



Advancing Horizon In Dairy Farming And Processing: A Review

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Abstract

The dairy processing industry transforms raw milk into products such as butter, cheese, and milk powder. Essential processes encompass milk production, butter creation, cheese manufacturing, and milk powder generation. Environmental consequences include significant water usage, discharge of effluent containing high levels of organic substances, and energy consumption. Contemporary dairy facilities prioritize reducing water consumption, typically aiming for rates between 1.3 and 2.5 liters of water per kilogram of milk input. Environmental metrics, like water consumption and effluent discharge, are vital for evaluating opportunities for cleaner production. The industry has experienced consolidation, leading to fewer but larger plants, and has adopted more effective equipment and procedures to mitigate environmental impact.

Objective

- * The dairy industry is divided into primary production of milk on farms and processing of milk into dairy products.
- * Dairy processing involves heat treatment, separation, pasteurization, and packaging to extend shelf life.
- * Environmental impacts include high water consumption, effluent discharge with high organic loads, and energy consumption.
- * Water consumption can be reduced through advanced equipment and good housekeeping practices.
- * Effluent discharge can be managed through proper treatment and disposal practices.
- * Energy consumption can be reduced through efficient equipment and practices.

* Proper management practices are crucial to minimize environmental impacts in dairy processing plants.

DAIRY PROCESSING: AN OVERVIEW

The dairy sector is broadly categorized into two principal areas of production:

Firstly, the primary production of milk on agricultural establishments, encompassing the husbandry of bovine livestock—along with other species such as caprines and ovines—for the express purpose of yielding milk intended for human consumption.

Secondly, the processing of milk, which is primarily aimed at prolonging its commercially viable lifespan. This is typically accomplished through:

- 1) Thermal processing to ensure the milk is safe for consumption and possesses enhanced preservation characteristics.
- 2) The manufacture of diverse dairy commodities in either a semi-desiccated or fully desiccated state (e.g., butter, firm cheeses, and milk powders), which are amenable to storage.

The main content of this paper covers the milk processing operations and milk product manufacturing processes which include butter production and cheese and milk powder inside the dairy processing facility. The first steps of milk production at the initial stages of dairy farming remain beyond the scope of this document because these activities fall under direct agricultural industry management. The distribution and retailing phases do not fall within the scope of this discussion.

There is global processing of milk products, but the industry organization is different in different countries. Milk is sold directly to the consumers in developing nations, but in the major milk-producing countries, the majority of the milk is sold at the wholesale level. There are numerous farmer-owned large-scale cooperatives in Australia and Ireland, but in the United States, there are two-party contracts that are negotiated between farmers and processors.

Dairy processing plants in top dairy-producing nations have reduced multiple smaller facilities to develop a system with fewer large plants that operate with fewer workers. The United States and Europe along with Australia and New Zealand host the majority of their dairy processing facilities as large operations.

Processing plants that make milk for the market as well as yogurt and cheese along with cream and related products will probably reside in rural areas close to consumer locations. Processing plants which manufacture long-lasting dairy products including butter and milk powder and cheese and whey powder are typically positioned near rural milk-producing regions.

The international trend, however, is towards concentration of large-scale plants with specialization in a narrow range of products. Exceptions are, of course, possible. In Eastern Europe, for instance, there remains the heritage of a supply-led model of the market, with the consequence of the survival of large-scale, multi-product 'city' processing plants making a wide variety of products.

The general tendency towards utilization of gigantic processing plants has given enterprise the means to purchase more massive, mechanized, and more efficient machines. This technological development has,

however, been accompanied by increased environmental effects elsewhere due to the need for long-distance shipment.

Basic dairy processing methods haven't changed much in the last ten years.

Specialized processes, including ultrafiltration (UF), and emerging drying processes, have supplemented the milk solids recovery potential that was previously wasted.

Furthermore, all processing is now energy efficient, and electronic control systems have allowed for greater processing efficiency and cost savings.

Process Overview

Milk Production

The primary activities performed in milk plants include two main processes:

- Raw milk enters the facility for filtering and clarification.
- The plant processes milk fat content through standardized milk production and cream butter fat products together with milk powder production and other products..
- Pasteurization.
- Homogenization, if necessary.
- Deodorizing, if required.
- Last treatment according to the final product intended.
- Packaging and storage, e.g., cold storage for perishable goods.
- Release of finished products.

