

## ABSTRACT

HANKS, TREVOR. The Impact of Fat Content and Water Addition on Physical and Sensory Properties of Milk. (Under the direction of Dr. MaryAnne Drake).

The demand for milk-based protein beverages continues to increase. Maintaining a desirable milky flavor in these beverages is a critical need for consumer acceptance. However, there is no previous research on how water addition and milk fat affect sensory and physical properties of fluid milk. In this study, tasting and visual Best Estimate Thresholds of added water in standardized skim, 2%, 4%, 6%, 8%, and 10% fat milk were evaluated using the ASTM ascending forced choice method. Chemical composition, particle size, freezing point, color, viscosity, and descriptive sensory properties of milk at all water addition levels were also evaluated. Water addition had a lower detection threshold by tasting compared to visual evaluation, and it was detected mainly by loss of basic tastes. The oral detection threshold of water addition decreased from skim to 6% milkfat (11.9% to 5.2%) then increased from 6% to 10% milkfat (5.2% to 10.0%). The visual detection threshold of water addition increased from skim to 10% milkfat (21.9% to 43.0%). Freezing point, b\*-value, and apparent viscosity changed linearly with increased water addition and increased milk fat. This study provides valuable information to the industry to help manufacture high quality fluid milk and milk-based beverages that can meet consumer needs.

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The Impact of Fat Content and Water Addition on Physical and Sensory Properties of Milk

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  
2026

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## **BIOGRAPHY**

Trevor Hanks was raised in Charlotte, NC. After graduating high school, Trevor attended Brigham Young University – Idaho located in Rexburg, Idaho. Trevor Graduated with a B.S. in Food Science in 2022. After graduating, Trevor joined the lab of Dr. MaryAnne Drake to study dairy processing and production. During his time there, he gained training and experience in operating small scale pilot facilities, small scale dairy and ice cream production facilities, and the use of various types of pasteurization and filtration equipment. Trevor looks forward to taking his knowledge and experience and applying it to the food industry.

## **AUTHORSHIP STATEMENT**

The Thesis submitted is comprised of two chapters.

The first chapter is the literature review for “The Impact of Fat Content and Water Addition on Physical and Sensory Properties of Milk.” The chapter was written by Trevor Hanks and co-authored by Dr. MaryAnne Drake with edits from Dr. Tess Liu.

The second chapter is the article “The Impact of Fat Content and Water Addition on Physical and Sensory Properties of Milk.” The experiment was designed by Dr. MaryAnne Drake and Dr. David Barbano. Trevor Hanks was responsible for the execution of the experiment and organization of the data collected with assistance and oversight from Dr. Tess Liu and Dr. MaryAnne Drake. Dr. Barbano conducted chemical and physical composition on base samples. The analysis of the data collected was performed by Dr. Tess Liu. Trevor Hanks wrote the second chapter with assistance from Tess Liu. Dr. Drake edited the chapter.

No Large Language Models (LLM) or Generative Artificial Intelligence (GAI) was used at any point during the experimentation or authorship of this thesis.

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**CHAPTER 1:**  
**LITERATURE REVIEW**

## **INTRODUCTION**

Milk, one of the most widely consumed food products, must meet rigorous quality standards to ensure it is safe, wholesome, and fit for consumption. From the moment it is collected on the farm to the time it reaches consumer households, milk undergoes a series of quality assurance processes. These include testing for contaminants, monitoring temperature controls, verifying nutritional content, and adhering to hygiene protocols. Quality assurance in milk production is not just about maintaining taste and freshness—it is a critical safeguard for public health, consumer trust, and the integrity of the dairy industry.

Quality control (QC) in fluid milk processing is focused on maintaining standards for safety, composition and sensory properties. The implementation of a quality control program ensures the safety, consistency, and appeal of fluid milk. When it comes to ensuring the quality of a product, safety is crucial, but it is equally important that the product tastes good and is consistent with consumer expectations. Ultimately, consumers make repeat purchase decisions based on how much they like the taste of the product. Thus, understanding the sensory properties of foods and ensuring the product meets these expectations during production are essential. Quality of fluid milk is ensured through the Food and Drug Administration (FDA) Grade “A” Pasteurized Milk Ordinance (PMO).

## **WHAT IS THE PMO?**

In the dairy production industry, there are two places that hold the majority of the guidelines specific for milk production, the code of federal regulations (CFR) and the PMO. The CFR is a collection of rulings made by the United States Government with specific sections focused on food, with title 21 being specific to food and drugs. The PMO is a set of minimum

standards for the production and processing of Grade A milk. The PMO was first started as the Standard Milk Ordinance in 1924 and was developed by the United States Public Health Service (FDA, 2024). The PMO is a voluntary program designed to promote uniform milk production in the United States. The PMO is updated by the FDA and National Conference on Interstate Milk Shipments (NCIMS) every two years to improve the quality and safety of all milk-based products. Approximately 99% of the milk produced in the United States follows these standards (Ma et al., 2015). The advantage of using this voluntary program is that milk being produced can be certified as grade “A” and then transported across state lines to other facilities with the understanding that the product has the same quality requirements.

## **HOW IS MILK PROCESSED?**

### *What is Milk?*

Milk is a lacteal secretion obtained by the milking of one or more cows (21 CFR 131.110(a)). Over time, bovine milk has increasingly been used for human consumption and nutrition. When milk is produced for human consumption, it is collected in a bulk holding tank and cooled to less than 4°C in less than 4 hours. The bulk tank is cleaned and sanitized regularly to maintain proper sanitation and minimize microbial contamination. Collected bulk tank milk from a farm is then transferred to a milk plant for processing.

### *Raw Milk*

For most operations, the milk is pumped into a refrigerated milk tank truck for transportation and delivery. A milk tank truck is defined as a vehicle comprising a truck with a large holding tank mounted on the back. When the tanker truck arrives at the milk plant, the raw

milk is checked for quality and safety. The milk is tested with respect to four categories: temperature, bacterial limits, antibiotics, and somatic cell count (FDA, 2023). For the temperature of raw milk, the regulations address the cooling of milk after milking. The milk must be cooled to below 45°F (7°C) within 4 hours of milking. The bacteria count for raw milk produced from one source should be less than 100,000 CFU per mL of milk. For commingled milk from multiple different sources, it should be less than 300,000 CFU per mL of milk.

### *Raw Quality Testing*

Milk is also tested for antibiotic residues and somatic cell count (SCC). Milk for the commercial supply chain should not test positive for any antibiotic residue and SCC should be less than 750,000 (Barbano et al., 2006). A high SCC is an indicator that the cow is sick and fighting off an infection. The most likely cause of a high SCC is mastitis which is inflammation of the mammary gland caused by a bacterial infection (Harjanti and Sambodho, 2020). When fighting the infection, the body sends specialized cells to fight the infection. This results in the milk of the animal having cells meant to fight infection in the milk and is what is generally referred to as a high SCC. A high SCC in fluid milk can cause a variety of problems including off flavors and an earlier onset of spoilage (Ma et al., 2000).

### *Milk Production*

After these quality tests have been completed and the milk is determined safe and of good quality, the milk is pumped out of the milk tank truck and stored in a cooled tank (an onsite temperature-controlled bulk tank). When production begins, the milk is separated into cream and skimmed milk. Cream is the liquid separated from milk that is high in fat (21 CFR 131.3(a)). Skimmed milk is milk that is not greater than 0.5% milk fat (21 CFR 131.143). After the

separation of cream and skim milk, the respective products are stored in separate tanks. The product streams can then be blended for different products.

### *Standardization*

Low fat milk is milk produced with a milkfat of 0.5%, 1%, 1.5%, and 2% with the most common being 1 or 2% (21 CFR 131.135). Whole milk is defined as not less than 3.25% milkfat (21 CFR 131.110(a)). Half-and-half is a mixture of milk and cream that is between 10.5% and 18.0% milkfat (21 CFR 131.180(a)). Light cream is cream which is less than 18.0% and 30.0% milkfat (21 CFR 131.155(a)). Heavy cream is cream that is less than 36.0% milkfat (21 CFR 131.150(a)).

