

A Review of Milk and Milk Products Chemistry Analysis Aspects

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ABSTRACT

Milk analysis plays a key role in evaluating its quality, nutritional content, safety, and shelf life, ensuring it is safe for consumption. Routine testing is essential to uphold high standards in dairy production and protect consumer health.

Keywords: Milk and Milk Products, Milk Analysis, Quality, Testing Procedures.

INTRODUCTION

Milk and dairy products are essential elements of many people's diets worldwide, providing a rich source of vital nutrients such as proteins, vitamins, and minerals.

1. Types of Milk

Milk varies based on the source of the animal, processing methods, and fat content. The primary categories are:

A. Animal-Based Milk

- **Cow Milk:** This is the most commonly consumed type of milk globally, used in various dairy products like cheese, butter, and yogurt.
- **Goat Milk:** With a tangier flavor, goat milk is easier to digest for some due to smaller fat globules and lower lactose levels.
- **Sheep Milk:** Richer in fat and protein than cow's milk, sheep milk is often used to produce cheeses like feta and Roquefort.
- **Buffalo Milk:** Predominantly consumed in South Asia, buffalo milk has a higher fat content, which is ideal for products like mozzarella and ghee.
- **Camel Milk:** While not as common, camel milk is nutritious, lower in fat compared to cow milk, and suitable for people with lactose intolerance.

B. Plant-Based Milk

Plant-based alternatives are gaining popularity, especially among people with

lactose intolerance, vegans, or those seeking healthier options:

- **Almond Milk:** A nutty, low-calorie alternative made from ground almonds.
- **Soy Milk:** Derived from soybeans, this milk offers a high protein content similar to cow's milk.
- **Oat Milk:** Known for its creamy texture and natural sweetness, often used in coffee and baking.
- **Rice Milk:** Lighter and naturally sweeter, rice milk is often fortified with nutrients.

2. Milk Processing Methods

Milk undergoes different processing techniques to improve its shelf life, flavor, and safety for consumption. These methods include:

A. Pasteurization

This involves heating milk to a certain temperature for a specified period to kill harmful bacteria, extending its shelf life. Pasteurized milk is typically safe to consume and has a milder taste.

B. Homogenization

This process breaks down fat molecules in milk, preventing cream from separating and ensuring a smooth, consistent texture.

C. Ultra-High Temperature (UHT) Processing

Milk is heated to high temperatures (around 135°C or 275°F) for a short time, which kills bacteria and allows it to be stored without refrigeration until opened.

D. Fortification

Some types of milk are fortified with additional nutrients such as calcium, Vitamin D, and sometimes Vitamin A, which helps address nutritional deficiencies in the population.

3. Nutritional Value of Milk

Milk provides several essential nutrients that are vital for maintaining good health:

- **Protein:** Crucial for growth, tissue repair, and immune function, with casein and whey proteins present in cow's milk.
- **Calcium:** Vital for strong bones and teeth, and milk is one of the best sources.
- **Vitamin D:** Important for the absorption of calcium and bone health, often added to milk.
- **Vitamins A and B12:** Vitamin A promotes eye health, while B12 supports nerve function and the production of red blood cells.
- **Magnesium and Phosphorus:** These minerals play a role in bone health and energy metabolism.
- **Fat:** Milk contains both saturated and unsaturated fats, especially in full-fat versions, while low-fat and skim options offer reduced fat content.

4. Milk Products

Milk can be transformed into various products, each with different uses in cooking, baking, or as stand-alone foods. The key dairy products include:

A. Dairy Products

- **Cheese:** Produced by curdling milk with rennet or acid, there are countless varieties, such as soft cheeses (e.g., brie), semi-soft (e.g., mozzarella), and hard cheeses (e.g., cheddar).
- **Butter:** Made by churning cream to separate the butterfat from the buttermilk. It is widely used in cooking and baking.
- **Yogurt:** A fermented dairy product with live bacterial cultures that promote gut health. Types include Greek yogurt, known for its thickness and high protein content.
- **Cream:** The fatty part of milk that rises to the top, used to make heavy cream, sour cream, and whipped cream.
- **Ice Cream:** A frozen dessert made from milk, cream, sugar, and flavorings, churned to incorporate air and create a smooth texture.

