Development of lemongrass essential oil nanoemulsion formulation as an edible coating to extend shelf life of tomato

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Abstract— **This study investigated the effect of lemongrass essential oil (LEO) nanoemulsion coatings on the shelf life of tomatoes. Two concentrations (0.5% and 1.0%) were prepared in a pectin-based matrix and applied by dipping for varying durations. The coated fruits were evaluated for spoilage, physiological loss in weight (PLW%), firmness, lycopene content, and redness during storage under ambient conditions. Both coatings effectively reduced spoilage and weight loss, maintained firmness, and delayed ripening compared to the control. Among treatments, 0.5% LEO nanoemulsion with longer dipping times provided the best preservation, extending tomato shelf life while retaining quality attributes. These findings suggest that LEO nanoemulsion is a safe, natural, and eco-friendly approach for reducing postharvest losses in tomatoes.**

Index Terms—**Tomato, Postharvest loss, Edible coating, Lemongrass Essential oil, Nanoemulsion, Nanotechnology.**

I. INTRODUCTION

Tomato (*Solanum lycopersicum*), a climacteric fruit of high nutritional and economic value, is rich in bioactive compounds such as lycopene, β-carotene, and phenolics that contribute to human health. However, its highly perishable nature results in rapid postharvest deterioration due to water loss, accelerated respiration, and microbial spoilage, leading to significant losses during storage and distribution [1][11].

Edible coatings have emerged as a sustainable preservation strategy to reduce such losses. These thin layers of biopolymers act as semi-permeable barriers, slowing moisture loss, gas exchange, and microbial growth while maintaining fruit quality [9][17]. Recent advances in nanotechnology have further improved coating efficiency by incorporating nanoparticles such as zinc oxide and chitosan, which exhibit strong antimicrobial properties [6][19].

Essential oils (EOs) are natural plant-derived compounds with proven antimicrobial and antioxidant activities, making them attractive as eco-friendly food preservatives [3][15]. However, their volatility and low solubility limit direct application in foods. Nanoemulsion systems, with droplet sizes of 20–200 nm, enhance EO stability, solubility, and controlled release, while minimizing negative sensory effects [8][10].

Thus, the integration of nanotechnology, essential oils, and nanoemulsion-based edible coatings offers an innovative and sustainable approach to extend the shelf life of tomatoes and reduce postharvest losses.

II. MATERIALS AND METHODS

The tomato variety “GAT-8,” known for having determinate type growth habit, ovoid shape with flat to pointed blossom end, firm texture, medium size, uniform ripening, high-yielding, disease-resistant tomato variety with desirable fruit characteristics and nutritional qualities was cultivated at the Main Vegetable Research Station of Anand Agricultural University, Anand. In the present study, lemongrass essential oil was utilized as a key component in the formulation of edible coating solutions. The oil, labelled as 100% pure on its packaging, was procured from a local market without any additional refinement or processing. All chemicals used in the preparation of nano-emulsion such as pectin, glycerol, and tween 80 were of analytical grade and procured from certified commercial suppliers.

The preparation of the nano-emulsion was carried out based on the method described by [13], with some modifications (Figure 1). 1 g of citrus pectin was dissolved in 100 ml of distilled water, and 1 ml of glycerol was added as a plasticizer. The solution was then homogenized using high speed homogenizer at 15,500 rpm for 4 min to ensure uniform mixing. Following this, Tween 80 was incorporated at a concentration of 100 µl as a surfactant, along with LEO at two concentrations – 0.5 ml and 1.0 ml. The mixture was further homogenized under the same conditions to produce a stable emulsion system.

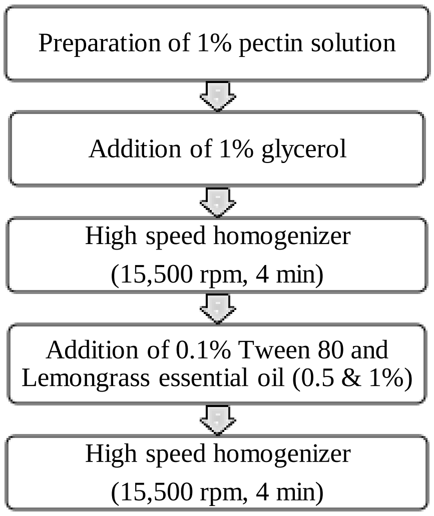


Fig. 1 Flowchart for preparation of nanoemulsion based coating solution

Following the preparation of the nano coating solution, its physicochemical properties were analysed using a dynamic light scattering (DLS) instrument. The analysis included measurement of particle size (nm), polydispersity index (PdI), count rate (kcps). These parameters were evaluated to assess the stability and uniformity of the nanoparticle coating formulations.

