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Paneer: An Indian soft cheese: A comprehensive review

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Abstract

Paneer is a traditional Indian unripened soft cheese produced by acid-heat coagulation of milk, followed by whey separation, pressing and rapid cooling. Its distinctive combination of mild flavour, cohesive body, tender-firm texture and high nutritional density has made it an important component of Indian cuisine and an increasingly significant product in organized dairy processing. However, the high moisture content and nutrient availability of fresh paneer, together with extensive post-heating handling and the absence of ripening-related preservation mechanisms, make the product highly susceptible to microbiological and physicochemical deterioration. This review synthesizes the technological principles governing paneer manufacture, including raw-milk quality, heat treatment, acidification, coagulation, pressing, yield and solids recovery, and relates these variables to physicochemical, nutritional, textural and sensory quality. Current approaches for improving safety and shelf life, including refrigeration, vacuum and modified-atmosphere packaging, hurdle technology, natural antimicrobials, edible coatings, active and intelligent packaging, high-pressure processing and supercritical carbon dioxide, are critically considered. Recent opportunities in value-added and low-fat paneer, whey valorization, sustainable processing and digital quality control are also discussed. An integrated approach combining standardized milk composition, controlled coagulation, hygienic handling, rapid chilling, high-barrier packaging and appropriately validated preservation technologies appears most promising for maintaining fresh-product quality while extending commercial shelf life.

Keywords: Paneer, Indian soft cheese, heat and acid coagulation, yield; texture, shelf life, packaging

Introduction

Paneer occupies a distinctive position among traditional dairy foods because a relatively simple manufacturing sequence produces a versatile, protein-rich fresh cheese. It is an unripened cheese manufactured by acidifying heated milk, separating the resulting curd from whey and pressing the curd into a cohesive mass. Unlike ripened cheeses, paneer is intended for consumption in the fresh state and therefore does not undergo the biochemical and microbiological changes associated with maturation. The same attributes that make paneer attractive—high moisture, soft structure and mild fresh flavour—also contribute to its short shelf life and sensitivity to contamination^[1-3].

The commercial importance of paneer has increased with the expansion of organized dairy processing, urbanization, food-service demand and the wider international consumption of Indian cuisine. At industrial scale, variation in incoming milk composition and processing conditions can produce substantial differences in yield, moisture, firmness, flavour and storage stability. Consequently, standardization of milk composition, calibrated acid addition, controlled coagulation, hygienic curd handling, rapid cooling and appropriate packaging are central to reproducible product quality^[1-2, 30-33].

Historical and Cultural Significance

Paneer is deeply embedded in South Asian food culture and is particularly important in vegetarian cuisine. It is used in curries, snacks, grilled foods, stuffed preparations and ready-to-eat meals. Its relatively neutral flavour and protein-rich structure allow it to absorb spices and sauces while retaining its physical integrity during cooking. The growth of organized dairy processing has progressively transformed paneer from predominantly household and local production into a standardized industrial dairy product^[1-2]. Technologically, paneer differs from many conventional Western cheeses because coagulation is principally achieved

by acidification, commonly after high-temperature treatment, rather than by rennet coagulation followed by ripening. The resulting fresh cheese has a comparatively short production cycle and requires preservation strategies appropriate for a high-moisture unripened product ^[1-2, 30-33].

Definition, Regulatory Identity and Standards

Indian food regulations recognize paneer/chhana as acid-precipitated dairy products manufactured from milk with permitted processing aids and ingredients, as applicable. The supplied source identifies the FSSAI standard for regular paneer as specifying a maximum moisture content of 60% and a minimum milk-fat content of 50% on a dry-matter basis; separate requirements apply to low-fat categories. Because regulatory requirements may be amended, the consolidated FSSAI regulations should be checked against the version in force at the time of submission or publication ^[35].

Conventional Manufacturing Technology

A standardized industrial process generally comprises milk reception and quality assessment, filtration, clarification, standardization, heat treatment, cooling to the coagulation temperature, controlled addition of coagulant solution, coagulation, whey draining, pressing, chilling, packaging and refrigerated storage. Each stage contributes to yield, texture, safety and shelf life of the product. Manual variation in coagulant dosing, coagulation endpoint, curd handling and pressing remains an important source of batch-to-batch inconsistency. mechanized plants can improve reproducibility through calibrated dosing, temperature monitoring, pH control and standardized pressing cycles ^[1-2, 30-33].