The amount of milkfat to be added to a desired milkfat content is usually calculated using a Pearson square calculation. The Pearson square calculation involves drawing a square and assigning values to each corner and the target is where the diagonals from the corners meet in the center of the square (Tetra Pak, 2025). To better explain this calculation, we will walk through the standardization of cream and skim to make 2% milk. Our starting values are cream that is 40.0% milkfat, skim that is 0.05% milkfat, and our target that is 2.0% milkfat. The first step is to find the ratio of needed components. For cream, subtract 0.05 from 2.0 to get 1.95 parts of cream in the mixture. For skim, subtract 2.0 from 40.0 to get 38.0 parts of skim in the mixture. The ratio of cream to skim is 1.95 parts cream to 38.0 parts skim. To calculate the percentage of each component of the mixture, divide the number of parts of the component by the total amount of parts and then multiply by 100. This means that for 2% milk, 4.88% of the mixture is cream and 95.12% of the mixture is skim. This percentage can then be used to calculate exact weights needed to make a target amount of 2% milk.

### *Vitamin Fortification*

Once the milk is standardized, vitamin mix may be added (vitamins A and D) for skim and low-fat milk; vitamin D only for whole milk. Added vitamin A cannot be less than 2000 International Units (IU) per quart of milk and added vitamin D should be at 400 IU per quart of milk (21CFR 131.110). Higher fat products (half and half, cream) are not vitamin fortified. Milk is fortified with vitamins to promote better nutrition in children and reduce vitamin A and D deficiency related illnesses (Yeh et al., 2017). Vitamin D aids in the absorption of calcium in the body and helps to strengthen bones (Ceglia et al., 2009). Vitamin A helps to improve eyesight and vision at night. For fortification of fluid milk vitamin D is added at all levels between skim and whole to provide better nutrition as it is not as present in milk. Vitamin A is only added to milk that has a reduction in fat due to its natural occurrence in milkfat. Vitamin A is not added to whole milk as it is not needed as the milkfat is still present but as the milkfat is removed Vitamin A needs to be supplemented due to the removal of the fat. The fortification of Vitamin D began in the 1930s to better the health of children who were at risk of deficiencies by adding it to milk (Holick, 2023). The addition of Vitamin A followed in the 1940s. (Bonrath et al., 2023).

### *Heat Treatment*

The standardized milk/cream is then pasteurized using specific time and temperature combinations. The majority of commercial milk is pasteurized using a plate heat exchanger. A plate heat exchanger is a stack of plates with small channels that allow for better heat distribution. These exchangers work with both heating and cooling. The design usually utilizes a counter current flow. This means that the product flows in one direction but the other side of the

plate usually uses a heating or cooling fluid in the opposite direction for better heating distribution. The standard configuration of the stack is divided up into three distinct sections: heating, cooling, and regeneration. In the heating section the milk is heated to pasteurization temperature using hot water and held for the specified amount of time before moving on to the next step. The tubes in the holding section are designed based on the flowrate and the distance needed to reach the desired holding time. If the milk does not reach pasteurization temperature, the valves do not divert it until it reaches that time for that temperature. The cooling section uses a cooling fluid such as glycol to reduce the hot milk from pasteurization temperature to refrigeration temperatures. The regeneration section uses the pasteurized product as the heat source to warm the raw milk from cold holding temperature before it enters the next section. This process is highly efficient as it uses the pasteurized product to heat the raw product and the raw product to cool the pasteurized product. The process can be 90-95% efficient. Throughout this process, the pressure is controlled to ensure no cross contamination occurs. While the plates in the pasteurizer are made of metal, perforations may occur. To control for this, more pressure is applied to the pasteurized side of the plates so if milk passes through the holes in the plate in the regen section of the plates, the milk will flow from pasteurized to raw (high pressure to low). This process ensures that pasteurized milk is not contaminated by raw milk ((Tetra Pak, 2025)).

The standard heat treatment in the US fluid milk industry is referred to as High Temperature Short Time (HTST) pasteurization. HTST consists of heating milk (skim through whole) to 161°F (72°C) and holding the milk at that temperature for at least 15 seconds before rapidly cooling (PMO, 2023). For milk with higher fat of 10.0% or greater, pasteurization temperatures must be 5°F higher (166°F or 74.5°C) (FDA, 2023). This higher temperature also applies to additions in the milk product. Ice cream mix, for example, has higher fat but also has

more added sugar. These additions raise the amount of total solids and change the heat transfer of the product. The shelf life of HTST milk is approximately 14-21 days (Lee et al., 2017). For milk with a longer shelf life (also called extended shelf life (ESL) milk), a higher temperature and shorter time combination is used. This process is referred to as ultra pasteurization (UP) or ultra high temperature (UHT) pasteurization. Ultra pasteurization is when milk is heat treated above 280°F for at least 2 seconds (21 CFR 131.3(c); FDA, 2023). Ultra pasteurized milk has a refrigerated shelf life of 65-75 days (Lee et al., 2017). If an aseptic filler is added to a UP line, the milk is shelf stable and can be stored for up to 6 months at room temperature (Cadwallader et al., 2025).

Ultra pasteurization can be achieved using various heating methods. One method is direct steam injection which uses steam to heat the milk. This requires a vacuum chamber to flash off the steam and avoid water addition to the milk (Roberts and Dill, 1962). Indirect heating uses a tube in shell configuration which heats the milk rapidly. A new method of higher heat pasteurization is steam infusion. By this method, milk is added to steam rather than steam injected into milk (steam injection).

### *Pasteurized Quality Checks*

Once the milk has been pasteurized and cooled (or filled and stored at 21C for aseptic product), several safety and quality checks must be done before the product is released into the supply chain. The required checks for pasteurized milk or milk products detailed in the PMO are temperature, bacterial limits, coliform, and phosphatase (FDA, 2023). The temperature of the milk should stay below 45°F unless it is a shelf stable (aseptic) product. For bacterial testing, microbial counts should be less than 20,000 CFU per mL of milk. For coliform testing, there

should be less than 10 CFU per mL of milk. Alkaline phosphatase is an enzyme naturally present in raw bovine milk and it is inactivated by the heat procedures applied for milk pasteurization. Thus, alkaline phosphatase activity is used as an indicator of adequate pasteurization. Phosphatase testing should show that the milk is less than 350 milliunits per liter of fluid milk.

## **FLUID MILK QUALITY ASSURANCE**

### *Fat Analysis*

The composition of milk is also evaluated for quality assurance. Compositional analysis of milk includes tests for water adulteration, total solids, fat and protein. For analysis of the fat in milk, there are several different methods. Which method is selected is based on time or accuracy needed. The Babcock, Gerber and Mojonnier methods use chemicals to release or extract the fat in milk in order to measure it. The Babcock method uses sulfuric acid digestion of milk. Following acid digestion, the fat is then centrifuged and measured volumetrically using a Babcock bottle designed for this specific purpose (AOAC method 989.04). The Gerber method is similar but differs in that amyl alcohol is added alongside the sulfuric acid and the extracted fat volume is measured in a Gerber bottle instead of a Babcock bottle (AOAC Method 2000.18). The Babcock method can take around 45 minutes to complete where the Gerber method is faster (Nielsen, 2017). The Mojonnier method also organic solvent extraction to separate the fat from the milk but the separated fat is measured by weight rather than volumetrically. This method takes longer but is generally regarded as more accurate. An indirect method, like MID Infrared (MIR) or near infra-red (NIR) can also be used. These methods take far less time but require regular calibration to reference (direct extraction) methods (Kornacki et al., 2024).

