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Effect of transportation and storage time on the frozen lamb quality in catering sector

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ABSTRACT

Ensuring the quality and safety of frozen lamb during transportation and storage is critical to preventing foodborne illnesses and maintaining product quality. Cold chain logistics (CCL) are essential for keeping meat fresh and safe, but long transportation times or unstable temperatures can lead to spoilage. This study evaluated the effects of transportation time and temperature variation within the CCL on the microbial and physicochemical quality of frozen lamb used in catering services in the UAE. Lamb samples were subjected to transport durations of 30, 45, and 90 minutes, followed by storage at -18°C for 30 days. Physicochemical analyses (pH, fat content, Total Volatile Basic Nitrogen (TVBN), and colour) and microbiological analysis (Total Viable Count (TVC)) were conducted at 10, 20, and 30-day intervals. Results showed that shorter transport times and stable storage conditions helped preserve quality, while extended durations led to significant spoilage. Longer handling periods (90 minutes of transportation and 30 days of storage) resulted in higher TVC, increasing from an initial 510 CFU/g to 8266 CFU/g, along with increased pH, fat content, and TVBN, indicating microbial growth and spoilage. Interestingly, colour remained stable throughout the storage period. These findings highlight the importance of maintaining strict temperature control during frozen meat transportation to ensure food safety and product quality.

Contribution/Originality: This study contributes to the existing literature by evaluating the effects of transportation duration and temperature fluctuations during transportation on the physicochemical and microbial quality of frozen lamb in the UAE catering service. It highlights the role of cold chain control in ensuring food safety and quality in catering services.

1. INTRODUCTION

Lamb meat is a culturally significant and highly valued protein across the Middle East and North Africa (MENA) region, including the United Arab Emirates (UAE), where its per capita consumption is notably higher than in many Western and Asian countries (Meat & Livestock Australia, 2024). The UAE's frozen lamb supply relies on both domestic farming and substantial imports of live animals, fresh/chilled meat, and frozen meat. The overall frozen lamb market in the UAE is forecasted for continued growth, with a compound annual growth rate (CAGR) of 5.2% by volume from 2020 to 2025 (Glasgow Insights, 2022). This growth is particularly relevant to the foodservice sector, which utilizes over half of Australian lamb meat exports to the broader MENA region, featuring lamb prominently on menus in various restaurant settings, including full-service and casual dining (Meat & Livestock Australia, 2024). Crucially, frozen lamb is a key component for the catering sector, and fresh meat is also commonly stored in deep freezers for later use by HORECA (Hotel, Restaurant, and Catering) companies (Glasgow Insights, 2022). Given the increasing awareness and appreciation for high-quality red meat among affluent consumers in the region, and the growing preference for products that offer a better eating quality experience even when cooked well-done, the quality of frozen lamb supplied through efficient cold chain logistics (CCL) becomes a critical consideration for UAE catering services.

50% of agrifood losses occur during transport and storage processes, which are often caused by inefficient refrigeration systems (Huang, Zhang, & Li, 2023). This is an even greater risk in the UAE, which is an import-reliant country that faces extreme ambient conditions, making it very difficult to maintain a consistent cold-chain performance. Thakur, Shyam, and Singh (2020) and Wang et al. (2020) show that relatively small fluctuations in temperature can cause a rapid increase in chemical changes and an increase in microbial activities. The deterioration of meat quality due to temperature fluctuation during distribution and storage is a major concern for food businesses, as physicochemical changes can occur at each stage (Wang et al., 2020; You, Her, Shafel, Kang, & Jun, 2020).