Milk Reception and Standardization

Milk intended for paneer should be clean, fresh and free from abnormal acidity, antibiotics and adulterants. Important quality-control parameters include fat, protein, solids-not-fat, total solids, pH, titratable acidity, microbial quality and sensory acceptability. A high initial microbial load can shorten product shelf life even when subsequent heat treatment is adequate ^[1-2]. Buffalo milk has traditionally been preferred because of its relatively high fat and total-solids content. Cow milk can also produce high-quality paneer, although differences in milk composition can influence moisture retention, texture and yield. Mixed milk may provide a practical balance among firmness, yield and sensory properties. Casein is particularly important because it forms the continuous protein network of the curd. Standardization to a target fat and solids composition can reduce batch variability and improve prediction of yield and product composition ^[1-2, 30-33].

Heat Treatment

Heat treatment contributes to microbial reduction and modifies protein functionality. Appropriate heating denatures whey proteins and promotes their interaction with casein, potentially increasing solids recovery. Excessive heating, however, may produce cooked flavour and excessive protein interactions that adversely affect texture. The heating profile should therefore be selected with both microbiological and functional objectives in mind ^[1-2, 30-33].

Coagulation

Coagulant Type and Concentration

Citric and lactic acids are commonly used acidulants. The choice and concentration of coagulant affect the rate of pH decline, curd particle characteristics, whey composition and flavour. Rapid acidification may produce a heterogeneous protein network, whereas insufficient acidification may leave casein incompletely recovered in the whey. Fruit-derived acids and juices have also been investigated as alternative coagulants, with associated changes in composition, texture and microstructure ^[5, 30-33].

Coagulation Temperature and Final pH

Coagulation temperature influences protein-aggregation kinetics and whey expulsion. Temperatures that are too low may produce weak curd formation, whereas excessive temperatures can yield a firm or irregular matrix. The optimum is dependent on milk composition and product specification and should therefore be established experimentally ^[1-2, 30-33]. Final coagulation pH is among the most critical process variables. An endpoint that is too high may leave proteins insufficiently aggregated and increase solids losses into whey, whereas excessive acidification can result in brittle texture and pronounced sourness. A validated pH endpoint is preferable to reliance on visual assessment alone ^[1-2, 30-33].

Whey Separation, Pressing and Cooling and packaging

Whey separation determines the extent of curd-solids recovery, while pressing establishes final moisture, density and mechanical properties. Excessive pressure can produce hard or rubbery paneer, whereas insufficient pressure may yield a weak and overly wet product. Hydraulic or pneumatic pressing can improve reproducibility. Rapid cooling stabilizes the curd structure and helps limit microbial growth before packaging ^[1-2].

Factors affecting quality of paneer

Paneer quality is governed by the interaction of raw-material composition and processing conditions. Important variables include milk protein and casein concentration, fat, total solids, heat treatment, acid type and concentration, acidification rate, coagulation temperature, final pH, curd particle size, whey drainage, pressing pressure and cooling rate. Because these variables interact, optimization of a single factor in isolation may not produce the desired product quality ^[1-2, 30-33].

Milk

Milk intended for paneer should be clean, fresh and free from abnormal acidity, antibiotics and adulterants. Important quality-control measurements include fat, protein, SNF, total solids, pH, titratable acidity, microbial load and sensory acceptability. High microbial counts in raw milk may reduce the effective shelf life even when subsequent heating is adequate because post-process contamination can rapidly dominate storage deterioration. Milk is the major determinant of paneer yield and structure. Buffalo milk, because of its relatively high fat and total solids content, has traditionally been favored for paneer preparation. Cow milk can also produce high-quality paneer but often differs in moisture retention, texture and yield. Mixed milk can provide a useful balance between firmness, yield and

sensory properties. The casein content is particularly important because casein forms the continuous protein network of the curd. Industrial plants should standardize milk to a target fat and SNF composition whenever possible. Standardization reduces batch-to-batch variability and permits prediction of yield and product composition. Protein-to-fat ratio, rather than fat alone, is especially useful for understanding curd-forming potential ^[1-2, 30-33].