## *Protein Analysis*

For dairy protein analysis, the Kjeldahl method remains the gold standard. The method is labor intensive but very accurate. The Kjeldahl method measures the amount of nitrogen which then can be used to calculate the amount of protein of a sample. To perform the analysis, the first step is to add sulfuric acid and other compounds to the sample to convert the protein into ammonium sulfate. Once the sample is cooled, sodium hydroxide is added to release the ammonia from the compound. The ammonia is then titrated with an acid to calculate the amount of total nitrogen in the sample (AOAC Method 991.20). The nitrogen is then converted to protein using a correction factor generated from N per weight of protein or from the known amino acid sequence of the major protein. The Kjeldahl method is used as calibration for other methods as well as to check accuracy or reliability of rapid tests (Lynch and Barbano, 1999). The other direct method is the Dumas method which measures N by combustion. Dye binding and colorimetric methods can also be used for milk protein evaluation. With these methods, protein concentration is determined using a standard curve generated from known concentrations of protein. These approaches, like other indirect methods, should be calibrated to a direct N measurement for accuracy (Hueso et al., 2022). Both MIR and NIR can also be used for rapid assessment of protein in a sample.

## *Solids*

Milk solids are measured gravimetrically. Oven drying of a known weight followed by measuring the solids left after evaporation is the approach. The method has been adapted to more speed in a CEM which includes microwave evaporation of moisture. Fat content can be subtracted from the final amount to obtain milk solids not fat. Solids can also be estimated by

specific gravity using a lactometer (Lampert, 1961). A lactometer is a hydrometer that has been calibrated with units for the density (specific gravity) of milk. The Golding bead test is another older rapid test that was applied for solids not fat analysis of milk. Milk is placed in a container into which 10 plastic beads with different specific gravity are placed. The mixture is shaken gently and the number of beads that sink versus those that float are counted to determine solids not fat (Erb et al., 1960; Golding, 1964).

### *Water Detection*

Water is the final compositional element that is commonly applied to milk quality assurance. Milk is approximately 85 to 88% water and production and processing steps (which apply water for cleaning) can lead to accidental adulteration with water. A total solids test can indirectly be used to evaluate the possibility of added water but is not a direct measurement. The best way to check for water addition in milk is to test the freezing point. The origin of fluid milk composition is the blood and due to the osmotic pressure of the blood of the animal, a lot of the components in milk stay consistent across all milk of the species (Tetra Pak, 2023). This means that while the freezing point of milk has some variation, it is generally between  $-0.54^{\circ}\text{C}$  and  $-0.59^{\circ}\text{C}$  (Sato et al., 1957); Dairy processing handbook). Lactose, minerals, and water-soluble components contribute to the freezing point of milk. A cryoscope measures the freezing point of milk compared to that of pure water and is used widely in industry to rapidly evaluate milk for the presence of water. The addition of water increases the freezing point of milk (Tetra Pak, 2025). In contrast, hydrolysis of lactose will decrease the freezing point of milk (Chen et al., 1981). As such, a cryoscope can be used to rapidly assess water adulteration of fluid milk in a processing facility, but it can also be used to follow enzymatic hydrolysis of lactose in fluid milk and to monitor removal of lactose by UF and MF in a filtration process.

Milk freezing point is measured in C and in degrees Hortvet. Hortvet first published his method in 1921 in an effort to standardize the freezing point of milk (Shipe, 1959). The Hortvet method is used to determine the calibration of cryoscopes in the official method to determine the addition of water in milk (AOAC 961.07). The freezing point of milk is generally checked when the milk is received into the processing facility (Tetra Pak, 2025). To convert Hortvet units to degrees Celsius, the formula is  $C = 0.9656 \text{ Hortvet}$ .

## **Sensory Analysis of Milk Flavor**

### *The Flavor of Milk*

An important factor for the consumption of fluid milk is its flavor. Milk has a mild flavor with a slight sweetness (Clark et al., 2023). The main component of sweetness in milk is lactose. Lactose is a disaccharide made up of glucose and galactose and is the most abundant carbohydrate in milk. Lactose is less sweet is 30 times less sweet than sucrose (Tetra Pak, 2025). The flavor of milk also changes based on the processing techniques used. When pasteurized, the heat treatment of the milk imparts a cooked flavor due to Maillard reactions. The quality and intensity of cooked flavor is impacted by the type of heat treatment. Ultra pasteurization imparts a more intense cooked flavor than traditional high temperature short time (HTST) pasteurization (Lee et al., 2017). Ultra pasteurization with aseptic fill imparts an additional cooked flavor since aseptic milk is not immediately cooked to less than 4C upon filling. Aseptic milk is filled and cooled to ambient temperature which imparts an additional cooked flavor (Cadwallader et al., 2025). Milkfat also contributes to the flavor of milk ((McCarthy et al., 2017)). Milk is also susceptible to off-flavors due to flavor migration from the surrounding storage environment or

from the package itself (Sipple et al., 2021; Cadwallader et al., 2023). Further, there are many steps in fluid milk receipt and processing that can accidentally introduce sensory quality issues.

There are a wide variety of sensory tools to assess sensory quality. The simplest tools for quality screening are traditional defect based sensory tests. These are comprised of traditional flavor defects that can occur to milk due to cow feed, handling, and processing (Thompson et al., 2007) and include a wide variety of sensory defects such as flat (added water), sanitizer, feed, free fatty acids, bitter, and lacks freshness. These sensory defects are useful for all plant employees to be familiar with as deviations in milk aroma/flavor can be detected before they become a larger scale problem for the QA lab to address. These defects can be quickly and objectively documented with a simple ballot that determines presence or absence and require minimal training and maintenance with plant employees.

### *Difference Testing*

More advanced objective sensory tests include differences tests and descriptive analysis. Difference tests are used to determine if two samples are different while descriptive analysis (DA) utilizes a small group (6-10) of trained individuals to document attributes and attribute intensities (Drake et al., 2023). DA also can determine the degree of difference among samples if a reference control product is provided. Difference tests can be utilized with untrained consumers and generally require at least 20 individuals while DA requires training to be effective.

Difference testing is used to determine the difference between two or more samples. The main tests used for difference testing are triangle, duo-trio, paired comparison, and tetrad. For triangle testing, panelists are given three samples and of those samples two of the three are the same while the other is different. The instruction given is to pick the sample that is different from

the rest. For duo-trio testing, panelists will receive a reference sample as well as two samples with three digit codes. The panelist is asked which sample matches the reference. Tetrad tests give the panelists four samples and ask them to separate the samples into two groups of similar samples. These three difference tests are non-directional meaning that panelists are asked to identify a difference and the nature of the difference remains unknown. The final difference test, paired comparison testing, also known as Alternative Forced Choice (AFC), is a directional test. Two or more samples are presented and panelists are asked which sample has more of a single specified attribute. Threshold tests determine sensory detection thresholds (orthonasal, retronasal or basic tastes). A sensory threshold can be defined as the concentration above which an individual with an average sensory ability would detect a signal and below which they would not. The most common method to determine thresholds is the ASTM E678 procedure which is a forced choice ascending concentration series. Panelists (typically at least 30) are presented with a series of triangle tests, each with a geometric increase in a sensory signal. The standard procedure is a 5-series or 7-series. The best estimate threshold (BET) for each individual is calculated based on the signal concentration at which they consistently could detect a signal.

### *Descriptive Analysis*

Descriptive analysis (DA) is a method of evaluating food using highly trained human subjects in a quantitative way similar to the way a machine would to document the objective sensory attributes of a food product. The quantitative aspect of DA is the use of intensity scales. DA also uses the qualitative aspects by using different descriptive attributes such as flavor, color, and texture. DA requires a panel of at least 7 people who have had extensive training in how to evaluate and determine differences between the products. There are two fundamental types of descriptive analysis, quantitative descriptive analysis (QDA) and the Spectrum method. Both

techniques emerged in the 1970's and are still in use today. Hybrid DA (DA that involves methods from both QDA and Spectrum is also in use today.

