

A Review on Dairy Ingredients Analysis Quality Parameters Applications Concepts and Its Aspects

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Abstract:

Dairy ingredients are fundamental components of numerous food products because of their nutritional value and functional properties. Their quality must be assessed through physical, chemical, microbiological, and sensory evaluations to ensure safety, consistency, and regulatory compliance. Monitoring important quality parameters such as composition, purity, microbial status, nutritional characteristics, functionality, and storage stability enables manufacturers to produce reliable, high-quality dairy ingredients. Effective quality management systems play a key role in delivering safe, nutritious, and commercially valuable dairy products to consumers.

Keywords: Dairy Ingredients, Nutritional Characteristics, Quality Management Systems

INTRODUCTION

1. Introduction to Dairy Adulteration

Dairy adulteration is the practice of altering milk and dairy products by adding unwanted substances, removing valuable components, or replacing original ingredients with cheaper alternatives. These modifications are usually carried out to increase product quantity, improve physical appearance, increase shelf life, or reduce production expenses.

Adulterated dairy products are a significant food safety concern because they can lower nutritional quality and may create health risks for consumers. Milk is especially susceptible to adulteration because it contains several components, including water, fats, proteins, minerals, and other nutrients that can be easily manipulated.

Adulteration may occur at various points in the dairy supply chain, including animal milking, milk collection centers, transportation, processing facilities, storage areas, and retail markets.

2. Major Types of Dairy Adulteration

A. Addition of Water

Reason for Addition:

Water is commonly mixed with milk to increase the total volume and obtain greater financial returns.

Impact on Quality:

- Reduces the nutritional value of milk
- Lowers protein and fat concentration
- Decreases mineral content
- May introduce harmful microorganisms when unsafe water is used

Detection Methods:

- Lactometer measurement
- Freezing point determination
- Milk density testing

B. Removal of Milk Fat

Reason for Practice:

Milk fat or cream may be extracted and replaced with less expensive materials to maintain quantity.

Effects:

- Reduces energy content
- Affects taste and texture
- Causes loss of fat-soluble vitamins

Detection Methods:

- Fat percentage analysis
- Complete milk composition testing

C. Starch Addition

Purpose:

Starch is sometimes added to increase the thickness of diluted milk and create the impression of higher solid content.

Common Sources:

- Corn starch
- Potato starch
- Rice starch

Possible Health Effects:

- Digestive discomfort
- Problems for individuals with certain metabolic disorders

Detection:

- Iodine testing, where starch produces a characteristic blue color reaction

D. Urea Addition

Purpose:

Urea may be mixed with milk to artificially increase nitrogen levels, which can make protein measurements appear higher.

Health Concerns:

Excess consumption may contribute to:

- Kidney stress
- Digestive disturbances
- Increased health risks, particularly among infants and sensitive individuals

Detection:

- Chemical analysis of nitrogen-containing compounds

E. Detergent Contamination

Purpose:

Detergents may be added to diluted milk to create foam and improve its visual appearance.

Effects:

- Gastrointestinal irritation
- Digestive system problems
- Potential toxic effects with high exposure

Detection:

- Chemical analysis for surfactant compounds

F. Synthetic Milk Adulteration

Synthetic milk is produced by combining different substances to imitate the characteristics of natural milk.

Possible Components:

- Detergents
- Vegetable oils
- Starch
- Chemical substances
- Artificial emulsifying agents

Health Risks:

- Digestive disorders

- Toxic reactions
- Potential long-term health problems

G. Unauthorized Preservative Addition

Purpose:

Certain chemicals may be added to delay spoilage and increase storage life.

Examples:

- Formalin
- Hydrogen peroxide
- Other unapproved preservatives

Effects:

- Toxic effects on the body
- Possible organ damage after prolonged exposure
- Increased health risks

H. Addition of Sugar or Artificial Sweeteners

Purpose:

Sweeteners may be added to improve taste or hide quality problems caused by dilution.

Effects:

- Changes the nutritional composition
- May create concerns for diabetic consumers

I. Adulteration in Milk Powder and Reconstituted Milk

Low-quality milk powders or improper reconstitution methods may be used to imitate fresh milk products.

Concerns:

- Reduced nutritional value
- Poor manufacturing quality
- Possible contamination risks

3. Adulteration in Various Dairy Products

Milk

Common adulterants include:

- Water
- Urea
- Detergents
- Starch
- Preservatives
- Synthetic ingredients

Ghee and Butter

Common Adulterants:

- Vegetable oils
- Animal fats
- Low-quality edible oils

Effects:

- Reduced purity

- Changes in fatty acid composition

Detection:

- Fat composition analysis
- Chromatographic techniques

Cheese

Possible Adulterants:

- Non-dairy fats
- Excess starch
- Low-quality milk materials

Effects:

- Reduced nutritional value
- Changes in texture and taste

Yogurt and Curd

Common Problems:

- Artificial thickening agents
- Excess starch
- Artificial flavors
- Use of poor-quality milk

Effects:

- Reduced probiotic activity
- Altered nutritional properties

Milk Powder

Possible Adulterants:

- Starch
- Sugar
- Low-quality fillers

Concerns:

- Reduced protein quality
- Food safety issues

4. Main Causes of Dairy Adulteration

Financial Motivation

Economic gain is one of the primary reasons for adulteration. It may involve:

- Increasing product quantity
- Reducing production costs
- Extending product shelf life

Supply Chain Challenges

Adulteration may occur because of:

- Long transportation periods
- Poor storage conditions
- Insufficient quality monitoring

Increasing Market Demand

High consumer demand for dairy products can encourage dishonest practices to increase supply.

Limited Testing Facilities

Small-scale producers may not have access to advanced equipment for quality verification.

5. Health Effects of Consuming Adulterated Dairy Products

Short-Term Health Effects:

- Stomach discomfort
- Vomiting
- Diarrhea
- Foodborne illness
- Allergic reactions

Long-Term Health Effects:

- Kidney-related problems
- Liver stress
- Possible hormonal disturbances
- Loss of nutritional benefits
- Greater risks for vulnerable groups

Children, pregnant women, elderly individuals, and people with existing health conditions may be more affected.

6. Methods Used to Detect Dairy Adulteration

Traditional Testing Techniques

Lactometer Test

Used to identify possible water dilution by measuring milk density.

