Effect of the gellan-based edible coating enriched with oregano essential oil on the preservation of the 'Tardivo di Ciaculli' mandarin (*Citrus reticulata* Blanco cv. Tardivo di Ciaculli)

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Mandarin, a globally recognized fruit esteemed for its nutritional content and bioactive compounds, as well as aromatic qualities, faces the critical challenge of post-harvest shelf life impacting its marketability and appeal to consumers. This study aims to assess the efficacy of edible coatings in preserving "Tardivo di Ciaculli" mandarin (*Citrus reticulata* Blanco cv. Tardivo di Ciaculli). Two distinct edible coating formulations, denoted as EC1(comprising gellan gum, glycerol, calcium chloride, and distilled water) and EC2 (comprising gellan gum, glycerol, calcium chloride, distilled water, and 2% oregano essential oil), were subjected to comparative analysis against control samples (CTR). In the experimental trial, mandarin fruits were immersed in the respective edible coating solutions for approximately 5 min and promptly stored at $6 \pm 1°C$. Qualitative, nutraceutical, microbiological, and sensory analyses were conducted throughout the cold storage period (7, 14, and 24 days at $6 \pm 1°C$) and during three distinct shelf-life phases (I shelf-life: 7 days at $6 \pm 1°C$ plus 7 days at $15 \pm 1°C$; II shelf-life: 14 days at $6 \pm 1°C$ plus 7 days at $15 \pm 1°C$; III shelf-life: 24 days at $6 \pm 1°C$ plus 7 days at $15 \pm 1°C$). Chemical analysis of the oregano essential oil in EC2 revealed the presence of 27 compounds, with carvacrol being the predominant chemical, constituting 83.42% of the total oil. The findings indicate that the application of edible coatings effectively preserved the quality parameters of mandarin fruits, minimizing weight loss and water loss. Notably, the microbiological analysis, using a culture-dependent approach, demonstrated that EC2, incorporating oregano essential oil, exhibited the capability to diminish the viability of molds throughout the entire study duration, thereby extending the shelf life of mandarin fruits.

KEYWORDS

mandarin, Tardivo di Ciaculli, edible coating, oregano essential oil, carvacrol, shelf life, physicochemical analysis, microbial decay

1 Introduction

Citrus fruits, globally renowned for their diverse applications, harbor numerous phytochemicals and bioactive components with manifold health-promoting properties, serving as rich reservoirs of vital nutrients such as vitamin C, folic acid, potassium, and pectin (Rafiq et al., 2018). Among these citrus varieties, the mandarin (*Citrus reticulata* Blanco) stands out as one of the earliest and most distinguished, acknowledged for its nutrient richness and potential medicinal value (Wang et al., 2019).

In recent decades, there has been a remarkable surge in both global production and consumption of mandarins. From 2010 to 2020, world production escalated from 22 million to 31.6 million tons, with parallel growth in consumption from 20 to 30 million tons (USDAF, 2023). Mandarins find prominence in regions characterized by temperate summers and mild winters, notably in Mediterranean countries such as Japan, Brazil, Argentina, the United States (referred to as tangerines), and Australia (Lota et al., 2000).

However, preserving the post-harvest quality of mandarins is imperative. Necessitating adherence to good practices, such as careful handling during harvest and transportation, as well as sanitation of packing and storage facilities, is crucial to mitigate postharvest decays (Zhang et al., 2009). Temperature management emerges as a pivotal factor in preserving the quality attributes of mandarins during storage and transportation, emphasizing the need for proper storage temperatures ranging between 5 and 10°C, with shelf temperatures reaching 20°C for marketable use (Cao et al., 2019). Consideration of the storage period is equally crucial in temperature selection to ensure enhanced fruit quality during the shelf life (Van Wyk et al., 2009).

Challenges such as chilling physiopathology, manifesting at temperatures above freezing point, and harvest pitting, characterized by browning of oil glands at temperatures near 21°C, pose threats to the citrus sector. Additionally, post-harvest water loss, although not a physiological disorder, can impact quality and consumer satisfaction through marketable weight loss, wilting, shriveling, and softening. Most physiological disorders affecting citrus fruits are intricately linked to water loss (Palou et al., 2015).