QDA was developed by Herb Stone (Tragon Corp) in 1974. This DA training approach is characterized by a product specific line scale and consumer-focused descriptors. The Spectrum method was developed by Gail Vance Civille (Sensory Spectrum) in 1974. This method is characterized by one universal intensity scale by which all products are scored. The sensory language can be consumer-focused or analytical in nature. Both methods require hours of training. The QDA method, using a product specific scale, generally requires less training than the Spectrum method (Murray et al., 2001; Drake et al., 2023). The advantage of the more training-intensive Spectrum method is that the same intensity scale is applied to all products. As such, one panel can readily evaluate multiple product categories – and attribute intensities can be compared across product categories. Spectrum panelists with universal intensity scale which is anchored with basic taste solutions are also less prone to panel drift compared with QDA or hybrid panels. Spectrum panelists typically use chemical references to evaluate the product. For example, a QDA panel may use the term buttery to describe a product flavor but a Spectrum panel would use diacetyl as the specific attribute. This allows the panel to base their evaluation using the chemical compound to determine its specific intensity. Chemical compounds may be used to create standard intensities as guidelines to aid in precise evaluation.

### *Consumer Preference Testing*

There are also a wide array of subjective sensory tests that are focused on measurement of consumer responses to foods and products. These include qualitative tests such as focus groups and interviews and quantitative tests such as a traditional acceptance tests and surveys.

Focus groups use a trained moderator to facilitate a group discussion with a group of 8-12 consumers (Meilgaard et al., 2016). Facilitators use group discussion to generate feedback for the product or product category. Focus groups are often video and voice recorded with the consent of the panelists so details and quotations can be extracted as stated. A similar process is applied with interviews. The purpose of these tests is to gain qualitative insights and/or details that might not be readily obtained from a survey or acceptance test.

Traditional quantitative consumer testing can be divided into different categories based on the method of testing. Product concepts, purchase intent and consumer attitudes can be evaluated by large numbers of consumers in an online survey format. Surveys are often used by companies to understand how consumers feel about a product or product concept. These tests typically include greater than 200 responses and are typically target specific segments of the market. These surveys generally try to target populations typically associated with the product and are users of that product. Due to the internet, companies can easily reach more people and areas of the market than ever before.

Alternately, traditional acceptance testing involves consumers directly evaluating products for degree of liking (DOL) and other attributes using numerical scales. This process is often referred to as Central Location Testing (CLT). Degree of liking is scaled using a 9-point hedonic scale with dislike extremely being a one, five being the mid-point, and like extremely being a nine. Other questions that are often scaled by consumers in acceptance tests include Just About Right (JAR), and Check all That Apply (CATA). JAR scales are a five-point scale with one being much too little, three being just about right, and five being much too much. This scale is often used to guide product formulations as consumers can answer JAR questions on well-understood product attributes such as sweetness, saltiness, firmness, etc. CATA questions ask

panelists to check all of the attributes that apply to the sample from a pre-determined list of attributes. This question can also be used to guide product formulations and to characterize how consumers perceive differences among products.

### *Conclusion*

Consumers today have many food choices, both dairy and plant. Fluid milk and dairy-based protein beverages provide a unique nutrition source and desirable flavor. The PMO places a limit of 3% added water to raw milk which is monitored by freezing point (cryoscope). Additional water can be inadvertently added to milk and milk ingredients during processing and can be monitored by cryoscope or by solids analysis. Previous studies have not determined the amount of added water that can be detected by humans nor the role of fat content on water sensory detection threshold. Fluid dairy products are frequently processed by direct steam injection ultra pasteurization where steam (water) is added to the product for rapid high heat transfer. Recent work has also demonstrated when lactose is removed from milk based beverages, there is a loss of milky flavor, even when fat and protein content are increased ((Hernandez et al., 2024); (Truong et al., 2024)) Understanding the non-fat, non-protein component of milk and its correlation with the loss of milky flavor when low molecular weight soluble components are removed from milk has importance in how to deliver flavor in dairy beverages where lactose is removed. Further, the source of desirable milky flavor (water phase vs fat phase) remains controversial. Our proposed work will determine sensory detection thresholds for fluid milk with variable fat content and the impact of water detection on sensory properties.

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## **CHAPTER 2:**

### **The Impact of Fat Content and Water Addition on Physical and Sensory Properties of Milk**

## **ABSTRACT**

The demand for milk-based protein beverages continues to increase. Maintaining a desirable milky flavor in these beverages is a critical need for consumer acceptance. However, there is no previous research on how water addition and milk fat affect sensory and physical properties of fluid milk. In this study, tasting and visual Best Estimate Thresholds of added water in standardized skim, 2%, 4%, 6%, 8%, and 10% fat milk were evaluated using the ASTM ascending forced choice method. Chemical composition, particle size, freezing point, color, viscosity, and descriptive sensory properties of these milk samples at all water addition levels were also evaluated. Water addition had a lower detection threshold by tasting compared to visual evaluation, and it was detected mainly by loss of basic tastes. The oral detection threshold of water addition decreased from skim to 6% milkfat (11.9% to 5.2%) then increased from 6% to 10% milkfat (5.2% to 10.0%). The visual detection threshold of water addition increased from skim to 10% milkfat (21.9% to 43.0%). Freezing point, b\*-value, and apparent viscosity changed linearly with increased water addition and increased milk fat. This study provides valuable information to the industry to help manufacture high quality fluid milk and milk-based beverages that can meet consumer needs.

## **INTRODUCTION**

Milk, one of the most widely consumed food products, must meet rigorous quality standards to ensure it is safe, wholesome, and fit for consumption. From the moment it is collected on the farm to the time it reaches consumer households, milk undergoes a series of quality assurance processes. These include testing for contaminants, monitoring temperature controls, verifying nutritional content, and adhering to hygiene protocols. Quality assurance in milk production is not just about maintaining taste and freshness—it is a critical safeguard for

public health, consumer trust, and the integrity of the dairy industry. Ultimately, consumers make repeat purchase decisions based on how much they like the taste of a product (Harwood & Drake, 2019; Liu et al., 2021). Thus, understanding the sensory properties of foods and ensuring a product meets consumer expectations is essential.

The composition of milk is one of the parameters evaluated for quality assurance. Compositional analysis of milk includes tests for water adulteration, total solids, fat and protein. Water adulteration is a major concern in fluid milk. Milk is approximately 85 to 88% water and production and processing steps (which apply water for cleaning) can lead to accidental adulteration with water. In addition, water adulteration is often used for the purpose of monetary gain. Currently, the widely used method to check for water addition in milk is to test the freezing point using a cryoscope when the milk is received into the processing facility (Shipe, 1959). A cryoscope measures the freezing point of milk compared to that of pure water and is used widely in industry to rapidly evaluate milk for the presence of water. Generally, the freezing point of milk is between  $-0.54^{\circ}\text{C}$  and  $-0.59^{\circ}\text{C}$  due to the osmotic pressure of the cow's blood. The addition of water increases the freezing point of milk (Barbano et al., 1983). A cryoscope can detect as little as 0.5% of water added to milk (Nussbaum, 1944). Conversely, lactose hydrolysis can decrease the freezing point and lactose hydrolysis of milk can be readily monitored by freezing point (cryoscope) (Baer et al., 1980; Chen et al., 1981).

Besides adulteration of fluid milk, characterization of water addition and its role on milk flavor is crucial for milk-based beverages. Removal of lactose by ultrafiltration plus diafiltration (UF-DF) is an alternative to lactose hydrolysis to make lactose free milk. With UF-DF, the nonfat, non-protein portion of milk is replaced by DF water at constant protein, and the sensory profile of the resulting product decreases as lactose and soluble milk minerals are removed and

replaced with water (Hernandez et al., 2024). To our knowledge, there are no published studies on the sensory thresholds for water addition to milk. Knowledge of the actual sensory detection thresholds for water addition to fluid milk and how milkfat may or may not impact sensory thresholds provides baseline information on the sensory impact of water replacement of the UF permeate portion of milk and will assist optimization of sensory properties of milk-based beverages with lactose removed by UF-DF. Therefore, the objective of this study was to determine the impact of water addition on physical and sensory properties of milk at different fat levels. The range of fat concentrations evaluated was from skim (less than 0.5% milk fat) to half and half (10.0% milk fat) with each interval being 2% milk fat.

