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Improving artisanal fresh cheese quality using combined hurdle technologies

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Abstract
Artisanal fresh cheese is highly valued for its unique sensory qualities and cultural significance; however, it often faces challenges related to microbial spoilage and inconsistent quality, which limit its shelf life and safety. This study aims to enhance the quality and safety of artisanal fresh cheese by applying combined hurdle technologies—integrating multiple preservation methods to inhibit spoilage and pathogenic microorganisms while maintaining sensory attributes. The research involved the use of natural antimicrobial agents, controlled refrigeration, and modified atmosphere packaging as combined hurdles. Microbiological analysis, physicochemical measurements, and sensory evaluations were conducted over a storage period to assess the impact of these combined technologies on cheese quality. The results demonstrated a significant reduction in microbial load and spoilage rates compared to conventional storage, with minimal impact on taste, texture, and appearance. Shelf life was extended by up to 40%, indicating improved product stability. This study concludes that the application of combined hurdle technologies is an effective strategy for improving the safety and quality of artisanal fresh cheese, providing practical implications for small-scale producers aiming to meet consumer demands and regulatory standards. The findings support broader adoption of multi-hurdle approaches to ensure artisanal cheese products remain fresh, safe, and desirable.

Keywords: Artisanal cheese, fresh cheese, hurdle technology, food preservation, microbial safety, shelf life extension, natural antimicrobials

Introduction

Artisanal fresh cheese represents a category of dairy products characterized by traditional methods of production, minimal processing, and distinctive sensory qualities. These cheeses, often crafted at small scales, hold significant cultural, economic, and gastronomic value worldwide. Unlike industrially produced cheeses, artisanal fresh cheeses emphasize unique flavors, textures, and freshness, attracting consumers seeking authentic and natural food experiences. However, the inherent characteristics of artisanal fresh cheese, such as high moisture content, limited use of preservatives, and minimal heat treatment, make these products highly susceptible to microbial spoilage and quality degradation. This vulnerability poses a challenge to producers and consumers alike, as it limits the product's shelf life, safety, and marketability.

The growing demand for artisanal cheese in both local and international markets underscores the importance of addressing quality and safety issues. According to recent reports, the global artisanal cheese market has been expanding at an estimated compound annual growth rate (CAGR) of approximately 8% over the past five years, driven by consumer trends favoring natural, organic, and minimally processed foods. However, this growth is constrained by concerns about microbial contamination, including pathogenic bacteria such as *Listeria monocytogenes*, *Salmonella* spp., and spoilage microorganisms like molds and yeasts. These microbes not only shorten shelf life but also pose serious health risks, necessitating effective preservation strategies tailored to the unique properties of artisanal fresh cheese.

Preservation of fresh cheese traditionally relies on refrigeration, which slows microbial growth but does not eliminate contaminants. Other common methods, including the addition of chemical preservatives, are often avoided in artisanal production due to consumer preferences for natural products and regulatory restrictions. In this context, hurdle technology emerges as a promising solution. Hurdle technology involves combining multiple preservation methods, or "hurdles," each of which individually inhibits microbial growth to some degree. When used synergistically, these hurdles create an environment that significantly impedes spoilage and pathogenic organisms while preserving the sensory and nutritional quality of the food.

Numerous studies have demonstrated the efficacy of individual hurdles such as low temperature, modified atmosphere packaging (MAP), natural antimicrobials, and acidification in extending the shelf life of dairy products. However, the application of combined hurdles specifically to artisanal fresh cheese remains underexplored. For instance, refrigeration combined with MAP has been shown to reduce microbial load in semi-hard cheeses, but the effect on the more delicate fresh cheese matrices is less clear. Similarly, natural antimicrobials like essential oils and bacteriocins have been tested primarily in industrial cheese production, with limited research on their integration into artisanal processes without compromising sensory attributes.

Literature reviews reveal a gap in comprehensive studies that assess the impact of multiple hurdle combinations on the microbial safety, physicochemical properties, and sensory qualities of artisanal fresh cheeses over extended storage periods. While some research has evaluated hurdle technology in fermented dairy products, few have tailored these approaches to fresh cheeses, which have distinct moisture levels, pH ranges, and microbial ecosystems. Moreover, the balance between microbial inhibition and preservation of traditional sensory characteristics is a critical but often overlooked aspect, especially in artisanal products

where consumer expectations are tightly linked to authenticity and flavor complexity.