Butter Production

The manufacture of butter, batch and continuous production, entails the following:

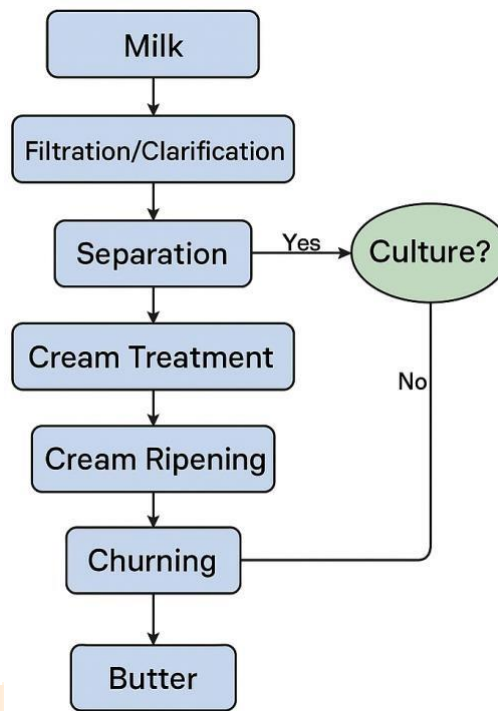
1. Preparation of the cream.
2. Destabilization and breakdown of the fat and water emulsion.
3. Aggregating and concentrating the fat particles such that they form a stable emulsion and ultimately packaged and stored.
4. Distribution.

A flow diagram is shown to depict the basic processing system used in a butter plant.

The initial sequence of operations, like filtration/clarification, separation, and pasteurization of milk, follows the sequence explained in

the above section. Milk intended for use in the manufacture of butter should not be homogenized, as the cream phase has to be separated and distinct.

The process begins by subjecting the separated cream to heat treatment followed by cooling under tightly monitored conditions that enhance butter churning and whipping efficiency. The next step involves ripening the cream by introducing specific cultures to boost diacetyl levels which enhance the butter's flavor profile. The process also allows the introduction of new cultures during the churning stage. The processed butter which develops strong flavors through this method receives the names lactic and ripened and cultured butter. This approach dominates food production in multiple European countries. The product delivers superior flavor yet maintains a shorter storage period. The vast majority of butter produced in English-speaking regions consists of sweet cream butter that does not undergo culturing.



Flow diagram that illustrates processes occurring at a typical milk plant

Cheese Production

The process of creating most cheese varieties consists of causing casein protein from milk to coagulate in a manner that forms a trapped network of milk fats and milk solids inside the curd. Following the formation of curd matrix the structure becomes solid which forces out the liquid component named cheese whey. The milk solids that remain in cheese whey consist almost entirely of lactose and soluble proteins and other substances that are not present in the curd mass.

Describes the general process in a cheese factory. Every process of making cheese entails some or all of the following:

- Milk receipt pretreatment and separation
- Pasteurization
- Addition of starter culture
- Coagulation
- Chopping and processing of curd
- Extraction of whey
- Salting
- Ripening
- Packaging
- Distribution