Various factors influence the microbiological safety of frozen lamb, emphasizing the need to ensure hygienic practices during processing, handling, and storage (Fernandes, De Alvarenga Freire, Da Costa Carrer, & Trindade, 2013). In research evaluating the stability of vacuum-packed lamb meat kept at -18°C for a whole year, Fernandes et al. (2013) emphasized the critical role that freezing plays in inhibiting microbial development, while also acknowledging that chemical and biological processes can still occur during storage. Freezing is a common method used in the lamb meat industry to extend storage time and maintain a steady supply of seasonal meat throughout the year (Stenberg et al., 2022). While freezing inhibits microbial growth and reduces metabolic activity, it is not a sterilization process, and psychrotrophic bacteria or spores can survive and cause spoilage or pose health risks (Holman, Coombs, Morris, Kerr, & Hopkins, 2018). During freezing, about 60% of the viable microbial population dies, but the remaining population gradually increases during frozen storage (Ghaly, Dave, & Ghaly, 2011). Although freezing does not merely stop microbial growth, it also helps preserve the meat's quality for longer storage (Lisitsyn, Chernukha, & Lunina, 2019). However, frozen meat quality, such as sensory attributes (Augustyńska-Prejsnar et al., 2023; Stenberg et al., 2022), physicochemical and microbial quality (Augustyńska-Prejsnar et al., 2023; Fernandes et al., 2013) can be affected during storage.

Although some studies have investigated the effects of frozen storage on various quality attributes of lamb, such as physicochemical and microbiological properties, not much research has focused on how transportation time affects these attributes, particularly within the UAE catering sector. Therefore, this study aimed to evaluate the impact of transportation and storage duration on the physicochemical and microbiological quality of frozen lamb in the UAE catering industry. Throughout the cold chain logistics, the temperature of the frozen lamb was maintained at −18°C, from loading through to 30 days of frozen storage.

2. MATERIALS AND METHODS

2.1. Materials and Sample Preparation

Petroleum ether (Sigma-Aldrich, USA) was used for fat extraction in the Soxhlet method. Trichloroacetic acid (TCA), manufactured by Chloritech Industries India; ammonium chloride, manufactured by Plater Group UK; Plate Count Agar (PCA), manufactured by Thermo Fisher Scientific USA; peptone water, manufactured by Thermo Fisher Scientific USA; Nessler's reagent agar, manufactured by Sismon Pharma Limited, India; and buffer solution, manufactured by Mettler-Toledo GmbH, Germany, were used in this study. All chemicals used were analytical-grade reagents.

The frozen lamb products used in this study were sourced from an Australian supplier and imported into the UAE by a local distributor. The samples were obtained by cutting sections from whole lambs under controlled conditions following food safety regulations. Three samples of frozen lamb products, labeled as A, B, and C, were prepared. Each product weighed approximately 20 kg and was cut into six uniform pieces, each measuring approximately 10.0 cm x 5.0 cm x 3.0 cm. These pieces were individually wrapped in Auto Irradiation (AI) bags made from polyethylene, providing an excellent barrier against moisture and contaminants. The products were then packed into cartons designed as Type 200 Base 186754, with dimensions of 56.4 x 36.0 x 20.0 cm. The Individual Wrap (IW) packaging ensured that the products remained fresh and uncontaminated throughout the storage period.

2.2. Transportation and Storage of the Lamb

The transportation process involved three different routes, each with a specific duration: product A was delivered after 30 minutes, product B after 45 minutes, and product C after 90 minutes. The changes in temperature during transportation were recorded using EBI 20-T1 data loggers (EBRO, Germany). These loggers have a measurement range between -30°C and +70°C, with an accuracy range between -20°C and +40°C, and can store up to 40,000 readings. The clocks can be set within waterproof enclosures (IP67), and clock repeaters may vary in intervals from 1 minute to 24 hours. Each transport vehicle carrying products A, B, and C was equipped with one logger. Upon arrival, all samples were placed in a JKS walk-in freezer (Italy), where the temperature was maintained constantly at -18°C. Offloading and loading of each frozen lamb took a maximum of 20 minutes. The freezer is a digital display type, regulating the temperature continuously within a range of -15°C to -18°C. Temperature checks were performed daily throughout the 30-day storage period. Sampling was conducted immediately after receiving products A, B, and C, and on days 10, 20, and 30 of storage.

