

UV-C light irradiation and ultrasonic infiltration of rosemary (*Rosmarinus officinalis* L.) essential oil nanocapsules into refrigerated chicken fajitas

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ABSTRACT

Objective: To evaluate the effect of the application of ultraviolet light (UV-C) treatments and/or ultrasonic infiltration of a marinade with and without rosemary (*Rosmarinus officinalis* L.) essential oil nanocapsules on the physical, physicochemical, and textural properties of vacuum-packed chicken fajitas stored at 2 °C for 11 days. **Design/Methodology/Approach:** Water holding capacity (WHC), lactic acid, electrical conductivity, shear force, pH, and color changes (ΔE) were evaluated. The treatments applied were fajitas without any treatment (C), marinated fajitas (M), UV-C irradiated, marinated with ultrasound (US), marinated with nanoencapsulated rosemary into zein nanocapsules (NCS), UV-C/US, NCS/UV-C, NCS/US, and NCS/UV-C/US. Each was marinated with vinegar and salt, except the control lot. To analyze the correlation between variables, the Pearson evaluation is used in the Minitab[®] 19 program, with $\alpha=0.05$.

Results: The NCS with US, UV-C, or US/UV-C, presented the highest WHC values ($52.49 \pm 1.43\%$), and lactic acid concentration at the end of storage (increase $18.52 \pm 0.44\%$). NCS treatment in combination with US and UV-C presented the highest EC values (7.31 ± 0.37 and 6.25 ± 0.33 mS/cm respectively). Maintaining pH around 5.5 during 11 days of storage and presenting 30% of stability in ΔE .

Limitations on study/implications: The use of UV-C requires additional training of operators for its correct operation, in addition, the use of ultrasound as a food treatment technology may present inconveniences for its scaling and application in an industrial production line.

Conclusions: The application of marinade in combination with emerging technologies and nanocapsules with rosemary essential oil favors their infiltration and chicken fajitas preservation during 11 days of refrigerated storage (2 °C).

Keywords: Emerging technologies, zein, meat, preservation, marination.

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INTRODUCTION

Fresh chicken breast is susceptible to surface contamination, affecting quality parameters during their storage and decreasing consumer acceptability (Rouger *et al.*, 2017). However, these variations in quality can be avoided by employing previous treatments, such as marinating, in which food is immersed in a dissolution to improve the flavor and texture of the meat (Yusop *et al.*, 2012). Marinating can be combined with emerging



technologies such as ultraviolet light (UV-C), nanotechnology, and ultrasound to promote the infiltration of marinade ingredients into the chicken. The emerging technologies are an alternative for food preservation and processing, decreasing food matrix degradation, maintaining the nutritional composition, as well as the organoleptic and physicochemical properties. Nanocapsules act as a reservoir, that can modify the release profile of bioactive substances, such as rosemary (*Rosmarinus officinalis* L.) essential oil, which has antibiotic, antimicrobial and antioxidant properties and is considered safe for human consumption, due its low toxicity level (Granata *et al.*, 2018). However, lipophilic nature compounds incorporation into mainly water matrix, such as food, is complicated. Nanoencapsulation of these components represents an alternative to their incorporation into food, enhancing its solubility (Bazzano *et al.*, 2016). For this reason, emerging technologies in conjunction with refrigeration can maximize the efficiency of food preservation and increase its shelf life by providing the necessary conditions to maintain the final quality of the product, *i.e.*, its physical and physicochemical properties during storage. This work aimed to evaluate the effect of the application of ultraviolet light treatments (UV-C) and ultrasonic infiltration (US) of a marinade (M) with nanoencapsulated rosemary (*Rosmarinus officinalis* L.) essential oil (NCS) on the physical, physicochemical, and textural properties of chicken fajitas, vacuum packed and refrigerated storage at 2 °C for 11 days.

