Impact of ceramic packaging on the quality and safety of Armenian fermented dairy product Matsoun

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ABSTRACT

Background: Packaging is essential for food safety, as it acts as a barrier against contaminants that can cause spoilage and affect human health. The Armenian fermented dairy product, matsoun, is packaged not only in plastic and glass but also in clay pots. However, the impact of traditional packaging on the quality and safety of matsoun, especially heavy metal migration, remains under-researched.

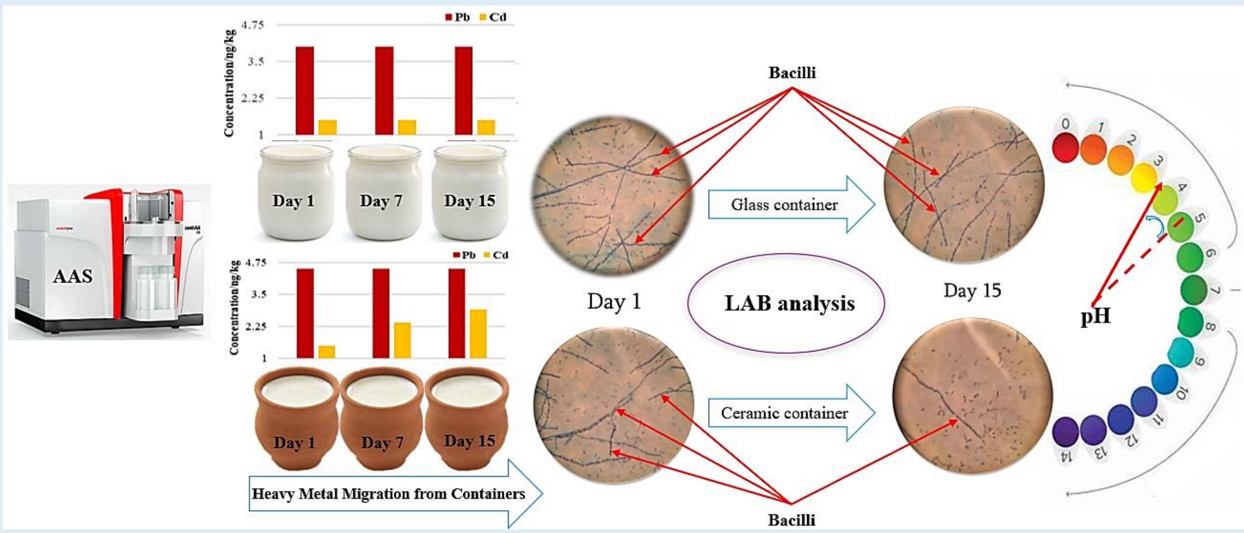
Objective: This study aimed to investigate the impact of ceramic packaging material on the quality and safety of matsoun during storage. Specifically, it compared the physicochemical properties (pH, titratable acidity), lactic acid bacteria (LAB) populations, and metal migration during storage.

Methods: Six samples of matsoun were prepared and packaged in sterilized glass and ceramic containers. The samples were stored at 4 °C and analyzed on days 1, 7, and 15 of storage. The parameters measured included pH, titratable acidity, and LAB counts (coccus and bacillus). Heavy metal migration (Cd, Pb, Hg, As) was analyzed using atomic absorption spectroscopy.

Results: The pH of samples packaged in ceramic and glass containers decreased over 15 days of storage, from 4.61 to 4.24 and 4.6 to 4.27, respectively. Titratable acidity increased in both groups, reaching 1.2 % lactic acid. A decrease in bacilli was observed in ceramic-packaged matsoun. The lead concentration remained constant at 0.0045 ppm across all samples. In ceramic containers, cadmium concentration increased from 0.0015 ppm to 0.0029 ppm by day 15.

Conclusion: This study observed a decrease in pH, an increase in titratable acidity, and a relatively constant number of lactic acid bacteria indicating ongoing fermentation. The results showed nondetectable concentrations of arsenic (As) and mercury (Hg). The lead (Pb) concentration in all samples remained within the World Health Organization's (WHO) allowed limit of 0.02 ppm. However, the concentration of cadmium (Cd) concentration in ceramic-packed increased, exceeding the WHO limit of 0.002 ppm. Further research is necessary to identify the sources of cadmium contamination.