B. Processed Milk Products

- **Condensed Milk:** Concentrated milk with water removed and typically sweetened. Commonly used in desserts like caramel and toffee.
- **Evaporated Milk:** Similar to condensed milk but without added sugar. It's used in recipes for its rich flavor.
- **Powdered Milk:** Milk dried into powder form for convenience, which can be reconstituted with water when needed.
- **Ghee:** Clarified butter commonly used in Indian cuisine, where the milk solids are removed, resulting in a pure butterfat product.

5. Health Benefits of Milk and Dairy Products

Milk offers numerous health benefits, including:

- **Bone Health:** Rich in calcium and Vitamin D, essential for building and maintaining strong bones and preventing osteoporosis.
- **Muscle Growth and Repair:** The high-quality protein in milk aids muscle recovery, making it a popular choice for post-workout nutrition.
- **Weight Management:** Some studies suggest that milk may assist in weight management by promoting fullness and supporting fat loss when consumed in moderation.
- **Heart Health:** Dairy products, especially fermented ones like yogurt, may contribute to improved cardiovascular health. Some milk fats have protective effects on the heart.
- **Lactose Intolerance:** For those who have trouble digesting lactose, lactose-free milk or fermented products like yogurt can provide a digestible alternative.
- **Immune Boosting:** The proteins in milk, along with probiotics found in yogurt, can help strengthen the immune system.

6. Challenges and Controversies

Despite its health benefits, there are several challenges and controversies related to milk:

- **Lactose Intolerance:** A significant portion of the population has difficulty digesting lactose, leading to digestive discomfort. Alternatives like lactose-free milk and plant-based milk are available.

- **Milk Allergies:** Some individuals, especially children, have allergies to milk proteins (casein and whey), leading to severe reactions.
- **Ethical Issues:** The treatment of dairy cows in factory farms raises concerns among animal rights advocates, prompting calls for more ethical farming practices.
- **Environmental Concerns:** Dairy farming can contribute to environmental issues, such as greenhouse gas emissions, water usage, and land degradation. There is growing interest in sustainable practices and plant-based alternatives to mitigate these effects.

The chemistry of milk is intricate and fascinating, involving a variety of organic and inorganic compounds. It is primarily composed of water but also contains essential nutrients such as proteins, fats, carbohydrates, vitamins, and minerals, all of which are important for human nutrition. The chemical structure of milk can be understood by looking at its various components and how they interact.

1. Water:

Water accounts for about 87% of milk's composition. It serves as a solvent, enabling other components of milk to be suspended in liquid form, thus maintaining milk's fluid state and allowing the dispersion of proteins, fats, and other solutes.

2. Proteins:

Milk proteins are a critical aspect of its nutritional value. They can be categorized into two primary types:

- **Casein Proteins:** Representing around 80% of milk's protein content, casein is present in the form of micelles. These are clusters of casein molecules that keep the proteins dispersed in milk. Casein is a complete protein, containing all the essential amino acids. The major components of casein are α -casein, β -casein, and κ -casein. Casein's ability to form curds when milk is acidified makes it vital in cheese production.
- **Chemical properties of casein:** Casein is amphiphilic, meaning it has both hydrophilic (water-attracting) and hydrophobic (water-

repelling) regions. This property allows casein to emulsify milk fat and form gels, which are slowly digestible in the human stomach.

- **Whey Proteins:** Comprising about 20% of milk's protein content, whey proteins are water-soluble and remain in the liquid portion of milk after it curdles. Important whey proteins include β -lactoglobulin, α -lactalbumin, and serum albumin. These proteins are rapidly digestible and are often used in dietary supplements.
- **Chemical properties of whey proteins:** Whey proteins are globular and more soluble than casein, making them easily digestible. They also offer high nutritional value, containing all the essential amino acids necessary for the body.