Tomato fruits were selected for uniformity in size, maturity stage, and colour, ensuring they were free from physical damage or signs of disease. Prior to treatment, the selected fruits were washed thoroughly with clean water and allowed to air-dry at room temperature.

The edible coating solutions, prepared using previously developed formulations were applied using the dipping technique. Fruits were dipped in each coating solution for five different time intervals: 2, 4, 6, 8, and 10 min. After dipping, excess coating solution was allowed to drain, and the coated fruits were kept under ambient conditions for surface drying by natural convection. Tomatoes dipped in distilled water served as the control (C).

Following the coating application, the fruits were stored at ambient temperature. Each treatment included 20 fruits. Observations and data collection were performed at intervals of every three days during the storage period and was replicated three times, assessing physical and chemical parameters to evaluate changes in quality and shelf life.

The experimental data obtained were subjected to factorial Completely Randomized Design (CRD) analysis to evaluate the individual and interaction effects of coating treatments and dipping durations on the measured parameters, thereby ensuring statistical reliability and precision of the results.

Determination of Spoilage (%)

The spoilage percentage of tomato fruits was calculated using the following formula:

$$\text{Spoilage (\%)} = \frac{\text{Number of spoiled tomatoes}}{\text{Total number of tomatoes}} \times 100 \qquad \text{Eq. 1}$$

Tomatoes were visually examined at regular intervals during storage to determine spoilage (equation 1). Fruits exhibiting clear signs of deterioration – such as fungal growth, black spots, softening, shrinkage, discoloration, unpleasant odour, or any visible lesions – were classified as spoiled. This assessment method, based on visual inspection, has been commonly applied in postharvest studies for identifying quality degradation in fruits [4][12]. The percentage of affected fruits was used as an indicator of shelf-life performance under different treatments.

Determination of Physiological Loss in Weight (PLW%)

Physiological loss in weight (PLW) of tomato fruits during storage was calculated to assess the rate of moisture and metabolic loss. The weight of each sample was recorded on day 0 (initial weight) and subsequently at regular intervals throughout the storage period. PLW was determined using the following formula:

$$\text{PLW (\%)} = \frac{\text{Initial weight - Weight on day of observation}}{\text{Initial weight}} \times 100 \qquad \text{Eq. 2}$$

Weight loss primarily results from transpiration and respiration, where moisture evaporates due to vapor pressure differences, and carbon is lost through metabolic activity [16]. Tomatoes stored under refrigerated conditions exhibited lower PLW compared to those stored at room temperature, due to reduced vapor pressure and metabolic activity. Additionally, the extent of weight loss was influenced by the type of treatment and packaging used, with protective packaging significantly minimizing moisture loss during storage [12].

Determination of Lycopene Content

Lycopene content in tomato samples was estimated using the spectrophotometric method described by [2]. Approximately 5 to 10 g of homogenized sample were extracted using acetone, and the extraction was repeated until the filtrate turned colourless. The pooled acetone extracts were transferred into a separating funnel containing 10-15 ml of petroleum ether and washed with 5% sodium sulphate solution to eliminate residual water. The acetone layer was repeatedly extracted with petroleum ether until it became clear. The final petroleum ether layer was collected, and the total volume was adjusted to 50 ml. Lycopene content was quantified using a UV-Visible spectrophotometer at an absorbance of 503 nm, with petroleum ether serving as the blank. The concentration of lycopene (mg/100 g) was calculated using the following formula:

$$\text{Lycopene content (mg/100 g)}=\frac{3.1206 \times A \times D \times 100}{W \times 1000} \qquad \text{Eq. 3}$$

Where A is the absorbance at 503 nm, D is the dilution volume in ml, and W is the weight of the sample in grams.

This method allows accurate quantification of lycopene, which is an important antioxidant responsible for the red pigmentation in tomatoes and has significant nutritional and health-related implications.