Keywords: food packaging, ceramic, matsoun, heavy metal migration, food safety



INTRODUCTION

Food quality and safety are significantly influenced by the choice of packaging materials [1], which serve as a barrier against microbiological, chemical, and physical contaminants. Beyond its protective function, the choice of packaging material is crucial for human health, as some materials may leach harmful chemicals into food [2-3]. Among various materials used for food packaging, plastic, glass, metal, and paper are the most common [4-5] each with its advantages and disadvantages. Some packaging materials used in the food industry can interact with food products, potentially leading to undesirable alterations.

Traditionally, clay pots were the primary storage and fermentation vessels for Armenian fermented dairy product matsoun. However, modernization has led to the widespread adoption of glass and plastic containers.

Since the mid-twentieth century, plastic packaging has dominated the market due to its economic and manufacturing advantages [6]. Glass packaging is renowned for maintaining product freshness and sensory qualities [7]. Its inert nature and ability to showcase products make it an appealing choice for consumers.

Beyond these widely used materials, traditional packaging options like clay pots continue to be used in various countries to store diverse products such as cheese, matsoun, milk, water, and wine [8]. However, all packaging materials, including clay pots, can present risks to product quality and human health if not prepared and utilized according to established safety standards.

The choice of packaging material is particularly important for matsoun, a traditional fermented dairy product with cultural significance in Armenia [9]. Fermented milk products, such as matsoun and tan, have been deeply ingrained in the traditional Armenian diet. The techniques employed in their production have remained largely unchanged for generations, preserving their unique characteristics [10].

Dairy products, including matsoun, have been a staple in the human diet for centuries, valued for their nutritional benefits and contribution to overall health. Their nutritional value is primarily attributed to their rich content of calcium, phosphorus, zinc, potassium, easily digestible protein, and vitamins [11]. Recent observational analysis showed that some dairy products like yogurt, can cause significant increases in IGF-1 (insulin-like growth factor-1) levels [12].

Matsoun is not only a culturally significant food but also boasts a range of desirable qualities, renowned for its thick, creamy texture, and unique tangy flavor [4]. Moreover, it serves as a rich source of essential nutrients such as vitamins A, B_2, and B_{12}, high-quality proteins, and essential fatty acids [13-14]. Armenian matsoun's chemical composition makes it an effective carrier for probiotics, offering a convenient way to incorporate these beneficial microorganisms into the diet [15-17]. The microbial composition of matsoun is a key factor contributing to its unique characteristics and potential health benefits. *Lactobacillus delbrueckii subsp. bulgaricus* and *Streptococcus thermophilus* have been identified as the primary microbial constituents. Matsoun is also abundant in other LAB strains and various yeast strains. However, matsoun's susceptibility to microbial contamination during processing, handling, and packaging [18-19] poses a risk of foodborne illnesses [20], highlighting the importance of proper packaging and handling practices.

Furthermore, the impact of packaging materials on matsoun's quality, shelf life, and safety, especially in traditional ceramic containers, remains under-researched.

Studies have demonstrated a clear link between ceramic packaging materials and the physicochemical properties (pH and titratable acidity) of food [8]. Research has shown that packaging can affect matsoun's microbial composition, particularly the lactic acid bacteria (LAB) responsible for fermentation and probiotic effects [21].

In addition to microbial concerns, the migration of heavy metals from packaging materials into food products is a significant food safety concern [2, 22-24]. Heavy metals, including lead, arsenic, mercury, and cadmium, are ubiquitous pollutants originating from both natural and anthropogenic sources. These metals pose a significant threat to humans, animal, and environmental health due to their widespread prevalence, toxicity, and bioaccumulative nature.

The potential migration of heavy metals from packaging materials into food products highlights the importance of careful material selection. Heavy metals from both natural and human-induced sources pose a serious health risk. Mercury, arsenic, lead, and cadmium are the most toxic heavy metals that can contaminate raw milk and its products, as reported by numerous researchers [25]. Their prevalence, toxicity, and tendency to accumulate in living organisms make them particularly concerned. Lead contamination from industrial activities and vehicle emissions can cause neurological damage, kidney dysfunction, and developmental problems [26]. Arsenic contamination in water and food poses severe health risks. Mercury, released into the environment through human activities, bioaccumulates in organisms and poses serious health risks. Cadmium entering the food chain through contaminated soil and water, can cause adverse health effects through contaminated food and water.

The appropriate choice of packaging materials is crucial for preserving the physicochemical and microbiological quality of food products throughout storage and distribution.

This study aims to address the knowledge gap by investigating the effects of packaging on the physicochemical properties (pH and titratable acidity), microbial composition (lactic acid bacteria), and safety (heavy metal migration) of matsoun. By comparing glass and ceramic packaging materials, we seek to understand the potential impact of traditional ceramic containers on the quality and safety of matsoun. This research will contribute to a better understanding of how packaging choices can influence the quality and safety of this traditional fermented dairy product.