While waxing is a prevalent practice in preventing these issues, the use of permeable waxes allowing sufficient gas exchange is imperative. This prevents undesirable odors due to restricted gas exchange, preventing anaerobic respiration, ethanol production, off-flavor formation, and overall quality loss (Olivas and Barbosa-Cánovas, 2009). Traditional postharvest treatments involving synthetic waxes and chemical fungicides, such as imazalil (IMZ), thiabendazole (TBZ), and sodium ortho-phenyl phenate (SOPP), have been employed to preserve fruit freshness, control decay, and extend shelf life (Palou et al., 2015).

Postharvest treatments with synthetic fungicides have been widely used for many years and are still used in citrus packing houses for preserving and maintaining the freshness of fruits (Berk, 2016). The application of chemicals fungicides is very expensive and time consuming, therefore the prolonged use of such fungicides has caused serious issues in the citrus industry: such as health and environmental troubles related to high and acute residual toxicity (Nicolopoulou-Stamati et al., 2016) and the increased resistance of

molds to continuously used synthetic products. Fungal pathogens have also developed resistance strains due to extensive use of pre-and post-harvest chemical fungicides (Sánchez-Torres and Tuset, 2011). Fungal pathogens, particularly *Penicillium digitatum* and *Penicillium italicum* causing green and blue mold, respectively, contribute significantly to postharvest citrus decay (Zhang et al., 2009). The most crucial factor leading to citrus fruit not-marketability is post-harvest decay.

In response to these challenges, the food industry has explored alternatives to synthetic products for inhibiting mold growth and preserving water content in citrus fruits. Edible coatings have emerged as a promising strategy, serving as semipermeable barriers against water vapor and gases. These coatings positively influence fruit tissue metabolism by reducing respiration rates, preserving color, decreasing firmness and moisture loss, controlling microbial growth, and extending fruit quality for prolonged periods (Liguori et al., 2021).

Edible coatings are typically made from biodegradable and non-toxic materials, utilizing various biopolymer matrices such as polysaccharides, proteins, lipids, and composite materials. Polysaccharide-based materials, including pullulan, chitosan, carrageenan, starch, alginate, cellulose, pectin, gellan gum, and xanthan gum, have been employed for this purpose (Dea et al., 2011; Han, 2014; Homayouni et al., 2017; Sondari, 2019; Zubair and Ullah, 2020).

Fruit coating is a well-known practice in citrus packing houses for replacing the natural waxes that may be removed during fruit washing and handling (Palou et al., 2015). Recent efforts have focused on using natural extracts, particularly essential oils, in food preservation instead of chemicals. Carvacrol, a phytochemical compound found in *Origanum vulgare* L., is a major constituent of oregano essential oil (EO). Laboratory tests have demonstrated the efficacy of wax coatings enriched with carvacrol or thymol EOs in reducing green mold incidence on lemons and decreasing fruit respiration rates (Pérez-Alfonso et al., 2012). Thymol, which belongs to the bioactive compounds of oregano EO, evidenced increasing inhibitory effect against some fungi, including *Aspergillus flavus* (Culmone et al., 2023). As the industry moves toward sustainable practices and environmentally friendly solutions with minimal impact, this study aims to evaluate the application of natural gellan-gum products enriched with oregano EO on the pomological, physio-chemical, nutraceutical, sensory, and microbial aspects of "Tardivo di Ciaculli" mandarins.

2 Materials and methods

2.1 Oregano crop farming

The hybrid plants between "*Origanum vulgare ssp. viridulum* × *Origanum vulgare* ssp. hirtum" were collected grown in a farm located in Grotte (Agrigento, Italy; Figure 1). This area represents a model of Sicilian environmentally friendly multifunctionality for soil protection (Mammano et al., 2023). The cultivation of oregano plants was carried out according to traditionally used management methods. Propagating materials were obtained from a local wild genotype previously
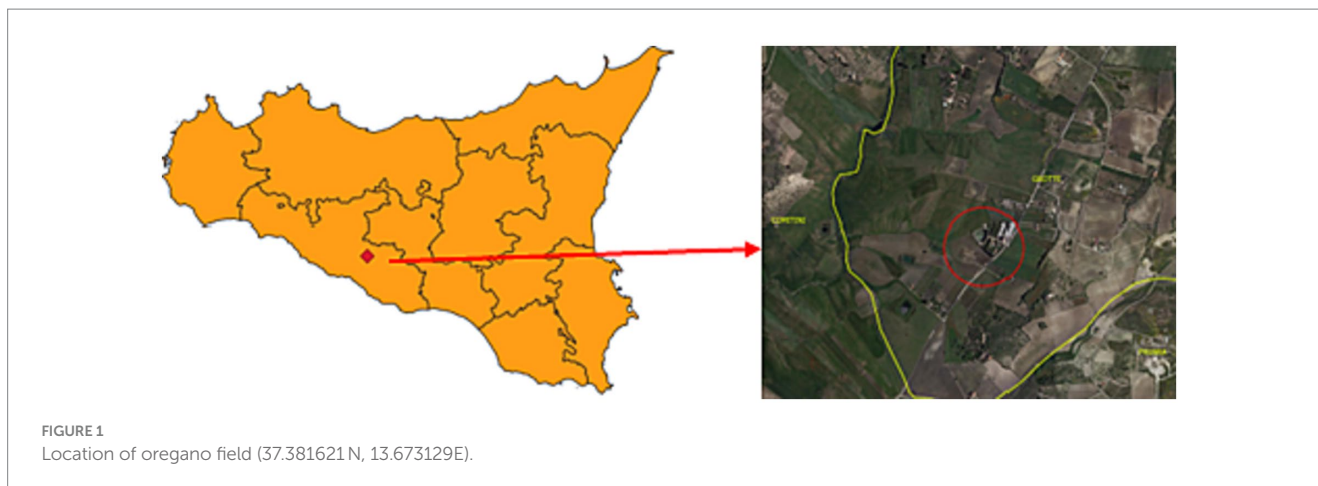
FIGURE 1
Location of oregano field (37.381621 N, 13.673129E).