Determination of Firmness

Firmness is a critical attribute in assessing the textural quality and market value of tomatoes, particularly in the context of mechanical harvesting and industrial processing. It is primarily influenced by fruit maturity and directly correlates with the fruit's resistance to deformation and mechanical damage. Soft or overripe tomatoes, though potentially rich in flavour, are more prone to cracking and are less suitable for whole-can applications, often resulting in their relegation to lower-value products like purees. Firmness is typically measured through mechanical tests such as compression, puncture, or impact analysis using devices like texture analysers. These methods quantify resistance to applied force, recoverable deformation, and skin breakage thresholds. Such objective evaluation not only supports postharvest quality control but also aids in selecting optimal harvesting times and minimizing transport losses [14].

The puncture test is a widely adopted method for evaluating the skin resistance of tomatoes, which is a key indicator of fruit firmness and structural integrity. In this test, a texture analyser equipped with a cylindrical steel probe (commonly 2 mm in diameter) is used to penetrate the skin of the tomato, typically in the equatorial region without removing the peel. The force required to pierce the skin—measured in grams (g) – is recorded and interpreted as the tomato's skin resistance. The test is carried out at a constant penetration speed, often around 0.83 mm/s, with the probe continuing to a depth of approximately 10 mm. Higher puncture force values indicate firmer fruits with greater resistance to mechanical damage, which is particularly important for postharvest handling, transport, and storage. This method offers a reproducible and objective approach to monitor textural changes during ripening and under various treatment conditions such as gamma irradiation or cold storage [7].

Determination of Colour Value

The surface colour of tomato fruits was quantitatively measured using a Lovibond RT850i colorimeter, which operates on the CIELAB colour space model [5]. For precise data acquisition, the device's nose cone was firmly positioned perpendicular to the tomato surface, ensuring no light leakage during measurement. The colorimetric values recorded include L*, a*, and b*, where L* denotes the degree of lightness (ranging from 0 for black to 100 for white), a* indicates the position on the red-green axis (positive values for red, negative for green), and b* reflects the yellow-blue axis (positive values for yellow, negative for blue). This system provides an objective and reproducible assessment of surface colour changes in agricultural and food products, allowing for accurate monitoring of quality parameters such as ripeness and shelf stability.

Evaluation of Shelf Life

Shelf life refers to the duration during which a fruit maintains its acceptable quality under specified storage conditions. In this study, the shelf life of tomatoes was assessed based on visible indicators of deterioration. Specifically, a batch was considered to have reached the end of its shelf life when more than 50% of the fruits displayed noticeable signs of spoilage, such as shrinkage or the development of sunken lesions typical of fruit rot. This method offers a standardized and practical approach for determining the usability of stored produce, allowing for consistent comparisons across different storage treatments. The assessment was carried out at regular intervals to accurately capture changes over time, enabling the identification of effective preservation strategies. This approach to shelf-life evaluation aligns with the protocol described by [18], who used similar visual parameters to assess storage outcomes in tomato fruits.

III. RESULTS AND DISCUSSION

Nanoemulsion-based formulations were successfully developed using lemongrass essential oil as the active ingredient, stabilized in a pectin-based matrix. Two concentrations of lemongrass oil, 0.5% and 1.0% (v/v), were incorporated into the formulation along with pectin (1% w/v), glycerol (1% v/v) as a plasticizer, and Tween 80 (0.1% v/v) as an emulsifier to promote uniform dispersion of oil droplets. High-speed homogenization was employed to achieve a fine emulsion with droplet sizes in the nanometer range. The formulated nanoemulsions were then characterized using Dynamic Light Scattering (DLS) to assess key parameters such as average droplet size (nm), polydispersity index (PdI), and mean count rate (kcps). The mean count rate values further supported the effective scattering behaviour, reflecting a stable colloidal system. These observations confirmed the successful formation of nanoemulsions suitable for application as edible coatings, with the potential to enhance the antimicrobial and shelf-life-extending effects when applied to perishable produce like tomatoes.

The droplet size, polydispersity index (PdI), and mean count rate of the lemongrass essential oil (LEO) nanoemulsion coating solutions were evaluated using dynamic light scattering (DLS), and the results are presented in Table 1.

At 0.5% concentration, the average particle size was 333.60 ± 4.996 nm, while the PdI was 0.287 ± 0.026, indicating a moderately narrow size distribution. The mean count rate was recorded as 355.53 ± 3.21 kcps, reflecting stable scattering intensity.