2.3. pH Analysis

The pH of the prepacked frozen lamb samples was determined using a digital pH meter (Hanna Instruments, Smithfield, USA). The pH meter was calibrated with standard buffer solutions at pH 4.0, 7.0, and 10.0 before each use to ensure accuracy. Lamb samples were homogenized with distilled water in a 1:10 (w/v) ratio. The pH of the homogenate was measured at different stages, including loading, transportation, and throughout the 30-day storage period.

2.4. Fat Content Analysis

The fat content of the lamb samples was determined using the Soxhlet extraction method with petroleum ether as the solvent. The Soxtec™ 2050 fat extractor was used for this purpose. Approximately 5 grams of each lamb sample were placed in a thimble and subjected to solvent extraction using 200 ml of petroleum ether (Sigma-Aldrich, USA). The extraction process was conducted for 6 hours. After extraction, the solvent was evaporated, and the extracted fat was weighed. The fat content was calculated as a percentage of the initial sample weight (Equation 1).

$$\text{Fat Content (\%)} = \left(\frac{\text{Weight of Extracted Fat}}{\text{Initial Sample Weight}}\right) \times 100 \quad (1)$$

2.5. TVB-N Analysis

Lamb samples were homogenized with TCA and centrifuged at 3000 rpm for 10 minutes. The supernatant was collected, and Nessler's reagent was added. The absorbance was measured at 410 nm using a spectrophotometer. The supernatant was reacted with Nessler's reagent, and absorbance was measured at 410 nm. TVB-N content was calculated using a standard curve prepared with known concentrations of ammonium chloride.

2.6. Colour Analysis

Colour values (L^*, a^*, b^*) of the lamb samples were measured using a colorimeter (CM 508-d, Hunter MiniScan TMXE). The colorimeter was first calibrated using a white reference standard. The probe was placed on the surface of the frozen lamb samples at three different points on each sample.

2.7. Microbiological Analysis

The Total Viable Count (TVC) test was conducted to determine the total number of viable bacteria in the lamb samples, following USFDA/BAM Chapter 3 guidelines (U.S. Food and Drug Administration, 2001). Samples of 500 grams were taken from each product, placed in sterilized bags, and transported to the laboratory in an ice box. A 25-gram portion from each product was homogenized in 225 ml of diluted buffer peptone water. The homogenate was then serially diluted and plated on Plate Count Agar (PCA). Plates were incubated at 37°C for 48 hours. Colonies were counted manually, and results were expressed as CFU/g.

2.8. Statistical Analysis

The statistical analysis for this study was conducted using SPSS software (Version 29, IBM Corporation). All experiments were conducted in triplicate (n=3). The results were presented as the mean ± standard deviation. Statistical analysis was performed using one-way analysis of variance (ANOVA), and Tukey's test ($p < 0.05$).

3. RESULTS AND DISCUSSIONS

3.1. Temperature Monitoring

In all stages of the Cold Chain Logistics (CCL), temperatures of products were ensured to be at −18°C. However, during transportation of all the products, temperature variations were observed: Product A: ±0.5°C, Product B: ±0.8°C, and Product C: ±1.2°C. Based on GSO 997/1998 standard, the frozen meat temperature during transport and storage shall not go beyond -18°C, and the fluctuations in the temperature of the freezer are minimal and not more than ±2°C (GCC Standardization Organization (GSO), 2016). Furthermore, temperature fluctuations were observed to increase with longer transportation durations, indicating that extended transit times inherently raise the risk of temperature deviations. As transport time increases, products are often exposed to multiple handling stages and varying environmental conditions, leading to greater departures from optimal temperature ranges (Jedermann, Ruiz-Garcia, & Lang, 2019).