3. Fats:

Milk fat accounts for approximately 3-5% of its composition. It mainly consists of triglycerides (molecules made up of three fatty acids bound to a glycerol molecule) and is a mixture of various fatty acids, including saturated, monounsaturated, and polyunsaturated fats.

- **Triglycerides:** The primary components of milk fat, these include fatty acids such as butyric acid (responsible for milk's characteristic taste), palmitic acid, oleic acid, and linoleic acid.
- **Chemical properties of milk fat:** Milk fat exists as small globules dispersed in an aqueous phase. These globules are surrounded by a membrane, which helps in stabilizing them. Short-chain fatty acids like butyric acid are easily digestible and provide energy. The emulsification of these fats is stabilized by proteins and phospholipids.
- **Butterfat:** The fat separated from milk, especially during butter-making, is known as butterfat. It plays a key role in dairy product flavor and texture.

4. Carbohydrates (Lactose):

Lactose is the main carbohydrate found in milk, making up about 4.7% of its composition. Lactose is a disaccharide sugar formed from glucose and galactose. It is vital for energy production,

particularly in infants, and aids in the absorption of calcium and other minerals.

- **Chemical properties of lactose:** Lactose is a reducing sugar, meaning it can participate in reactions like the Maillard reaction (which causes browning and flavor changes when milk is heated). People with lactose intolerance lack the enzyme lactase, which is required to break down lactose into glucose and galactose.

5. Minerals:

Milk is rich in several important minerals, particularly calcium, which plays a crucial role in bone and teeth development. Some key minerals include:

- **Calcium:** Milk is an excellent source of calcium, present in both ionic form and as part of the casein micelles.
- **Phosphorus:** Found in phosphate salts, phosphorus works alongside calcium for bone health.
- **Magnesium, Sodium, Potassium:** These minerals are present in smaller amounts but are essential for cellular function and electrolyte balance.
- **Chloride:** Present as an ionic salt, chloride helps maintain osmotic balance in milk.
- **Trace Elements:** Iron, zinc, copper, iodine, and selenium are trace minerals found in milk that support various biochemical processes.

6. Vitamins:

Milk is a rich source of various vitamins, including:

- **Vitamin A:** A fat-soluble vitamin, vitamin A in milk exists in the form of retinol and is essential for vision, immune function, and skin health.
- **Vitamin D:** Often added to milk (fortified milk), vitamin D is necessary for calcium absorption and bone health.
- **Vitamin B12:** Crucial for red blood cell production and the maintenance of the nervous system.
- **Riboflavin (Vitamin B2):** This water-soluble vitamin is involved in energy metabolism and is responsible for milk's yellow color.

- **Vitamin C:** Present in small amounts, vitamin C is vital for immune function and skin health, although milk is not as rich in this vitamin as some other dairy products like yogurt.

7. pH and Acidity:

Milk has a slightly acidic pH, typically ranging from 6.5 to 6.7. This acidity is due to lactic acid, a byproduct of bacterial fermentation. When milk spoils, bacteria convert lactose into lactic acid, reducing the pH. This change in pH is also important in milk coagulation during cheese-making.

- **pH and coagulation:** Lactic acid, along with rennet (an enzyme), causes the casein proteins to aggregate and form curds. The level of acidity influences the coagulation process, affecting the texture of cheese.

8. Enzymes:

Milk contains several enzymes, including:

- **Lactase:** Responsible for breaking down lactose into glucose and galactose, lactase is essential for milk digestion.
- **Lipases:** These enzymes aid in the breakdown of milk fats.
- **Proteases:** These enzymes break down proteins like casein and whey, contributing to milk's digestibility.

9. Milk's Colloidal Nature:

Milk is a colloidal system, meaning it contains particles suspended in a liquid without dissolving. The fat globules, proteins (especially casein), and minerals are dispersed in the aqueous phase, creating a stable liquid. The casein micelles help maintain this dispersion of fat and protein in the liquid phase.

Common Methods Used for Milk Analysis

1. Physical and Sensory Tests

These simple, on-site methods give quick insights into milk quality.