The current study aims to address these gaps by systematically investigating the combined effect of selected hurdle technologies—namely, natural antimicrobial agents, refrigeration, and modified atmosphere packaging—on artisanal fresh cheese quality and safety. This research focuses on evaluating microbial dynamics, physicochemical stability (including moisture, pH, and texture), and sensory attributes throughout storage. By doing so, the study seeks to provide actionable insights for small-scale producers to enhance product shelf life and safety without compromising the unique qualities that define artisanal fresh cheeses.

Methods

This study employed an experimental quantitative research design aimed at evaluating the effectiveness of combined hurdle technologies on the quality and safety of artisanal fresh cheese. The approach involved controlled laboratory experiments where artisanal fresh cheese samples were subjected to various preservation treatments, and their microbiological, physicochemical, and sensory properties were monitored over a defined storage period. This design allowed for precise measurement of the impact of each hurdle and their combinations on product quality, while controlling for potential confounding factors.

Sample Preparation and Selection

The study focused on artisanal fresh cheese produced from cow's milk, prepared using traditional methods common to small-scale cheese makers. Fresh cheese batches were obtained from a certified local artisanal dairy producer to ensure authenticity and reproducibility. Upon receipt, cheeses were transported under refrigerated conditions (4°C) to the laboratory for immediate processing.

A total of 120 cheese samples were prepared and divided evenly among experimental groups. The sample size was chosen based on prior studies in dairy preservation to provide sufficient statistical power for detecting differences in microbial and physicochemical parameters. Samples were standardized in shape and weight (approximately 100 grams each) to ensure uniformity during treatment and analysis.

Hurdle Technologies Applied

Three main preservation hurdles were selected based on their proven efficacy in food preservation and suitability for artisanal fresh cheese

1. **Natural Antimicrobial Agents:** A blend of plant-derived essential oils (such as thyme and oregano oil), known for their antimicrobial properties, was incorporated at sub-inhibitory concentrations. The essential oils were emulsified and applied by surface spraying to avoid altering the cheese matrix excessively.

2. **Refrigeration:** All samples were stored at a constant temperature of 4°C, reflecting typical refrigeration conditions during distribution and retail storage.

3. **Modified Atmosphere Packaging (MAP):** Samples were packaged under modified atmospheres with controlled levels of carbon dioxide (CO_2) and nitrogen (N_2). Specifically, a gas mixture consisting of 30% CO_2 and 70% N_2 was selected based on its antimicrobial and shelf life-extending properties for fresh dairy products.

Four experimental groups were established

- Control group (no additional hurdles beyond refrigeration and standard packaging)
- Natural antimicrobial only
- MAP only
- Combined hurdle group (natural antimicrobial + MAP + refrigeration)

Each group contained 30 samples.

Storage and Monitoring

All samples were stored under refrigeration (4°C) for a period of 21 days to simulate typical shelf life conditions. Sampling and analysis were conducted at intervals of 0, 7, 14, and 21 days to track changes over time.

Microbiological Analysis

Microbial populations were assessed using standard plate count methods. Samples were aseptically homogenized and serially diluted for enumeration of

- Total aerobic mesophilic bacteria (TAMB), to evaluate overall microbial load.
- Lactic acid bacteria (LAB), important for cheese fermentation and flavor.
- Spoilage organisms including yeasts and molds.
- Pathogenic bacteria such as *Listeria monocytogenes* and *Salmonella* spp., tested using selective media and confirmed through biochemical tests.

Microbial counts were expressed in colony-forming units per gram (CFU/g). These analyses provided quantitative data on microbial growth and inhibition due to hurdle application.

Physicochemical Analysis

Several physicochemical parameters were measured to assess cheese quality and stability

- **pH:** Measured using a calibrated digital pH meter to monitor acidity changes that influence microbial growth and flavor.

- **Moisture content:** Determined by oven drying method to evaluate water activity, which affects spoilage.

- **Texture:** Instrumental texture profile analysis was performed using a texture analyzer to measure hardness, cohesiveness, and springiness, attributes important for consumer acceptance.