METHODOLOGY

A chicken breast was processed to obtain fajitas (7×1.5×0.8 cm) that were pretreated under different conditions before their refrigerated storage (2±1 °C) for 11 days, evaluating the variation in quality parameters every third day to determine the effect of the application of individual and combined technologies on chicken fajitas for their preservation. The different studied treatments were fajitas without any treatment (C), marinated fajitas (M), UV-C irradiated, marinated with ultrasound (US), marinated with nanoencapsulated rosemary into zein nanocapsules (NCS), UV-C/US, NCS/UV-C, NCS/US, and NCS/UV-C/US. Subsequently, pretreated fajitas (20 g) were packed in a high-density polyethylene bag (10×15 cm) under vacuum conditions (50 bar). US treatment application required a Hielscher® 200Ht equipment, with a 40 mm sonotrode (S26d40), at 26kHz frequency, 80% amplitude, and 50% duty cycles, during 15 s. A UVP XX-15S lamp (254 nm, 15 W) was used for the UV-C irradiated samples for 2 min. The marinated samples were immersed for 5 min at room temperature on an aqueous dissolution of apple cider vinegar (100 mL/L) and NaCl (75 g/L). The marinade samples with NCS incorporate rosemary essential oil (1 g/L) zein nanocapsules (150±18 nm). Changes in the chicken fajitas were monitored during storage. The color variation (ΔE) of the surface was carried out with a Konica Minolta® colorimeter (CM-600d), according to (Domínguez *et al.*, 2022).

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \quad (\text{Equation 1})$$

The color parameter is expressed on the CIELAB scale (L*, a*, b*). L* represents Luminosity, a* green-red scale, and b* yellow-blue scale. The Brookfield® CT3 texturometer

equipped with a 25 kg load cell was used for shear resistance evaluation, employing a Warner-Braztler cell (0.07 N, 1 mm/s). It also was used for the water holding capacity (WHC) determination, using a compression method as described by (Barbut, 2024) and (Jankowiak *et al.*, 2021). Samples of meat were put between two layers of filter paper (5 cm diameter) and a constant compression force (10 N, 20 s), using an acrylic cylinder (TA 25/1000) and an activation force of 0.07 N. The WHC was calculated based on

$$WHC \left[\frac{g_{H_2O}}{100 g_{H_2O}} \right] = \frac{(m_1 * H) - (m_2 - m_3)}{(m_1 * H)} * 100 \quad (\text{Equation 2})$$

and the results were reported as g of water per 100 g of water in the sample. Where m_1 is the sample mass, m_2 is the initial mass of the filter paper, m_3 is the mass of the filter paper after the test, and H is the theoretical moisture of the chicken meat. The pH determination was performed with a pH-meter with a knife blade electrode, model HI99163, from Hanna Instruments (Woonsocket, USA) as reported by (Jankowiak *et al.*, 2021). Lactic acid was measured by titration, employing a 0.1 N NaOH solution (Terefe, 2017). The obtained result is reported as the percentage of acidity, calculated according to:

$$Lactic\ acid(\%) = \frac{m_{eq} * V * N * V}{W} \quad (\text{Equation 3})$$

Where m_{eq} is the milliequivalents for the quantified acid (lactic acid), V is the volume of NaOH solution spent, N is normality, V is the volume of water used in the dilution and W is the weight of the sample. The electrical conductivity was measured as an indicator of membrane integrity in meat according to (Saelin *et al.*, 2017), 5 g of sample were homogenized with 50 mL of distilled water, and electrical conductivity was evaluated using a conductivity meter, model ST3100C from Ohaus.

RESULTS

Water-holding capacity (WHC)

The WHC presented a statistically significant difference ($p \leq 0.05$) during the storage time. Figure 1 shows a decrease for all treatments. The increase in water loss during meat storage is related to protein degradation and structure modification due to oxidation, and protein denaturation leaving the hydrophobic groups exposed (Saelin *et al.*, 2017).

WHC results for the first day do not present significant differences ($p \geq 0.05$) between treatments except for the C, M, US, and the NCS/UV/US. The samples treated with UV-C individually or combined, were the ones that presented the highest WHC values at the beginning ($52.33 \pm 1.5\%$) and the end of the storage ($26.67 \pm 0.83\%$). UV-C irradiation can stimulate reactive oxygen species (ROS) formation, leading to an increased protein charge state by increasing ionic strength and the subsequent exposure of more (Monteiro *et al.*, 2019). The samples with infiltrated nanocapsules (NCS) did not demonstrate significant