3.2. pH

Figure 1 shows the pH values recorded during the loading, unloading, and 30-day storage periods for all products. Product A exhibited the lowest pH, while Product C had the highest pH across all stages. The pH for Product A is significantly lower than B and C throughout all the CCL stages ($p<0.05$). Product A demonstrated the most consistent pH values throughout the Cold Chain Logistics (CCL). According to the GSO 997/2016 standard for beef, buffalo, mutton, goat meat, chilled and frozen, the pH of frozen meat should not exceed 6.00; however, it is preferably maintained within the deviation range of 5.4 to 6.2 (GCC Standardization Organization (GSO), 2016). Product A recorded pH values ranging from 5.29 to 5.80 at all stages, which fall within this preferred range. Product B showed an extreme increase in pH from 5.37 to 6.75 by the end of the 30-day storage period. In contrast, Product C exceeded a pH of 6.00 during unloading and continued to rise throughout the storage period, ultimately recording a maximum pH of 6.50. Research has repeatedly demonstrated a rise in pH with extended frozen storage, attributed to biochemical and microbiological alterations over time (Zhao et al., 2022). Muscle pH variations may arise from differing ratios of red and white muscle fibers, the degree and speed of postmortem glycolysis, and microbial activity affected by storage and thawing methods (Jones, 2021).

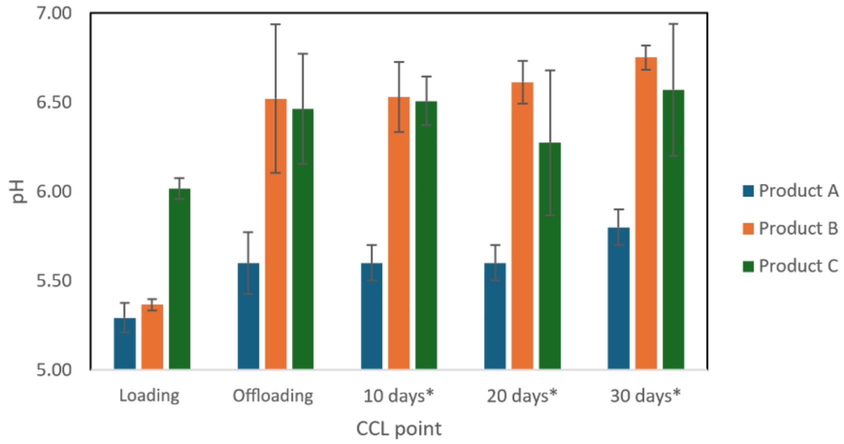


Figure 1. pH values of samples A, B, and C measured at loading, offloading and storage.
Note: Bars represent the mean ± standard deviation (SD) from three independent measurements.
* represents the storage time.

3.3. Fat Content

Figure 2 shows the fat content of all the products during 30-day storage periods. The fat content of Product A was stable, whereas the fat content of Products B and C decreased during the 30 days of frozen storage. Prolonged transportation time often exposes the product to temperature fluctuations or delays in reaching the optimal freezing point (Hadidi et al., 2022; Nandi, Yan, Jana, & Das, 2019). These fluctuations can accelerate lipid oxidation, which leads to the degradation of fatty acids, resulting in a measurable decrease in fat content.