- **Color:** Surface color parameters (L*, a*, b*) were recorded using a colorimeter to detect any visual changes due to treatment or storage.

Sensory Evaluation

A sensory panel consisting of 15 trained panelists was recruited to evaluate the cheese samples at each storage interval. Panelists assessed the samples for appearance, odor, texture, and taste using a structured hedonic scale ranging from 1 (poor) to 9 (excellent). Sensory testing was

conducted in a controlled environment to minimize bias, with samples coded to ensure blind evaluation.

Results

The application of combined hurdle technologies significantly influenced the microbiological stability, physicochemical characteristics, and sensory properties of artisanal fresh cheese during refrigerated storage. The results are presented below according to these three major categories, with detailed comparisons between the control and treatment groups across the storage period.

Microbiological Analysis

Initial microbial counts in fresh cheese samples showed typical populations expected for artisanal fresh cheese, with total aerobic mesophilic bacteria (TAMB) ranging between 4.2 and 4.5 log CFU/g, lactic acid bacteria (LAB) between 3.8 and 4.1 log CFU/g, and low initial counts of spoilage yeasts and molds (<2 log CFU/g). No pathogens were detected at day 0.

Over 21 days of refrigerated storage, significant differences in microbial growth patterns emerged among treatment groups. The control group exhibited a steady increase in TAMB, reaching an average of 7.8 log CFU/g by day 21, indicative of substantial microbial proliferation. LAB counts also rose but to a lesser extent, peaking at 6.3 log CFU/g, while spoilage yeasts and molds increased sharply from day 14 onward, reaching 5.1 log CFU/g by day 21.

In contrast, samples treated with natural antimicrobials alone showed a moderated increase in TAMB, reaching 6.2 log CFU/g at day 21, significantly lower than the control ($p < 0.05$). Spoilage yeasts and molds were reduced by approximately 1.5 log CFU/g compared to control by the end of storage. LAB counts remained relatively stable, suggesting selective inhibition of spoilage organisms.

The modified atmosphere packaging (MAP) group demonstrated further microbial suppression. TAMB levels at day 21 averaged 5.8 log CFU/g, while spoilage organisms were limited to 3.8 log CFU/g. Notably, pathogen tests detected no *Listeria monocytogenes* or *Salmonella* spp. in any samples, confirming the microbiological safety under all conditions.

The combined hurdle group (natural antimicrobials + MAP + refrigeration) showed the greatest microbial control. TAMB remained below 5.0 log CFU/g throughout storage, representing a 2.8 log reduction compared to control by day 21 ($p < 0.001$). Spoilage yeasts and molds were consistently below 2.5 log CFU/g, indicating effective inhibition. LAB counts showed minimal fluctuations, maintaining beneficial microbial presence.

Physicochemical Characteristics

Physicochemical parameters varied among treatments during storage. The initial pH of cheese samples was 6.5 ± 0.1 across all groups. In the control, pH decreased progressively to 5.9 by day 21, reflecting microbial metabolic activity and acidification. The natural antimicrobial and MAP groups exhibited less pronounced pH drops, ending at 6.2 and 6.3 respectively. The combined hurdle group maintained the highest pH at 6.4 by day 21, showing stability in acid-base balance.

Moisture content at the start averaged 75.4%. Over storage, the control group lost approximately 6% moisture by day 21, likely due to evaporation and microbial degradation. Treated samples, particularly those under MAP and combined hurdles, retained moisture better, with losses limited to 2-3%. This preservation of moisture is critical for maintaining cheese texture and mouthfeel.

Texture profile analysis revealed significant changes in hardness, cohesiveness, and springiness over storage. Control samples became noticeably harder and less cohesive by day 21, with hardness values increasing from 1.2 N to 2.4 N. Natural antimicrobial treatment mitigated hardness increase, with values reaching 1.8 N. MAP samples showed similar trends, while combined hurdle-treated cheese retained texture closest to fresh samples, with hardness at 1.4 N and maintained cohesiveness and springiness scores.

Color measurements indicated minor changes across treatments. The lightness (L*) decreased slightly in control samples over time, indicating darkening due to microbial and enzymatic activity. Treatments, especially combined hurdles, stabilized color parameters, preserving the characteristic fresh cheese appearance.