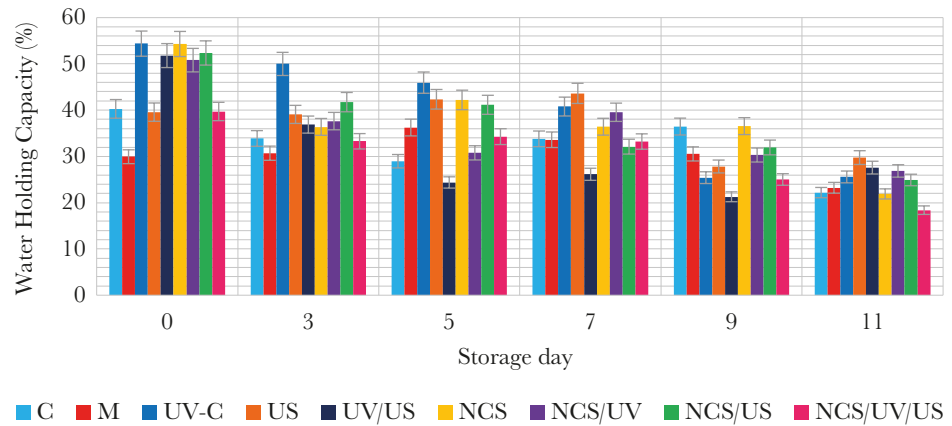


Figure 1. Water-holding capacity (WHC) variation during storage.

differences with UV-C samples, presenting high WHC values ($52.49 \pm 1.43\%$) related to the zein polymeric structure of the NCS and the lipophilic nature of rosemary essential oil. Some researchers have demonstrated that the protein oxidation with ROS like hydrogen peroxide (H_2O_2) can bring about formation of hydroxyl and carbonyl groups even on hydrophobic amino acid residues with aliphatic side chains such as leucine, isoleucine, valine, and alanine, and oxidize proline to hydroxyproline and pyroglutamic acid. These amino acids are predominant in zein (Taylor *et al.*, 2016), enhancing the WHC even in zein that contains more than 50% hydrophobic amino acids and low water solubility (soluble at 55-90% aqueous ethanol solutions) (Chen *et al.*, 2024). Also, the addition of NCS from hydrophobic compounds can enhance the WHC by acting like a polymeric (Ranjan *et al.*, 2016). Despite US and UV-C treatments suggesting higher cell damage, the application in combination with NCS may generate a preservation system with the formation of ROS that could enhance WHC by water binding points formation in protein structure, without incrementing the tissue deterioration due to the rosemary essential oil antioxidant effect. Usually, the US is used as a tenderization process for meat, due to its effect on myofibril protein fragmentation (Yoon *et al.*, 2024). The lower WHC presented by M samples implies that meat cannot bind successfully aggregated water without the implementation of an external technology such as UV-C, US, or NCS. In contrast, the marinated samples were the samples that presented the lower decrease of WHC during the storage time ($22.42 \pm 0.62\%$) due to the lack of external energy addition during the process that promotes the formation of ROS, indicating more stable WHC values during the storage, only exhibiting significant differences until the fifth storage day. WHC presented a significant correlation ($p \leq 0.05$) with electric conductivity, lactic acid, due to the leakage of hydrophilic compounds from cell structure in samples with low WHC, and with shear force, related to the amount of water trapped in the meat tissues.

Lactic acid

Figure 2 shows the inverse correlation between lactic acid production and WHC variation during the storage time for the different treatments. The samples with a higher

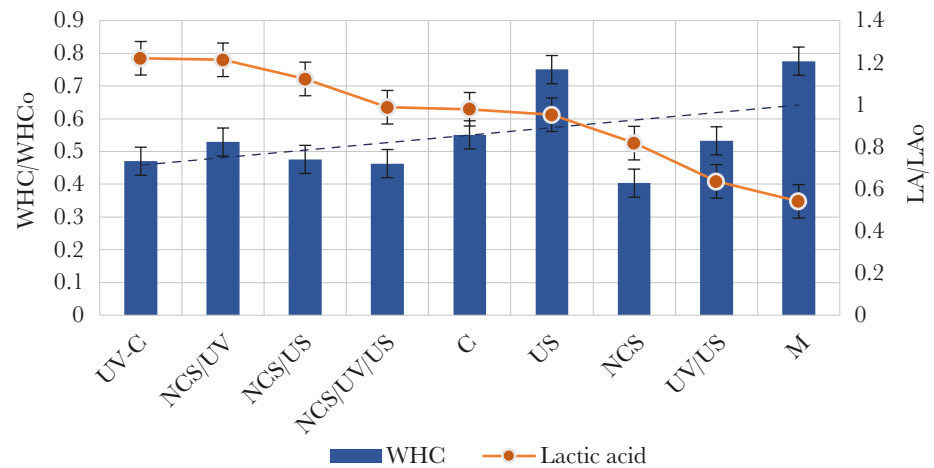


Figure 2. WHC and lactic acid correlation.