Acidity Testing

Helps determine milk freshness and detect spoilage.

Chemical Tests

Used for identifying substances such as:

- Starch
- Urea
- Detergents
- Preservatives

7. Advanced Technologies for Dairy Adulteration Detection

Artificial Intelligence (AI)

AI systems can process information from:

- Milk composition analysis
- Sensor measurements
- Spectroscopic data

Applications:

- Instant quality assessment
- Automated adulteration identification
- Supply chain monitoring

Near-Infrared Spectroscopy (NIR)

NIR technology examines milk composition without damaging the sample.

It can evaluate:

- Fat concentration
- Protein levels
- Moisture content
- Possible contaminants

Biosensor Technology

Advanced biosensors can quickly identify:

- Chemical contaminants
- Microbial hazards
- Unwanted substances

Blockchain-Based Traceability

Blockchain technology can create transparent records of:

- Farm details
- Transportation history
- Processing information
- Quality test results

This improves product authenticity and reduces fraud.

8. Prevention and Control Strategies

At Dairy Farms

Important practices include:

- Maintaining hygienic milking conditions
- Using clean water sources
- Monitoring animal health
- Following proper storage methods

During Transportation

Measures include:

- Maintaining proper cold-chain conditions
- Using hygienic sealed containers
- Performing regular quality checks

At Processing Facilities

Requirements include:

- Routine laboratory testing
- Automated quality control systems
- Compliance with food safety regulations

Consumer Awareness

Consumers should:

- Buy products from reliable sources
- Check quality certifications and labels
- Avoid suspiciously low-priced products
- Store dairy products correctly

9. Future Technologies for Dairy Adulteration Control

Future dairy safety systems are expected to increasingly depend on:

- Artificial intelligence
- Machine learning
- Internet of Things (IoT)
- Smart sensors
- Rapid molecular testing methods
- Blockchain-based tracking systems

These technologies will enable faster identification of adulteration, improve transparency, and support a safer dairy supply chain.

Milk is a naturally occurring biological secretion produced by the mammary glands of healthy female mammals during lactation. It is considered a complete natural food because it contains essential nutrients such as proteins, lipids, carbohydrates, minerals, vitamins, enzymes, and water in an appropriate nutritional balance. Due to the presence of various bioactive compounds, milk and its derived products have significant nutritional, therapeutic, and pharmacognostic importance.

Biological Source

Milk is obtained from the mammary glands of healthy, lactating animals. It is collected without the addition or removal of any natural constituents.

Important Commercial Sources

- Cow (*Bos taurus*)
- Buffalo (*Bubalus bubalis*)
- Goat (*Capra hircus*)
- Sheep (*Ovis aries*)
- Camel (*Camelus dromedarius*)

Family

Most commonly used dairy animals belong to the family **Bovidae**, which includes:

- Cow
- Buffalo
- Goat
- Sheep

Geographical Distribution

Milk production is practiced globally and represents one of the most important agricultural activities. Major milk-producing regions include India, the United States, China, Pakistan, Brazil, Germany, France, New Zealand, Australia, and the Netherlands. India is among the leading milk-producing nations, with cow and buffalo milk forming the major contribution to total production.

Collection and Processing of Milk

Milk is collected from healthy animals under hygienic conditions to maintain quality and prevent contamination.

The general processing steps include:

Filtration

Removes physical impurities and foreign particles.

Standardization

Adjusts the fat and solid content according to product requirements.

Homogenization

Breaks large fat globules into smaller particles to improve texture and prevent cream separation.

Pasteurization

Heat treatment used to destroy disease-causing microorganisms while maintaining nutritional quality.

Cooling and Storage

Rapid cooling reduces microbial growth and improves shelf life.

Packaging

Milk is packed under hygienic conditions using suitable containers to prevent contamination.

Depending on the final product, milk may undergo additional processes such as fermentation, evaporation, drying, churning, or clarification.

Organoleptic Characteristics

Appearance

Milk is a white to creamy-white, opaque liquid.

Odor

It possesses a mild, pleasant characteristic smell and should be free from abnormal odors.

Taste

Milk has a slightly sweet taste due to lactose, along with a creamy flavor contributed by milk fat.

Consistency

It has a smooth, uniform, and homogeneous consistency.

Chemical Composition of Milk

1. Water

Water is the major component of milk, representing approximately 86–88% of its total composition. It acts as a medium for dissolving and suspending nutrients such as lactose, proteins, minerals, and vitamins. Water content influences the physical properties and processing behavior of milk.

2. Milk Fat

Milk fat generally accounts for 3–6% of milk composition. It mainly consists of triglycerides along with smaller amounts of phospholipids, cholesterol, and fat-soluble vitamins.

Functions of Milk Fat

- Provides concentrated energy
- Improves flavor and texture
- Acts as a carrier for vitamins A, D, E, and K
- Supplies essential fatty acids

3. Milk Proteins

Milk contains approximately 3–4% protein, which contributes significantly to its nutritional value.

Major Protein Groups

Casein Proteins (Approximately 80%)

Casein is the primary milk protein responsible for curd formation during cheese and paneer production.

Functions:

- Provides essential amino acids
- Helps calcium transport
- Forms the structural basis of cheese products

Whey Proteins (Approximately 20%)

Important whey proteins include:

- β -Lactoglobulin
- α -Lactalbumin
- Lactoferrin
- Serum albumin
- Immunoglobulins

Functions:

- High biological value protein source
- Supports immune function
- Easily digested

4. Carbohydrates

Lactose is the principal carbohydrate present in milk, usually ranging from 4.5–5%.

Functions:

- Provides energy
- Enhances calcium absorption
- Serves as a substrate for fermentation by beneficial bacteria

5. Minerals

Milk contains essential macro and trace minerals.

Major Minerals

Mineral Importance

Calcium Bone and teeth formation

Phosphorus Skeletal health and energy metabolism

Potassium Fluid balance

Sodium Electrolyte regulation

Magnesium Enzyme activity

Trace Minerals

- Zinc
- Iron
- Copper
- Selenium
- Iodine

6. Vitamins

Fat-Soluble Vitamins

- Vitamin A
- Vitamin D
- Vitamin E
- Vitamin K

Water-Soluble Vitamins

- Vitamin B1
- Vitamin B2
- Vitamin B6
- Vitamin B12
- Niacin
- Folic acid
- Vitamin C

Bioactive Components of Milk

Milk contains several biologically active substances responsible for its health-promoting effects.