## **MATERIALS AND METHODS**

### *Experimental Design*

Pasteurized homogenized skim and 12% fat milk were obtained from the North Carolina State University (NCSU) Dairy Enterprise System and were used to standardize milk to six fat levels (0, 2, 4, 6, 8, and 10% fat). Particle size, fat globule size, and composition analysis were conducted for the standardized milk at all six fat levels. Tasting and visual Best Estimate Thresholds (BET) of added water in standardized skim, 2%, 4%, 6%, 8%, and 10% fat milk were evaluated using the ASTM ascending forced choice method procedure E679-04 (ASTM 2011) (Liu et al., 2023) with a step factor of 1.5. For each water addition evaluated within a milk fat content for tasting BET, composition, apparent viscosity, instrumental color, and freezing point were measured. For each water addition concentration evaluated within a milk fat content for visual BET, composition and instrumental color were measured. A trained panel (n=7) evaluated

milk with water added at 1 step factor above, 1 step factor below, and at the tasting BET value to characterize the sensory impact of water addition. The entire experiment was replicated twice.

All sensory testing was conducted in compliance with NCSU IRB regulations.

### *Milk Standardization*

Skim and 12% milk were produced by the NCSU Dairy Enterprise System. The fat content of the skim and 12% milk were measured by Fourier-Transform Infrared Spectroscopy (FTIR) (LactoScope FTA, Perkin Elmer, Waltham, MA). These milks were used to standardize milk to 6 fat levels: skim, 2%, 4%, 6%, 8%, and 10%. The amount of skim and 12% milk used were calculated using the Pearson square formula and then weighed using a calibrated scale (Model ICS4x9-1, Metler Toledo, Columbus, Ohio).

### **Analysis Methods**

#### Chemical Analyses

The standardized milk at skim, 2%, 4%, 6%, 8%, and 10% milk fat for chemical analysis were preserved with the addition of thimerosal (Thermo Fisher Scientific, Ward Hill, MA) at a rate of 1 mL of 10% (w/v) aqueous thimerosal per 1000 g test material. After the addition of thimerosal, the preserved beverages were portioned into lidded 89 mL vials (capitol vial polypropylene flip top 90 mL, catalogue # 1224V27, Manufacture # 03CL, Thermo Scientific, Waltham, MA) and stored at 4 °C until proximate analysis.

The standardized milks were analyzed in duplicate for total solids (TS), fat, total nitrogen (TN), and nonprotein nitrogen (NPN) content using forced-air oven drying (AOAC, 2019; method 990.20), ether extraction (AOAC, 2019; method 989.05), Kjeldahl (AOAC, 2019; method 991.20), and Kjeldahl (AOAC, 2019; method 991.21), respectively. The non-casein nitrogen (NCN) content

of retentates was determined using Kjeldahl (AOAC, 2019; method 998.05). The total protein (TP) was calculated by subtracting NPN from TN and multiplying by 6.38; casein nitrogen (CN) was calculated by subtracting the NCN from TN and multiplying by 6.38; and whey protein content was calculated by subtracting NPN from NCN and multiplying by 6.38.

### Particle Size Analysis

The standardized milks were analyzed using a Malvern Mastersizer 2000 (Malvern Instruments Ltd., Enigma Business Park, Malvern, Worcestershire, UK, software version 5.4) as described by Di Marzo et al. (2016). Refractive indices of 1.57 for the protein particles and 1.33 for the water (42 °C) suspending liquid were used for a range of particle size from 0.02 to 2000 µm. The Malvern multiple narrow mode model for spherical particles was used. The measure time for sample and background was set at 5 s with 5,000 snaps. A light obscuration range limit was set to fall with a range of 7 to 9%, with 3 measurement cycles per sample with zero time delay between measurements.

### Threshold Testing

Untrained consumers were recruited from the online database maintained by the Sensory Service Center (Raleigh, NC) to participate in threshold tests. Panelists had to be a minimum of 18 years old to participate. For threshold determination, the ASTM ascending forced choice method procedure E679-04 (ASTM 2011) was utilized. Tasting and visual BETs were determined separately at skim, 2%, 4%, 6%, 8%, and 10% milk fat. A step factor of 1.5 was used to allow for higher precision in determining the threshold of water addition in milk. The ballot was created using Compusense Cloud (Guelph, Canada) and allowed for the enforcement of 2-minute breaks between samples to avoid fatigue. For water addition, bottled spring water (Harris

Teeter, NC) was added to the standardized milk measured by weight (Metler Toledo PR8002 delta range) on a scale calibrated daily using standardization weights (Metler Toledo, Columbus Ohio). Sixty mL of sample was poured into lidded 118 mL foam cups for tasting BET testing (without visual cues) and 118 mL soufflé cups for visual BET testing with three digit codes (Dart Container Corporation, Mason, MI). Samples were prepared the day of each threshold test and served at 4°C (Best et al., 2025). All preparations were conducted with overhead lights off to prevent light oxidized flavors or aromas. A minimum of 60 consumers participated in each threshold test. No more than 2 fat contents (visual or tasting) were conducted daily. Consumers received a \$5 Amazon card for participation.

#### *Color and Viscosity Analysis*

Color was determined on milk in duplicate using an Ultra Scan Pro Spectrophotometer (Hunter Associates Laboratory, Inc., Reston, VA) at 4°C. A water bath (PolyScience, SD7LR-20, Warrington, PA) was used to maintain sample temperature at 4°C. Beverages were measured in reflectance mode, wavelength from 360 to 750 nm with a 5 nm resolution, using Illuminant A at a 10 degree viewer angle and reflectance curves were recorded, as described by Cheng et al (2018). The cuvette was glass with a 20 mm path length. Color data were collected and Hunter L, a, and CIE b\*-values were reported as recommended for dairy products (Cheng et al., 2018).

Apparent viscosity (AV) was measured using a rotational viscometer (LV-DV2T, Brookfield Engineering Laboratories Inc., Middleboro, MA) equipped with a jacketed cup-and-bob fixture (Enhanced UL Adapter, Brookfield Engineering Laboratories Inc.) (Adams et al., 2015; Liu et al., 2025). The calibration of the viscometer was checked using a calibration template (Brookfield Engineering Laboratories Inc., 2021), general purpose silicone standards [5 cP (5 mPa.s) and 100 cP (100 mPa.s), Brookfield Engineering Laboratories Inc.] were run on the

viscometer over a range of torques (~10, 30, 70%) at 25 °C and recorded in the calibration template provided by the manufacturer. Measurements were conducted at 4°C. The samples were tempered to 4°C in a circulating water bath (PolyScience, SD7LR-20) for 30 min. The shear rates were chosen by selecting the revolutions per minute (RPM) that fell within a torque range of 10 to 100% for all samples using the ULA(0) spindle (Brookfield Engineering Laboratories Inc.) at 4°C at 60 RPM.

### Freezing Point Analysis

Freezing point was measured using an Advanced Instruments milk cryoscope (model 4250, Norwood, MA). The instrument was calibrated using Advanced Instruments milk cryoscope calibration standards 422 and 621, as well as milk cryoscope reference solution 530 (Norwood, MA).