With an increase to 1.0% LEO concentration, the particle size significantly increased to 630.50 ± 3.438 nm. Interestingly, despite the increase in size, the PdI decreased slightly to 0.230 ± 0.048, suggesting a relatively more uniform distribution of particles. The mean count rate also increased to 436.23 ± 2.14 kcps, implying enhanced light scattering due to the larger droplet size.

The results suggest that increasing the concentration of essential oil in the nanoemulsion formulation tends to increase the droplet size due to the higher oil phase content, which can affect the emulsion's stability and performance. However, the PdI values in both treatments remained below 0.3, which is generally acceptable for nanoemulsion stability, indicating that both formulations were reasonably monodisperse.

Table 1 Characterization of LEO nanoemulsion coating solution for particle size (nm), PdI and mean count rate (kcps)

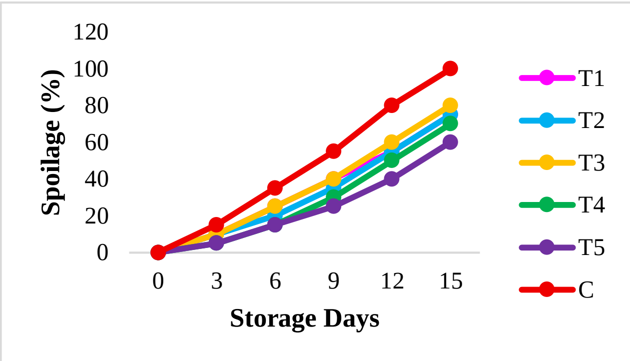
Concentration (%)	Size (d. nm)	Poly-dispersity Index (PdI)	Mean Count Rate (kcps)
0.5	333.600 ± 4.996	0.287 ± 0.026	355.533 ± 3.209
1.0	630.500 ± 3.438	0.230 ± 0.048	436.233 ± 2.137

Values are expressed as Mean ± SE(m); n=3

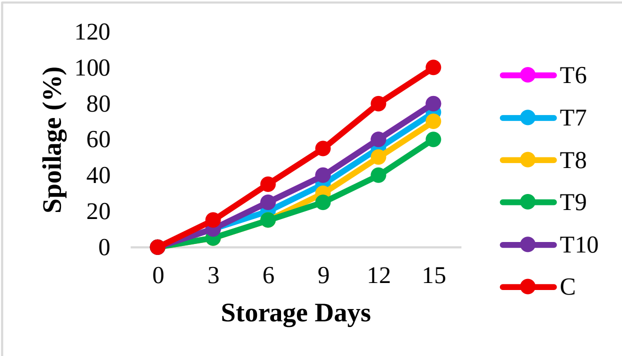
Effect of dipping duration in 0.5% and 1.0% LEO nanoemulsion-based edible coating on spoilage (%) of tomato during storage

Figure 2 (A) illustrates the effect of varying dipping durations in 0.5% LEO nanoemulsion-based edible coatings on spoilage during tomato storage. The results show that spoilage increases progressively over time across all treatments, but the coated samples exhibited significantly lower spoilage compared to the control. Among the treatments, T_5 consistently showed the lowest spoilage, with only 60% spoilage by day 15, whereas the control reached complete deterioration by the same period. This indicates that the use of LEO nanoemulsion coatings effectively slows down spoilage and provides better preservation of tomatoes during storage. In Figure 2 (B), the impact of dipping in 1.0% LEO nanoemulsion on spoilage percentage is depicted. Spoilage levels increased progressively with time in all treatments, but coated tomatoes exhibited much lower spoilage than the control, which reached 100% spoilage by day 15. Among the treatments, T_9 exhibited the least spoilage (60%), followed closely by T_8 (70%), suggesting that longer dipping durations are more effective in reducing spoilage.

In comparison, both 0.5% and 1.0% LEO nanoemulsion coatings significantly delayed spoilage, with longer dipping durations showing the most effective results. However, the 0.5% LEO nanoemulsion treatment demonstrated superior results compared to the 1.0% concentration. Specifically, T_5 from the 0.5% concentration exhibited the lowest spoilage, confirming that a lower concentration of LEO nanoemulsion, along with longer dipping durations, provides better preservation. These findings suggest that both the concentration of LEO nanoemulsion and the dipping duration play crucial roles in enhancing the shelf life of tomatoes by significantly reducing spoilage.