Immunoglobulins

Immunoglobulins are protective proteins that provide passive immunity and assist in defense against microorganisms.

Lactoferrin

Lactoferrin is an iron-binding glycoprotein that exhibits:

- Antimicrobial activity
- Antiviral effects
- Antioxidant properties
- Anti-inflammatory activity

Bioactive Peptides

These peptides are generated during digestion or fermentation and may show:

- Antihypertensive effects
- Antioxidant activity
- Antimicrobial action
- Immune-modulating effects

Growth Factors

Milk contains biological growth factors, including insulin-like growth factors, which support tissue development and repair.

Conjugated Linoleic Acid (CLA)

CLA is a naturally occurring fatty acid associated with antioxidant and anti-inflammatory properties.

Pharmacological Activities of Milk Products

Nutritional Activity

Milk provides complete proteins, essential amino acids, minerals, vitamins, and energy required for growth and maintenance.

Antioxidant Activity

Milk-derived proteins and vitamins help reduce oxidative damage by neutralizing free radicals.

Antimicrobial Activity

Components such as lactoferrin, lysozyme, immunoglobulins, and lactoperoxidase help inhibit harmful microorganisms.

Immunomodulatory Effects

Bioactive proteins improve immune responses and enhance resistance against infections.

Anti-inflammatory Activity

Certain milk peptides can regulate inflammatory processes.

Bone Protective Effect

Calcium, phosphorus, and vitamin D contribute to bone mineralization and help reduce osteoporosis risk.

Gastrointestinal Benefits

Fermented dairy products containing probiotics support digestive health by maintaining beneficial intestinal microorganisms.

Cardiovascular Effects

Milk-derived bioactive peptides may contribute to blood pressure regulation through ACE inhibitory activity.

Pharmacognostic Evaluation of Milk

Evaluation procedures are performed to determine identity, quality, purity, and safety.

Organoleptic Evaluation

Includes examination of:

- Color
- Odor
- Taste
- Texture and consistency

Physical Evaluation

Parameters include:

- Density
- Specific gravity
- Freezing point
- Viscosity
- pH
- Titratable acidity

Chemical Evaluation

Analysis includes:

- Fat content
- Protein content
- Lactose content
- Moisture percentage
- Ash content
- Total solids
- Solids-not-fat (SNF)

Microbiological Evaluation

Tests include:

- Total bacterial count
- Coliform detection
- Yeast and mold estimation
- Identification of pathogenic organisms

Milk Adulteration

Milk adulteration involves the addition of unwanted substances or removal of valuable components.

Common Adulterants

- Water
- Starch
- Urea
- Detergents
- Neutralizing agents
- Added sugar
- Synthetic milk substances
- Formalin
- Hydrogen peroxide

Adulteration decreases nutritional value and may create health hazards.

Identification and Quality Tests

Common analytical tests include:

- Lactometer test for measuring specific gravity
- Gerber method for fat estimation
- Kjeldahl method for protein determination
- Alcohol stability test
- Methylene blue reduction test for microbial quality
- Phosphatase test for pasteurization efficiency

- Chemical tests for detection of starch, urea, detergents, and added water

Therapeutic Applications of Milk Products

Milk products are used in nutritional and supportive therapy.

Applications include:

- Prevention of protein-energy deficiency
- Dietary support for bone disorders
- Nutrition during pregnancy and lactation
- Infant and pediatric nutrition
- Recovery nutrition after illness or surgery
- Maintenance of muscle protein in elderly individuals
- Development of probiotic functional foods

Pharmacognostic Importance of Major Milk Products

Butter

Butter is a concentrated source of milk fat containing fat-soluble vitamins and provides high energy value.

Ghee

Ghee contains almost pure milk fat and contains antioxidant compounds with excellent storage stability.

Cheese

Cheese is a concentrated source of proteins, calcium, and phosphorus beneficial for muscle and bone health.

Paneer

Paneer provides high-quality proteins, minerals, and essential nutrients with good digestibility.

Yogurt

Yogurt contains probiotic microorganisms that improve digestion, maintain intestinal health, and support immunity.

Whey Protein

Whey protein is a highly digestible protein source with excellent biological value and is used in nutritional supplements and clinical diets.

Storage Conditions

Milk should be stored under refrigeration, generally around 4°C, to limit microbial growth and maintain quality.

Milk powders should be stored in airtight containers away from moisture and excessive heat.

All dairy products should be protected from:

- High temperature

- Direct sunlight
- Moisture
- Microbial contamination

Dairy ingredients are food components obtained by processing milk into different functional and nutritional products. They are widely used in the preparation of dairy products, bakery foods, confectionery, beverages, infant nutrition, pharmaceuticals, and health supplements. These ingredients are valued for their rich content of proteins, fats, carbohydrates, vitamins, and minerals, which improve the nutritional profile, texture, taste, and stability of food products. Careful analysis of dairy ingredients is essential to maintain product quality, ensure consumer safety, comply with food regulations, and achieve consistency during manufacturing.

1. Types of Dairy Ingredients

Dairy ingredients are manufactured by separating or concentrating specific components of milk for use in different food and industrial applications.

A. Milk Fat

Milk fat is an important constituent of milk that contributes to its characteristic flavor, creamy consistency, and high energy content.

Examples

- Butter
- Fresh cream
- Anhydrous milk fat
- Ghee

Functions

- Improves the flavor and richness of foods.
- Produces a smooth and creamy texture.
- Supplies a concentrated source of dietary energy.
- Enhances the keeping quality of several dairy products.

B. Milk Proteins

Milk proteins are complete proteins because they provide all the essential amino acids required for human nutrition.

Types

- Casein
- Whey protein
- Milk Protein Concentrate (MPC)
- Milk Protein Isolate (MPI)

Functions

- Support growth and repair of body tissues.
- Improve emulsifying and water-binding properties.
- Enhance texture and structure in processed foods.
- Increase the nutritional value of food products.

C. Milk Carbohydrates

Lactose is the naturally occurring sugar present in milk and serves several technological and nutritional functions.

Functions

- Provides energy for the body.
- Contributes mild sweetness to dairy products.
- Supports fermentation during yogurt and cheese manufacture.
- Serves as an ingredient in pharmaceutical formulations.