Heat treatment

Heating affects both microbial safety and protein functionality. Adequate heat denatures whey proteins and promotes their association with casein, which can increase solids recovery. Excessive heat can produce cooked flavour and excessive protein interactions, potentially altering texture ^[30-33].

Coagulant type and concentration

Citric and lactic acids are widely used in research and practice. The acidulant affects the rate of pH decline, curd particle characteristics, whey composition and flavour. Rapid acidification can create heterogeneous microstructure, while inadequate acidification can cause incomplete recovery of casein ^[30-33].

Coagulation temperature

Coagulation temperature affects the kinetics of protein aggregation and whey expulsion. Too low a temperature may produce weak curd formation, whereas excessive temperature can result in a firm or irregular matrix. The optimum is product- and milk-dependent and should be validated experimentally ^[30-33].

Final pH of the coagulum

Final coagulation pH is one of the most critical variables. A value too high leaves proteins insufficiently aggregated and increases solids losses into whey. A value too low can produce a brittle, sour and overly acidic product. Process control should therefore target a validated endpoint rather than rely solely on visual observation ^[30-33].

Pressing

Pressing removes whey and establishes final moisture and density. Excessive pressure can produce hard, rubbery paneer, whereas insufficient pressure produces weak, wet curd. Automated hydraulic or pneumatic pressing offers improved reproducibility.

Paneer Yield and Solids Recovery

Yield is a major economic indicator in paneer manufacture and may be expressed gravimetrically as the mass of paneer obtained relative to the mass of milk processed. However, gravimetric yield alone can be misleading because a high-moisture product weighs more than a low-moisture product. Industrial assessment should therefore consider both gross yield and component recovery, particularly fat and protein recovery. Higher milk solids generally increase yield, whereas losses of casein and fat into whey can be minimized through controlled coagulation and gentle curd handling. Excessive acidification, cutting or shear may increase fines and solids losses, while excessive pressing can reduce apparent yield through moisture removal ^[1-2, 30-33].

Factors affecting yield of paneer

Milk Composition

Milk composition is one of the strongest determinants of paneer yield because the curd is formed principally from milk proteins together with entrapped fat, minerals and serum components. Milk with higher total solids generally provides more recoverable material per unit mass of milk. In particular, protein and casein are central because casein forms the structural network of the curd, while fat contributes to the mass and is partly retained in the coagulum ^[1-2, 30-33].

- **Protein and casein:** Higher casein availability generally increases the amount of coagulum that can be recovered ^[30-33].
- **Fat:** Higher initial milk-fat levels have been associated with higher paneer yield because part of the fat becomes entrapped in the curd.
- **SNF and total solids:** Increasing recoverable non-fat solids generally increases potential yield.
- **Milk type:** Buffalo milk commonly produces higher paneer yield than cow milk because of differences in fat, protein and total-solids composition.
- **Standardization:** Adjusting milk to a defined fat and SNF composition reduces batch-to-batch variation and improves yield prediction ^[1-2].
- Reported typical yields for paneer containing approximately 51-54% moisture are about 21-23% from buffalo milk and 17-18% from cow milk. These values are not universal targets; they depend on milk composition, standardization and process conditions ^[1-2].

Type of Milk

Buffalo milk has traditionally been preferred for paneer manufacture because its relatively high fat and solids content supports high curd recovery. Cow milk can also produce good-quality paneer, but lower solids and differences in casein and mineral composition can result in lower yield and a softer or more fragile product. The recent literature also recognizes paneer manufacture from other milk sources, including goat, sheep, camel and yak milk. Differences in protein and fat composition can change coagulation behaviour, curd structure and yield, demonstrating that process conditions cannot always be transferred directly between milk types ^[30-33].

Heat Treatment of Milk

Heat treatment affects yield through both microbiological and protein-functional mechanisms. Heating denatures whey proteins, particularly β -lactoglobulin, and promotes their association with casein. Upon acidification, these denatured whey proteins can co-precipitate with the casein network instead of remaining in the whey, thereby increasing total-solids recovery. Heat treatment also affects colloidal calcium phosphate and protein interactions. The literature reports several effective heat-treatment combinations, including approximately 80-90°C with or without a short holding period. The exact optimum depends on milk type and desired product characteristics. Excessive heating, however, may modify texture and flavour and should not be assumed to increase yield indefinitely ^[30-33].