MATERIALS AND METHODS

Matsoun: The matsoun samples used for the study were obtained from a milk production company located in the Kotayk region. Matsoun preparation involves general processing steps which include pasteurizing the milk and cooling it down to 42 °C. A starter culture containing *Lactobacillus bulgaricus* and *Streptococcus thermophilus* was then added to ferment the milk. The mixture was incubated for 24 hours.

Containers: After adding the starter culture, the matsoun was immediately packaged in two types of containers: glass and ceramic (Figure 1). Each container held an equal volume of 700 ml. Glass containers, known for their chemical inertness, served as the control group in this study, providing a comparative baseline against the ceramic containers. The ceramic containers were in direct contact with matsoun without any interior surface treatment or coating. Before use, all containers were sterilized using heat treatment at 160°C.

Figure 1. Matsoun samples in glass and ceramic packaging

Study design: This study employed a comparative experimental design to assess the impact of ceramic and glass packaging on Armenian matsoun. A total of six samples were analyzed. Matsoun samples from a local producer were packaged in ceramic and glass containers and stored under controlled conditions (4°C) for 15 days. Samples were analyzed at specific time points (days 1, 7, and 15) to track changes in physicochemical properties (pH, titratable acidity), microbial composition (lactic acid bacteria), and the migration of heavy metals (Pb, Cd, Hg, As) from the packaging materials into the matsoun.

pH measurements: The pH of the samples was measured using a pH meter (Milwaukee, pH electrode MA991B/1, temperature probe MA831R) through direct contact with the electrode with the matsoun, without requiring further processing. Measurements were performed on the same day as the remaining analyses on days 1, 7, and 15 of storage.

Titratable acidity measurements: The titratable acidity provides information about the total amount of acid present in the fermented milk, measured in terms of lactic acid content [27]. The percentage of lactic acid (titratable acidity) was determined by titration using a standard sodium hydroxide solution, according to [28].

Detection and determination of lactic acid bacteria: A liquid medium (skimmed milk) was used to detect microorganisms in the samples. The growth of organisms on selected media was examined microscopically to identify the organism's colony morphology. The method for determining lactic acid bacteria is based on the growth abilities of mesophilic lactic acid bacteria in skim milk at 30 ± 1 °C and thermophilic lactic acid bacteria at 37 ± 1°C, which ferment lactose to lactic acid and form a curd within 72 hours. After 72 hours of incubation, 10^{-7} dilutions were selected for colony characterization and counted accordingly. Lactic acid bacteria were examined closely using an oil immersion objective to identify their cell shape and arrangement.

Elemental analyses: The release of elements from ceramic and glass containers into matsoun was analyzed using atomic absorption spectrometry. The analyses focused on four main elements: As, Cd, Pb, and Hg. All determinations were carried out on untreated matsoun samples. The elements were quantified after digestion with 67% nitric acid. These elements were chosen because they pose the greatest risk to human health. The following wavelengths **(λ)** were used for elemental determination: As (193.7 nm), Cd (228.8 nm), Hg (194.164 nm), and Pb (217.0 nm) [29, 231].

RESULTS AND DISCUSSION

Physicochemical characteristics: pH and titratable acidity are key parameters for evaluating the acidity of food products. Table 1 illustrates the changes in pH and titratable acidity (percent lactic acid) in all samples over 15 days of storage. During this period, pH values decreased in all samples (Figure 2). Notably, pH values in ceramic and glass containers remained similar, with a slightly lower pH value (4.24) observed in samples stored in ceramic containers on the last day of the experiment. Titratable acidity increased gradually during storage, reaching 1.2 % after 15 days (Figure 3). Both container types exhibited identical lactic acid percentages. The increase in titratable acidity corresponds with the observed decrease in pH.

Table 1. Evolution of pH and titratable acidity of matsoun in ceramic and glass containers during 15 days of storage.