D. Milk Minerals

Milk supplies essential minerals required for normal body functions and healthy growth.

Major Minerals

- Calcium
- Phosphorus
- Potassium
- Magnesium
- Sodium

Functions

- Promote healthy bones and teeth.
- Assist muscle contraction and nerve function.
- Help regulate body fluid balance.
- Support enzyme activity and metabolic processes.

E. Milk Vitamins

Milk naturally contains a variety of vitamins that contribute to overall health.

Fat-Soluble Vitamins

- Vitamin A
- Vitamin D
- Vitamin E
- Vitamin K

Water-Soluble Vitamins

- Riboflavin (Vitamin B2)
- Vitamin B12
- Niacin

- Pantothenic acid

Functions

- Maintain healthy vision and immune function.
- Support bone development.
- Aid energy metabolism.
- Help maintain a healthy nervous system.

F. Whey Ingredients

Whey is the nutrient-rich liquid obtained as a by-product during cheese production and is processed into valuable food ingredients.

Examples

- Whey Protein Concentrate (WPC)
- Whey Protein Isolate (WPI)
- Whey Powder

Applications

- Sports nutrition supplements.
- Infant nutrition products.
- Bakery formulations.
- Functional beverages.
- Health and wellness foods.

2. Analysis of Dairy Ingredients

The quality of dairy ingredients is determined through physical, chemical, microbiological, and sensory evaluation to ensure they meet quality and safety standards.

A. Physical Analysis

Physical testing evaluates the external appearance and physical characteristics of dairy ingredients.

Parameters Evaluated

- Colour
- Appearance
- Texture
- Viscosity
- Density
- Solubility

Significance

- Confirms product uniformity.
- Identifies physical defects.
- Assesses consumer acceptance.

B. Chemical Analysis

Chemical analysis measures the composition and purity of dairy ingredients.

Moisture Content

Moisture determination is important because excess water can reduce product stability and encourage microbial growth.

Importance

- Influences storage life.
- Helps maintain product quality.

Fat Content

Fat content is measured using standardized laboratory techniques.

Importance

- Determines nutritional composition.
- Influences taste and texture.
- Ensures compliance with product standards.

Protein Content

Protein concentration is commonly measured using Kjeldahl or Dumas analytical methods.

Importance

- Indicates nutritional quality.
- Confirms product specifications.

Lactose Content

Lactose analysis determines the amount of milk sugar present in dairy products.

Importance

- Supports the manufacture of lactose-free products.
- Ensures consistent product formulation.

Ash Content

Ash analysis estimates the total mineral content after complete combustion of the sample.

Importance

- Reflects mineral composition.
- Helps identify adulteration or formulation errors.

pH and Titratable Acidity

Measurement of pH and acidity provides information about product freshness and stability.

Importance

- Controls microbial growth.
- Indicates product quality.
- Influences flavor and texture.

3. Microbiological Analysis

Microbiological examination verifies that dairy ingredients are safe for human consumption.

Common Tests

Total Plate Count (TPC)

Determines the total number of viable microorganisms present in the product.

Coliform Test

Used to assess hygienic quality and detect possible contamination during processing.

Yeast and Mold Count

Measures spoilage microorganisms that may affect product quality and shelf life.

Pathogen Testing

Samples are examined for harmful microorganisms such as:

- *Salmonella*
- *Listeria monocytogenes*
- *Escherichia coli*
- *Staphylococcus aureus*

Importance

- Protects consumer health.
- Prevents foodborne diseases.
- Ensures compliance with food safety regulations.

4. Sensory Analysis

Sensory evaluation measures the quality of dairy ingredients using human senses.

Parameters Evaluated

Appearance

Products should exhibit a clean, uniform, and attractive appearance without visible defects.

Colour

The colour should be typical of the product and free from discoloration.

Aroma

Fresh dairy ingredients should possess a pleasant characteristic aroma without undesirable odors.

Taste

The flavour should be fresh and free from bitterness, rancidity, excessive sourness, or other off-flavours.

Texture

The texture should be smooth, uniform, and free from lumps or excessive graininess.

5. Quality Parameters of Dairy Ingredients

A. Composition

High-quality dairy ingredients contain appropriate levels of:

- Fat
- Protein
- Lactose

- Minerals
- Moisture

B. Purity

Products should be free from:

- Adulterants
- Foreign materials
- Chemical contaminants
- Heavy metals

C. Microbiological Quality

Safe dairy ingredients should have:

- Low microbial counts.
- No pathogenic microorganisms.
- Good hygienic quality.

D. Nutritional Quality

The processing and storage of dairy ingredients should preserve their natural nutritional value.

E. Functional Properties

Important functional characteristics include:

- Solubility
- Emulsifying ability
- Foaming capacity
- Water-holding ability
- Heat stability
- Gel-forming properties

These characteristics determine the performance of dairy ingredients in different food products.

F. Shelf Stability

Quality dairy ingredients should remain safe and maintain their desired characteristics throughout their recommended storage period.

G. Safety

Safe dairy ingredients must satisfy food safety requirements and remain free from:

- Disease-causing microorganisms
- Pesticide residues
- Veterinary drug residues
- Toxic chemical contaminants

6. Factors Affecting the Quality of Dairy Ingredients

Several factors influence the final quality of dairy ingredients, including:

- Health and breed of dairy animals.
- Quality of feed and nutrition.
- Hygienic milking practices.
- Processing methods.
- Heat treatment conditions.

- Packaging quality.
- Storage temperature and humidity.
- Transportation and distribution practices.
- Sanitation maintained during manufacturing.

7. Quality Control Measures

Manufacturers maintain product quality through effective quality assurance systems by:

- Procuring milk from healthy animals.
- Following Good Manufacturing Practices (GMP).
- Implementing Hazard Analysis and Critical Control Point (HACCP) principles.
- Maintaining clean processing equipment.
- Conducting regular laboratory testing.
- Storing products under recommended environmental conditions.
- Using suitable packaging materials to prevent contamination.
- Monitoring shelf life and product stability throughout storage.

8. Importance of Dairy Ingredient Analysis

Comprehensive analysis of dairy ingredients provides several benefits:

- Ensures the safety of food products.
- Maintains consistent product quality.
- Verifies nutritional composition.
- Detects adulteration and contamination.
- Meets national and international food regulations.
- Builds consumer confidence.
- Supports research and product innovation.
- Minimizes economic losses caused by spoilage or product recalls.

