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Research Article

A study on coating of Hydroxypropyl methylcellulose incorporated with a nano-emulsion of Piper betel leaf essential oil to enhance shelf-life and improve postharvest quality of Tomato (*Solanum lycopersicum* L.)

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Abstract

Edible coating films derived from essential oils effectively preserve farm produce, especially fruits and vegetables, and the technology is widely prevalent in improving their shelf life. The present study aimed to reduce the post-harvest loss and extend the shelf life of tomatoes using edible coatings based on Hydroxypropyl methylcellulose (HPMC) containing Piper betel leaf essential oil nano-emulsion as an antibacterial and bioactive compound. It also aimed for optimal extraction of essential oils (EO) from Piper betel leaves which contain various medicinal, antimicrobial, and antioxidant compounds such as chavibetol, eugenol, and other compounds. The essential oils were extracted, and nano-emulsion was prepared by a low-energy emulsification method and incorporated into edible HPMC composite to determine whether the edible coatings of the nano-emulsion of Piper betel leaf could delay the changes that lead to deterioration of the fruit. Results showed that the coatings delayed 5 % changes in color, 8% weight loss, titratable acidity, ascorbic acid content, soluble solids concentration, lycopene, and decay percentage, compared to uncoated control fruits. It was inferred that tomatoes that were coated with 15% nano-emulsion containing dipping solution showed a significant increase in the shelf life of tomatoes up to 8 days. Therefore, it is suggested to use HPMC containing the *Piper betel* oil nano-emulsion as an edible coating, extending the shelf-life of tomato fruits post-harvest.

Keywords: Edible polymer Essential oils, HPMC-lipid composite (Hydroxypropyl methylcellulose), Nano-emulsion, *Piper betel*, PEOs, Tomato

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is a commonly consumed fruit, rich in minerals such as potassium and vitamins such as ascorbic acid and folates. Due to its high moisture content and perishability, this fruit has restricted marketability resulting in significant post-harvest losses. Accelerated ripening, post-harvest infections, and ageing are just factors limiting storage (El-Ramady *et al.*, 2015). The respiration rate is very high and has been the primary causative factor for reduced post-harvest shelf life, fruit ripening, and quality degradation (Ali *et al.*, 2010). Operational management such as cold storage @ 8 to 10°C, and control of humidity @ 30 to 32% Relative Humidity in cold rooms is one approach to regulate tomato ripening and extend the shelf life of the fruit. Using controlled environmental storage conditions, tomatoes can have their shelf life extended, but the technique is expensive. Edible coatings are one option for extending post-harvest life and lowering production costs (Fagundes *et al*., 2015). Edible polymers are completely safe because the polymeric substance can be taken whole or orally by humans or lower animals. To retain the product's quality and stability, edible polymers can be coated directly to the surface as an additional layer of protection. Edible polymers have emerged as food, safe for consumption and as an alternative to plastics for storage (Kumar *et al*., 2020). The primary benefit of edible polymers is that they can be consumed together with the products. The FDA recognizes essential oils derived from several plant sources as GRAS (Generally recognised as safe) materials. Due to their antioxidant and antibacterial characteristics to preserve foods and reduce the number of infections, essential oil emulsions and nano-emulsions have been examined and show promise as an additive to the food industry (El-Sayed and El-Sayed, 2021). A number of essential oils and their nano-emulsions have been tested and demonstrated the potential to extend food's shelf life, including thyme essential oil nano-emulsion in yoghurt, laurel essential oil nano-emulsion on fish, and ginger oil, either alone or in combination with coatings, on papaya fruit (Miranda *et al*., 2021).