difference between initial and final WHC presented higher lactic acid concentrations. The lactic acid concentration of US, NCS/UV-C/US, and C samples did not present a significant difference ($p \geq 0.05$) during the storage time. The irradiated samples with UV-C and infiltrated with NCS in combination with UV-C, and US, presented an increase in the concentration of lactic acid at the end of storage, not presenting a significant difference between treatments ($18.52 \pm 0.44\%$). The increase of the concentration of lactic acid in the tissues favors protein denaturation and chemical changes in the meat structure, decreasing the WHC during the storage. However, since these samples are the ones with the highest initial WHC, they continue exhibiting the highest net values at the end of storage.

Electrical conductivity

Figure 3a shows the effect of WHC during the last day of storage on the evaluated parameters, electrical conductivity (EC), and shear force (SF). A significant direct correlation existed between the lower WHC value on the last day of storage and a lower EC, due to the release of electrolytes and water-soluble minerals. NCS/UV-C/US samples presented the lowest EC (2.02 ± 0.16 mS/cm) and the lowest WHC ($18.38 \pm 0.93\%$), due to greater myofibrillar structural damage, originated by the use of all treatments at the time, promoting protein oxidation and cell injury (Mancini, 2013).

Despite US samples presenting the highest WHC value ($29.75 \pm 0.18\%$) at the eleventh storage day, they exhibited an EC with no significant differences ($p \geq 0.05$) with the NCS/UV-C/US treatment (1.99 ± 0.14 mS/cm). This can be explained by the “sponge effect” or mechanical stress, successive compressions and expansions of the food material like a sponge because of acoustic vibrations during US treatment (Astráin-Redín *et al.*, 2021). This phenomenon promotes the release of salts due to cellular and tissue deterioration, not affecting the WHC because the change in the structure of the proteins and ROS formation can originate cross-linking and a gel-like structure capable of retaining water (Domínguez *et al.*, 2022). NCS treatment in combination with US and UV-C presented the highest EC values (7.31 ± 0.37 and 6.25 ± 0.33 mS/cm respectively). Figure 3 shows despite not finding

