
carpet	1166	1493	E-2-nonenal	+	+	+			+	+	
licorice	1173		Estrogole								
pasta/fatty	1175	1687	Methyl-2-methyl-3-furyl disulfide					+			+
bell pepper	1182		Isobutylmethoxypyrazine								
fatty hay	1221	1677	E,E- 2,4-Nonadienal	+			+				
minty hay	1220		2-octyl-furan								
stale/grapy/tortilla	1333		o-aminoacetophenone								
phenolic rubbery	1347		Benzolthiazole	+							
sweet/peach	1448		Gamma-decalactone								
coconut/soapy	1503		Delta-decalactone								
popcorn	1107	1757	2-acetyl-2-thiazoline								

[a]Retention indices of the aroma event on the ZB-5 column. [b]Retention indices of the aroma event on the ZB-Wax column [c]Method of identification by RI (retention indices). (+) indicates the presence of compound detected by two experienced sniffers, () blanks-indicates the absence of compound. D=full fat samples, E=reduced fat samples, F=light samples, G=fat free samples

Table 10 continued. Aroma active compounds in all sour creams.

Aroma	**RI (DZ-5)**	**RI (DZ-WAX)**	**Possible Compound**	**885[f]**	**888[d]**	**951[d]**	**969[f]**	**987[d]**	**996[d]**	**999[d]**
sulfur	<600	680	Dimethyl Sulfide	+	+	+	+	+	+	+
Ether/solvents	<600	<600	2-Butanone					+	+	
Butter	<600	876	2,3-Butanedione	+	+	+	+	+	+	+
Acetic/vinegar	<600	1335	Acetic Acid	+	+	+	+		+	+
malty/choc.	611	614	2 or 3-Methyl Butanal	+			+		+	
Garlic/cabbage	615		Methylethyl sulfide							
Rubbery	680		1-hexen-3-one	+	+		+		+	+
cheesey/ffa	806	1631	Butyric acid		+			+		+
Grassy	802	1011	Hexanal							
Fruity	859	1159	Isopropyl butanoate							
cooked/brothy	866	1262	2-methyl-3-furanthiol	+	+		+	+	+	+
Green	890		2-Hexanol							
fishy/fatty	899	1146	Z-4 Heptenal	+		+		+		
Potato	905	1395	Methional	+	+	+	+	+	+	+
Popcorn	921	1345	2-acetyl pyrroline		+			+		
Fruity	924		Ethyl isohexanoate							
sulfur (cabbage, garlic)	969		Dimethyl Trisulfide	+	+		+	+	+	+
Mushroom	976		1-octene-3-one	+				+		+
green, metal	987	1205	2-pentyl furan	+		+	+	+	+	
Fruity	996		Ethylmethyl pyrazine							+
citrus/fruity	1002	1263	Octanal	+	+	+	+	+		+
Fruit, Cocoa	1051		Butyl methylbutyrate							
sweet/caramelized sugar	1064	1416	Furaneol							

[a]Retention indices of the aroma event on the ZB-5 column. [b]Retention indices of the aroma event on the ZB-Wax column [c]Method of identification by RI (retention indices). (+) indicates the presence of compound detected by two experienced sniffers, () blanks-indicates the absence of compound. D=full fat samples, E=reduced fat samples, F=light samples, G=fat free samples

Table 10 continued. Aroma active compounds in all sour creams.

Aroma	RI (DZ-5)	RI (DZ-WAX)	Possible Compound	885^{f}	888^{d}	951^{d}	969^{f}	987^{d}	996^{d}	999^{d}
citrus/sweet	1075		Dimethylheptenal						+	
sweet/smokey	1081	1479	Guaiacol	+	+		+			+
sweet fatty cukes	1100	1331	Nonanal	+		+	+	+		+
popcorn	1110	1757	Acetylthiazoline				+			
maple/curry	1129		Sotolone			+				
green,cukes	1151	1530	E,Z,-2,6-Nonadienal	+				+		+
carpet	1166	1493	E-2-nonenal	+	+		+			
licorice	1173		Estrogole		+					
pasta/fatty	1175	1687	Methyl-2-methyl-3-furyl disulfide							
bell pepper	1182		Isobutylmethoxypyrazine							
fatty hay	1221	1677	E,E- 2,4-Nonadienal							
minty hay	1220		2-octyl-furan							
stale/grapy/tortilla	1333		o-aminoacetophenone							
phenolic rubbery	1347		Benzolthiazole							
sweet/peach	1448		Gamma-decalactone							
coconut/soapy	1503		Delta-decalactone							
popcorn	1107	1757	2-acetyl-2-thiazoline				+			

[a]Retention indices of the aroma event on the ZB-5 column. [b]Retention indices of the aroma event on the ZB-Wax column [c]Method of identification by RI (retention indices). (+) indicates the presence of compound detected by two experienced sniffers, () blanks-indicates the absence of compound. D=full fat samples, E=reduced fat samples, F=light samples, G=fat free samples