There is research that combines several oils in binary and tertiary combinations, such as the nano-emulsion of ginger, cinnamon, and cardamom (Jafarizadeh-Malmiri *et al*., 2022). Nano-emulsion has been regarded as an effective antibacterial agent in recent decades (Rafiee *et al*., 2021). Essential oil is extracted from the betel leaf or vine (Piper betel). On a dry weight basis, the quantity of essential oil found in different varieties such as *Mitha, Bangla,* and *Sanchi* is around 2.0 percent, 1.7 percent, and 0.8 percent, respectively (Guha, 2007). Fresh, stale, de-chlorophyll, or partially decaying betel leaves can be used to extract the essential oil (Khalil *et al*., 2017). Immobilized HPMC can be used in the creation of bioactive food packaging to reduce the bacterial load on food surfaces in various food products. There has been a paradigm change in recent years toward using biodegradable packaging materials and procedures due to environmental conservation consciousness (Sogvar *et al*., 2016). As a result, the idea of biodegradability has benefits for both humans and the environment. Because this edible plant derivative has demonstrated the ability to form transparent, odourless, tasteless, oil-resistant, water-soluble films with very efficient oxygen, carbon dioxide, aroma, and lipid barriers, but with moderate resistance to water vapour transport, biodegradable polymer hydroxypropyl methylcellulose (HPMC) edible films are appealing for food applications (Nechitaand Roman, 2020). Even though betel leaf essential oil is utilized for different purposes, betel leaf extracts are employed as an antibacterial agent in foods (Karunanithi *et al*., 2022). Starch-based materials have gained a lot of interest in the food packaging industry because of their biodegradability, edible nature, availability, low cost, no allergic nature, ease of usage, and thermal process ability. Hydroxyl Propyl Methyl Cellulose (HPMC) is a film-forming, stabilizer, thickening, and suspending agent that has been authorized as a direct food additive (Grover *et al*., 2020). The incorporation of hydrophobic chemicals, such as fatty acids, into the cellulose ether matrix to form a composite film, can improve HPMC's poor moisture barrier characteristics (Chappalwarand Ojha, 2018). Here are also studies blending different oils in binary and tertiary combinations, for example, ginger-cinnamon-cardamom essential oil nano-emulsion (Jafarizadeh-Malmiri *et al*.,2022). The use of nano-emulsions increases bioactivity and physical stability and decreases sensory taste changes. Edible coatings based on cellulose derivatives have been widely utilized to postpone ripening and quality loss in fresh fruits such as pearsandcherries (Zhou *et al*., 2011). Therefore, this study was conducted to use HPMC containing nano-emulsion of essential oil as a novel edible coating to enhance the shelf-life of tomato fruits post-harvest.

MATERIALS AND METHODS

Collection of *Piper betel* leaves

Freshly harvested *Piper betel* L. leaves were procured from the local markets in Chennai, Tamil Nādu, in June 2021.

Hydro distillation using Clevenger apparatus

Fresh *Piper betel* leaves were procured, cleaned, cut, and dried in a hot air oven for 3-4 hours at 50°C. Dried leaves were ground to 10 mesh size and extracted by mixing with distilled water in a ratio of 1:10 in Clevenger's hydro distillation set up for 6-8 hours. The essential oil was extracted using Guha (2007) methodology and its characterization was carried out using GC-MS.

Preparation of nano-emulsion by low-energy emulsification

Extracted essential oil (EO) was mixed with Tween 20 (emulsifier) in a ratio of 1:3 and vortexed in a cyclomixer for 2-3 minutes. This mixture was added to a volume of Milli Q water (pre-stirred in a magnetic stirrer for 15 minutes), making the emulsion EO concentration to 5% (v/v). The final emulsion was magnetically stirred at 300 rpm for 30 minutes. The nano-emulsion thus formed was stored in a non-reactive Borosil container at 4°C. The nano-emulsions prepared were studied using DLS (Dynamic Light Scattering) analysis following Anton and Vandamme (2009).

Preparation of dipping solution

Hydroxypropyl methylcellulose (HPMC) powder (12.5 g) and glycerol (0.550 ml) were mixed with 500 ml of distilled water using a magnetic stirrer at 80 °C for 1 hour, followed by cooling to room temperature. Betel leaf essential oil nano-emulsion was added at 15% (µl/ml) concentrations with HPMC and mixed by ultrasonication for 5 minutes (Ding *et al*., 2015).

Treatment of tomatoes

Tomatoes were procured fresh, surface washed, weighed, examined, and dipped in the coating solution. Coatings on tomatoes were dried by natural convection at room temperature. The coated tomatoes were packed in perforated boxes to avoid further atmosphere modifications. Boxes were kept at 25° C and 60% RH in the stability chamber (Nawab *et al*., 2017).

Total acidity, total soluble solids, ascorbic content, and lycopene content

The tomatoes from each treatment were ground in a blender and juice from the fruit was used to determine the soluble solids concentration (SSC) using a handheld refractometer. The instrument was standardized using purified water before the readings were taken. Titratable acidity (TA) was determined by measuring the amount of 0.1N NaOH required for neutralization, ascorbic acid content was estimated using the dye 2,6-dichlorophenol–indophenol titration (DCPIP) method, and the lycopene content was determined calorimetrically all described by Oberoi and Sogi (2015).