classified as *Origanum vulgare* L., and transplanted in the field in winter 2020, with plant distances of 2.0 × 0.3 m, thereby achieving a plant density of 16,660 plants ha^{-1}.

2.2 Oregano balsamic time individuation, collecting and drying

At the beginning of the flowering (25th May 2022), measurements were carried out every 10 days using a UAV DJI Phantom 4, equipped with a multispectral camera. The high-resolution multispectral images were ortho-mosaicked and thematic maps of NDVI (Normalized Difference Vegetation Index) were generated to assess the right balsamic time for oregano harvesting. Mechanical harvesting was carried out according to the technique described by Comparetti et al. (2022). The harvested oregano was then dried following the technique described by Mammano et al. (2023) and Catania et al. (2020). The employed drying technique utilizes forced convective hot air for moisture removal. It consists of passing a forced flow of dry air over the herb biomass, which is distributed over large areas in one or more layers. The drying temperature is maintained at 40°C, with a relative humidity of 25% throughout the process. The aim of this drying method is to reduce the water content of the herbs and preserve their quality by limiting microbial and enzymatic reactions (Figure 2).

2.3 Oregano essential oil extraction and chemical composition

The essential oil was extracted from dried oregano leaves and flowers as described by Garofalo et al. (2023). EOs were extracted from flowers and leaves using a 12 L volume steam distiller (Spring Extractor, Albrigi Luigi, Verona, Italy). At the end of the process, the EO were collected in 25 mL amber glass bottles with screw caps (Laboindustria, Arzergrande, Italy) and stored at 4°C.

The analysis of volatile organic components (VOC) of OEO was conducted using the solid-phase microextraction (SPME) GC–MS technique, following a dilution with hexane at a ratio of 1:100. A SPME fiber (DVB/CAR/PDMS, 50 mm, Supelco) was exposed to the diluted oils while stirring at a temperature of 60°C. After an extraction time of 5 min, the fiber was inserted into a GC spitless injector, and

FIGURE 2
Oregano plants scalar flowering.

the volatile organic components were desorbed for 1 min at 250°C. A DB-624 capillary column (Agilent Technologies, 60 m in length, 0.25 mm in diameter, and coated with a 1.40 μm film) was utilized for chromatographic separation. The oven temperature program was set with a 5-min isotherm at 40°C, followed by a linear temperature increase of 5°C per minute up to 200°C. The temperature was held at 200°C for 2 min. The carrier gas, helium, was maintained at a flow rate of 1 mL/min. The interface temperature was set at 230°C, and mass spectra were recorded in the range of m/z 40–400 amu using the full-scan acquisition mode. Identification of individual volatile organic compounds was performed by comparing each mass spectrum with the NIST05 commercial library. The analysis was performed in triplicate, and the reported values are expressed as percentages relative to the significant peak.