(A)



(B)

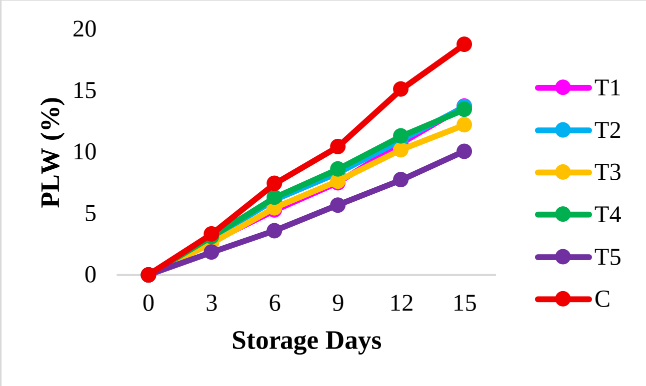
Fig. 2 Effect of dipping duration in 0.5% (A) and 1.0% (B) LEO nanoemulsion-based edible coating on spoilage (%) of tomato during storage

Where, T_1: 2 min dipping; T_2: 4 min dipping; T_3: 6 min dipping; T_4: 8 min dipping; T_5: 10 min dipping (0.5% LEO NE Solution)
T_6: 2 min dipping; T_7: 4 min dipping; T_8: 6 min dipping; T_9: 8 min dipping; T_{10}: 10 min dipping (1.0% LEO NE Solution)

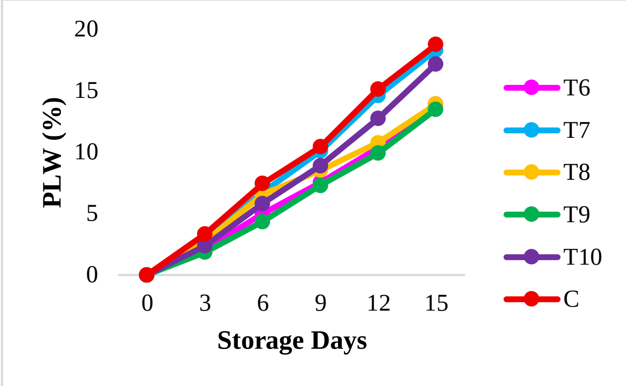
Effect of dipping duration in 0.5% and 1.0% LEO nanoemulsion-based edible coating on PLW (%) of tomato during storage

Figure 3 illustrates the influence of dipping duration in 0.5% (A) and 1.0% (B) LEO nanoemulsion-based edible coatings on the physiological loss in weight (PLW) of tomatoes during storage. In both concentrations, PLW increased progressively with storage duration, but coated fruits consistently demonstrated lower values than the untreated control. At 0.5% concentration, the lowest PLW (10.06%) was observed in T_5 at day 15 compared to the control (18.74%). Similarly, at 1.0% concentration, T_9 exhibited the least PLW (13.47%), while the control again recorded the highest weight loss (18.74%). These results indicate that LEO nanoemulsion coatings effectively reduce moisture loss and maintain fruit quality, with prolonged dipping durations offering enhanced protective effects.

A comparison between the two concentrations shows that the 0.5% LEO nanoemulsion coating with longer dipping duration (T_5) was more effective in reducing PLW than the 1.0% concentration (T_9). This suggests that while both concentrations limit postharvest weight loss, the efficiency of the coating is not solely dependent on concentration but also on the dipping duration, with extended exposure enabling better film formation and improved barrier properties.



(A)



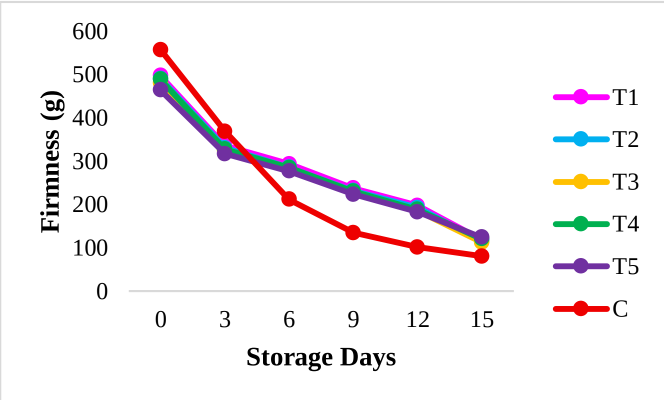
(B)