Weight loss percentage

Tomato samples (3 fruits per replication) were weighed at day 0 and at the end of each storage interval. The difference between the initial and final fruit weight was considered as total weight loss during that storage interval and calculated as percentages on a fresh weight basis by the standard method (AOAC, 1975).

Decay percentage

The decay percentage of coated and uncoated fruit was calculated as the number of decayed fruits divided by the initial number of all fruits and multiplied by 100 (El-Anany *et al*., 2009).

Determination of lycopene content

The extraction of crude lycopene was done following the procedure of (Ranganna, 1986) with slight modifications (Kehili, 2019). Thirty grams of the dried powdered tomato waste were transferred into a beaker containing 150 ml of acetone and agitated with a magnetic stirrer for 30 min. The filtrate was taken and re-extracted with an extra 150 ml of acetone for another 30 min collected, and the extraction was repeated until the colour disappeared. Sixty ml of petroleum ether was added into a separatory funnel and a small portion of the acetone extract was added. Distilled water was slowly added along the walls of the funnel. Two phases were separated, and the lower aqueous-acetone phase was discarded. Another portion of the acetone extract was added and the partitioning with petroleum ether was repeated until all of the extracts, were transferred into petroleum ether. Successive washings with distilled water were used to remove the residual acetone. An aliquot of 50 ml was diluted with petroleum ether and assessed using Varian Cary 50 UV - VIS spectrophotometer at 503 nm. The lycopene content was determined using the following equation no. 1:

$$\text{Total lycopene content } (\mu g/g) = A \times \text{volume (ml)} \times 10^4 / A^{1\%}_{1cm} \times \text{sample weight (g)} \quad \text{....Eq.1}$$

Where A = absorbance; Volume = total volume of extract; $A^{1\%}_{1cm}$: absorption coefficient of lycopene in petroleum ether = 3450

Statistical analysis

Statistical analysis of experimental data in triplicates from the experiment was carried out by statistical software SPSS Version 22. The F-test used a 0.05 probability level of significance.The analysis of variance was calculated following Panse and Sukhatme (1967).

RESULTS AND DISCUSSION

GC-MS analysis of essential oil

Various compounds were identified in the essential oil, using Agilent technologies 6890 N JEOL GC Mate II GC-MS and were referenced with chemical databases such as PubChem and their complete chemical and structural data were obtained. It was seen that the compound Chavicol, with Retention time (RT)= 3.17, was the key compound present in this fraction as it had the highest peak area and ion concentration. The diterpenoid profile among the primary EOs was similar, although the abundance of the diterpenoids is also influenced by different environmental factors, genetic conditions and chemical reactivity (Gabetti, *et al.*, 2021). The gas chromatogram is shown in Fig. 1. The chromatographic details and chemical properties of the identified compounds are shown in Table 1 and the 2-D and 3-D structures are depicted in Fig. 1. GC-MS analysis identified that the extracted EO was rich in compounds such as Eugenol, Chavicol, and Camphene expressing antifungal and antimicrobial properties (Table 1).

Dynamic light scattering particle size distribution analysis

To study the particle size distribution, polydispersity index, and zeta potential of the prepared nano-emulsion, a Dynamic light scattering (DLS) analysis was conducted using Nanotrac Wave II. The polydispersity index (PI) is a measure of the heterogeneity of a sample based on size showed in Fig.2. Zeta potential is a scientific term for electro kinetic potential in colloidal dispersions. Zeta potential can be used to predict the long-term stability of particles. For example, particles with zeta potentials larger than ±60 mV have excellent stability, whereas particles with zeta values between -10 mV and +10 mV will experience rapid agglomeration unless they are sterically protected showed in Table 2. It was observed that the size of the nanoparticles ranged around 10 nm, which was corresponding to the previously observed results in the literature (Basak and Guha, 2018). The polydispersity index of the nano-emulsion was observed to be 0.0537 and the zeta potential was -200 mV. A peak summary of nano-emulsion Dynamic light scattering analysis is given in Table 3.