2.4 Mandarins fruit samples

Mandarins, *Citrus reticulata* Blanco "Tardivo di Ciaculli," collected from a commercial orchard in Palermo (38° 40'N, 13° 23' E, 99–104 m a.s.l.), were moved to the laboratory immediately after picking. Mandarins were hand-picked at ripe fruit stage (RF) and placed in boxes before being taken to the laboratory. Mandarins, were

then washed under tap water, sanitized by immersion in 200 mg kg^{-1} of sodium hypochlorite for 5 min, and left to dry at room temperature (~15°C). Immediately after washing, fruit quality parameters were analyzed on 30 fruits. Only mandarin fruits with no external injuries were used for the following research and fruit processing operations were performed in sanitary conditions at 15 ± 1°C.

2.5 Coating preparation and application

The edible coating was prepared in the laboratory of the Department of Agricultural, Food and Forestry Sciences, University of Palermo. Two different edible coatings were tested and compared with the untreated sample, used as control:

- CTR: untreated fruits.
- EC1: fruits treated with edible coating based on gellan gum (special ingredients, Savona,Italy) glycerol (Lubrisolve, Long Sutton United Kingdom), calcium chloride (CaCl₂), and distilled water. The edible coating solution was placed in a 1 L beaker: 935 mL distilled water; 5 g gellan gum; 30 g CaCl₂; 30 mL glycerol. The solution was subjected to magnetic stirring (30°C) for 2 h and immediately afterwards was applied to the fruits.
- EC2: fruits treated with edible coating based on gellan gum specialin gredients, Savona, Italy glycerol (Lubrisolve, Long Sutton, United Kingdom), calcium chloride (CaCl₂), distilled water, and high-carvacrol oregano essential oil (EC2). The edible coating solution was placed in a 1 L beaker: 933 mL distilled water; 5 g gellan gum; 30 g CaCl₂; 30 mL glycerol; and 2 mL of OEO. The solution was subjected to magnetic stirring (30°C) for 2 h and immediately afterwards was applied to the fruits. This composition imparts specific characteristics to EC2, including potential antimicrobial and antioxidant properties attributed to the oregano essential oil. The thorough mixing and application of EC2 contribute to its potential in safeguarding the fruits and maintaining their freshness during storage.

The mandarin fruits were immersed in the two different edible coating solutions (EC1 and EC2) for approximately 5 min to ensure uniform coverage of the entire fruit surface, creating a consistent coating. Subsequently, both the samples treated with edible coatings and the control samples were placed in plastic commercial boxes and stored. At each sampling date, 5 samples for treatment were analyzed, with each sample comprising 3 replicates.

2.6 Quality parameters: firmness, soluble solid content, titratable acidity, pH, weight loss, and color

Quality evaluations were conducted at various stages, encompassing the harvest, cold storage periods (7, 14, and 24 days at 6 ± 1°C), and distinct shelf-life phases (I: 7 days at 6 ± 1°C plus 7 days at 15 ± 1°C; II: 14 days at 6 ± 1°C plus 7 days at 15 ± 1°C; III: 24 days at 6 ± 1°C plus 7 days at 15 ± 1°C).

During each assessment, a comprehensive analysis was performed on 15 mandarin fruits for each treatment. The examinations included both destructive and non-destructive analyses:

- Texture: Evaluated using a "Fruit Texture Analyzer" (GS-15 Qa Supplies United States) equipped with a pipette tip.
- Total Soluble Solids (TSS) Content: Determined using a digital refractometer (Atago, Tokyo).
- Titratable Acidity (TA): Measured by titrating 10 mL of mandarin juice with a 0.01 M NaOH solution and expressed as a percentage of citric acid.
- pH: Assessed with a digital pH meter (model HI8453, HANNA INSTRUMENTS, Ronchi di Villafranca Padovana, Italy).
- Weight Loss: Verified by weighing the samples during storage with a digital scale (Beurer Italia Srl, Milan, Italy). The percentage reduction in weight for each treatment (CTR, EC1, EC2) was determined based on measurements taken during cold storage on days 0, 7, 10, 14, 17, 21, 24, 27, and 30 at 6 ± 1°C. The formula used for % Weight Loss calculation was:

$$\% \text{Weight loss} = \left[\left(\text{Wi} - \text{Ws} \right) \right] / \text{Wi} \times 100$$

- Color: Measured by assessing the parameters L*, a*, and b* with a colorimeter (Minolta chroma-meter CR-400) at two opposite points of the equatorial zone of the fruits. CIE L*a*b* coordinates, representing lightness (L*), reddish or greenish color (a*), and yellowish or bluish color (b*), were recorded. The instrument was calibrated using a manufacturer's plate.