- **Visual Inspection:** Examines milk for abnormalities such as curdling, unusual color, or foreign particles. Fresh milk should be white or creamy, depending on its fat content.
- **Smell:** Fresh milk has a clean, neutral scent. Sour, rancid, or off smells suggest contamination or spoilage.

- **Taste:** Milk should have a sweet, creamy flavor without any bitterness, sourness, or rancid taste.
- **Specific Gravity (Density):** Measures the milk's density (relative weight compared to water). This test can provide indirect information about milk's composition, such as fat and water content.

2. Chemical Analysis

Chemical tests are essential for determining the milk's nutritional composition and identifying contaminants or adulterants.

a. Fat Content

- **Gerber Method:** A widely used technique to measure fat. It involves adding sulfuric acid and amyl alcohol to the milk sample, which is then centrifuged to separate the fat.
- **Babcock Method:** A similar method to Gerber, using sulfuric acid in a graduated bottle and centrifuging to separate the fat.
- **Rose-Gottlieb Method:** A detailed method that uses petroleum ether to extract the fat from the milk sample.
- **Infrared Spectroscopy (FTIR):** A rapid, modern technique that passes infrared light through milk and analyzes absorption patterns to determine fat content.

b. Protein Content

- **Kjeldahl Method:** This method measures nitrogen content, which is used to calculate the protein content by digesting the milk with sulfuric acid and then performing distillation and titration.
- **Dumas Method:** A quicker method where the milk is combusted in a sealed chamber, and nitrogen is measured via gas chromatography.
- **Milk Protein Electrophoresis:** Separates milk proteins (such as casein and whey) based on their electrical charge, helping quantify the protein fractions.

c. Lactose Content

- **Polarimetry:** Lactose rotates polarized light, and this rotation is used to determine lactose content in milk.
- **HPLC (High-Performance Liquid Chromatography):** Separates components in

milk using a chromatographic column, precisely quantifying lactose.

d. Mineral Content (Ash)

- **Ash Content Test:** Involves heating the milk to burn off organic material, leaving only minerals (like calcium, phosphorus, and magnesium).

- **Inductively Coupled Plasma (ICP) Spectrometry:** This advanced technique measures the light emitted by atoms in the milk sample to quantify minerals.

e. pH and Acidity

- **pH Meter:** Used to measure the milk's acidity. Fresh milk typically has a pH of 6.6 to 6.8. A drop in pH suggests spoilage.
- **Titrateable Acidity:** This test measures the concentration of lactic acid in the milk, commonly used to assess milk's freshness.

3. Microbial Analysis

Microbial testing ensures milk is free from harmful pathogens and bacteria.

- **Total Plate Count (TPC):** A count of all viable microorganisms present in the milk, indicating general hygiene and milk quality.
- **Coliform Count:** Detects coliform bacteria (such as *Escherichia coli*), which suggests contamination from poor hygiene.
- **Somatic Cell Count (SCC):** A high SCC indicates mastitis in cows. A low SCC reflects good udder health.
- **Standard Plate Count (SPC):** Measures the number of aerobic microorganisms in the milk.
- **Pathogen Testing:** PCR (Polymerase Chain Reaction) or culture methods detect specific harmful bacteria like *Salmonella*, *Listeria*, or *E. coli*.

4. Adulterant Detection

Detecting milk adulteration is essential to ensure milk's nutritional value and safety. Common adulterants include water, starch, detergents, or synthetic milk.

- **Water Addition Detection:** Methods like freezing point depression or measuring specific gravity can detect the presence of added water, which lowers milk's freezing point and alters density.

- **Starch Detection:** Iodine tests or enzymatic assays identify starch in milk, a common adulterant.
- **Detergent Detection:** Detergents can be detected by measuring milk's surface tension or using tests like the "Sudan III" test.
- **Chemical Methods:** Spectrophotometric or colorimetric tests detect adulterants like formalin or urea, which may be added to preserve milk or alter its composition.

5. Rheological Properties

Rheological testing measures the milk's texture and behavior during processing.

- **Viscosity Measurement:** Instruments like a viscometer or rheometer assess milk's viscosity, which is influenced by the fat, protein, and carbohydrate content.