Table 1. Phytochemical components present in the identified compounds of *Piper betel essential oil*

RT	Common name	IUPAC	Molecular formula	CAS No.	TIC	Scan	Base	#ions
1.28	Cyclopentene diol	(1S,3R)-cyclopent-4-ene-1,3-diol	$C_5H_8O_2$	29783-26-4	12438672	12	100% FS	1263
3.17	Chavicol	4-Allylphenol	$C_9H_{10}O$	501-92-8	17381664	87	100%FS	1215
7.50	Eugenol	*4-Allyl-2-methoxyphenol*	$C_{10}H_{12}O_2$	97-53-0	14490432	260	100%FS	1200
3.95	p-Cymene	4-isopropyl toluene	$C_{10}H_{14}$	99-87-6	10305984	118	100%FS	1063
5.47	Camphene	2,2-dimethyl-3-methyli	$C_{10}H_{16}$	5794-03-6	12847008	179	100%FS	1186
6.08	Carvacrol	5-Isopropyl-2-methylphenol	$C_{10}H_{14}O$	499-75-2	11902720	203	100%FS	1138
6.53	Epi-camphor	(1R)-4,7,7-trimethylbicycloheptan-2-one	$C_{10}H_{16}O$	21368-68-3	15432384	221	100%FS	1144
8.58	Thujopsene	4,4,4a,6-tetramethyl-3,7,8,9-tetrahydro-2H-benzo	$C_{15}H_{24}$	MS 3 of 852 (DB# 69377)	22918096	303	100%FS	1115
8.93	Humulen-(v1)	(3Z)-4,11,11-trimethyl-8-methylidenebicyclo	$C_{15}H_{24}$	MS 850 of 852488)	21750112	317	100%FS	1076
10.4	Caryophyllene	(1R,4E,9S)-4,11,11-	$C_{15}H_{24}$	87-44-5	10415360	376	100%FS	1065
12.9	Tetradecahedr	Bicyclo[7.7.0]hexadec-1(9)-e	$C_{16}H_{28}$	MS 5 of	7872800	475	54.8%F	1102
13.8	Dimethyl-dodecanoic acid	Dodecanoic acid, 2,10-dimethyl-, methyl ester	$C_{14}H_{28}O_2$	55955-7	8331312	513	100%FS	1065
14.6	Corymbolone	(4S,4aR,6R,8aR)-4a-hydroxy-4,8a-dimethyl-6-)	$C_{15}H_{24}O_2$	97094-19-4	18852915	543	100%FS	1009
16.4	Diethyl decadienedioic acid	2,8-Decadienedioic acid, diethyl ester	$C_{14}H_{22}O_4$	15898-70-1	8674112	614	87%FS	1024
17.95	Palmitic acid	n-Hexadecenoic acid	$C_{16}H_{32}O_2$	57-10-3	8794688	676	36%FS	1005
20.$_{07}$	Propyl myristate	Tetra decanoic acid, propyl ester	$C_{17}H_{34}O_2$	14303-70-9	8992752	760	99%FS	1010
20.72	Oleic acid	(Z)-octadec-9-enoic acid	$C_{10}H_{16}$	80-56-8	17381664	87	100%FS	1215
3.17	à-Pinene	2,6,6-trimethylbicyclo[3.1.1] hept-2-ene	$C_{10}H_{16}$	80-56-8	17381664	87	100%FS	1215
4.62	γ-Terpinene	1-methyl-4-propanyl-2-cyclohexa-1,4-diene	$C_{10}H_{16}$	99-85-4	17693600	145	100%FS	1187
6.90	Borneol	1,7,7-trimethylbicyclo[2.2.1] heptan-2-ol	$C_{10}H_{18}O$	507-70-0	20395632	236	100%FS	1171
7.67	4-Terpinyl acetate	3-Cyclohexene-1-ol, 4-methyl-1-(1-methyl ethyl)-, acetate	$C_{12}H_{20}O_2$	4821-04-9	14495664	266	100%FS	1125