Parameters	Container type		
	Contact Period	**Ceramic**	**Glass**
pH	Day 1	4.61	4.6
	Day 7	4.42	4.36
	Day 15	4.24	4.27
Titratable Acidity/°Th	Day 1	1.06	1.10
	Day 7	1.18	1.18
	Day 15	1.20	1.20

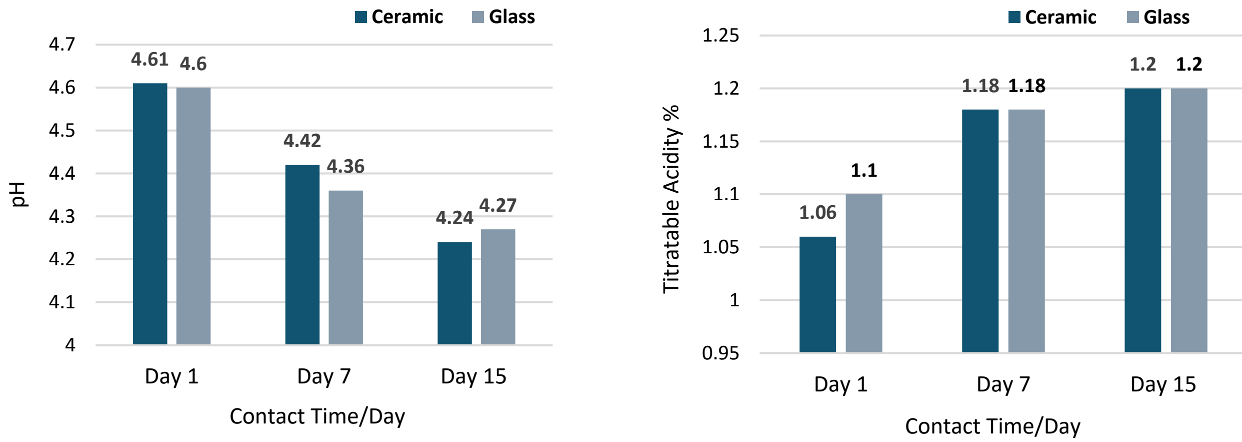


Figure 2. The pH and the titratable acidity of the samples stored in glass and ceramic containers for 15 days

Microbial modification: The number of lactic acid bacteria in both ceramic and glass packaged samples remained stable throughout the 15-day storage period, showing 1.1 x 10^8 colony-forming units (CFU) per sample. Notably, this slightly exceeds the standard requirement of 1 x 10^8 CFU, as specified in the Normative Document.

While no changes in the composition or number of lactic acid bacteria were observed in glass containers, a significant decrease in the number of bacilli was recorded in ceramic containers on the 15th day of storage, compared to glass-packaged matsoun (Figure 4). Considering the important role of bacilli, with their probiotic properties, in the human gut microbiota, this significantly reduces the usefulness of matsoun as a dairy product with probiotic properties [30]. This observation could be attributed to several factors; however, we hypothesize that the porous nature of ceramic may have allowed for a gradual increase in oxygen concentration within the container over time. This increased oxygen level could have negatively impacted the bacilli population, which is generally less tolerant to oxygen than cocci. An alternative hypothesis suggests that cocci may be more resistant to cadmium than bacilli. However, we are inclined towards the notion that the porosity factor plays a greater role. Further research is necessary to fully understand and characterize these processes.

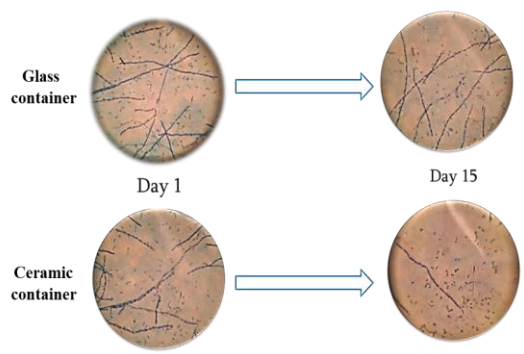


Figure 3 . Effect of glass and ceramic packaging on composition and number of lactic acid bacteria during 15 days of storage.

Migration of elements: Heavy metals, even in trace amounts, pose a serious health risk due to their tendency to accumulate in the body over time. Bioaccumulation, the process where toxins build up faster than the body can eliminate them, amplifies this threat. To safeguard human health, international organizations like the World Health Organization (WHO) have established maximum residual limits (MRLs) for metals in food. Milk and milk products, particularly important for vulnerable groups like children, are a focal point due to their susceptibility to contamination from heavy metals like lead, cadmium, arsenic, and mercury. Studies have revealed alarmingly high levels of these metals in milk from certain regions, surpassing recommended limits [31-32]. WHO has set the maximum acceptable lead concentration for milk and milk products at 0.02 ppm [33].

Considering these concerns, careful consideration of packaging materials is crucial in mitigating the risk of heavy metal contamination in food products like matsoun.