- Insufficient heat treatment may leave more whey protein in the whey and reduce recoverable solids ^[30-33].

- Appropriate heat treatment promotes whey-protein denaturation and co-precipitation.
- Excessive thermal treatment can adversely affect product quality even if solids recovery is improved.

Coagulant Type

Acid coagulation is the central step in paneer formation. Traditional and experimental coagulants include citric, lactic, tartaric, malic, phosphoric and hydrochloric acids, sour or cultured whey and fruit-derived acids or juices. Coagulant selection changes the rate of pH decline, the characteristics of the protein aggregates and the quantity of solids retained in the curd. Recent review evidence also reports interest in calcium lactate and glucono-delta-lactone as alternative coagulants, with potential effects on yield and sensory characteristics. The choice of coagulant should therefore be based on both recovery efficiency and the desired sensory and textural profile [5, 30-33].

Coagulant Concentration and Strength

Coagulant concentration has a major effect on curd formation. The amount required depends on milk type, buffering capacity, coagulant identity and coagulation temperature. Excessive acid strength can promote rapid protein aggregation and produce a dense, hard or brittle curd, while inadequate acidification may leave casein incompletely precipitated and increase protein losses in whey. The objective should be controlled acidification to a validated coagulation endpoint rather than simply maximizing acid addition. This is especially important because excessive acidification can reduce moisture retention and alter the quality of the curd [30-33].

Coagulation Temperature

Coagulation temperature affects protein aggregation, whey expulsion, moisture retention and therefore gravimetric yield. Classical studies reported that increasing coagulation temperature from approximately 60 to 90°C decreased paneer moisture from about 59% to 49%, demonstrating the strong effect of temperature on water retention and product mass. For buffalo milk, coagulation around 70°C has frequently been associated with desirable paneer quality, while cow-milk paneer has often been prepared at higher temperatures. However, the relationship between temperature and yield differs with milk type. The classical literature reports that increasing coagulation temperature reduced buffalo-milk paneer yield but increased cow-milk paneer yield under the conditions studied. Therefore, a universal temperature should not be assumed [30-33].

- Too low a temperature may produce a weak, loose curd and poor whey separation.
- Intermediate temperatures can balance curd strength, moisture retention and sensory quality.
- Excessive temperature can expel more moisture, reducing apparent yield.

Final Coagulation pH

Final coagulation pH is one of the most influential variables affecting paneer yield. Casein aggregation occurs as milk pH is reduced toward the casein isoelectric region. However, the optimum endpoint for paneer is not necessarily the same as the pH at which maximum protein precipitation occurs because product quality and moisture retention must also be considered. The classical literature

reports that lowering coagulation pH from approximately 5.5 toward 5.0 reduced moisture retention and yield. In one study, increasing coagulation pH from 5.1 to 5.4 increased moisture from 50% to 58.6% and yield from 20.8% to 24.8%. Sensory quality, however, was best around pH 5.3-5.35 for buffalo milk, while approximately 5.20-5.25 has been recommended for cow-milk paneer. Thus, higher apparent yield at a higher pH may partly reflect greater moisture retention rather than greater recovery of milk solids. This is a key reason to report both yield and solids recovery [30-33].

Rate and Mode of Acid Addition

The way acid is introduced can influence local pH gradients and curd microstructure. Rapid or poorly mixed acid addition can create localized over-acidification and heterogeneous aggregation, potentially increasing fines and solids losses. Controlled dilution, uniform distribution and appropriate agitation are therefore important for reproducible curd formation [30-33].

Calcium Addition

Calcium salts, particularly calcium chloride, can improve curd formation by influencing protein interactions and calcium-mediated aggregation. The classical review reports that calcium chloride addition increased total-solids recovery and yield under several experimental conditions and was especially useful for improving paneer made from cow milk or diluted milk. Reported concentrations in the literature include approximately 0.08-0.15% CaCl₂ for some cow-milk paneer applications. Such concentrations should not be adopted without process validation because calcium level interacts with milk composition, heat treatment and coagulation conditions [1-2, 30-33].