### Descriptive Analysis

Standardized milk with water added at 1 step factor above, 1 step factor below, and at the tasting BET value were evaluated by seven trained and experienced panelists (3 males, 4 females, ages 22 to 49 y) to document the impact of water addition at threshold concentration on objective sensory properties. Each panelist had a minimum of 80 h of prior descriptive analysis experience documenting flavors of milk using the Spectrum™ method with a 0 to 15 point intensity scale (Meilgaard et al., 2007). Sixty mL of each sample was poured into 118 mL souffle cups, capped (Dart Container Corp., Mason, MI), and labeled with a randomized 3-digit blinding code. Samples were prepared with overhead lights off to prevent light oxidation. Milks with and without added water were evaluated at 4°C. Panelists evaluated each treatment in duplicate in a randomized balanced order of presentation. A 3 min rest was enforced between samples.

Panelists expectorated samples and rinsed their palates with bottled spring water. Data were collected electronically on the NCSU secure network. The water added milks were evaluated for overall aroma intensity, sweet aromatic, cooked-milky, and milk fat flavors as well as sweet taste, salty taste, astringent mouthfeel, and viscosity. These attributes were previously established for liquid milk (McCarthy et al., 2017).

### Statistical Analysis

The individual BET of each threshold test was taken as the geometric mean of the last concentration with an incorrect response and the first concentration with a correct response from each panelist. Group BET values were taken as the geometric mean of the individual BET values. Analysis of variance (**ANOVA**) was conducted using a general linear model procedure (**PROC GLM**) with means separation (Fisher's least significant difference [**LSD**]) on the trained panel data using **XLSTAT** (version 2025, Addinsoft Inc., New York, NY). Regression analysis was conducted on chemical composition, BET, color, apparent viscosity, and freezing point data for all fat standardized milk and water added milk within each milk fat concentration. All analyses were performed at 95% confidence ( $P < 0.05$ ).

## **RESULTS AND DISCUSSION**

Milk composition was evaluated for fluid milk at every standardized fat concentration (results not shown). Fat globule size was also evaluated at standardized fat concentrations. Fat globule sizes were consistent across fluid milk at all milk fat concentrations (results not shown). Freezing points were within the regular range for milk at all milk fat concentrations with no added water and increased linearly as water was added (Figure 1).

The oral detection threshold of water addition without visual cues in skim milk was 11.8% added water (Figure 2). As fat content increased in threshold testing, the oral detection threshold decreased, with 6% milk having the lowest BET (5.2%). Above 6% milk fat, the BET of water detection increased, and at 10% fat, the BET was 10% added water. Skim milk generally has a mild flavor and thin viscosity, and not surprisingly, this matrix had the highest BET. As milk fat increased to 6%, water addition was easier to detect. Milks at low fat concentrations have moderate intensities of cooked/milky and milk fat flavors and some viscosity due to milkfat, making it easier to detect the difference between the control and the water added milk in a threshold test. As the amount of milk fat increased to 10%, detection of the water became more difficult, likely due to the presence of flavor and mouthfeel from higher milkfat and a reduced aqueous phase. To our knowledge, there is no previous oral threshold data on water addition. The only other relevant study tested Just Noticeable Difference (JND) thresholds of milk fat in skim, 1%, 2%, and whole milk (3.25%), which focused on the amount of stimulus required to elicit a change in response (McCarthy et al., 2017). The JND thresholds of milk fat for tasting without visual cues increased as milk fat increased from 0.1% to 3.25% (McCarthy et al., 2017).

Descriptive analysis results provided more information on how water addition impacted milk sensory properties (Table 1). As more water was added to milk, there was a decrease in the intensity of sweet taste in milk at all milk fat concentrations ( $p < 0.05$ ). Similarly, salty taste and viscosity were decreased in most milk containing fat with water addition at BET ( $p < 0.05$ ). Aromatics (sweet aromatic and cooked/milky flavor) were also decreased in milk containing fat at the water BET. These results are consistent with the oral BET results that skim milk and 10% milk had the highest oral BET values (Figure 1). These changes in sensory properties are

associated with the flavor defect of fluid milk referred to as flat (Alvarez, 2016). The BET values for water addition determined in this study are in fact the concentration when people can detect the flat defect.

Visual detection threshold of water addition in skim milk was 21.9% (Figure 3). As milk fat concentration increased, the visual detection threshold of water addition increased, with the threshold being 42.9% in 10% milk (Figure 3). As milk fat increases, it is harder to visually detect added water. This is expected, because milk became more opaque and look whiter with more milk fat (Phillips et al., 1995; Hernandez et al., 2024). Previous research has also shown an increase in the visual JND threshold of milk fat as fat levels were increased (McCarthy et al., 2017). Color analysis results help explain this finding. At all milk fat concentrations, the  $b^*$ -value (yellowness) decreased linearly while the L-value (whiteness) increased linearly as water addition increased (Figure 4). Skim milk had the largest absolute change, because it was missing the fat globules that can scatter the lights and affect yellowness and whiteness of fluid milk (Marzo et al., 2016). As milk fat concentration increased, light scattering by fat globule increases and that increased the reflect light from 510 to 750 nm, resulting in increased whiteness (Cheng et al., 2018). Compared to oral thresholds results, it is significantly more difficult to detect added water in milk visually than it is orally.

Apparent viscosity increased linearly as milk fat increased from skim milk to 10% milk (Figure 5), and apparent viscosity decreased linearly regardless of milk fat concentrations as water was added (Figure 6). Apparent viscosity could be a fast and accurate way to evaluate water addition in milk ( $p > 0.05$ ). Apparent viscosity is also commonly used as a parameter to evaluate the quality and stability of dairy based beverages, since protein content, protein

aggregation, and fat content can affect apparent viscosity (Hernandez et al., 2024; Ow-Wing et al., 2024; Hargrove et al., 2025).

Milk based beverages have gained popularity in recent years, as consumers look for good tasting and healthy products (Guneser et al., 2019). A major issue that limits the consumption of dairy products is lactose intolerance. A 240-mL serving of fluid milk contains approximately 12 g of lactose. However, there are 65%-70% of people in the world who experience lactose intolerance (Bayless et al., 2017). Moreover, lactose and lactose hydrolysis products provide carbohydrate calories. Lactose and calories are also a limiting factor as consumers are more cautious about their sugar and calorie intake (Miller et al., 2024). The process of UF-DF removes lactose and soluble minerals and is an alternative to lactose hydrolysis to make reduced lactose or lactose free protein beverages. The resulting product is a milk beverage base that can be used to make beverages that have different protein concentrations, fat concentrations, and flavors. Results from this study indicate that removal of lactose by UF-DF will have more impact on sensory properties at lower fat levels. Therefore, a low level of fat and/or partial removal of lactose followed by enzymatic lactose hydrolysis may optimize milk beverages.

## **CONCLUSION**

There is no previous research on how water addition and milk fat affect sensory and physical properties of fluid milk nor on detection thresholds and mechanisms of water addition in fluid milk. Water addition had a lower detection threshold by tasting compared to visual, and water addition was detected mainly by loss of basic tastes. Freezing point,  $b^*$ -value, and apparent viscosity all changed linearly with increased water addition and increased milk fat. This study provides valuable information to the industry to help manufacture high quality milk-based beverages that can meet consumer needs.

## **ACKNOWLEDGMENTS**

Funding provided in part by Dairy Management, Inc. (Rosemont, IL), Dairy West (Meridian, ID) and The Dairy Alliance (Atlanta, GA). The use of trade names does not imply endorsement or lack of endorsement of those not mentioned.

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Table 2.1. Mean trained panel intensity scores of skim milk with water added at one step factor above BET, at BET, and below BET.

Means represent data from duplicate evaluations of 7 trained panelists using the Spectrum™ method with a 0 to 15 point intensity scale.