Industrial dairy products are manufactured from milk using controlled and standardized processing methods to ensure product safety, nutritional quality, and consistency. The chemical composition of these products varies depending on factors such as the animal source (cow, buffalo, goat, or sheep), processing technology, and the intended application. Milk is a complex biological fluid that contains water, lipids, proteins, carbohydrates, minerals, vitamins, enzymes, and, in fermented products, beneficial microorganisms.

1. Composition of Raw Milk

Raw milk is a nutritionally balanced food that contains all the essential nutrients required for growth and maintenance. The average composition of cow's milk is shown below.

Component	Average Content (%)	Primary Role
Water	86–88	Medium for dissolving and transporting nutrients
Milk Fat	3.0–6.5	Provides energy, flavor, and texture
Protein	3.0–4.0	Supports growth, repair, and metabolic functions
Lactose	4.5–5.2	Principal carbohydrate and energy source
Minerals (Ash)	0.7	Essential for bone formation and physiological functions
Vitamins	Trace amounts	Regulate metabolism and support health

A. Water

Water represents the largest proportion of milk, accounting for approximately 86–88% of its composition. It acts as the medium in which lactose, proteins, minerals, and vitamins remain dissolved or dispersed. Water also influences the physical properties of milk, including viscosity, density, heat transfer, and processing efficiency.

B. Milk Fat

Milk fat is naturally present as microscopic fat globules surrounded by a protective membrane. It contributes significantly to the sensory qualities and nutritional value of dairy products.

Typical Milk Fat Composition

Constituent	Approximate Percentage
Triglycerides	97–98
Diglycerides	1–2
Phospholipids	0.5–1
Cholesterol	About 0.3

Fat-soluble vitamins Small quantities

The major fatty acids found in milk include butyric, palmitic, stearic, oleic, linoleic, and myristic acids.

Milk fat serves as an important source of energy, carries fat-soluble vitamins (A, D, E, and K), enhances flavor, and improves the creamy texture of dairy products.

C. Milk Proteins

Milk proteins account for approximately 3–4% of total milk solids and are categorized into casein and whey proteins.

Casein Proteins

Casein represents nearly 80% of the total protein in milk and is responsible for curd formation during cheese and paneer manufacture. The principal fractions are alpha-casein, beta-casein, and kappa-casein. These proteins facilitate calcium transport, contribute to cheese structure, and provide high-quality nutrition.

Whey Proteins

Whey proteins comprise about 20% of milk protein and remain dissolved after casein coagulation. Major whey proteins include beta-lactoglobulin, alpha-lactalbumin, serum albumin, immunoglobulins, and lactoferrin. These proteins are highly digestible, possess excellent biological value, and contribute to immune defense.

D. Lactose

Lactose is the primary carbohydrate in milk and is generally present at concentrations of 4.6–5.0%. It supplies energy, enhances calcium absorption, and serves as the substrate for fermentation by lactic acid bacteria during yogurt and cheese production. During fermentation, lactose is converted into lactic acid, which lowers pH and improves product preservation.

E. Minerals

Milk contains both major and trace minerals that are essential for normal physiological functions.

Major Minerals

- Calcium – Bone and tooth development
- Phosphorus – Energy metabolism and skeletal health
- Potassium – Fluid and electrolyte balance
- Sodium – Maintenance of osmotic pressure
- Magnesium – Activation of numerous enzymes

Trace Minerals

- Zinc
- Copper

- Iron
- Selenium
- Iodine

F. Vitamins

Milk supplies both fat-soluble and water-soluble vitamins.

Fat-soluble vitamins

- Vitamin A
- Vitamin D
- Vitamin E
- Vitamin K

Water-soluble vitamins

- Vitamin B1 (Thiamine)
- Vitamin B2 (Riboflavin)
- Vitamin B6
- Vitamin B12
- Niacin
- Folic acid
- Vitamin C

2. Composition of Industrial Dairy Products

Pasteurized Milk

Pasteurized milk is produced by heat treatment that destroys pathogenic microorganisms while preserving nutritional quality.

Typical Composition

- Water: Approximately 87%
- Fat: About 3.5%
- Protein: About 3.2%
- Lactose: About 4.8%
- Minerals: Around 0.7%

The manufacturing process includes filtration, standardization, homogenization, pasteurization, rapid cooling, and hygienic packaging.

Whole Milk Powder

Whole milk powder is obtained by removing water from whole milk through evaporation and spray drying.

Typical Composition

- Moisture: 2–4%
- Fat: 26–28%
- Protein: 25–27%
- Lactose: 36–38%
- Minerals: 5–6%

Skim Milk Powder

Skim milk powder is manufactured from defatted milk and contains very little fat.

Typical Composition

- Moisture: 3–4%
- Fat: Less than 1.5%
- Protein: 34–36%
- Lactose: 50–52%
- Minerals: 8–9%

It is widely used in bakery products, confectionery, dairy beverages, and infant nutrition.

Butter

Butter is a concentrated milk-fat product produced by churning cream.

Typical Composition

- Fat: 80–82%
- Water: 15–17%
- Protein: Approximately 0.5%
- Salt: 0–2%

The predominant fatty acids include palmitic, oleic, stearic, and butyric acids.

Ghee

Ghee is clarified butter containing almost pure milk fat.

Typical Composition

- Fat: 99–99.8%
- Moisture: Less than 0.5%
- Protein: Negligible
- Lactose: Negligible

It is also a source of vitamins A and E and contains conjugated linoleic acid (CLA).

Cheese

Cheese is produced by coagulating milk proteins followed by whey removal and maturation.

Typical Composition

- Moisture: 35–45%
- Fat: 25–35%
- Protein: 20–30%
- Minerals: 3–5%

Casein is the predominant protein, while whey proteins are present in smaller quantities.

Paneer

Paneer is an acid-coagulated fresh cheese commonly consumed in South Asia.

Typical Composition

- Moisture: 52–56%
- Fat: 20–25%
- Protein: 18–21%
- Lactose: 2–3%

- Minerals: 1.5–2%

Yogurt

Yogurt is a fermented dairy product prepared using selected starter cultures.