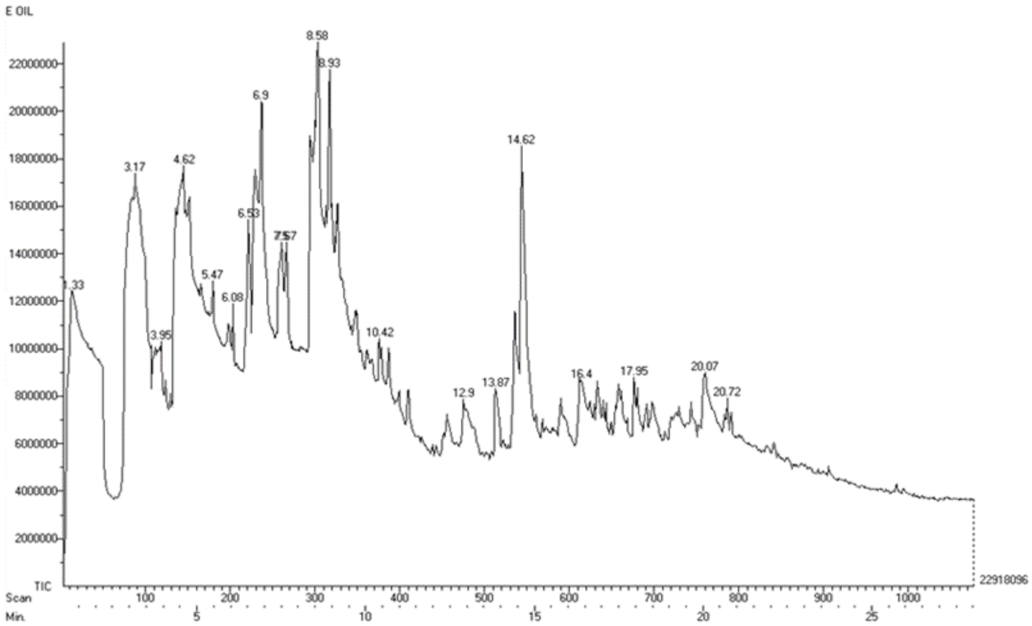

Fig. 1. *Showing photochemical components*

Physicochemical properties in control and coated tomato:

Weight loss percentage in control and coated tomato

There was a significant difference observed between the control and coated samples. Tomatoes coated with (HPMC containing 15% nano-emulsion and HPMC) had less weight loss during the storage than control, and weight loss gradually increased during the storage period shown in Table 4. The basic mechanism of weight loss from fresh fruits and vegetables is by varying vapour pressure at different storage locations, though respiration also causes a weight reduction. This reduction in weight loss was probably due to the effect of coating as a semi-permeable barrier against O_2, CO_2, moisture, and solute movement (Nawab *et al.*, 2017).The HPMC coating prevented the evaporation of moisture from coated tomatoes. The lowered water permeability of the coating will thus prevent water loss while antimicrobial compounds in the coating will prevent weight loss by reducing old growth. The influence of the essential oil and HPMC reduce the water permeability of the coating, thus reducing the weight loss during the storage period and maintaining the freshness of tomatoes. This significant effect of nano-emulsions present in coatings on weight loss percentage can be observed in Table 4. This was similar to the results of study in cherry tomatoes, postharvest application of HPMC with a combination of Zein significantly delayed colour changes throughout storage at 20°C by a modified atmosphere in the fruit (Patil *et al*., 2022). Similarly, at 20°C, postharvest application of HPMC with a combination of beeswax was effective in inhibiting the alternaria black spot and showed reduction in weight loss of tomatoes (Fernandez Catalan *et al*., 2021). Similarly, the study of Fagundes *et al*. (2015) reported HPMC + Beeswax, maintained weight loss, and maintained the quality features. Thus, results of our study agree with above studies wherein the weight loss in the coated sample has been less compared to the control sample.

Total soluble sugars content in control and coated tomato

During catabolism, high-energy substrates like sugar molecules and polysaccharides are consumed to maintain metabolic homeostasis. This process converts complex molecules to simpler molecules due to the action of enzymes (both endogenous and from microbial infection) and pH. After harvest, the sugar content drastically increases in tomatoes due to ripening and maturation. Total soluble sugars (TSS) in the tomatoes during the storage period showed a similar trend as discussed above. TSS increased in the range of 5-5.8

Table 2. Dynamic light scattering analysis of nano-emulsion

S. No.	Percentile (%)	size(nm)
1	10	4914
2	20	296.3
3	30	212.6
4	40	11.51
5	50	10.04
6	60	9.12
7	70	8.36
8	80	7.65
9	90	6.78
10	95	6.20