Fig. 3 Effect of dipping duration in 0.5% (A) and 1.0% (B) LEO nanoemulsion-based edible coating on PLW (%) of tomato during storage

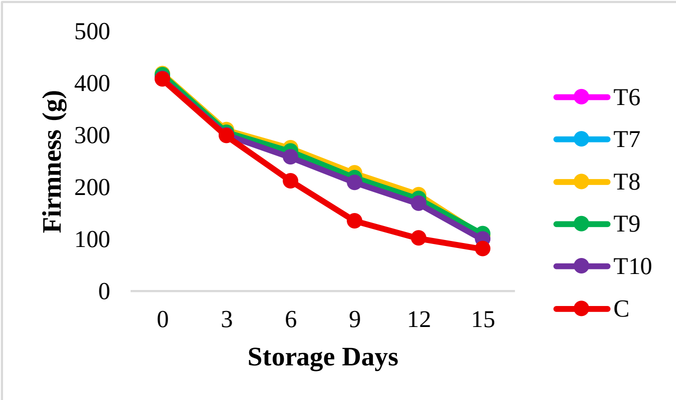
Effect of dipping duration in 0.5% and 1.0% LEO nanoemulsion-based edible coating on firmness (g) of tomato during storage

Figure 4 illustrates the effect of dipping duration in 0.5% (A) and 1.0% (B) LEO nanoemulsion-based edible coatings on tomato firmness during storage. In both concentrations, firmness decreased gradually with the extension of storage time, but coated tomatoes consistently retained higher values than the untreated control. At 0.5% concentration, T_5 exhibited the highest firmness (124.32 g) on day 15 compared to the control (80.77 g), while at 1.0% concentration, T_9 preserved the maximum firmness (143.52 g) by the end of storage. These results suggest that LEO nanoemulsion-based coatings effectively delayed tissue softening, reduced degradation processes, and helped maintain the texture of tomatoes during storage, with longer dipping durations enhancing this protective effect.

A comparison between the two concentrations reveals that tomatoes coated with 1.0% LEO nanoemulsion (T_9) retained greater firmness than those treated with 0.5% (T_5). This indicates that while both concentrations were effective in slowing the loss of firmness, the higher concentration provided a stronger barrier effect and better protection against softening. Therefore, increasing the coating concentration, alongside longer dipping duration, appears to enhance firmness retention and extend the postharvest quality of tomatoes more effectively.



(A)



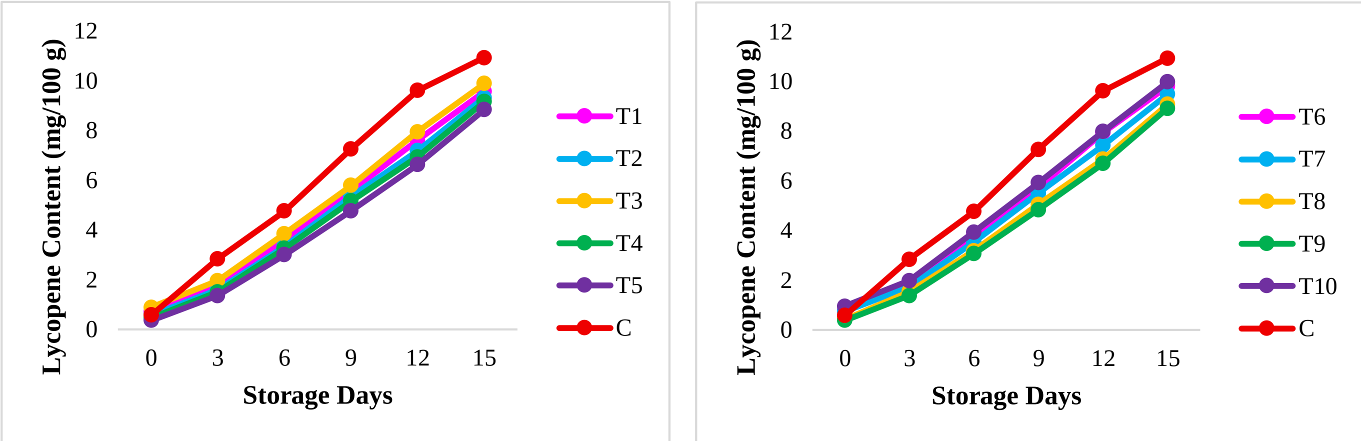
(B)