Typical Composition

- Water: 84–88%
- Protein: 3–4%
- Fat: 3–4%
- Lactose: 3–4%
- Lactic acid: 0.8–1.2%

The principal starter cultures are *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus*. Fermentation improves digestibility, supports beneficial intestinal microorganisms, and increases calcium availability.

Ice Cream

Ice cream is a frozen dairy dessert containing milk fat, milk solids, sweeteners, stabilizers, and emulsifiers.

Typical Composition

- Fat: 10–16%
- Milk solids-not-fat: 9–12%
- Sugar: 12–16%
- Stabilizers: 0.2–0.5%
- Emulsifiers: 0.1–0.3%
- Water: 55–65%

Whey Products

Liquid whey contains approximately 93% water, 4.8% lactose, 0.8% protein, and 0.5% minerals. Commercial whey products include whey protein concentrate (WPC), whey protein isolate (WPI), and lactose powder.

Functional Ingredients Used in Dairy Processing

Several additives and processing aids improve product quality and stability, including stabilizers (carrageenan, guar gum, and pectin), emulsifiers (lecithin and mono- and diglycerides), approved preservatives where permitted, flavoring agents, food colors, and enzymes such as rennet and lactase.

Microbiological Characteristics

Beneficial microorganisms commonly associated with fermented dairy products include *Lactobacillus*, *Bifidobacterium*, *Streptococcus thermophilus*, and *Lactococcus lactis*. Common spoilage organisms include *Pseudomonas*, *Bacillus*, yeasts, and molds. Food safety programs aim to eliminate pathogens

such as *Salmonella*, *Listeria monocytogenes*, *Escherichia coli* O157, and *Staphylococcus aureus*.

Chemical Quality Parameters

Typical quality indicators for milk include a pH of 6.6–6.8, titratable acidity of 0.13–0.17% as lactic acid, density of 1.028–1.034 g/cm³, freezing point of approximately –0.54°C, total solids of 12–13%, and solids-not-fat content of 8.5–9.0%.

Nutritional Importance

Industrial dairy products provide high-quality proteins containing all essential amino acids, readily absorbable calcium and phosphorus, vitamins A, D, B₂, and B₁₂, essential fatty acids, and bioactive compounds such as probiotics and bioactive peptides in fermented products. These nutrients support growth, bone health, immune function, and overall nutritional well-being.

Quality Assessment

Quality evaluation of industrial dairy products typically includes determination of fat, protein, moisture, solids-not-fat content, acidity, microbial load, detection of adulterants, monitoring of heavy metals and pesticide residues, and assessment of packaging integrity and shelf-life stability.

1. Overview of the Global Dairy Trade Sector

The dairy industry is one of the most important segments of the global agricultural economy. International trade in dairy commodities includes a wide range of products manufactured from milk through different processing technologies.

Major dairy products traded internationally include:

- Milk powders
- Cheese varieties
- Butter and anhydrous milk fat
- Whey-based products
- Infant milk formulations
- Condensed and evaporated milk products
- Fermented dairy products such as yogurt
- Fresh milk and cream

The international movement of dairy products is influenced by several factors, including differences in milk production capacity, consumer requirements, industrial processing facilities, climatic conditions, economic conditions, and food security needs.

The most commercially important dairy commodities in world trade are:

- Skim Milk Powder (SMP)
- Whole Milk Powder (WMP)
- Cheese
- Butter
- Whey protein ingredients
- Milk protein concentrates
- Infant formula products

2. Global Milk Production Scenario

Worldwide milk production is estimated to be approximately **930–950 million tonnes annually**. Milk production is concentrated in regions with developed dairy farming systems as well as areas with rapidly increasing consumer demand.

Major Milk-Producing Countries

Rank	Country/Region	Approximate Production	Annual
1	India	More than 220 million tonnes	
2	European Union	More than 150 million tonnes	
3	United States	Around 100 million tonnes	
4	Pakistan	Around 60 million tonnes	
5	China	Around 40 million tonnes	
6	Brazil	Around 35 million tonnes	
7	Russia	Around 30 million tonnes	
8	New Zealand	Around 22 million tonnes	

Important Dairy Production Regions

Major milk-producing areas include:

- South Asia
- European Union
- North America
- Oceania
- South America

These regions contribute significantly to global milk supply and dairy product exports.

3. International Dairy Export Market

The worldwide dairy export market represents a major agricultural trade sector with an estimated annual value of approximately **US\$80–100 billion**, depending on global prices, production levels, and demand patterns.

Leading Dairy Exporting Countries

Major exporters include:

- New Zealand

- European Union
- United States
- Germany
- Netherlands
- France
- Ireland
- Australia
- Belarus
- Argentina

These countries have strong dairy processing industries and export both consumer products and dairy ingredients.

4. Major Dairy Exporting Nations

4.1 New Zealand

New Zealand is recognized as the world's leading dairy exporting country due to its efficient dairy farming systems and export-oriented processing industry.

Main Export Products

- Whole milk powder
- Skim milk powder
- Butter
- Cheese
- Whey products

Export Characteristics

- A significant proportion of national milk production is processed for international markets.
- The country has strong dairy trade relationships with Asian and Middle Eastern markets.
- Advanced dairy processing and supply-chain systems support exports.

Major Export Destinations

- China
- Southeast Asian countries
- Middle East
- North Africa

A major dairy company from New Zealand is: Fonterra Co-operative Group

4.2 European Union

The European Union is among the largest dairy exporters worldwide, supported by advanced dairy technology and diversified product manufacturing.

Major Export Products

- Cheese

- Butter
- Milk powders
- Infant nutrition products
- Whey proteins

Important Exporting Countries

- Germany
- Netherlands
- France
- Ireland
- Denmark

Main Export Markets

- Middle East
- China
- Southeast Asia
- African countries

4.3 United States

The United States has a strong position in global dairy trade, particularly in dairy ingredients and processed products.

Exported Dairy Products

- Cheese
- Non-fat dry milk
- Whey protein concentrates
- Lactose
- Butter

Major Export Markets

- Mexico
- China
- Japan
- South Korea
- Southeast Asian countries

4.4 Australia

Australia is an important dairy-exporting country supplying high-quality dairy products.

Major Export Products

- Milk powders
- Cheese
- Butter
- Infant formula

Main Markets

- China
- Japan
- Southeast Asia
- Middle East

4.5 Belarus

Belarus has developed a significant dairy export sector, especially for processed dairy commodities.