Brix till 16days of storage for both coated and uncoated tomatoes (Fig. 3). The inclination in Fig. 4 denotes the increase of sugars and total soluble sugar content during the maturation period. This finding corroborates with (Sousa *et al*., 2021). HPMC-coated tomato and strawberries showed increased level of sugar, ripening and maturation of fruits and total soluble content during the maturation period after the harvest. The following onset of increase in TSS was relatively prolonged in tomatoes coated with a higher concentration of nano-emulsion coating; this occurs due to antimicrobial and antifungal effects of coatings. This property of the coating helps to maintain the tomato's biochemical composition. All examined samples showed a steady rise in total soluble solids concentration over the course of the storage period. When compared to coated tomatoes containing (15%ul/ml) of nano-emulsion, the soluble solids in the control tomatoes were noticeably greater around 5.8 Brix. According to edible coatings alter the interior atmosphere by increasing CO_2 and/or decreasing O_2, which slows down respiration and inhibits the formation of ethylene (Ali *et al*., 2010: Arroyo *et al*.,2020). In turn, slow respiration rates delayed synthesis and use of metabolites that results in lowering the total soluble solids concentration (Gol *et al*., 2015). At the end of the storage period, the lowest TSS was noted for coating containing nano-emulsion of piper betel leaf oil indicating its effectiveness in controlling the ripening of fruit. Similar results were observed in a study by Kumar & Saini 2021 which shows the acidity decreased with maturation and increased with higher percentage of sugar content in tomato fruits.

Table 3. Peak summary of nano-emulsion Dynamic light scattering analysis

S.No	Diameter (nm)	Volume (%)	Peak Width
1	5640	11.4	1163
2	276.8	22	134
3	8.6	66.6	3.91

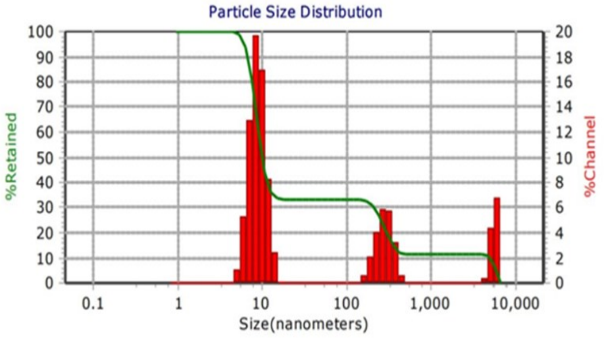

Fig. 2. *Particle size distribution of nano-emulsion*

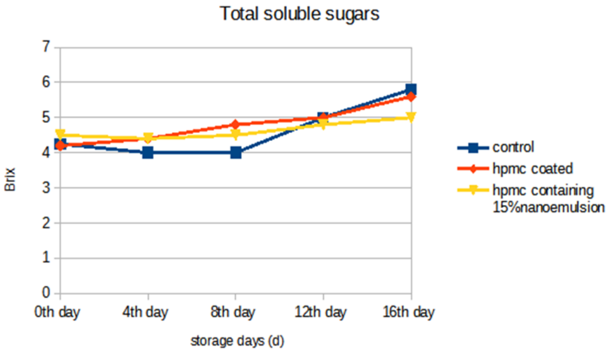

Fig 3. *Total soluble sugars in control and coated tomatoes*

Table 4. Effect of nano-emulsion in weight loss percentage in control and coated tomato

Concentration of nano-emulsion	0th day	4th day	8th day	12th day	16th day
Control	1.185 ±0.116	1.5133 ±0.802	8.7687 ±0.329	9.497 ±0.114	1.185 ±0.116
Coated with HPMC	1.644 ±0.498	1.9747 ±0.515	5.1927 ±5.333	12.267 ±5.906	1.895 ±0.858
Coated with HPMC containing 15% (nano-emulsion)	1.543±0.508	1.3667 ±0.456	2.086 ±0.409	1.3213 ±0.473	1.5987 ±0.559

Values representing Mean ± SE

Table 5. Titratable acidity in control and coated tomatoes

	Titratable acidity (%)				
Treatments	**0th day**	**4th day**	**8th day**	**12th day**	**16th day**
Control	0.975± 0.245	0.996± 0.549	2.911± 0.295	0.998± 0.253	0.987± 0.427
HPMC coated	2.911± 0.154	1.959± 0.26	3.882± 0.845	1.854± 0.914	0.875± 0.325
HPMC containing 15% nano-emulsion	1.941± 0.541	1.989± 0.597	2.911± 0.741	2.569± 0.956	1.882± 0.154