Fig. 4 Effect of dipping duration in 0.5% (A) and 1.0% (B) LEO nanoemulsion-based edible coating on firmness (g) of tomato during storage

Effect of dipping duration in 0.5% and 1.0% LEO nanoemulsion-based edible coating on lycopene content (mg/100 g) of tomato during storage

Figure 5 shows the effect of dipping duration in 0.5% (A) and 1.0% (B) LEO nanoemulsion-based edible coatings on the lycopene content of tomatoes during storage. In both concentrations, lycopene levels increased gradually as ripening progressed, but coated samples consistently exhibited lower accumulation than the untreated control. At 0.5% concentration, the control reached 10.93 mg/100 g by day 15, whereas T_5 recorded the lowest lycopene content (8.33 mg/100 g). Similarly, at 1.0% concentration, the control reached 10.94 mg/100 g by day 15, while T_9 maintained the lowest level (8.92 mg/100 g). These results suggest that the application of LEO nanoemulsion coatings slowed down lycopene synthesis, thereby delaying ripening and contributing to prolonged storage stability, with longer dipping durations showing greater effectiveness.

When comparing the two concentrations, the 0.5% coating with extended dipping duration (T_5) demonstrated slightly stronger inhibition of lycopene accumulation compared to the 1.0% treatment (T_9). This indicates that while both concentrations effectively delayed pigment formation, the efficiency of the coating depended more on dipping duration than on concentration. Hence, longer exposure to coating solution appears to enhance the protective barrier, better regulating ripening and extending the shelf life of tomatoes.



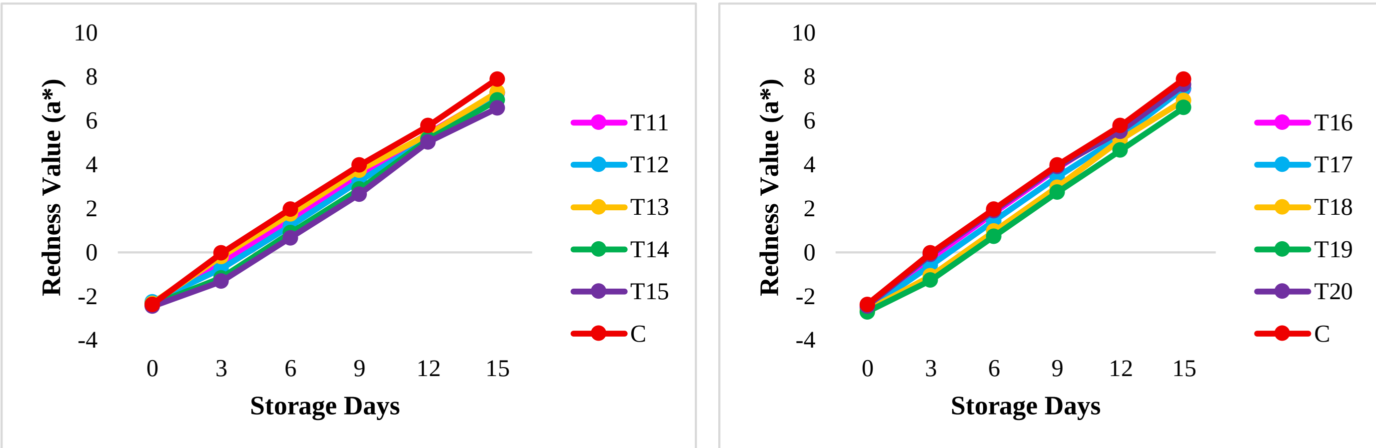
(A) (B)

Fig. 5 Effect of dipping duration in 0.5% (A) and 1.0% (B) LEO nanoemulsion-based edible coating on lycopene content (mg/100 g) of tomato during storage

Effect of dipping duration in 0.5% and 1.0% LEO nanoemulsion-based edible coating on redness value (a*) of tomato during storage

Figure 6 illustrates the effect of dipping duration in 0.5% (A) and 1.0% (B) LEO nanoemulsion-based edible coatings on the redness value (a*) of tomatoes during storage. In both concentrations, redness values increased gradually with storage time as ripening advanced, but coated fruits consistently exhibited slower colour development than the untreated control. At 0.5% concentration, the control reached the highest redness value (7.89) by day 15, while T_5 recorded the lowest value (6.57). Similarly, at 1.0% concentration, the control showed the highest redness value (7.90) at the end of storage, whereas T_9 maintained the lowest level (6.60). These findings indicate that LEO nanoemulsion coatings effectively delayed the progression of redness associated with ripening, with longer dipping durations contributing to a stronger inhibition of colour change and enhanced preservation of fruit quality.