6. Advanced Techniques

- **Near-Infrared Spectroscopy (NIR):** A quick, non-destructive method for analyzing multiple components such as fat, protein, and lactose, applicable to both raw and processed milk.
- **Gas Chromatography (GC):** Detects volatile compounds produced by spoilage or contamination.
- **DNA-Based Methods (PCR):** Uses molecular techniques like PCR to detect specific pathogens or genetic markers related to milk quality and safety.

7. Milk Flavor Profile and Sensory Testing

The flavor of milk is vital for consumer acceptance. Sensory evaluations help identify off-flavors caused by spoilage or poor production practices.

- **Descriptive Sensory Analysis:** A trained panel assesses the milk's sweetness, bitterness, and off-flavors, creating a sensory profile.
- **Gas Chromatography-Mass Spectrometry (GC-MS):** Used to analyze the volatile compounds responsible for milk's flavor, offering a detailed understanding of its taste characteristics.

Common Types of Milk Adulteration:

1. **Water:** Water is commonly added to milk to increase its volume. This dilution reduces the nutritional content, and the added water may

introduce harmful microorganisms, which can lead to infections.

2. **Starch:** Starch, typically derived from rice or potatoes, is added to milk to thicken its consistency and give it a creamy appearance. While starch is inexpensive and abundant, it adds no nutritional value.
3. **Detergents:** Some vendors use detergents to improve the foaminess and appearance of milk. These chemicals can cause significant health problems, including nausea, vomiting, and long-term digestive issues.
4. **Urea:** Urea, a substance found in fertilizers and urine, may be mixed with milk to increase its protein content and lower production costs. However, urea is harmful and can lead to kidney damage and other health complications if consumed regularly.
5. **Formalin:** Used as a preservative in the embalming process, formalin is sometimes added to milk to extend its shelf life. Consumption of formalin can result in poisoning, gastrointestinal issues, liver damage, and even death.
6. **Synthetic Milk:** This dangerous adulterant consists of a mixture of chemicals such as urea, detergents, synthetic fats, and starch, mimicking the appearance of real milk. Synthetic milk has no nutritional value and poses significant health risks.
7. **Refined Vegetable Oils:** Some producers mix refined vegetable oils into milk to artificially increase the fat content. While not immediately harmful, these oils reduce the milk's quality and may cause long-term health issues due to the types of oils used.
8. **Sodium Bicarbonate:** Commonly known as baking soda, sodium bicarbonate is sometimes added to milk to neutralize acidity, especially if the milk is spoiling. It can cause digestive issues when ingested.
9. **Whitening Agents:** Chemicals like titanium dioxide are added to milk to enhance its white appearance. These substances can be toxic when consumed.

10. **Lactose:** Extra lactose is occasionally added to milk to increase its sweetness and mask lower-quality milk or other adulterants.

Methods of Detecting Adulterated Milk:

1. **Visual Inspection:** Changes in color, consistency, or foam formation may indicate adulteration. For instance, milk with detergent forms excessive foam.
2. **Boiling Test:** If the milk contains starch or detergent, it may form a thin film or leave a residue after boiling.
3. **Water Test:** When a few drops of milk are added to water, adulterated milk will either form a separate layer or immediately show signs of dilution.
4. **Iodine Test:** Adding iodine to milk can detect starch adulteration, as iodine turns blue in the presence of starch.
5. **Alcohol Test:** When milk is mixed with alcohol (like ethanol), it will curdle if it is synthetic or adulterated with certain chemicals.
6. **Chemical Tests:** Special chemical tests and laboratory kits can be used to detect specific adulterants such as urea, detergent, formalin, or synthetic chemicals.

Health Risks of Adulterated Milk:

1. **Food Poisoning:** Adulterants such as formalin, detergents, or urea can lead to immediate symptoms of food poisoning, including vomiting, nausea, diarrhea, and abdominal pain.
2. **Long-Term Health Effects:** Continued consumption of adulterated milk can cause kidney damage (due to urea), liver problems (from formalin), or neurological damage (due to synthetic chemicals and detergents).
3. **Nutritional Deficiencies:** Adulteration reduces milk's nutritional content. For example, adding water dilutes essential proteins, fats, and vitamins, which may contribute to malnutrition, particularly in children.
4. **Cancer Risk:** Some adulterants, such as certain detergents or whitening agents, are carcinogenic, increasing the risk of cancer with long-term consumption.