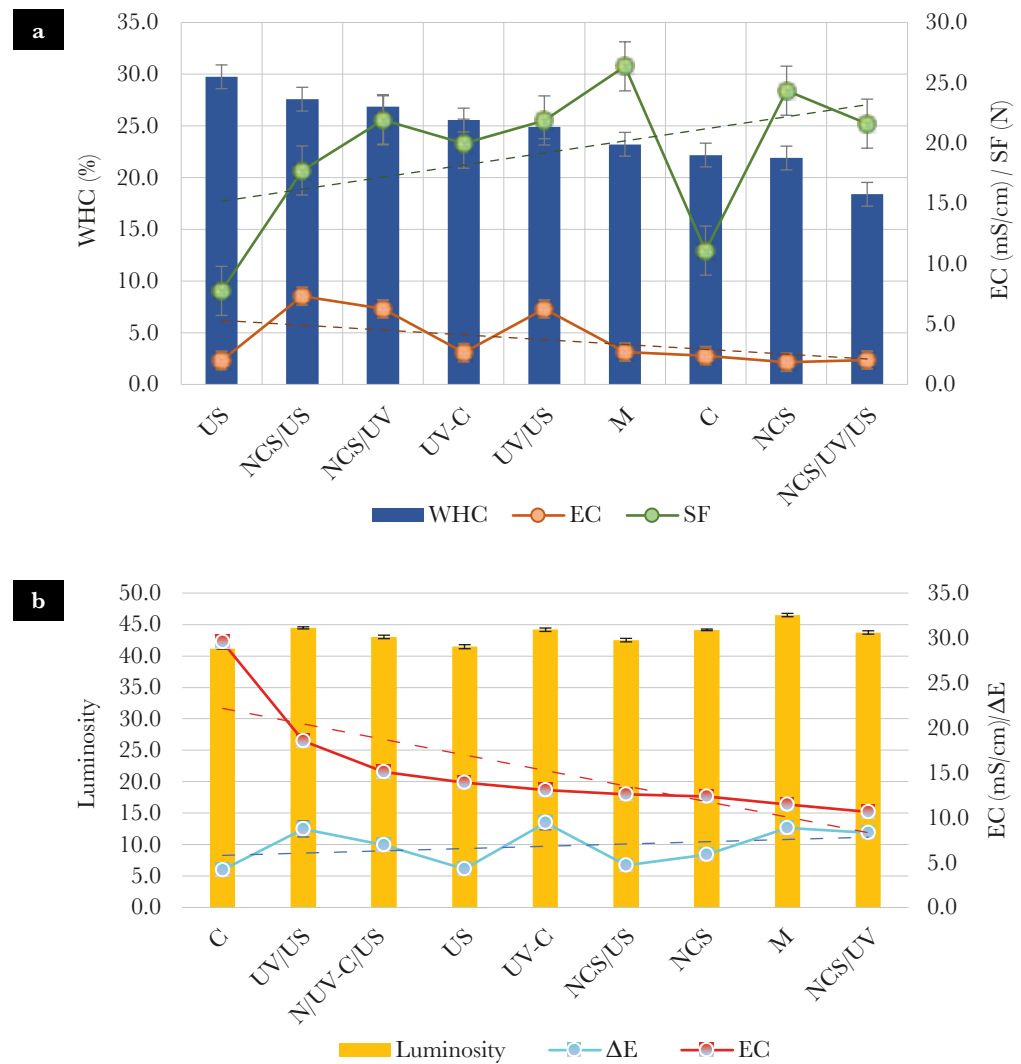


Figure 3. (a) WHC, EC, and SF correlation (b) Luminosity, EC, and ΔE correlation.

a significant correlation ($p \geq 0.05$) between WHC and ΔE , the variation in electrical conductivity could exhibit an inverse relation in both parameter behavior during meat storage. In Figure 3a a direct relation between the decrease in electrical conductivity and WHC is associated with a leakage of salts and inorganic compounds due to cell disruption (Mancini, 2013). Figure 3b exhibits an inverse relation between average ΔE and average electrical conductivity during the storage time. A higher ΔE is related to myoglobin oxidation from oxymyoglobin (Fe^{2+}) to metmyoglobin (Fe^{3+}) and myoglobin release due to its hydrophilic nature (Mancini, 2013), favored by marination, enhancing pigment loss.

Shear Force

As Figure 3 demonstrated, the shear force (SF) presented a significant inverse correlation ($p \leq 0.05$) with the WHC. The less water retained in the meat tissues increases the required SF, developing hardness and loss of tenderness in the meat. The control sample is the

only did not found within this behavior, presenting a lower SF (8.7 ± 0.37 N) at a low WHC ($22.18 \pm 1.08\%$). In the absence of an external treatment that would increase the presence of external ROS and provide energy, the oxidation of lipids and proteins resulted in polymeric fragmentation and a decrease in hardness as the meat structure lost its integrity.

pH

In the NCS, NCS/US, NCS/UV and NCS/UV/US treatments, pH values were lower and remained stable, with no statistically significant differences ($p \geq 0.05$) during the 11 days of storage (Figure 4). The quality of the final meat is a result of the evolution of temperature and pH during the post-mortem period (Hamoen *et al.*, 2013). It has been reported that if the pH is above the isoelectric point (5.0 to 5.1) for myofibrillar proteins, the filaments open, and more space is left for water molecules (Andújar *et al.*, 2003). In the same way, the excess of positive charges at low pH values causes repulsion and increases the volume of the myofilaments, which can favor the infiltration of the nanocapsules. In addition, the incorporation of the nanocapsules generated an effect on the surface luminosity of the chicken fajitas during storage at 2 °C due to the modification of the pH of the product. The ingredients used for marinating, in this case apple cider vinegar present a dark color, similar to coffee color, for this reason, luminosity in all treatments is low. However, the application of ultrasound has a direct relationship with the changes in luminosity because it favors the infiltration of the marinade into the fajitas, decreasing the luminosity and influencing the penetration of the color from the marinade ingredients (Chemat *et al.*, 2011). In addition, the nanocapsules, due to their nanometric size, favored the infiltration of the rosemary oil and provided stability to the system. It has been shown that there is a relationship between breast pH and luminosity (Chun *et al.*, 2010). When marinating chicken fajitas, the luminosity increases and is maintained during the conservation of the food due to the stabilization of the surface acidity caused by the incorporation of vinegar. The treatment (C) had a decreasing trend in luminosity, due to the physicochemical changes in the chicken breast caused by the deterioration of the breast causing a darkening of the surface of the product.