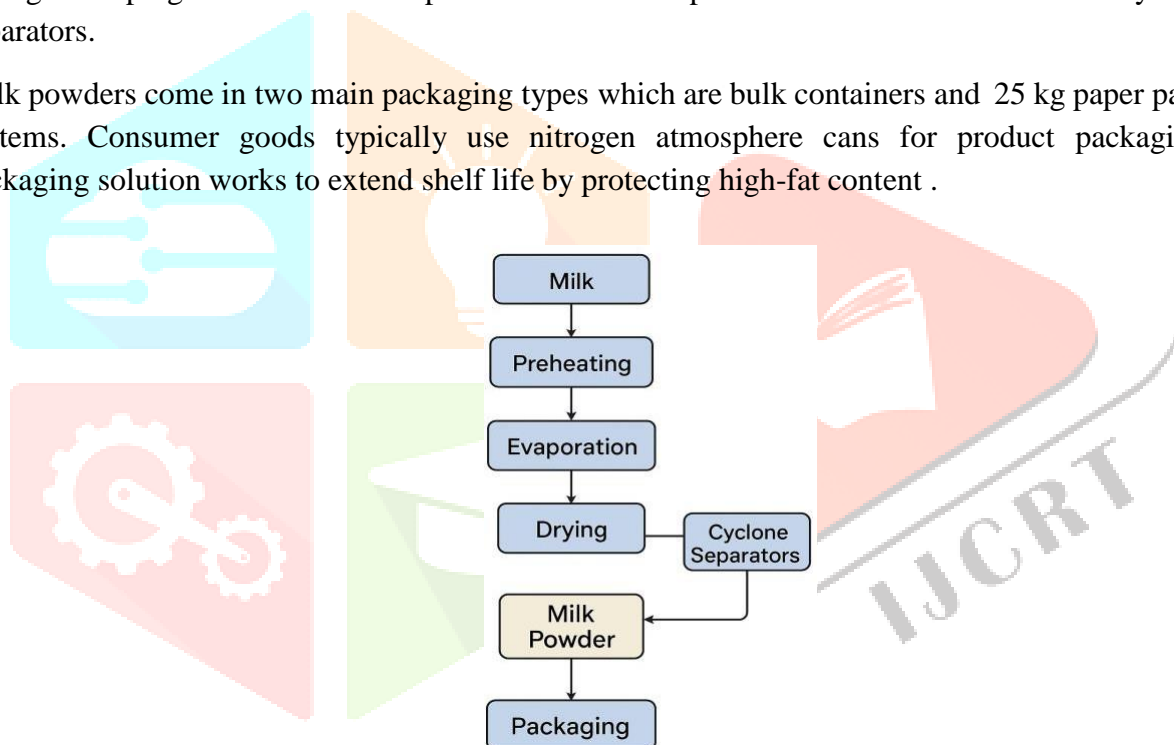
Production of Milk Powder

Milk powder manufacturing operations do not require pasteurization of the total milk or skim milk which serves as feedstock. The preheating operation takes place in tubular heat exchangers immediately before the drying stage. The preheating temperature varies based on seasonal changes as well as the effects on protein stability and the powder's final desired properties.

After reaching high temperatures through the evaporation process the milk passes through an evaporator which increases the total solid concentration. The equipment efficiency and heat levels determine the maximum degree of solid concentration without damaging milk proteins.

The atomiser of a drying chamber receives the concentrated milk through a pump system. The drying chamber works by transforming milk into fine droplets through atomization which occurs inside a high-velocity air stream that leads to immediate droplet evaporation. After evaporation occurs the milk powder collects at the chamber base where it needs to be collected through scraping. The hot air suspends the smaller particles which are eliminated by cyclone separators.

Milk powders come in two main packaging types which are bulk containers and 25 kg paper packaging systems. Consumer goods typically use nitrogen atmosphere cans for product packaging. The packaging solution works to extend shelf life by protecting high-fat content .



Flow diagram illustrating a typical milk drying plant.

Environmental Impacts

The content delivers a quick explanation about the environmental consequences that emerge during initial milk production and dairy processing. The paper examines the environmental impact from dairy product processing while acknowledging that milk production causes substantial ecological effects.

Environmental Effects of Primary Production

Dairy farming has some major environmental issues:

1. The production of solid and liquid manures slurries have the capability to pollute the surface water supply as well as groundwater resources.
2. Application of synthetic fertilizers and pesticides in fodder crop and pasture cultivation also causes surface water and groundwater contamination.
3. Pesticide, antibiotic, and other chemical residues milk contamination is also an issue.

Generally, solid manure

is applied to land and pasture, quantities applied being restricted in some places. Dairy effluent and slurry are normally treated by lagoon sedimentation and biological decomposition before land irrigation. Dairy effluent biological treatment sludge is suitable for use on pasture if it is at suitable regulatory concentration in terms of named pollutants. Sludge may also be employed to produce methane-rich biogas, which can be employed as an energy supply supplement. Manure waste is an important source of nutrient worth. Regardless of this, poor storage and manure and slurry land application can cause extensive surface and groundwater contamination that can pollute drinking supplies.

The extensive use of nitrogenous chemical fertilizers has led to pollution of surface and groundwater in most nations.

Potable water nitrite is a known carcinogen and at levels of above 25–50 mg/L has been implicated in causing infant cyanosis ('blue babies').

Nitrate and phosphate salts dissolved in surface water can cause excessive algal growth (eutrophication). The process leads to the reduction of dissolved oxygen, and therefore fish and other aquatic organisms die. Application rate and mode of chemical fertilizers are hence critical in sensitive areas.

Farmers across the majority of agricultural practices identify pesticide usage as a substantial environmental concern. Toxic chemicals which persist in the environment tend to accumulate in living organisms before causing damage to nature and human health. Through agricultural practices, pesticides spread to pollute crops as well as ground and surface water and in exceptional cases contaminate human food through milk consumption.