Major Export Products

- Butter
- Cheese
- Milk powders

Main Markets

- Russia
- Kazakhstan
- Commonwealth of Independent States (CIS) countries

5. Global Dairy Import Market

Countries import dairy products due to limited domestic production, increasing consumer demand, population growth, and the need for dairy ingredients in food industries.

Major Dairy Importing Countries

Rank	Country/Region	Common Products	Imported
1	China	Milk powder, whey products, infant formula	
2	Mexico	Milk powder, cheese	
3	Indonesia	Milk powder	
4	Algeria	Milk powder	
5	Japan	Cheese, butter	
6	Saudi Arabia	Milk powder, cheese	
7	United Arab Emirates	Dairy ingredients	
8	Philippines	Milk powder	
9	Vietnam	Milk powder	
10	Malaysia	Dairy ingredients	

6. International Trade of Major Dairy Products

A. Milk Powder Trade

Milk powder is one of the most widely traded dairy commodities because it has a long shelf life and can be transported easily.

Main Types

- Whole Milk Powder (WMP)
- Skim Milk Powder (SMP)

Major Exporters

- New Zealand
- European Union
- United States
- Australia

Major Importers

- China
- Algeria
- Indonesia
- Saudi Arabia
- Vietnam

Industrial Applications

- Infant formula production
- Bakery products
- Chocolate manufacturing
- Dairy beverages
- Food ingredient processing

B. Cheese Trade

Cheese is a high-value dairy product with strong international demand.

Major Exporters

- European Union
- United States
- New Zealand
- Australia

Major Importers

- United Kingdom
- Japan
- Mexico
- China
- South Korea

Common Exported Cheese Types

- Cheddar
- Mozzarella
- Gouda
- Parmesan

C. Butter Trade

Butter trade mainly occurs between countries with surplus milk production and regions with high consumer demand.

Major Exporters

- New Zealand
- European Union
- Belarus
- United States

Major Importing Regions

- China
- Middle East
- North Africa
- Southeast Asia

D. Whey Protein Trade

Whey products are valuable dairy ingredients used in nutrition and pharmaceutical applications.

Applications

- Sports nutrition
- Clinical nutrition
- Infant foods
- Functional foods

Major Exporters

- United States
- European Union
- New Zealand

Major Importers

- China
- Japan
- South Korea
- Southeast Asian countries

7. Dairy Export and Import Status of India

India's Position in Global Dairy Production

India is the world's largest milk-producing country.

The dairy sector depends mainly on:

- Buffalo milk
- Cow milk
- Goat milk

Important dairy organizations include:

Amul

National Dairy Development Board

Major Dairy Products Exported from India

India exports:

- Skim milk powder
- Whole milk powder
- Butter
- Ghee
- Cheese
- Casein
- Milk protein ingredients

Main Export Destinations

- Bangladesh
- United Arab Emirates
- Saudi Arabia
- Singapore
- Bhutan
- Malaysia
- Egypt

Dairy Products Imported by India

Although India has a large domestic dairy sector, certain specialized products are imported.

Imported Products Include:

- Milk protein concentrates
- Specialty cheeses
- Lactose
- Whey proteins
- Dairy ingredients for food processing

Major Sources

- New Zealand
- European Union
- United States

8. Factors Influencing International Dairy Trade

Production-Related Factors

- Availability of animal feed
- Climate conditions
- Dairy animal productivity
- Farm management practices
- Processing infrastructure

Economic Factors

- International dairy prices
- Currency fluctuations
- Trade agreements
- Government support programs

Consumer Factors

- Population increase
- Rising demand for protein-rich foods
- Health awareness
- Growth of functional dairy products

Regulatory Factors

- Food safety requirements
- Veterinary regulations
- Residue standards
- Import and export restrictions

9. International Dairy Quality Requirements

Dairy products involved in international trade must comply with strict quality and safety regulations.

Microbiological Standards

Quality monitoring includes:

- Total bacterial count
- Coliform testing
- Absence of pathogenic microorganisms

Chemical Standards

Testing includes:

- Fat percentage
- Protein content
- Moisture level
- Antibiotic residue detection

- Heavy metal analysis

International Regulatory Organizations

- Food and Agriculture Organization of the United Nations (FAO)
- World Health Organization (WHO)
- Codex Alimentarius Commission

10. Future Developments in Global Dairy Trade

Increasing Market Demand

Growth of the dairy sector is expected due to:

- Increasing global population
- Expansion of middle-income consumers
- Higher demand for protein foods
- Urbanization

Emerging Dairy Products

Future growth opportunities include:

- Whey protein isolates
- Lactose-free dairy products
- Probiotic dairy foods
- Infant nutrition products
- Organic dairy products
- Functional dairy beverages

Sustainability Initiatives

The dairy industry is increasingly focusing on:

- Reduction of greenhouse gas emissions
- Renewable energy adoption
- Efficient water utilization
- Environment-friendly packaging systems

The global dairy industry is a major contributor to agricultural trade, with milk powders, cheese, butter, whey products, and specialized dairy ingredients forming the backbone of international commerce. Countries such as New Zealand, the European Union, and the United States dominate dairy exports, while China, Southeast Asia, and Middle Eastern countries represent major import markets. Future growth of the dairy sector will depend on innovation, sustainable production methods, improved food safety systems, and increasing demand for nutritious functional dairy products.

Industrial dairy products are produced through scientifically controlled processing methods that preserve nutritional quality while ensuring safety and consistency. Their composition varies depending on the product type and manufacturing process, but they remain valuable sources of proteins, essential fats, vitamins, minerals, and beneficial microorganisms.

Careful quality control and adherence to processing standards are essential for delivering safe, nutritious, and high-quality dairy products to consumers.

Artificial Intelligence (AI) is set to bring major changes to the dairy sector by enhancing milk production, improving quality monitoring, supporting animal health management, optimizing supply chains, and enabling the development of innovative dairy products. The dairy industry of the future will integrate AI technologies with robotics, smart sensors, biotechnology, and advanced data analytics to build a more efficient, sustainable, and consumer-focused food system.