Legal and Regulatory Aspects:

1. **Regulations:** Many countries have laws prohibiting milk adulteration. For example, the **Food Safety and Standards Authority of India (FSSAI)** enforces standards for milk purity and safety. Other countries, such as the **FDA in the U.S.**, also regulate milk quality.
2. **Penalties for Adulteration:** The penalties for adulterating milk vary by jurisdiction but can include heavy fines, imprisonment, and the closure of businesses involved in such illegal practices.

Preventive Measures:

1. **Awareness:** Educating consumers about the risks of adulterated milk and how to identify it can help reduce demand for such products.
2. **Regulation and Monitoring:** Governments and regulatory authorities should strengthen monitoring of milk production and distribution to ensure its purity.
3. **Strict Penalties for Offenders:** Enforcing severe penalties for violators can serve as a deterrent to those involved in adulterating milk.
4. **Consumer Vigilance:** Consumers should buy milk from trusted, certified sources and report any suspicious products to relevant authorities.
5. **Technological Advancements:** Innovations like portable devices for milk testing can help both consumers and authorities quickly detect milk adulteration and verify its authenticity.

CONCLUSION :

As global demand for milk and dairy products continues to rise, several trends and advancements are shaping the future of dairy products and their analysis:

Plant-Based Alternatives

The growing popularity of plant-based milks, including almond, oat, soy, and coconut milk, is driving dairy producers to diversify their product lines. These alternatives cater to lactose-intolerant and dairy-free consumers while closely mimicking the nutritional benefits of cow's milk. Future analysis will focus on comparing the nutritional

profiles of plant-based options and traditional dairy products to ensure they meet consumer needs.

Healthier Formulations

There is an increasing preference for healthier dairy options, such as low-fat, low-sugar, and reduced-calorie products. Innovations like reduced-fat cheeses, probiotic yogurts, and lactose-free milk are becoming more common. Future testing will prioritize creating dairy products that maintain their nutritional value while minimizing harmful components like saturated fats and sugar.

Personalized Nutrition

Advances in nutrition science and technology are paving the way for personalized milk products tailored to individual health needs, such as high-protein, lactose-free, or fortified milk. Milk analysis will likely evolve to include more precise assessments of how different milk formulations affect the health and nutrition of various groups, including children, athletes, and older adults.

Sustainability and Environmental Impact

The environmental footprint of dairy farming, including issues like greenhouse gas emissions and water consumption, has become an increasing concern. The dairy industry is actively exploring more sustainable farming methods. Milk product analysis will need to address the environmental impact, including measuring the carbon footprint of production processes and exploring sustainable packaging solutions.

Food Safety and Quality

With the rise in dairy consumption, ensuring the safety and quality of milk products is a priority. Efforts to prevent contamination, spoilage, and adulteration are ongoing.

Advanced testing techniques, like rapid pathogen detection, are expected to become more widespread to ensure the safety of dairy products for consumers.

Functional Dairy Products

Consumers are increasingly interested in dairy products with added health benefits, such as milk enriched with vitamins, minerals, and probiotics. Future analysis will focus on verifying the bioavailability and effectiveness of these functional ingredients, ensuring that they are properly incorporated into products for maximum consumer benefit.

Innovation in Dairy Processing

Emerging techniques in dairy processing, such as ultrafiltration, microencapsulation, and high-pressure processing, are being explored to extend shelf life, preserve nutrients, and minimize the need for additives or preservatives. The analysis of these advancements will be essential to ensure they meet safety standards while maintaining product quality and nutrient integrity.

In the future of dairy products will be shaped by innovations in plant-based alternatives, healthier formulations, personalized nutrition, sustainability, and cutting-edge processing techniques. Ongoing analysis will play a key role in ensuring the quality, safety, and nutritional value of these evolving products.

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