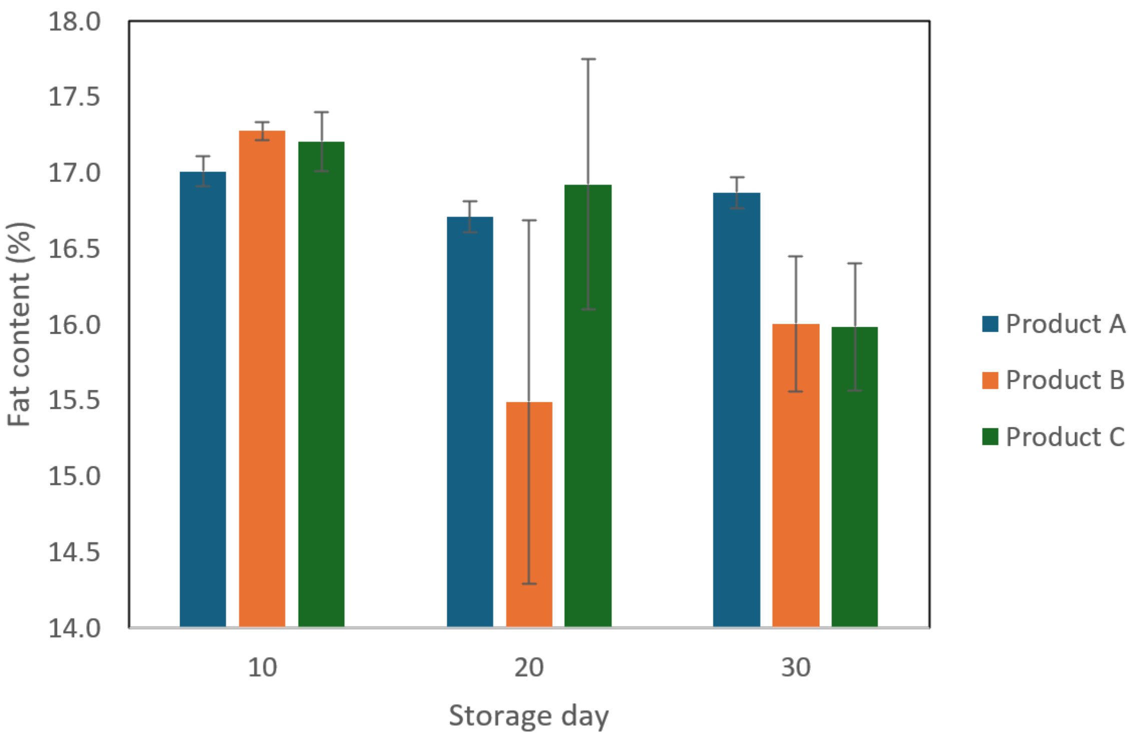


Figure 2. Fat content (%) changes during lamb storage at -18°C for 30 days.
Note: Bars represent the mean ± standard deviation (SD) from three independent measurements.

3.4. Total Volatile Basic Nitrogen (TVBN)

TVBN is a key indicator of meat freshness and spoilage, including for frozen lamb. It measures the amount of nitrogenous compounds such as ammonia (NH_3), trimethylamine (TMA), and dimethylamine (DMA). These compounds are produced mainly by the degradation of proteins and microbial activity during storage. Figure 3 shows the TVBN of all the products during 30-day storage periods. The TVBN value for Product A decreased over the storage period, which may indicate reduced microbial or enzymatic activity, possibly due to better initial handling or faster freezing, limiting protein degradation. For Product B, the TVBN values remained stable throughout storage, suggesting effective cold chain maintenance and minimal spoilage-related nitrogen compound formation. In the case of Product C, TVBN levels were stable up to 20 days but decreased thereafter. This decline could be due to the volatilization or breakdown of nitrogenous compounds at later stages, or possibly interactions with other chemical reactions that reduce measurable TVBN content.