Values representing Mean ± SE

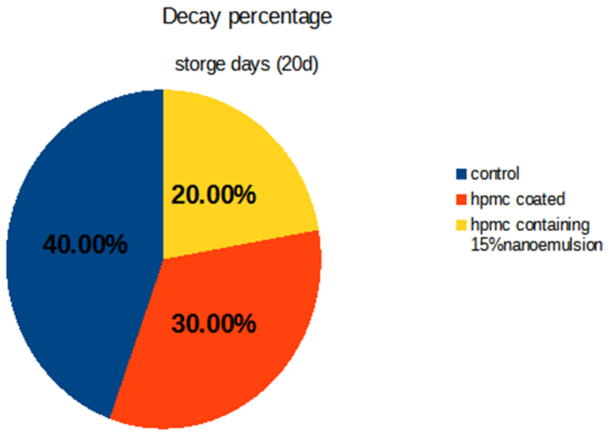

Fig. 4. *Fruit decay percentage in tomato*

Titratable acidity in control and coated tomato

The titratable acidity showed a similar trend to that of the ascorbic acid content, along with the increase in storage time in both uncoated and coated fruits. The titratable acidity decreased along with the increase in storage time in both uncoated and coated fruits. The results (Table 5) show a decrease of acidity during storage which demonstrates the ripening, ageing, and decay periods of fruit during storage. In fresh tomatoes, coatings slowed down the changes in titratable acidity and effectively delayed fruit maturation. Similar to the result Formiga *et al*. (2019) discussed the decay periods of fruit, titratable acidity and fruit maturation in tomatoes coated and uncoated with HPMC. The titratable acidity of the tomatoes decreased with maturity and was not significantly affected by coating treatment and the same results were observed in a study by (de Brito *et al*., 2022), which shows the titratable acidity decreased with maturation and increased with a high percent of sugar content in fruit. This may be because the semi-permeable film formed on the surface of the fruit would have modified the internal atmosphere, i.e., the endogenous Carbon dioxide (CO_2) and Oxygen (O_2) concentration of the fruit, thus retarding ripening. But the control showed a steep increase in acidity after the 8th day of storage due to high mycelial growth consuming organic acids from the fruit.

Fruit decay in control and coated tomatoes

There was no noticeable indication of deterioration or decay in control as well as coated tomato fruits until 4th day of the storage period. However, the control sample progressively showed visible decay after 4th day and a large fraction of uncoated tomatoes (almost 40%) completely spoiled after 12days of storage shown in Fig. 4. On the contrary, the coated samples showed a significant reduction in decay process and retained their appearance for longer. The best results were obtained for tomatoes coated with HPMC containing nano-emulsion, which remained fungal-free even after 16 days of storage. The decrease in the decay percentage of coated fruits was due to the retarding effect of the coating on ripening and senescence. During the ripening process, cellular or tissue integrity is lost continuously, making the fruits more susceptible to pathogenic infection (Hong *et al*., 2012).

The four main factors contributing to the decay of tomatoes include overall catabolism of complex molecules inside the tomatoes due to enzyme activity, surface contamination of tomatoes with fungal and bacterial growth, the low moisture content in the air, and high temperature (Peralta-Ruiz *et al*., 2020). When the enzymatic reduction of complex molecules is high, the resulting simpler sugars and nutrients act as more promising catabolises for fungal and bacterial growth, ultimately fastening the fruit decay process (Manzoor *et al*., 2021). The signs of mold development appeared in uncoated tomatoes during early periods of storage on the 8th day. Comparatively, the coated tomatoes did not show any decay symptoms until the 16thday of storage. The tomatoes coated with HPMC alone; containing 0µl/ml of nano-emulsion showed mycelial growth after the 8th day of storage, whereas the tomatoes coated with 15 µl/ml of nano-emulsions did not show decay symptoms till the 16th and 20thdayof storage respectively (Fig. 4). At the end of 18 days of storage, 40 % of uncoated fruits were infected by molds, while the incidence of decay of the coated fruit was relatively lower in the range of 0% to 20%.

Lycopene content present in control and coated tomatoes

The changes in lycopene content of HPMC-containing nano-emulsion coated and uncoated tomatoes are shown in the Table 6. During ripening the chlorophyll content decreased, and there was a rapid synthesis of the red pigment lycopene. The lycopene content of control during its red stage on the 16th day was 7.513 ug/g, whereas lycopene of tomato coated with HPMC containing 15% nano-emulsion on the same day was 2.742 ug/g. The lycopene content of tomato increased during its ripening. This might be due to the increased maturity to ripening stages and then decreased toward senescence during storage. However, the pattern of lycopene accumulation may be influenced by different treatments and storage conditions (Formiga *et al*., 2019).And also, some of the results confirmed that coating tomatoes and plum fruit with HPMC and arborescence gels significantly delayed ripening the chlorophyll content, which leads to preserving the quality of climacteric fruit (Alonso-Salinas *et al*.,2022). Delayed senescence in tomato fruits may result from lowering microbial activity that leads to maintenance of the overall quality of chlorophyll content and red pigment lycopene in tomato fruits (Shakir *et al*., 2022). The lycopene