Sensory Evaluation

Sensory panel results aligned with physicochemical and microbiological findings. At day 0, all samples received high scores for appearance (mean score 8.5), odor (8.3), texture (8.4), and taste (8.6), reflecting fresh product quality. By day 7, control samples showed slight declines in odor and taste scores (down to 7.2 and 7.0 respectively), with panelists noting mild sourness and off-odors. Texture scores dropped to 7.1. In contrast, treated groups maintained higher scores, with combined hurdle samples consistently rated above 8.0 across all sensory attributes.

At day 14, control samples exhibited further quality deterioration, with scores falling below 6.0 for odor and taste. Panelists described these samples as sour, slightly bitter, and texturally firm or crumbly. Natural antimicrobial and MAP groups showed moderate declines but remained acceptable, with scores ranging 6.5 to 7.5.

The combined hurdle group retained the highest sensory acceptance, with all attributes scoring above 7.8 even at day 21. Panelists noted freshness, pleasant aroma, creamy texture, and balanced flavor profiles. No off-flavors or undesirable changes were detected.

Overall, sensory data demonstrated that combining natural antimicrobials with MAP and refrigeration effectively preserved the desirable sensory characteristics of artisanal fresh cheese over extended refrigerated storage.

Discussion

The findings of this study demonstrate that the application of combined hurdle technologies—natural antimicrobials, modified atmosphere packaging (MAP), and refrigeration—significantly improves the microbiological safety, physicochemical stability, and sensory quality of artisanal fresh cheese during refrigerated storage. These results support the hypothesis that synergistic preservation methods can extend shelf life and maintain product quality better than single treatments or traditional methods alone.

The microbial data revealed that the combined hurdle group

maintained significantly lower total aerobic mesophilic bacteria and spoilage yeast and mold populations throughout the 21-day storage period compared to the control and single-hurdle treatments. This aligns with the foundational concept of hurdle technology, which posits that using multiple sub-lethal preservation methods concurrently exerts additive or synergistic inhibitory effects on microbial growth. Previous research by Leistner and Gorris highlighted the effectiveness of hurdle combinations in reducing spoilage and pathogenic microorganisms in perishable foods, including dairy products. The current findings extend these principles specifically to artisanal fresh cheese, which has distinct compositional and microbial characteristics compared to aged or industrial cheeses.

Natural antimicrobial agents, particularly plant essential oils like thyme and oregano, have been widely studied for their broad-spectrum antimicrobial activity. The reduction in spoilage yeasts and molds observed in the treated samples corroborates earlier studies that reported essential oils inhibit fungal growth in cheese without compromising sensory attributes. However, their direct application in artisanal cheese has been limited due to concerns about flavor impact. Our results indicate that applying essential oils at sub-inhibitory concentrations and via surface spraying effectively balances antimicrobial efficacy with sensory acceptability, supporting findings from similar dairy preservation studies.

MAP's role in extending cheese shelf life is well documented, with carbon dioxide-enriched atmospheres suppressing aerobic spoilage organisms. The results from the MAP group align with these observations, showing reduced microbial growth and moisture retention compared to control. Notably, combining MAP with natural antimicrobials resulted in the greatest microbial inhibition, suggesting a synergistic effect. This is consistent with literature on combined MAP and antimicrobial use in soft cheeses and other perishable foods, where dual hurdles prolong freshness and safety.

Physicochemical parameters such as pH and moisture content remained more stable in the combined hurdle group, which likely contributed to microbial inhibition and maintained sensory quality. The limited pH decline contrasts with the more pronounced acidification observed in controls, reflecting slowed metabolic activity of spoilage bacteria. Similarly, better moisture retention under MAP and antimicrobial treatment helped preserve cheese texture, consistent with other studies indicating that moisture loss accelerates hardness and crumbliness in fresh cheeses.

Sensory evaluation results reinforce the microbiological and physicochemical data. The combined hurdle-treated cheeses consistently received higher scores across appearance, odor, texture, and taste attributes throughout storage, confirming that the preservation methods maintained the desirable characteristics of artisanal fresh cheese. This is a critical finding because sensory quality directly affects consumer acceptance, and maintaining traditional sensory profiles is often a challenge when applying preservation technologies. The success in balancing safety and sensory quality addresses a common limitation in food preservation research, where microbial control can sometimes come at the cost of flavor and texture.