<b>added water</b>	overall aroma	sweet aromatic	Cooked/milky	milk fat	sweet taste	salty taste	astr mf	viscosity
<b>0.0%</b>	1.6 a	1.9 a	3.6 a	ND	3.1 a	2.0 a	2.0 a	1.5 a
<b>7.9%</b>	1.7 a	1.7 b	3.7 a	ND	2.5 b	1.9 a	2.1 a	1.6 a
<b>11.8%</b>	1.7 a	1.9 a	3.8 a	ND	2.1 c	1.4 b	2.1 a	1.6 a
<b>17.7%</b>	1.6 a	1.4 c	3.8 a	ND	1.8 d	1.1 c	2.1 a	1.5 a

Means in the same column followed by a different superscript differ ( $P < 0.05$ ).

ND (not detected)

Table 2.2. Mean trained panel intensity scores of 2% milk with water added at one step factor above BET, at BET, and below BET.

Means represent data from duplicate evaluations of 7 trained panelists using the Spectrum™ method with a 0 to 15 point intensity scale.

<b>added water</b>	overall aroma	sweet aromatic	Cooked/milky	milk fat	sweet taste	salty taste	astr mf	viscosity
<b>0.0%</b>	1.7 a	2.1 a	3.8 a	2.2 a	3.0 a	2.1 a	1.7 a	2.0 a
<b>6.3%</b>	1.6 a	2.2 a	3.8 a	2.3 a	2.9 ab	1.8 b	1.8 a	1.8 b
<b>9.4%</b>	1.6 a	2.1 a	3.8 a	2.2 a	2.8 b	1.9 b	1.8 a	1.7 b
<b>14.1%</b>	1.7 a	2.1 a	3.7 a	2.2 a	2.1 c	1.6 c	1.8 a	1.6 b

Means in the same column followed by a different superscript differ ( $P < 0.05$ ).

Table 2.3. Mean trained panel intensity scores of 4% milk with water added at one step factor above BET, at BET, and below BET.

Means represent data from duplicate evaluations of 7 trained panelists using the Spectrum™ method with a 0 to 15 point intensity scale.

<b>added water</b>	overall aroma	sweet aromatic	Cooked/milky	milk fat	sweet taste	salty taste	astr mf	viscosity
<b>0.0%</b>	1.7 a	2.6 a	4.0 a	2.7 a	3.2 a	2.2 a	1.7 a	2.4 a
<b>5.2%</b>	1.6 a	2.1 b	4.0 a	2.4 b	2.5 b	1.7 b	1.7 a	2.2 b
<b>7.8%</b>	1.7 a	2.1 b	3.6 b	2.5 ab	2.5 b	1.6 b	1.7 a	2.1 bc
<b>11.7%</b>	1.5 a	1.6 c	3.5 b	2.5 b	2.4 b	1.6 b	1.7 a	2.0 c

Means in the same column followed by a different superscript differ ( $P < 0.05$ ).

Table 2.4. Mean trained panel intensity scores of 6% milk with water added at one step factor above BET, at BET, and below BET.

Means represent data from duplicate evaluations of 7 trained panelists using the Spectrum™ method with a 0 to 15 point intensity scale.

<b>added water</b>	overall aroma	sweet aromatic	Cooked/milky	milk fat	sweet taste	salty taste	astr mf	viscosity
<b>0.0%</b>	1.6 a	2.1 a	3.8 a	3.3 a	2.6 a	1.8 ab	1.8 a	2.5 a
<b>3.5%</b>	1.5 ab	1.7 b	3.7 ab	3.1 b	2.7 a	1.7 ab	1.9 a	2.3 b
<b>5.2%</b>	1.4 b	1.6 b	3.8 a	3.1 b	2.6 a	1.9 a	1.8 a	2.3 b
<b>7.8%</b>	1.6 a	1.6 b	3.6 b	3.1 b	2.3 b	1.6 b	1.9 a	2.2 b

Means in the same column followed by a different superscript differ ( $P < 0.05$ ).

Table 2.5. Mean trained panel intensity scores of 8% milk with water added at one step factor above BET, at BET, and below BET.

Means represent data from duplicate evaluations of 7 trained panelists using the Spectrum™ method with a 0 to 15 point intensity scale.

<b>added water</b>	overall aroma	sweet aromatic	Cooked/milky	milk fat	sweet taste	salty taste	astr mf	viscosity
<b>0.0%</b>	1.6 ab	2.2 a	3.9 a	3.6 a	2.8 a	1.9 a	1.8 ab	2.7 a
<b>4.0%</b>	1.8 a	1.8 bc	3.6 bc	3.2 b	2.5 a	2.0 a	1.8 b	2.4 b
<b>5.9%</b>	1.7 ab	1.9 b	3.7 ab	3.3 b	2.5 a	1.9 a	1.8 b	2.4 b
<b>8.9%</b>	1.5 b	1.6 c	3.5 c	3.1 b	2.1 b	1.8 a	1.9 a	2.2 b

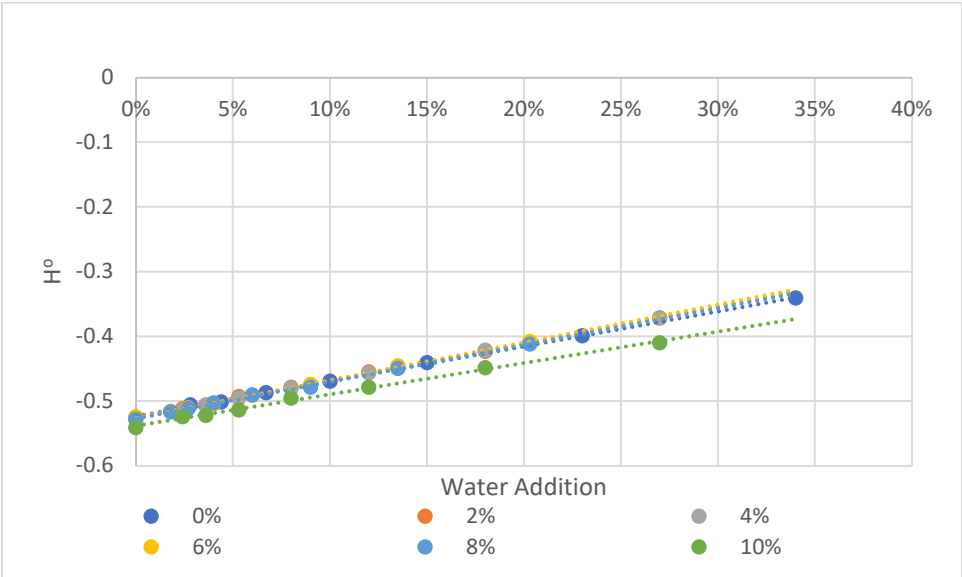
Means in the same column followed by a different superscript differ ( $P < 0.05$ ).

**Table 2.6.** Mean trained panel intensity scores of 10% milk with water added at one step factor above BET, at BET, and below BET. Means represent data from duplicate evaluations of 7 trained panelists using the Spectrum™ method with a 0 to 15 point intensity scale.