Homogenization and Milk Pre-treatment

Homogenization can alter fat-globule size and interactions between fat and the protein network. The classical paneer literature reports that homogenization significantly increased yield under some processing conditions. More recent reviews also identify homogenization and other pre-treatments as important determinants of paneer quality. Other emerging pre-treatments, including high-pressure processing and pulsed electric field treatment, have been investigated primarily for quality and microbial effects; their influence on yield should be assessed together with changes in protein functionality and process economics.

Whey Drainage

After coagulation, the curd is allowed to settle and is transferred to a draining cloth or hoop. The extent and rate of whey removal determine how much serum remains associated with the curd before pressing. Excessive loss of fine particles with whey decreases protein and fat recovery, whereas inadequate drainage can produce a wet and weak curd [30-33].

- Large curd particles generally reduce fines losses compared with excessive cutting or agitation.
- Gentle handling helps retain protein and fat within the curd.
- Potable, hygienic process water and equipment are essential because post-coagulation contamination can compromise product safety [30-33].

Curd Cutting, Stirring and Mechanical Losses

Curd handling can influence yield through physical losses of fines. Excessive cutting, stirring or agitation breaks curd particles into small fragments that can escape with whey. Gentle transfer and controlled curd size help minimize these losses. The relationship is particularly important at industrial scale, where mechanical handling can be more intense than in small-batch manufacture.

Pressing Pressure and Pressing Time

Pressing removes whey and establishes the final moisture content and density of paneer. Because water contributes substantially to product mass, pressing pressure and duration have a direct effect on apparent yield. The classical literature reports that moisture content is inversely related to pressing pressure under several experimental conditions. Excessive pressing can reduce mass yield by removing more water and may produce a hard, rubbery product. Insufficient pressing can result in weak, wet paneer. The optimum pressing regime therefore depends on the target moisture content and desired texture rather than yield alone.

Final Moisture Content

Final moisture is one of the most important determinants of gravimetric paneer yield. Two batches with identical recovery of milk solids can have substantially different mass yields if their moisture contents differ. This explains why yield values should always be interpreted together with moisture and total-solids recovery. For commercial manufacturing, the target moisture should be selected according to the product standard, sensory specification, packaging system and intended use. Increasing moisture may increase apparent yield but can simultaneously increase softness and potentially reduce storage stability.

Recovery of Fat and Protein

The yield of paneer depends not only on the amount of milk entering the process but on the proportion of milk fat and protein recovered in the curd. Protein losses occur mainly when casein is not fully precipitated or when curd fines escape into whey. Fat can also be lost through whey and fine curd particles. Therefore, a useful process-development strategy is to measure whey fat, whey protein and total solids in addition to paneer mass. A high-yield process with high whey solids losses may be less efficient than a process with slightly lower moisture but substantially better component recovery [30-33].

Additives and Solids-Enhancing Ingredients

The classical literature reports that certain additives and milk-solids ingredients can increase yield. Examples include calcium salts, sodium chloride and non-fat dry milk, although their effects depend on formulation and product category. Such ingredients should be evaluated for regulatory acceptability, sensory effects and compositional compliance before commercial adoption.

Physicochemical, Textural and sensory Characteristics Physicochemical Properties

Paneer is a multiphase protein-fat-water system in which moisture is held within a casein-rich network containing dispersed fat globules and soluble serum components. Moisture influences hardness, chewiness, water activity and microbial growth; fat contributes flavour and lubrication;

and protein provides the primary mechanical framework. Routine instrumental assessment may include moisture, fat, protein, ash, pH, titratable acidity, free fatty acids, peroxide value, texture-profile parameters, colour and microbiological counts. Analytical methods and replication should be clearly reported in research studies [20, 30-33].

Texture

The texture of paneer is characterized by a continuous or semi-continuous protein phase with dispersed fat and entrapped serum. The density and connectivity of the protein network determine hardness, cohesiveness and water retention. Buffalo-milk paneer generally tends to form a denser and firmer structure than cow-milk paneer because of differences in milk composition. Texture-profile analysis commonly evaluates hardness, cohesiveness, springiness, gumminess and chewiness. Instrumental measurements should be interpreted alongside sensory firmness because very high mechanical strength does not necessarily correspond to consumer preference [1-2].