The practice of using antibiotics in cattle to fight mastitis has raised major concerns about milk contamination through several decades. Antibiotic milk contamination exists primarily in countries which have well-developed dairy production systems because they enforce strict antibiotic usage limitations along with routine milk antibiotic residue analysis and comprehensive regulatory monitoring and staff training programs. Countries worldwide have instituted programs to examine milk for radioactivity and these nations currently maintain standards for both domestic and imported milk supplies. The processing of milk causes small concentrations of contaminants to accumulate which makes even the slightest pollution levels in milk problematic.

Environmental Effects of Dairy Processing

The main problems faced by dairy processing facilities include excessive water consumption and organic effluent discharge alongside high energy consumption. All dairy processing plants face the same environmental challenges that stem from water overconsumption and the release of effluent with high organic content alongside energy consumption.

Some dairy processing facilities experience additional problems related to noise pollution and unpleasant smells and solid waste generation.

The dairy processing industry requires a substantial amount of fresh water for its operations. The primary purpose of using water in dairy processing facilities is for maintaining sanitation standards through equipment and area cleaning.

The most severe environmental damage caused by dairy processing operations comes from the massive discharge of liquid effluent. The typical characteristics of dairy processing effluents include the following attributes:

1. Higher organic pollution levels because of milk component properties.
2. The system experiences pH changes because of the application of caustic and acidic cleaning agents and related chemicals.
3. These facilities experience higher concentrations of nitrogen and phosphorus.
4. Dairy processing facilities experience temperature changes.

When whey, a byproduct from cheese manufacturing, gets discharged with other wastewaters instead of being reused, it elevates the organic load in the final effluent which intensifies the environmental consequences. The environmental effect of dairy processing effluent requires a brief examination of milk characteristics. The biological composition of milk includes water, milk fat, proteins in both suspended and dissolved forms, lactose milk sugar, and mineral salts.

The dairy food group includes milk elements as well as other ingredients which vary based on product form and processing methods that might include sugar and sodium chloride as well as flavorings and emulsifiers and stabilizers.

Urban areas with nearby factories often channel their industrial waste into municipal sewage systems. Some cities face significant challenges in sewage treatment because local dairy processing plants discharge their effluent into the municipal systems. Waste milk solids entering sewage systems can surpass the organic load of domestic waste in the township under certain extreme circumstances which leads to system failure.

Land in rural areas receives dairy processing effluent as an irrigation water source. The presence of dissolved salts in effluent water leads to negative effects on soil structure and salinity development. The effluent carries pollutants which infiltrate underground water systems thus causing their quality to deteriorate.

1. **Consumption:** - Electricity is necessary for the operation of machinery, refrigeration, ventilation, lighting, and production of compressed air in dairy processing plants. Like water use, energy for cooling and refrigeration has an important role to play in maintaining the quality of dairy products, with storage temperatures often being regulated. Thermal

energy, which mostly comes from steam, serves to provide heat and for cleaning. Energy consumption not only exhausts limited fossil fuel reserves but also leads to air pollution and greenhouse gas emissions, elements that have been implicated in global warming.

2. **Solid Waste:** - Dairy items, such as milk, cream, and yogurt, are usually packaged in plastic-coated paperboard cartons, plastic cups and bottles, plastic bags, or reusable glass bottles. Other items such as butter and cheese are usually wrapped in foil, plastic film, or tiny plastic containers. Milk powders are usually packaged in multi-layered kraft paper sacks or tinned steel cans, while canned milk and others similar to it are often packaged in cans.
3. **Emissions to Air:** - These dairy processing plant emissions are primarily from the high levels of energy intake for production purposes. Steam to support heat process operations like pasteurization, sterilization, and drying typically comes from in-plant boilers. Electricity used for cooling and equipment is derived from the power grid. Air pollutants, such as nitrogen oxides, sulphur oxides, and suspended particulate matter, are produced from the burning of fossil fuels employed in the generation of these energy sources. In addition, milk powder emissions from spray drying plant exhausts can deposit on adjacent surfaces. When these deposits are wet, they have acidic characteristics and, in extreme cases, can cause corrosion.
4. **Refrigerants:-** In operations employing refrigeration systems reliant on chlorofluorocarbons (CFCs), the inadvertent release of these gases into the atmosphere represents a noteworthy environmental concern, given the established role of CFCs in contributing to atmospheric ozone depletion. Consequently, for such operations, the transition from CFC-based systems to systems utilizing non-CFC or reduced-CFC alternatives constitutes a matter of considerable importance.
5. **Noise:-** To produce dried casein factories must utilize hammer mills that serve the purpose of product grinding. The ongoing noise produced by these machines has emerged as a primary reason for upsetting residents in the surrounding neighborhoods. Thermal milk processing and pressure reduction in evaporation operations through steam injection systems create loud sounds.