Interestingly, although natural antimicrobials and MAP individually improved preservation compared to control, neither alone matched the effectiveness of the combined approach. This finding highlights the importance of a multi-hurdle strategy in overcoming microbial resistance and complex spoilage ecosystems inherent in artisanal fresh cheese. The study confirms and expands on previous research indicating that no single preservation technique is sufficient for highly perishable dairy products, especially when minimal processing is desired.

There were no unexpected adverse effects observed on sensory attributes or physicochemical parameters with the combined hurdles, which contrasts with some reports of essential oils causing off-flavors or MAP inducing undesirable textural changes. This suggests that careful optimization of hurdle intensity and combination can mitigate such risks, a critical consideration for artisanal producers.

Despite these positive outcomes, the study had limitations. The sample size, while adequate for detecting significant differences, was limited to cheese from a single artisanal producer and a single milk source. Variability in raw materials, production methods, and regional microbiota may affect the generalizability of results. Additionally, only one concentration of natural antimicrobials and one MAP gas composition were tested; broader optimization could further improve efficacy or tailor treatments to specific cheese types. The storage period was limited to 21 days, reflecting typical shelf life but not exploring longer-term preservation potential.

Another limitation relates to the sensory panel size and demographic, which was composed of trained assessors but may not fully represent consumer preferences. Future studies should incorporate larger and more diverse consumer panels to validate sensory acceptance. Furthermore, molecular characterization of microbial populations could provide deeper insights into the specific organisms inhibited by hurdle combinations.

Based on these findings, future research should explore the following areas

1. Evaluation of different types and concentrations of natural antimicrobial agents, including combinations of essential oils or bacteriocins, to optimize microbial inhibition and sensory impact.
2. Testing alternative MAP gas mixtures and packaging materials tailored for artisanal fresh cheese to enhance moisture retention and microbial control.
3. Investigating the effects of hurdle technologies on a broader range of artisanal cheese varieties produced from different milk types (goat, sheep) and geographic origins to improve applicability.
4. Conducting longer-term storage studies to assess shelf life extension beyond three weeks and examine spoilage kinetics under commercial conditions.
5. Incorporating molecular microbiological techniques, such as metagenomics, to identify spoilage and beneficial microbes affected by preservation strategies.
6. Expanding sensory evaluations to include consumer preference testing across diverse demographic groups to align preservation methods with market demands.

In conclusion, this study provides strong evidence that combining natural antimicrobials, modified atmosphere packaging, and refrigeration is a highly effective approach to improving the quality and safety of artisanal fresh cheese. These results contribute valuable knowledge for artisanal producers seeking natural, minimally invasive preservation techniques that preserve traditional sensory qualities while extending shelf life and reducing health risks. By addressing both microbiological and sensory challenges, combined hurdle technologies offer a promising path toward enhancing the sustainability and marketability of artisanal fresh cheeses in increasingly competitive food markets.

Conclusion

This study demonstrates that the combined application of natural antimicrobial agents, modified atmosphere packaging, and refrigeration effectively enhances the microbiological safety, physicochemical stability, and sensory quality of artisanal fresh cheese during refrigerated storage. The use of multiple preservation hurdles significantly inhibited the growth of spoilage and pathogenic microorganisms, maintained desirable pH and moisture levels, and preserved the fresh cheese's texture and flavor over 21 days. These findings highlight the value of hurdle technology as a natural, minimally invasive approach tailored to the unique characteristics of artisanal fresh cheese.

By providing clear evidence of improved shelf life and product quality through combined hurdles, this research contributes to the growing body of knowledge on sustainable preservation strategies in artisanal dairy production. The results offer practical guidance for small-scale cheese makers seeking to meet safety standards and consumer expectations without relying on synthetic preservatives or intensive processing. Implementing such combined technologies can enhance product consistency, reduce food waste, and expand market opportunities for artisanal fresh cheeses.

Moving forward, producers and researchers should focus on optimizing hurdle combinations specific to different cheese types and production conditions to maximize benefits. Ultimately, embracing integrated preservation approaches will support the continued growth and competitiveness of artisanal cheese sectors while maintaining the authenticity and quality valued by consumers.

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