Table 6. Lycopene content in control and coated tomatoes

	Lycopene content (µg/g)				
Treatment	**0th day**	**4th day**	**8th day**	**12th day**	**16th day**
Control	0.232± 0.214	0.328± 0.154	0.515± 0.563	0.783± 0.050	7.513± 1.205
HPMC coated	0.174± 0.241	0.206± 0.654	0.38± 0.54	0.515± 0.184	1.402± 0.035
HPMC containing 15% nano-emulsion	0.834± 0.362	1.12± 0.845	1.298± 0.350	1.409± 0.651	2.742± 0.951

Values representing Mean ± SE

Table 7. Ascorbic acid content in control and coated tomatoes

	Ascorbic acid content (mg of acid/100g)				
Treatments	**0th day**	**4th day**	**8th day**	**12th day**	**16th day**
Control	6.65± 0.21	6.68± 0.21	9.90 ± 0.65	16.60 ± 1.54	8.61± 0.87
HPMC coated	6.68± 0.65	8.58± 0.34	9.24± 1.51	13.80 ± 1.04	7.92± 0.98
HPMC containing 15% nano-emulsion	5.97± 0.41	8.58± 1.20	7.92± 0.78	10.56± 1.54	7.92± 0.64

content of HPMC containing 15% nano-emulsion is lower than that of the tomatoes coated only with HPMC and control. It indicates that 15% Nano-emulsion incorporated in the HPMC helped delay the ripening and extended the tomatoes' shelf life.

Ascorbic acid content present in control and coated tomatoes

The ascorbic acid content of coated and uncoated tomato fruits increased to a maximum up to the 12th day and then decreased (Table 7). The highest level of ascorbic acid (16.16mg/100g pulp) was observed on the 12th day of uncoated tomatoes, and the lowest level (10.56 mg/100g pulp) in coated tomatoes containing nano-emulsion on 12 days after storage. Highest level of ascorbic acid content is mainly due to the mature-green tomato fruit that self-ripened, the AA content generally increased but higher concentration is due to the HPMC coating and this result is supported by the tomatoes and indicates the higher level of ascorbic acid in coated tomatoes (Mirdehghan and Valero 2017). From the experimental result, coated fruits retained more ascorbic acid than uncoated fruits, with a significant decrease in the ascorbic acid content of tomatoes to 8.61 mg/100 g of pulp when compared to coated ones which have less decrease in its ascorbic acid. This may be due to the HPMC and nano-emulsion coating, which acted as a gas barrier, inhibiting oxygen from entering the fruit, thus reducing the oxidation of ascorbic acid (Srivastav *et al*., 2022, Gogliettino *et al*., 2022). Ascorbic acid is lost at a later stage due to the activities of phenol oxidase and ascorbic acid oxidase enzymes during storage (Salunkhe *et al*., 199; Rafiee *et al*., 2021). In tomato fruit, ascorbic acid content increases with maturity and stage of ripening, however, once fruit reaches the fully ripe stage, ascorbic acid content starts to decline (Mathooko, 2003 Srivastav, 2022).The tomato fruit ripens, and the ascorbic acid content decreases. Therefore, rapid ripening of tomato fruit has a great influence on nutrient retention as well as the extension of the storage shelf life of the coated fruit (Moneruzzaman, 2008).

Conclusion

The investigative study validates that applying Hydroxypropyl methylcellulose (HPMC) edible coating containing nano-emulsion of piper betel essential oil on tomatoes is effective in shelf-life extension and quality and quality stability maintenance. Coatings showed a beneficial effect on quality by reducing weight loss, colour changes, and decay of the tomatoes. The coating acted as a physical barrier for the gas and moisture exchange between the fruit and the environment, yielding an infection-free surface fruit. It demonstrated that the coating delayed fruit softening and changes in its texture. There was a decrease in the decay rates of tomatoes stored under refrigerated conditions (25°C and 60% Relative Humidity), increasing the shelf life up to 18 days (observed in the highest nano-emulsion concentration of 15(µl/ml). Compared to tomato preservation and other industrially adopted technologies, the present study shows a significant amelioration in terms of days of shelf-life extension of tomatoes. The study has revealed that this edible coating is an efficacious preservative technology for tomatoes' post-harvest shelf life extension. Hence, the formulated coating could be used as a preservation technology for various other agricultural and food products.

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Conflict of interest

The authors declare that they have no conflict of interest.

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