The dairy plant has no choice but to handle a significant amount of traffic directly because of the continuous milk delivery that takes place 24 hours each day and the regular transport of packaging materials along with frequent product shipments. The selection of plant location requires a thorough evaluation of noise-related aspects.
6. **Hazardous wastes:-** These include oily sludge from gearboxes of mechanical machinery, byproducts of laboratory, cooling mediums, oil-saturated paper filters, batteries, paint cans, and so forth. Presently, in western Europe, some of these wastes are gathered by specialized waste collection companies. Whereas some of the waste is subjected to incineration, a large amount is dumped by landfilling.

Environmental indicators

Environmental indicators play a crucial role in the evaluation of Cleaner Production opportunities and evaluation of the environment performance of the dairy processing industries compared to one another. They provide information concerning the use of resources and production of waste with respect to production capacity.

The flowchart depicted in Figure. shows the total process with overall inputs of resources and outputs as wastes. Sections below will deal with the significant inputs and outputs and will represent the quantitative figures where possible.

Water consumption:-

Dairy production, like most food processing operations, uses a lot of water to clean and sanitize the machinery and building in order to maintain food hygiene standards. A dairy processing plant's water use is broken down by area in Table 2-1, which also provides an estimate of the proportion of water used by each section.

Over the past few decades, the dairy processing industry has seen a notable drop in water consumption as a result of increased water and effluent disposal prices implemented in some countries to account for environmental concerns. The water use reductions per kilogram of product that have been achieved throughout this time are shown in Table 2-3. These improvements can be attributed to improvements in sanitary practices and process control.

Although an average of 1.3 to 2.5 liters of water per kilogram of milk consumed is normal in today's dairy processing facilities, an average of 0.8 to 1.0 liters of water per kilogram of milk drank is conceivable (Bylund, 1995). It takes advanced equipment, excellent cleanliness, and a high degree of awareness among management and staff to achieve such low consumption rates.

TABLE 2–1 WATER CONSUMPTION

Area of water consumption	Extent of water use
Cleaning and sanitising	High
Cooling	Medium
Heating	Medium
Other uses (including feed water, and flushing)	Low
Low	Low

Effluent Discharge

Effluent from dairy processing mainly consists of milk and milk by-products that are lost during processing, in addition to detergents and acidic and caustic cleaning products. The key elements in this wastewater consist of milk fat, protein, lactose lactic acid, sodium, potassium, calcium, and chloride. Milk waste in the effluent flow can range from 0.5% to 2.5% of the input milk reaching 3% to 4%.

The total effluent load of a dairy plant comes from the combined impact of small and, in some instances significant milk losses. These losses happen, for example when workers remove pipes during tank transfers or when they rinse equipment. Table 2–3 shows the various sources of milk losses that end up in the effluent stream.

Scientists measure the organic pollutant concentration in dairy effluent as the 5-day biochemical oxygen demand (BOD5) or as the chemical oxygen demand (COD). A liter of whole milk has about 110,000 mg BOD5 or 210,000 mg COD.

COD levels in dairy plant effluent vary widely from 180 to 23,000 mg/L. Low levels are usually characteristic of milk reception operations, and high levels represent whey from cheese manufacture. An average COD level for dairy plant effluent is about 4000 mg/L. This indicates that some 4% of the milk solids entering the plant are lost to the effluent stream, on the basis of a whole milk COD of 210,000 mg/L and calculated effluent COD loads of about 8.4 kg/m³ of milk intake (Marshall and Harper, 1984).

Surveys carried out in Denmark (see the box below) indicated that dairy processing plant effluent loads to some degree depend on the nature of the product being produced. In addition, the size of operations and use of batch or continuous operations have a major impact on effluent, especially concerning cleaning processes. This is mainly due to the fact that smaller batch operations call for more regular cleaning cycles. The trend in the industry towards bigger plants is, thus, advantageous with respect to decreasing pollutant loading per unit of output.

In 1989, researchers carried out a study involving 72 Danish dairy companies that operated 134 processing plants (Danish EPA, 1991). The products these surveyed firms made included:

- 44 dairies made butter
- 90 produced cheese
- 29 were market milk factories
- 11 created concentrates like milk powder

The plants in the study had up-to-date technology, and most reported a 30–50% drop in effluent pollutant load compared to previous years. The study showed that, on average, each plant generated 1.3 m³ of effluent for every tonne of milk it processed.