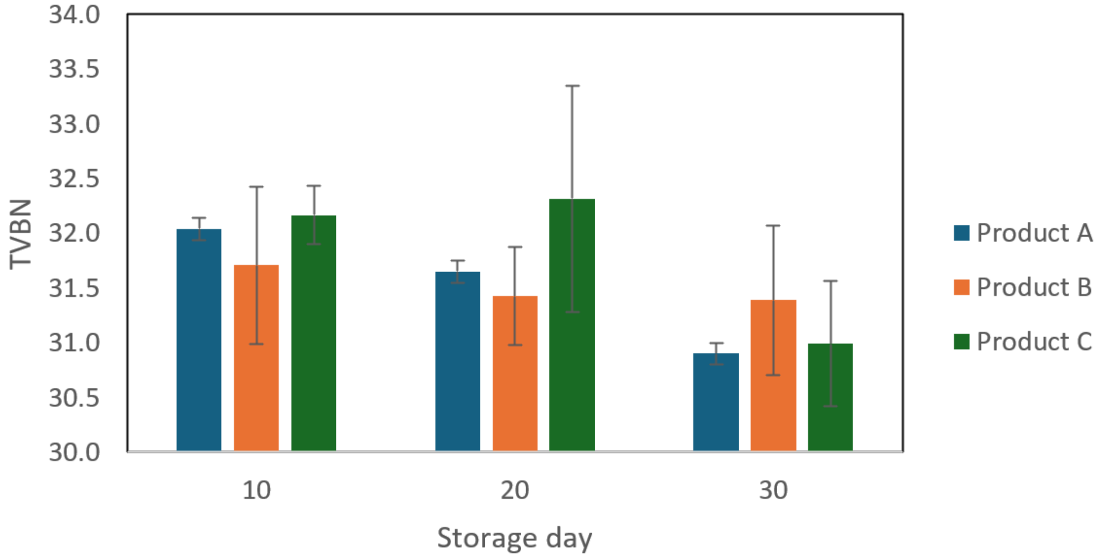


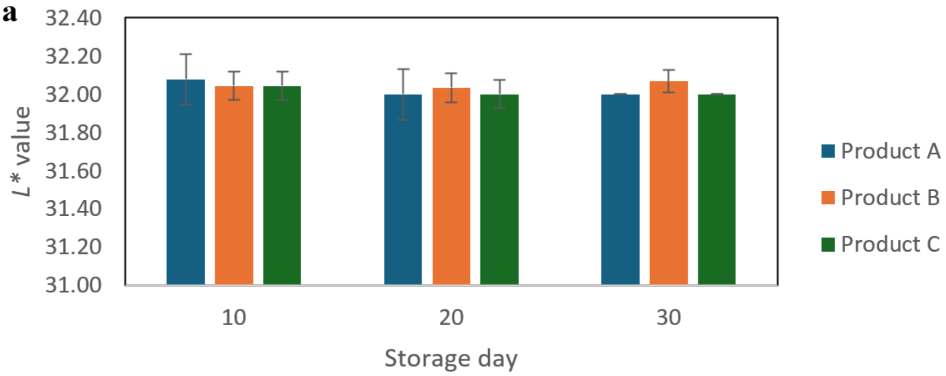
Figure 3. TVBN values during lamb storage at -18°C for 30 days.

Note: Bars represent the mean ± standard deviation (SD) from three independent measurements.

3.5. Colour

Figure 4 shows the colour changes in lamb stored at -18°C for 30 days. The L^* values remained stable, ranging narrowly between 32.0 and 32.2, indicating no significant change in lightness as shown in Figure 4a (p>0.05). Although Figures 4b and 4c show statistically significant changes in a and b* values (p<0.05), the variations were minimal, ranging from 11–13 and 8.5–11.33, respectively. Therefore, the overall colour can be considered stable throughout the storage period. Interestingly, a* value, which represents redness, decreased in Samples B and C. The results align with previous findings in raw beef, where redness decreased during storage (Olivera, Bambicha, Laporte, Cárdenas, & Mestorino, 2013) due to the oxidation of oxymyoglobin to metmyoglobin, a brown pigment, as myoglobin undergoes chemical transformation over time (Suman, Rajasree, Kanchana, & Elizabeth, 2013). It is important to highlight that temperature fluctuations can cause structural changes, which in turn affect the colour and overall quality of frozen beef (Wang et al., 2020). Moreover, the results show that shorter transportation times contributed to better colour stability in frozen lamb during storage, suggesting that minimizing transit duration can help preserve meat quality.