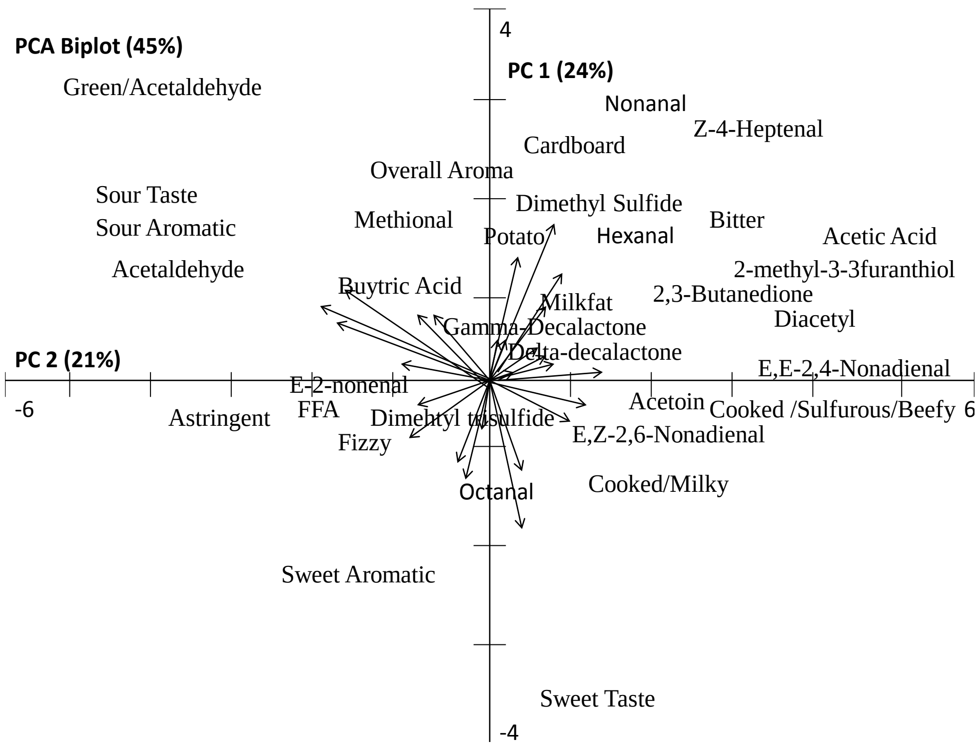

Figure 7. Principle Component Analysis biplot (PC 1 and 2) of sensory flavor attributes and instrumental data of sour creams.

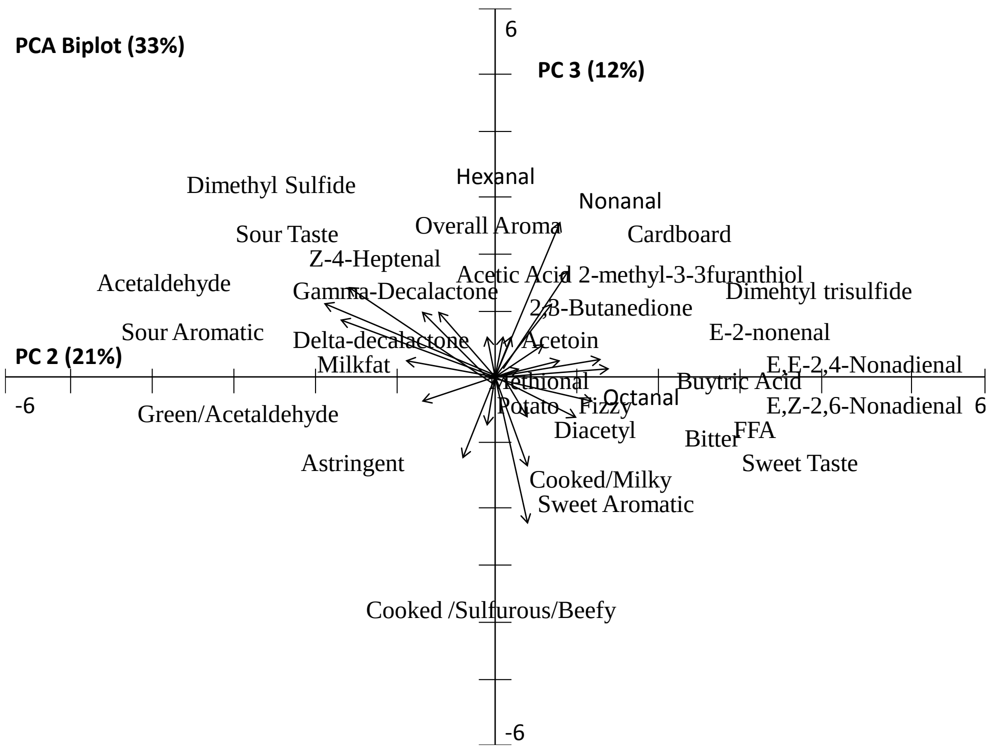

Figure 8. Principle Component Analysis biplot (PC 2 and 3) of sensory flavor attributes and instrumental data of sour creams.