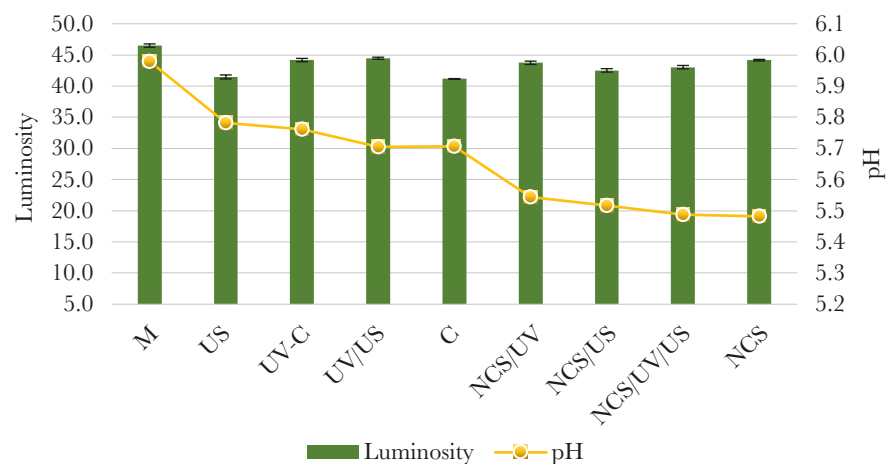


Figure 4. Luminosity and pH correlation.

Changes in ΔE

Color changes are very important, as it is the most important sensory characteristic for consumers at the point of sale. The values of ΔE obtained are between (3.0-6.0) (Inguglia *et al.*, 2021) and considered very visible, where treatments C, US, NCS, NCS/US are found, however, they present a great variation of color during the 11 days of storage (Figure 5). In the remaining treatments, the ΔE is between (6.0 and values above 12.0) and is highly visible (Inguglia *et al.*, 2021). With the above, the treatments that showed less color variation during the 11 days of storage are mainly preferred, being treatment C with 33%, NCS/UV and NCS/UV/US with 30%, where again the infiltration of the NCS in combination with UV and UV/US, presented greater color stability, due to their infiltration into the tissue.

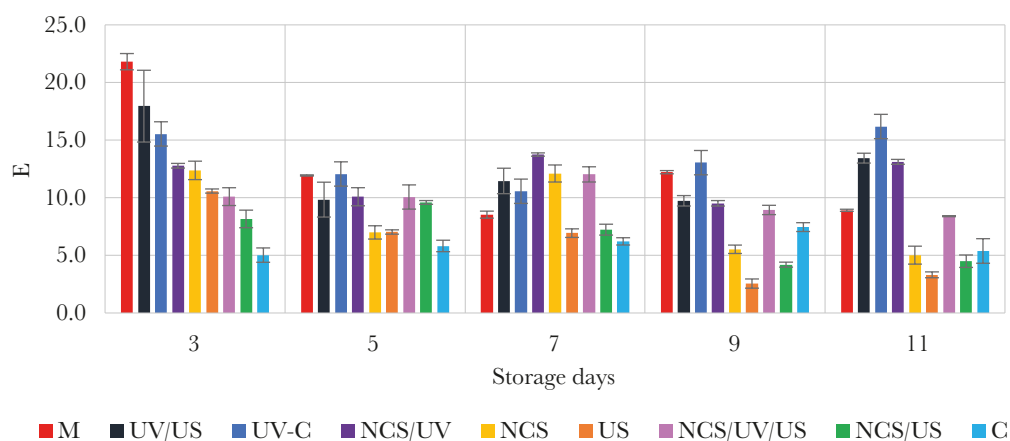


Figure 5. Changes in ΔE .

CONCLUSION

In this research, the combined use of emerging technologies for meat pre-treatment before refrigerated storage has demonstrated an inhibition of meat quality parameters variation. The marinate exhibits its importance in preserving the WHC during storage. Nevertheless, the incorporation of zein NCS in combination with other technologies presented higher WHC on the first and final storage day, affecting the electrical conductivity and shear force on the final storage day. These treatments presented a lower shear force compared to marinated samples (25.86%) and an electrical conductivity increase versus marinated (42.8%) and control samples (38.17%), suggesting less generated cell damage due to the treatment and storage. Despite these advantages, the marinated samples single and combined with other technologies presented higher ΔE due apple cider vinegar effect, meaning the control sample presented a lower variation. However, the NCS combined with US, UV-C, and US/UV-C also exhibits color stability.

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