The dairy industry's processing sector has long focused on cutting down milk fat loss. This focus stems from old payment structures for raw milk. These structures paid for milk based on its mass or volume, with an extra payment or bonus for milk fat weight. Today's payment structures in many countries recognize the value of non-fat milk parts. Systems to manage both protein and fat loss are everywhere in the industrialized world. However, they're not as common in developing countries.

Processing whey, a cheese byproduct, is a significant issue for the dairy industry. Whey is the liquid remaining after curd derived from milk through an enzyme process. Whey accounts for 80-90% of the total volume of milk used in the whole cheese manufacturing process; whey contains over 50% of the original whole milk solids, of which 20% is protein and contains virtually all of the lactose. Whey has a very high organic content, with a COD around 60,000 mg/L (Morr, 1992). Only in the second half of the twentieth century with advancements in the technology it became economically possible to recover soluble proteins from cheese whey and some recovery of value from lactose.

Most dairy processors acknowledge the fact that fat and protein losses increase the organic load of the effluent stream and that grease traps have been used in most ingredients for several decades (even in developing countries). It seems that most businesses do not directly follow through on the step of reducing organic contamination from other factors affecting milk quality. Increasingly, with legal, or economic constraints, dairy businesses are being forced to reduce the amount of pollutant and contaminant weights and concentrations in their effluent streams.

Thus, in most cases wastewater treatment, or at least pre-treatment must be made, and every effort should be made to achieve a level of organic load that will cause the least possible impact to the environment and which is not hazardous to health. Pretreatment will usually include pH balancing, settling out the solids, and separating the fats.

Energy consumption

Energy is utilized for many processes in dairy processing facilities including operating electric motors in process equipment, heating, evaporation, drying, cooling, refrigeration, and compressed air supply.

Energy needs of the plant is met mostly through combustion of fossil fuels (e.g., oil, gas) which is used to generate steam and hot water for evaporative and heating purposes. About 80 percent of a plant's energy needs are related to combustion of fossil fuels. The remainder (about 20 percent) is met by electricity. Electricity is used to operate electric motors, refrigeration equipment, and lighting.

Energy utilization is dependent on the variability of products that are being made. It is common for operations that involve concentration and drying of milk, whey or buttermilk to require more energy than those operations that manufacture market milk that only include heat treatment and packaging. That said, the specifics of energy usage will depend on the energy consumption pattern for various dairy products.

The amount of energy used also depends upon the size of the plant and the age of the plant coincident with the degree of automation. Generally, plants producing powdered milk will realize a range of efficiencies of energy use due to the various methods of evaporation and drying. The energy consumed is related to the number of effects of evaporation (i.e. how many evaporation units are run in cascade) and how efficiently the powder dryer functions.

The trend towards more automated plants has also generated increased usage of electricity in considerable amounts. This is mainly due to pumping costs as formerly evaporator sizes have also increased and refrigeration costs have increased.

Increased amounts of electricity may also occur from a variety of reasons that are not generally associated with inefficient design considerations, for example, old electric motors, inefficient lighting or lack of sufficient power factor correction.

Conclusion

Dairy farming constitutes an essential agricultural endeavor that underpins rural livelihoods, bolsters food security, and invigorates local economies. The sector has undergone considerable transformation, propelled by advancements in animal husbandry, processing technologies, and supply chain management. Contemporary dairy farms emphasize animal well-being, feeding protocols, and hygiene standards to enhance milk quality. The dairy processing continuum encompasses collection, transportation, processing, packaging, and distribution, with a dedicated emphasis on preserving freshness and quality. Innovative tools and technologies, such as automated milking systems and health monitoring devices, have augmented efficiency and animal welfare. Sustainability is of escalating importance, with farms implementing environmentally conscious practices, including water reuse and manure management. Despite prevailing challenges, such as climate variability, price volatility, and animal health concerns, the industry can ensure resilience and profitability through concerted collaborative initiatives. The trajectory of dairy farming resides in smart farming methodologies, digital integration, and sustainable practices, with an emphasis on transparency, animal welfare, and nutritional innovation. By embracing these emergent trends, the industry can effectively meet evolving consumer preferences and ensure a sustainable future. Key areas of focus encompass the reduction of environmental impact, the enhancement of animal welfare standards, and the development of innovative products that cater to shifting consumer demands.

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