Table 11. Correlations between sensory flavor attributes and selected volatile compounds.

Variables	Overall aroma	Sour aromatic	sweet aromatic	Green/acetaldehyde	Cooked/milky	Cooked/sulfurous/beefy	Diacetyl
Gamma-decalactone	0.51	**0.74**	-0.38	**0.72**	**-0.60**	-0.28	-0.26
2,3Butanedione	-0.30	-0.24	-0.14	-0.29	0.52	-0.53	**0.59**
Acetoin	-0.33	-0.18	-0.32	-0.29	0.40	-0.51	0.48
delta decalactone	0.57	0.55	-0.37	**0.77**	-0.56	-0.28	-0.08
methional	0.33	0.15	-0.14	**0.76**	-0.39	-0.36	-0.50
2-methyl-3-furanthiol	0.01	0.11	-0.17	-0.04	0.24	-0.48	**0.75**
dimethyl trisulfide	0.37	-0.04	-0.36	0.41	-0.28	-0.23	-0.04
E-2-nonenal	**0.66**	-0.04	-0.28	**0.62**	**-0.60**	-0.10	-0.27
hexanal	-0.32	-0.17	-0.30	-0.26	0.36	-0.49	0.41
octanal	-0.07	0.03	-0.29	-0.26	-0.02	0.20	0.02
nonanal	0.13	0.04	**-0.70**	0.09	-0.19	-0.32	0.40
acetic acid	**-0.59**	-0.35	-0.20	-0.36	**0.62**	-0.53	0.45
butyric acid	0.41	0.10	-0.32	0.34	-0.26	-0.15	0.04
dimethyl sulfide	0.17	**0.62**	-0.09	**0.59**	-0.09	-0.39	0.03
z4heptenal	0.09	0.46	-0.41	0.08	-0.22	-0.04	0.29
E,Z-2,6-Nonadienal	-0.24	-0.30	-0.01	-0.08	0.21	-0.39	0.44
E,E-2,4-Nonadienal	**0.59**	-0.12	-0.08	0.40	-0.26	-0.25	0.25
Acetaldehyde	0.36	**0.61**	-0.42	**0.62**	-0.46	-0.27	-0.03

Numbers in **bold** represent a significant correlation (P<0.05)

Table 11 continued. Correlations between sensory flavor attributes and selected volatile compounds.

Variables	Milkfat	FFA	Potato	Cardboard	Astringent	Fizzy	Sweet taste	Sour taste	Bitter
Gamma-decalactone	-0.07	0.01	0.22	0.03	0.45	-0.07	-0.18	**0.76**	-0.33
2,3-Butanedione	0.20	-0.24	-0.02	0.51	-0.50	-0.25	-0.38	-0.04	0.47
Acetoin	0.18	-0.16	0.06	0.38	-0.43	-0.16	-0.40	0.02	0.26
delta decalactone	-0.05	0.41	0.19	0.05	0.34	0.23	-0.09	**0.67**	-0.19
methional	-0.10	-0.17	**0.85**	0.28	0.32	0.02	0.16	0.54	-0.23
2-methyl-3-furanthiol	0.22	-0.17	-0.18	0.58	-0.43	-0.31	-0.49	0.23	**0.61**
dimethyl trisulfide	-0.33	0.10	0.56	**0.60**	0.08	0.03	0.41	0.37	0.12
E-2-nonenal	-0.38	0.36	0.34	0.41	0.11	0.14	0.31	0.22	0.00
hexanal	0.21	-0.21	0.11	0.37	-0.45	-0.20	-0.42	0.00	0.21
octanal	-0.20	**0.63**	-0.05	-0.21	0.22	0.45	**0.63**	0.19	-0.27
nonanal	-0.52	0.00	-0.19	0.41	0.24	-0.22	-0.38	0.17	0.45
acetic acid	0.36	-0.11	0.23	0.16	-0.44	0.15	-0.32	-0.05	0.11
butyric acid	-0.11	**0.85**	0.10	0.18	0.04	0.28	0.32	0.30	-0.01
dimethyl sulfide	0.31	-0.31	0.30	0.08	0.17	-0.35	-0.54	0.52	-0.03
z4heptenal	-0.05	-0.14	0.05	0.22	0.11	-0.45	-0.26	0.43	0.23
E,Z-2,6-Nonadienal	0.09	-0.22	0.07	0.20	-0.16	0.53	-0.05	0.19	0.22
E,E-2,4-Nonadienal	-0.22	0.01	0.12	**0.81**	-0.29	-0.04	0.18	0.18	0.46
Acetaldehyde	0.17	0.27	0.24	-0.01	0.18	-0.15	-0.45	**0.58**	-0.13

Numbers in **bold** represent a significant correlation ($P<0.05$)