A comparison between the two concentrations shows that the 0.5% treatment with extended dipping duration (T_5) resulted in slightly lower redness values than the 1.0% treatment (T_9). This suggests that while both concentrations effectively suppressed pigment development, the coating performance was more dependent on dipping duration than concentration. Therefore, prolonged exposure to the coating solution enhanced its protective effect, contributing to delayed ripening and extended marketability of tomatoes during storage.



(A) (B)

Fig. 6 Effect of dipping duration in 0.5% (A) and 1.0% (B) LEO nanoemulsion-based edible coating on redness value (a*) of tomato during storage

Statistical Reliability of Data

The statistical reliability of data for different quality parameters of tomato under 0.5% and 1.0% LEO nanoemulsion-based coatings was assessed using a two-factorial CRD with three replications, where factor A represented dipping time and factor B represented storage days. The results in table 2 indicated that the calculated CD values for A, B, and their interaction (A × B) varied across parameters, showing the minimum differences required among means to be considered significant. The SEM values were relatively low, reflecting good precision of the experiment, while the CV values were within acceptable limits (<10%) for all traits, confirming the reliability of the data. Notably, firmness and lycopene content exhibited very low CVs (<2%), indicating high consistency across replications, whereas redness value showed slightly higher variability but remained within the acceptable range. Overall, the low SEM and CV values validate that the experimental results were statistically sound and dependable for interpreting the effects of dipping time and storage duration on PLW, firmness, lycopene, and redness in tomatoes.

Table 2 Statistical Reliability of Data (CD, SEM and CV) for PLW, Firmness, Lycopene and Redness of Tomato as Influenced by Dipping Time and Storage Days under Factorial CRD

Parameter	Concentration (%)	(A)		(B)		(A × B)		CV (%)
		CD	*SE(m)*	*CD*	*SE(m)*	*CD*	*SE(m)*	
PLW (%)	0.5	0.365	0.129	0.333	0.118	0.816	0.288	5.95
	1.0	0.351	0.124	0.32	0.113	0.784	0.277	5.408
Firmness (g)	0.5	0.81	0.287	0.81	0.287	1.985	0.704	0.456
	1.0	0.744	0.264	0.744	0.264	1.823	0.646	0.454
Lycopene content (mg/100 g)	0.5	0.051	0.018	0.051	0.018	0.124	0.044	1.573
	1.0	0.049	0.017	0.049	0.017	0.119	0.042	1.494
Redness value (a*)	0.5	0.149	0.053	0.149	0.053	0.365	0.13	9.498
	1.0	0.158	0.056	0.158	0.056	0.188	0.138	9.849

Experimental design: factorial CRD; n=3

IV. CONCLUSION

The application of lemongrass essential oil (LEO) nanoemulsion as an edible coating significantly improved the storage quality of tomatoes by reducing spoilage and physiological loss in weight while maintaining firmness and delaying ripening-related changes such as lycopene accumulation and redness development. Both 0.5% and 1.0% concentrations were effective; however, the 0.5% coating with longer dipping times showed superior results in extending shelf life under ambient conditions. The low SEM and CV values obtained in factorial CRD analysis confirmed the reliability and precision of the data. Overall, LEO nanoemulsion-based edible coating can be considered a promising, eco-friendly, and sustainable approach to minimize postharvest losses and enhance the marketability of tomatoes.

From a future perspective, further research may focus on testing different essential oils or blends to enhance antimicrobial and antioxidant activity, scaling up the coating process for industrial application, and evaluating its compatibility with other preservation techniques such as refrigeration or modified atmosphere packaging. Additionally, consumer acceptability studies and cost–benefit analyses would help establish the commercial feasibility of LEO nanoemulsion coatings in the fresh produce supply chain.

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