Sensory Quality

Acceptable paneer should exhibit a clean white to creamy-white appearance, a mild milky and slightly acidic flavour, a cohesive body and a tender-firm texture. Excessive sourness may indicate over-acidification or microbial activity, bitterness may accompany proteolysis, and rancidity may indicate lipid oxidation. Sensory evaluation should use standardized scales covering appearance, flavour, body, texture and overall acceptability [30-33].

Packaging

Packaging serves as a barrier against contamination, oxygen exposure, moisture loss, physical damage and environmental odours. Conventional polymeric films remain widely used because of their cost and barrier performance. Vacuum packaging reduces oxygen and external contamination, while multilayer structures can improve oxygen and moisture barrier properties.

Vacuum Packaging

Vacuum packaging is comparatively simple to implement and can reduce oxygen exposure. Its effectiveness depends on adequate seal integrity and uninterrupted refrigeration.

Modified-Atmosphere Packaging

Modified-atmosphere packaging (MAP) replaces air with a selected gas mixture, commonly involving carbon dioxide and nitrogen. Carbon dioxide can inhibit many spoilage microorganisms, whereas nitrogen functions primarily as an inert filler. Gas composition, film permeability, headspace and storage temperature must be optimized as an integrated system. Studies on paneer have reported improved storage stability when MAP is combined with hurdle approaches [4, 17-18].

Active and Intelligent Packaging

Active packaging may incorporate oxygen scavengers, antimicrobial agents, moisture regulators or antioxidant systems, providing sustained protection while potentially reducing direct preservative addition. Intelligent packaging can provide information about time-temperature history, oxygen exposure or spoilage status and may be integrated

with cold-chain monitoring to support quality assurance and reduce food waste [24, 27].

Edible Coatings

Edible coatings can form a thin protective layer on the paneer surface and may provide oxygen and moisture barriers while serving as carriers for antimicrobial or antioxidant compounds. Materials investigated in dairy applications include whey proteins, casein, gelatin, chitosan, alginate, pectin, starch and cellulose derivatives. Whey-based coatings are particularly attractive because they provide an opportunity to valorize a dairy by-product. Recent studies have examined whey-based antimicrobial coatings for paneer preservation. Further development should address coating uniformity, adhesion, mechanical stability, sensory neutrality, drying or setting time, regulatory compliance and high-throughput industrial application [6, 13-16, 30-33].

Application of novel technologies and advances in paneer making.

Hurdle Technology

Hurdle technology combines multiple preservation factors, each applied at a moderate intensity. Potential hurdles for paneer include heat treatment, acidification, refrigeration, reduced oxygen, carbon dioxide, reduced water activity, natural antimicrobials and hygienic packaging. The objective is to create a combined environment that microorganisms cannot readily overcome while avoiding the severe treatment conditions that may compromise fresh texture and flavour. Hurdle systems should be validated through challenge studies and shelf-life trials conducted under realistic commercial distribution conditions [20, 30-33].

Natural Antimicrobials and Bioactive Ingredients

Interest in clean-label preservation has stimulated research on plant-derived antimicrobials and antioxidants. Essential oils and extracts from clove, oregano, lemongrass, rosemary, turmeric, black pepper and other plants have been investigated for antimicrobial or antioxidant effects in paneer and related dairy products. A central limitation is sensory impact: concentrations required for antimicrobial efficacy may impart strong flavours or aromas. Encapsulation and controlled-release coating systems may help separate antimicrobial performance from sensory intensity. Product-specific optimization is essential because consumer acceptance must be considered alongside microbial efficacy [7].

High-Pressure Processing and Other Non-Thermal Technologies

High-pressure processing (HPP) is a non-thermal preservation technology capable of reducing microbial populations while limiting some of the thermal damage associated with conventional heat processing. Pressure can affect microbial cell membranes, proteins and other cellular structures, although food matrices respond differently depending on composition and pressure history. Research on paneer indicates that treatment of milk by HPP can influence yield and texture, while HPP combined with lactic-acid treatment may delay microbial deterioration during refrigerated storage. The major limitations of HPP include capital cost, batch or semi-continuous equipment requirements, possible pressure-induced texture changes and

the need for validated process conditions. Commercial adoption is most plausible where extended distribution and product value can justify investment [1-3, 11, 28-29].