a



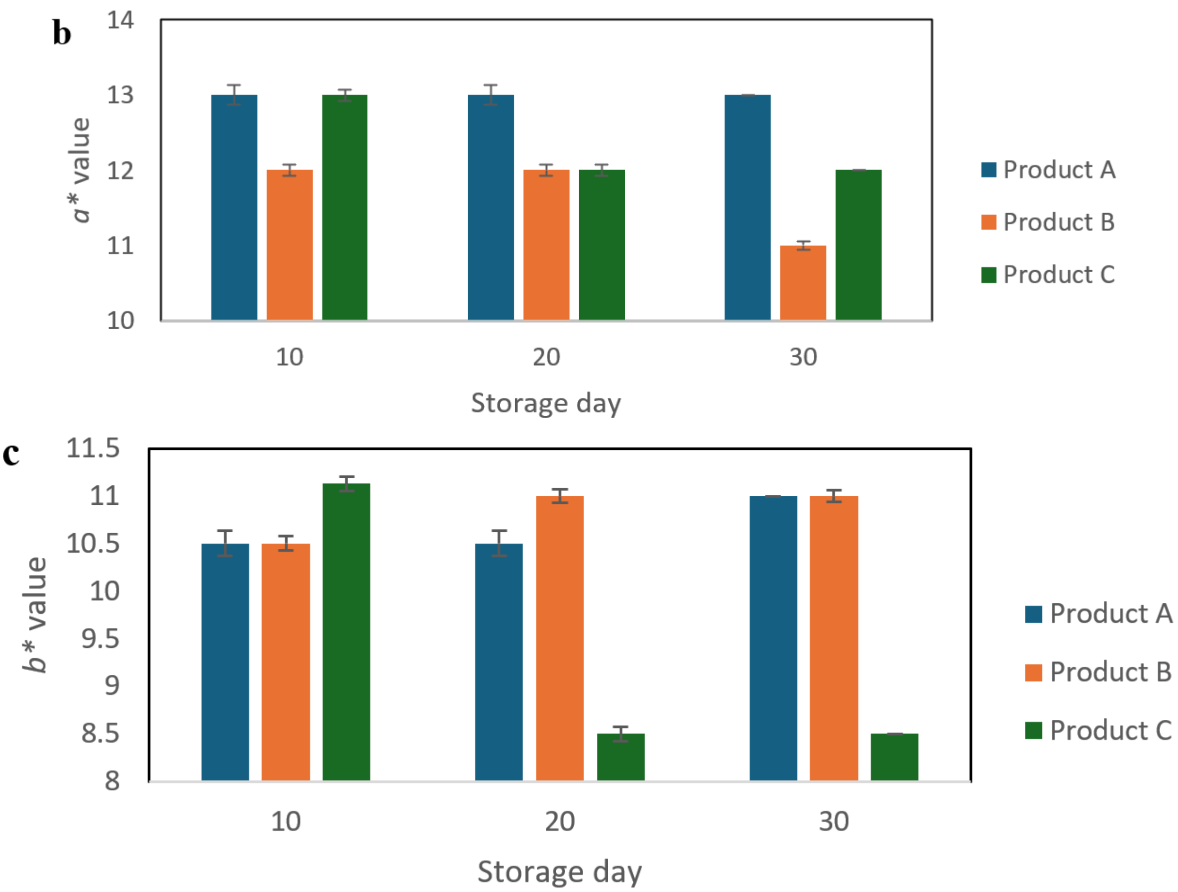


Figure 4. Colour changes of (a) *L**, (b) *a** and (c) *b** values during lamb storage at -18°C for 30 days.
Note: Bars represent the mean ± standard deviation (SD) from three independent measurements.

3.6. Total Viable Count (TVC)

Figure 5 shows the Total Viable Count (TVC) during the loading, offloading, and 30-day storage periods for all products. Product A has the lowest microbial contamination in all the CCL stages in this study. Its initial TVC was 400 CFU/g and fluctuated between 966 to 1166 from offloading until the end of 30 days of storage. Conversely, the initial TVC for Product B was 1153 CFU/g and increased significantly to 3700 CFU/g upon offloading, reaching 5100 CFU/g on the 10th day of storage, fluctuating to 3566 CFU/g on the 20th day, and finally reaching 4633 CFU/g after 30 days of storage. Product C exhibited a gradual increase in TVC from 510 CFU/g at loading, escalating rapidly to an offloading level of up to 1636 CFU/g. Rapid acceleration was observed thereafter, with TVC reaching 3700 CFU/g on Day 10 and 8266 CFU/g after 30 days. The accelerated microbial growth in Product C strongly indicates a breakdown in cold chain maintenance, likely caused by extended transportation time (90 minutes) or temperature excursions during storage. It also suggests the ability of psychrotrophic microorganisms to gain a foothold and multiply even at chilled conditions whenever temperature levels lack appropriate control. Augustyńska-Prejsnar et al. (2023) also reported a gradual increase in the total bacterial count and the number of *Pseudomonas* spp. in the breast meat of hens along with increasing storage duration. The findings of the study confirm that strict supervision of temperature and time during transportation and storage is required to maintain food safety for catering services.