1. AI Applications in Modern Dairy Farming

a) Smart Animal Health Monitoring

AI-based systems using wearable sensors, cameras, and digital monitoring tools can continuously collect information about dairy animals, including:

- Health conditions
- Body temperature variations
- Activity and movement patterns
- Feeding and drinking behavior
- Changes in milk production
- Reproductive performance

By analyzing this information, AI can identify early warning signs of diseases such as mastitis before serious symptoms appear. This helps farmers reduce treatment costs, improve productivity, and maintain better animal welfare.

b) AI-Based Precision Feeding

AI can create customized feeding programs by analyzing factors such as:

- Animal age
- Body weight
- Milk production capacity
- Nutritional requirements
- Feed composition and quality

Personalized feeding strategies can improve milk yield, reduce unnecessary feed consumption, and increase farm efficiency.

c) Automated Robotic Milking

Robotic milking technology will become increasingly common in advanced dairy farms. These systems can:

- Recognize individual animals
- Perform automatic milking operations
- Check milk quality parameters

- Record production information
- Work continuously with minimal human involvement

Automation can improve hygiene standards, reduce labor requirements, and provide accurate production data.

2. AI-Based Dairy Quality and Safety Management

AI will play an important role in ensuring the safety and quality of dairy products.

Real-Time Milk Testing

Advanced AI systems combined with sensors can analyze milk characteristics and identify:

- Microbial contamination
- Antibiotic residues
- Possible adulteration
- Fat and protein content
- Lactose levels
- Freshness indicators

Future dairy farms may perform instant quality checks during milking and processing rather than depending only on traditional laboratory testing.

AI-Based Visual Inspection

Computer vision technology can examine dairy products for:

- Packaging damage
- Product appearance
- Cheese structure and texture
- Yogurt consistency
- Possible contamination issues

This will improve quality control and reduce defective products.

3. AI-Driven Dairy Product Innovation

AI will help dairy companies design new products by studying:

- Consumer preferences
- Nutrition trends
- Market requirements
- Ingredient combinations

Future AI-assisted dairy products may include:

- High-protein beverages
- Personalized nutrition-based milk products
- Reduced-sugar dairy items
- Probiotic and functional dairy foods
- Specialized products for different health needs

AI models can predict consumer acceptance of flavors, textures, and formulations before companies invest in large-scale manufacturing.

4. Personalized Dairy Nutrition Using AI

In the future, AI platforms may recommend dairy products according to individual needs by analyzing:

- Age
- Lifestyle patterns
- Physical activity
- Health information
- Dietary choices

Examples include:

- Calcium-enriched products for bone support
- Protein-rich dairy products for active individuals
- Lactose-free options for sensitive consumers
- Probiotic products for digestive wellness

This approach can move dairy consumption toward personalized nutrition.

5. AI in Dairy Supply Chain Optimization

AI will improve the movement of dairy products from farms to consumers.

Intelligent Logistics Management

AI systems can forecast:

- Milk demand
- Transportation requirements
- Storage conditions
- Efficient delivery routes

Benefits include:

- Reduced food waste
- Lower transportation expenses
- Faster distribution
- Improved product freshness

Smart Cold Chain Monitoring

AI-enabled sensors can track:

- Temperature levels
- Humidity conditions
- Storage duration

If storage conditions become unsafe, AI systems can immediately notify operators and prevent product losses.

6. AI for Sustainable Dairy Production

AI can support environmentally responsible dairy farming by improving resource management.

Reducing Environmental Impact

AI technologies can help farmers:

- Improve feed efficiency
- Reduce methane emissions
- Manage animal waste effectively
- Decrease energy consumption

Efficient Use of Natural Resources

AI-based analysis can reduce:

- Water consumption
- Unnecessary fertilizer usage
- Energy waste

This can contribute to a more sustainable dairy industry.

7. AI in Dairy Processing and Manufacturing

Future dairy factories will become more automated through AI-controlled systems.

AI may manage processes such as:

- Milk pasteurization
- Fermentation
- Cheese manufacturing
- Yogurt production
- Packaging operations

Advantages include:

- Improved product consistency
- Reduced production errors
- Lower operational costs
- Enhanced food safety

8. AI and Future Alternative Dairy Technologies

AI will also contribute to the growth of alternative dairy solutions.

Plant-Based Dairy Development

AI can improve the formulation of:

- Soy-based milk
- Almond-based beverages
- Oat-based dairy alternatives
- Coconut-based products

Precision Fermentation Technology

AI can support the production of dairy proteins using microorganisms instead of conventional animal-based production methods.

Potential future products include:

- Animal-free dairy proteins
- Sustainable cheese alternatives
- Environment-friendly dairy ingredients

9. AI in Dairy Marketing and Consumer Engagement

AI will transform how dairy products are promoted and sold.

Predictive Consumer Analysis

AI can study:

- Purchasing behavior
- Regional preferences
- Seasonal trends

Companies can use this information to create better marketing strategies and reduce unnecessary inventory.

Intelligent Packaging

Future dairy packaging may include:

- Digital traceability systems
- Freshness monitoring indicators
- Smart labels
- QR-based product information

Consumers may access details about:

- Farm source
- Production history
- Nutritional information
- Environmental impact

10. Challenges of Implementing AI in Dairy

Although AI offers many advantages, several challenges must be addressed.

High Technology Costs

Advanced AI equipment and automation systems may be difficult for small-scale dairy farmers to afford.

Data Security

Large amounts of farm and consumer information must be stored and protected responsibly.

Need for Technical Knowledge

Farm workers will require training to operate and manage AI-based systems.

Employment Transformation

Automation may reduce some traditional tasks but may also create new opportunities in technology, data management, and farm automation.

Ethical Considerations

AI adoption must ensure responsible use, animal welfare protection, and sustainable farming practices.

Future Development Timeline of AI in Dairy

Time Period	Expected Progress
2025–2030	Expansion of AI sensors, smart farming tools, and automated quality testing

- 2030– Greater adoption of robotic farms,
2040 connected dairy systems, and AI-based
nutrition solutions
- 2040– Highly automated dairy production,
2050 personalized dairy foods, and advanced
biotechnology applications

Conclusion

Artificial Intelligence will become a key driver of transformation in the dairy industry. By combining AI with robotics, sensors, biotechnology, and data analytics, the dairy sector can achieve higher productivity, improved food safety, sustainable resource management, and personalized nutrition. The future of dairy production will depend on balancing technological innovation with responsible farming practices and consumer needs.

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