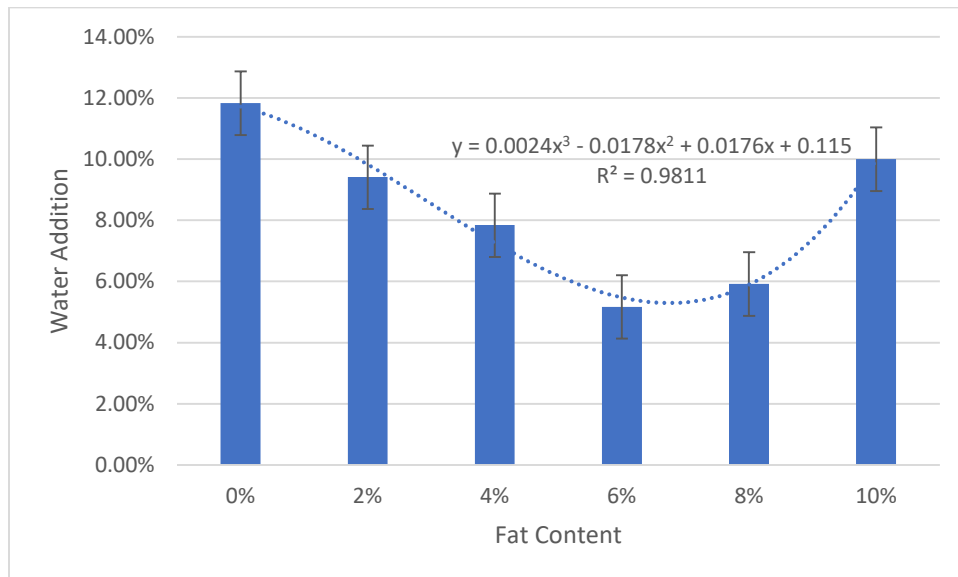
<b>added water</b>	overall aroma	sweet aromatic	Cooked/milky	milk fat	sweet taste	salty taste	astr mf	viscosity
<b>0.0%</b>	2.2 a	2.4 ab	3.9 a	3.3 a	2.8 a	2.1 a	1.9 a	2.6 a
<b>6.7%</b>	2.1 a	2.5 a	4.0 a	3.3 a	2.6 ab	1.9 a	1.9 a	2.5 ab
<b>10.0%</b>	2.0 a	2.2 bc	3.9 a	3.3 a	2.4 b	1.9 a	1.8 a	2.4 b
<b>15.0%</b>	2.0 a	2.1 c	3.9 a	3.0 a	2.0 c	1.9 a	1.9 a	2.4 b

Means in the same column followed by a different superscript differ ( $P < 0.05$ ).

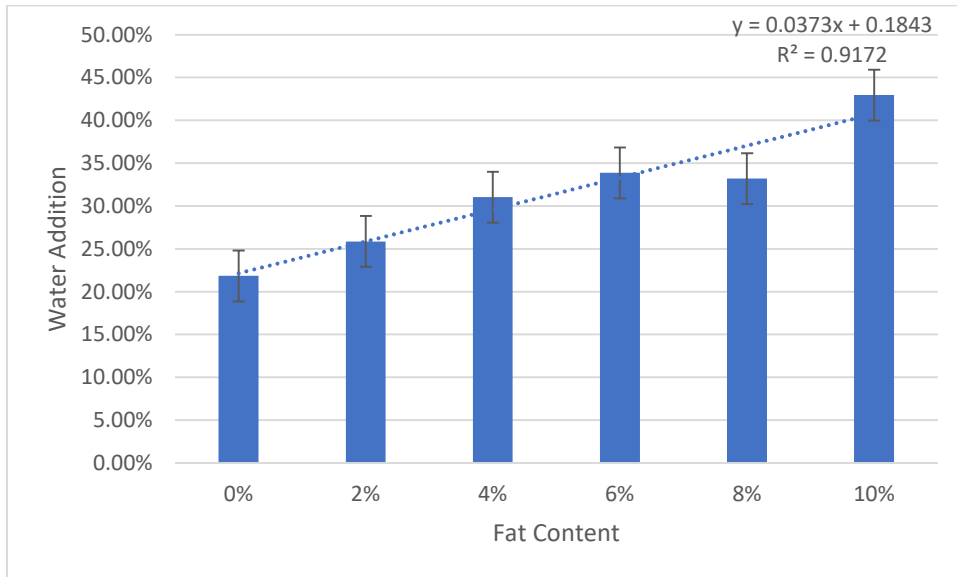
**Figure 1.** Freezing point of skim, 2%, 4%, 6%, 8%, and 10% milk at all water addition levels.



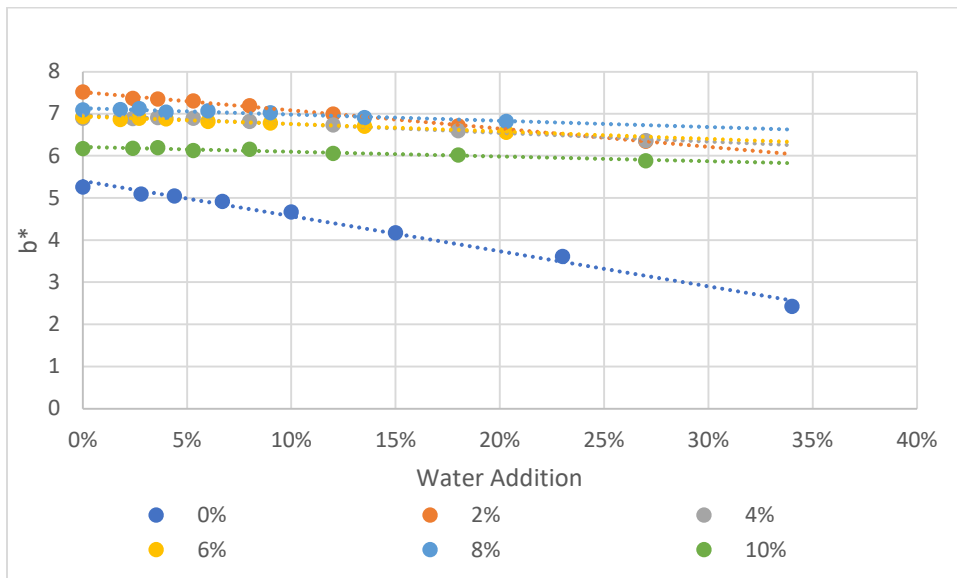
**Figure 2.** Oral detection BET of water addition without visual cues in skim, 2%, 4%, 6%, 8%, and 10% milk at all water addition levels with standard error bars (n=60).



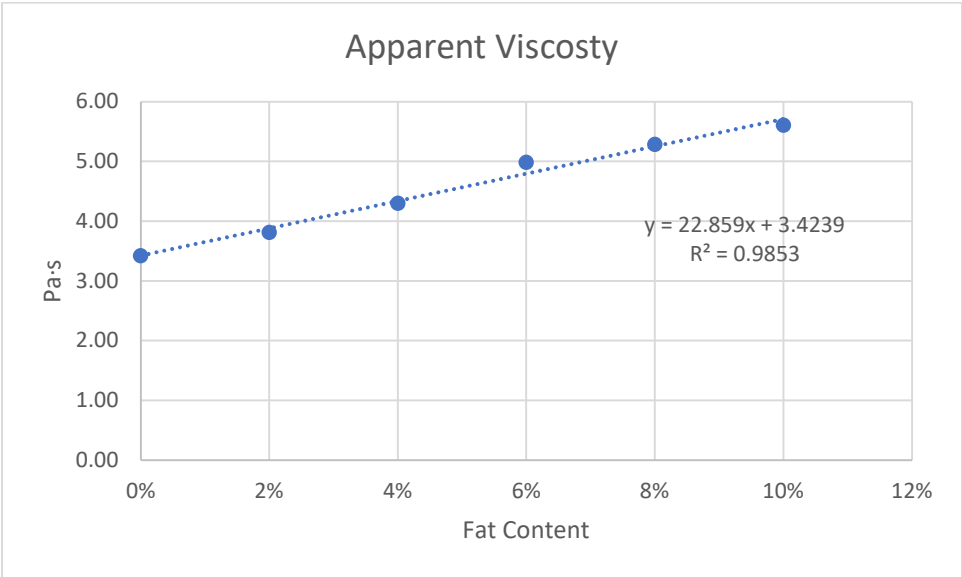
**Figure 3.** Visual detection BET of water addition in skim, 2%, 4%, 6%, 8%, and 10% milk at all water addition levels with standard error bars (n=60).



**Figure 4.** Color (Yellowness) of skim, 2%, 4%, 6%, 8%, and 10% milk at all water addition levels.



**Figure 5.** Apparent viscosity of skim, 2%, 4%, 6%, 8%, and 10% milk.



**Figure 6.** Apparent viscosity of skim, 2%, 4%, 6%, 8%, and 10% milk at all water addition levels.