Our analysis of samples packed in glass and ceramic containers revealed that arsenic and mercury were not detected in any samples (Table 2). Lead concentrations in both types of containers remained within the WHO limit of 0.02 ppm and stable throughout the 15-day storage period (Figure 45). However, considering the bioaccumulative property of heavy metals, even low concentrations cannot be ignored, as continuous exposure can lead to hazardous health effects.

Initially, the cadmium concentration in both glass and ceramic-packed samples was 0.0015 ppm. After one week of storage, the concentration of Cd in ceramic-packed samples rose to 0.0024 ppm, exceeding the WHO limit of 0.002 ppm. Notably, this exceeded the recommended limit within the product's 7-day shelf life determined by the producer. By the final day of storage (15 days), cadmium levels reached 0.0029 ppm.

These results suggest that consumers should exercise caution when choosing matsoun, particularly when opting for traditional packaging. Further investigation is necessary to identify the sources of cadmium contamination.

Table 2. The concentration of heavy metals in matsoun samples in ceramic and glass containers during 15 days of storage.

Element (mg/kg)	Ceramic	Glass	Ceramic	Glass	Ceramic	Glass
	01/02/2024		08/02/2024		15/02/2024	
Pb	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045
Cd	0.0015	0.0015	0.0024	0.0015	0.0029	0.0015
As	nd (<0.1)	nd (<0.1)	nd (<0.1)	nd (<0.1)	nd (<0.1)	nd (<0.1)
Hg	nd	nd	nd	nd	nd	nd

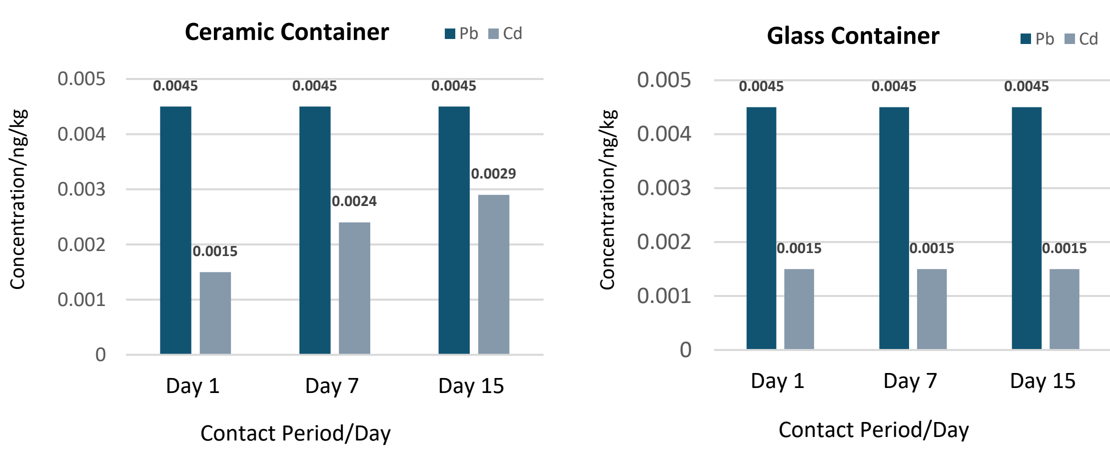


Figure 4. Release of elements from ceramic and glass containers to matsoun identified by AAS

CONCLUSIONS

This study aimed to investigate the impact of packaging material (glass versus ceramic) on the quality and safety of matsoun during storage. Our findings revealed matsoun packaged in both glass and ceramic exhibited decreased pH and increased acidity over storage, indicating ongoing fermentation. Lactic acid bacteria count remained stable, whereas bacillus levels in ceramic-packed matsoun decreased significantly compared to glass-packed matsoun by day 15. The results showed no contamination of the samples with toxic trace elements like arsenic (As) and mercury (Hg). The identified concentration of lead (Pb) in all samples was within the limits (0.02 ppm) allowed by the World Health Organization. However, in the case of cadmium (Cd), the concentration in the ceramic-packed samples increased, exceeding the WHO limit (0.002 ppm). The increasing trend of cadmium during storage warrants further investigation to identify its source. Notably, our results indicate that consuming ceramic-packed matsoun poses a risk to human health if the storage period exceeds one week. In contrast, no increase in Cd concentration was observed in glass-packed matsoun.

Abbreviations: AAS: Atomic Absorption Spectrometry, LAB: Lactic Acid Bacteria, CFU: Colony Forming Unit, WHO: World Health Organization, MRLs: Maximum Residual Limits

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My article meets all the manuscript section requirements.

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