Ohmic Heating and Irradiation

Ohmic heating provides rapid volumetric heating through electrical resistance and may offer uniform temperature distribution. Evidence specific to paneer remains more limited than for conventional heating, and its benefits should be assessed against optimized thermal processing. Irradiation has also been investigated for microbial control, although regulatory requirements and consumer acceptance remain important considerations [19, 21-23].

Value-Added and Functional Paneer

Paneer is a suitable matrix for incorporating herbs, spices, vegetables, fruit-derived ingredients, dietary fibre, plant proteins and antioxidant compounds. Such formulations can diversify the product portfolio and increase nutritional or functional value. Reported concepts include carrot, turmeric, black pepper, cardamom, garlic, lemongrass and fruit-peel-derived ingredients [5, 7].

Low-Fat Paneer

Reducing milk fat can lower energy density but often produces a firmer, less lubricated and less flavourful product. The relative dominance of the protein network and altered water distribution can adversely affect texture and eating quality. Potential strategies include the use of whey protein concentrates, milk protein concentrates, hydrocolloids, dietary fibres, microparticulated proteins and process optimization. Future research should evaluate fat reduction in conjunction with protein-network structure, lubrication, water distribution, sensory acceptability and cooking behaviour rather than treating fat content as the sole target [30-33].

Shelf Life and Storage

Fresh paneer traditionally has a short shelf life because its high moisture content, relatively permissive pH range, extensive handling and lack of ripening-related preservation mechanisms provide favourable conditions for microbial deterioration. Shelf life is determined by initial microbial load, post-process contamination, storage temperature, packaging, moisture migration and oxygen exposure [1-3].

A scientifically designed shelf-life study should assess microbiological, chemical, physical and sensory endpoints rather than rely on a single indicator. Relevant variables include total viable counts, coliforms or Enterobacteriaceae where appropriate, yeasts and moulds, pH, acidity, moisture, texture, colour, lipid oxidation, sensory acceptability and package integrity.

Research Gaps and Future Directions

Despite substantial progress, several important research gaps remain. First, predictive models are needed to connect milk composition with optimum coagulation and pressing conditions. Second, shelf-life studies should use standardized challenge organisms and realistic commercial temperature profiles. Third, edible coatings and active packaging require industrial-scale application systems together with migration and regulatory assessment. Fourth, HPP and other non-thermal technologies should be compared economically with MAP and conventional

refrigerated storage. Future work should also integrate microscopy and spectroscopy for microstructural characterization, low-field nuclear magnetic resonance for water distribution, advanced analytical methods for protein interactions and machine-learning approaches for digital process monitoring [1-2, 4, 11, 17-18, 24, 28-33].

Conclusion

Paneer is an important Indian soft cheese with substantial nutritional, cultural and commercial significance. Its manufacture is based on a relatively simple sequence of heat treatment, acid coagulation, whey separation, pressing and cooling, yet each stage is sensitive to milk composition and process control. Protein, casein, fat and total solids strongly influence yield and structure, whereas coagulation temperature, acid concentration, final pH and pressing determine microstructure and texture. The principal limitation of conventional paneer is its short shelf life, driven by high moisture, nutrient availability and opportunities for post-process contamination [1-3, 30-33].

Modern preservation technologies—including vacuum and modified-atmosphere packaging, hurdle technology, edible coatings, natural antimicrobials, active packaging, HPP and supercritical CO₂—provide opportunities to improve storage stability. Integrated preservation systems are likely to be more effective than reliance on a single hurdle because they can distribute the preservation burden across several moderate interventions while better retaining fresh-product characteristics. Whey-derived edible coatings are particularly promising because they couple preservation with by-product valorization [10-11, 24, 28-29].

The future development of paneer should focus on standardized, data-driven manufacturing that links milk composition, coagulation chemistry, solids recovery, microstructure, packaging and cold-chain history. Industrial validation, consumer acceptance, cost analysis, sustainability assessment and regulatory compliance should accompany laboratory-scale innovation. Such integration could support the transition of paneer from a highly perishable traditional product to a consistently manufactured, safe, nutritionally valuable and globally marketable Indian dairy specialty [1-2, 30-33].

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