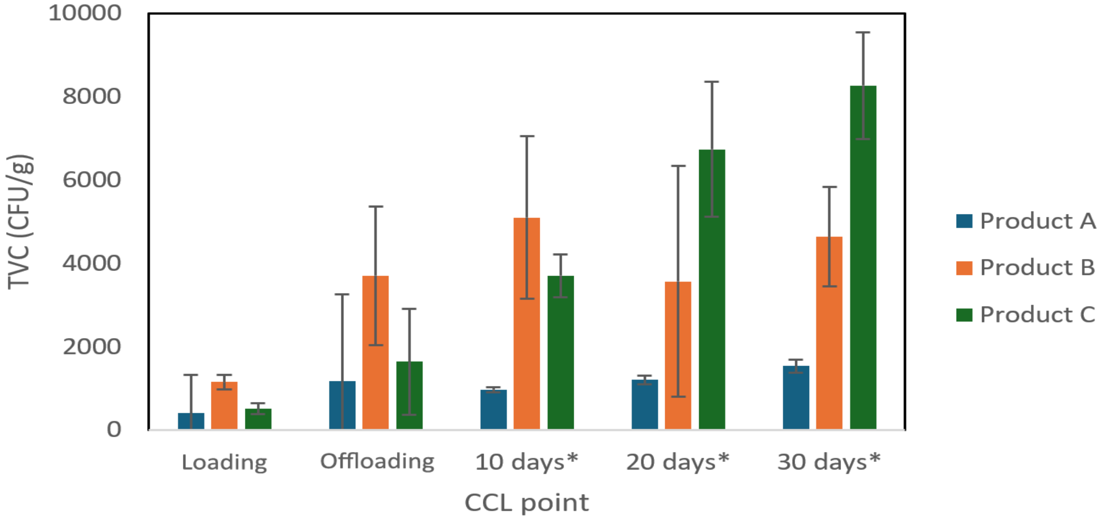


Figure 5. TVC of samples A, B, and C measured at loading, offloading and storage.

Note: Bars represent the mean ± standard deviation (SD) from three independent measurements. * represents the storage time.

4. CONCLUSION

This study demonstrates that the physicochemical and microbial stability of frozen lamb used in catering services is significantly affected by transportation time, temperature fluctuations during transit, and storage duration. Lamb samples subjected to extended transportation times exhibited increased microbial growth, higher pH and TVBN levels, and decreased fat stability. These findings underscore the urgent need for strict temperature control and optimal transportation durations to maintain meat quality throughout a 30-day storage period. Despite minimal changes in color, internal quality indicators revealed substantial deterioration, highlighting the unreliability of visual inspection alone. Future research should focus on microbial profiling, improved packaging solutions, and real-time temperature monitoring to reduce cold chain quality losses. It is also recommended to establish strict limits on transportation duration, implement internal quality assessments such as pH and TVBN measurements, and revise visual inspection protocols, as external appearance may not accurately reflect product deterioration. Adopting shorter transit times, staff training, and continuous monitoring will be essential for preserving frozen lamb quality in UAE catering services.

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Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: Both authors contributed equally to the conception and design of the study. Both authors have read and agreed to the published version of the manuscript.
Disclosure of AI Use: The author(s) used OpenAI's ChatGPT to improve the language and readability. All outputs were reviewed and verified by the authors.

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