2.7 Nutraceutical attributes

Total phenolic content, ascorbic acid content, and antioxidant activity of treated (EC1 and EC2) and untreated were assessed soon after coating (0 d) and during the shelf-life (I shelf-life: 7 days at 6 ± 1°C plus 7 days at 15 ± 1°C; II shelf-life: 14 days at 6 ± 1°C plus 7 days at 15 ± 1°C and III shelf-life: 24 at 6 ± 1°C plus 7 days at 15 ± 1°C). For each sampling date and experimental treatment (CTR, EC1 and EC2), three samples were randomly chosen and analyzed.

2.7.1 Fruit extract preparation

Mandarin fruit samples were frozen at −80°C pending extract preparation. Upon thawing, the samples underwent chopping, and the seeds were separated from the pulp. The pulp was homogenized, and fruit extracts were prepared following a previously described procedure with minor modifications (Kanner et al., 2001). In brief, 10 g of the whole homogenate were weighed and then extracted using 80% (v/v) methanol containing 2% formic acid. The samples were vortex-mixed for 5 min and sonicated at room temperature for 15 min (~25°C). The mixtures were allowed to stand for 2 h at room temperature. Following centrifugation (10 min at 8000× g, 4°C), the supernatants were filtered, aliquoted, and stored at −20°C. The extraction procedure was iterated to obtain three distinct technical replicates.

2.7.2 Total phenolic and content

Total phenolic content (TPC) of extracts from treated and untreated fruits was determined by the reduction of phosphotungstic–phosphomolybdic acid (Folin–Ciocalteu's reagent) to blue pigments, in alkaline solution according to Folin–Ciocalteu's method (Singleton

and Rossi, 1965). Total phenolic content was expressed as mg gallic acid (GA) equivalent (GAE).

2.7.3 DPPH radical scavenging analysis

The 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging analysis was performed on 2 g of frozen tissue with 5 mL 50% (v/v) ethanol according to Wang et al. (2020). The homogenate was centrifuged at 12,000× g for 20 min at 4°C, then the supernatant was collected. The reaction mixture consisted of 0.1 mL supernatant and 1.9 mL 120 μmol L−1 DPPH. Results were calculated using the following formula: DPPH radical scavenging activity (%) = [(A0 − A1)/A0] × 100, with A0 referring to absorbance of the control, A1 referring to absorbance of the samples. DPPH radical scavenging was expressed as a percentage.

2.7.4 Ascorbic acid content

Ascorbic acid in CTR, EC1 and EC2 samples was determined by extracting 10 g of blended fruit sample in 100 mL metaphosphoric acid (HPO_3), then filtered through Whatman no 1 filter paper. A volume of 10 mL from filtered solution was determined volumetrically with the 2–6 dichlorophenol-indophenol reagent until a slightly pink coloration was observed and persisted for 15 s (Allegra et al., 2017). The reading of ascorbic acid content was expressed in mg/100 g FW.

2.8 Microbiological analyses

Edible coating samples (1 mL) were directly subjected to the serial decimal dilution into 15 mL-volume conical sterile tubes (Biosigma S.p.A., Cona, Italy) containing 9 mL of Ringer's solution (Sigma–Aldrich, Milan, Italy), while of mandarin fruit samples (25 g) were first suspended in Ringer's solution (225 mL) (Sigma–Aldrich) and then homogenized and diluted as reported by Liguori et al. (2021). Microbial cell suspensions were analyzed for the main microbial groups associated with the horticultural products following the approach reported by Miceli et al. (2019). Briefly, serial dilutions were plated on agar media to allow the development of: Total Mesophilic Microorganisms (TMM), *pseudomonads, Listeria monocytogenes*, Coagulase-Positive Staphylococci (CPS), *Salmonella* spp., *Escherichia coli*, yeasts, and molds. All agar plates were inoculated by spread plating and incubated in aerobiosis (Passafiume et al., 2022), except those for members of Enterobacteriaceae family, which were counted by pour plating on double-layered agar media to determine the microanaerobiosis conditions. Microbiological analyses of mandarin fruit samples were performed in triplicate.

2.9 Sensory analysis and visual score

Sensorial analysis and visual score were evaluated at each sampling date. Sensory analysis was carried out at the Department (SAAF) and three sections per fruit were used for each treatment.

The panel consisted of 10 people who habitually consumed mandarins and who were trained for a period of 2 weeks on the evaluation method and on the identification of the main sensory descriptors of mandarins (sweetness, juiciness, chewiness, typical tangerine flavor, off-flavor, bitterness, acidity). Because of the addition of Oregano essential oil in one of the three treatment Oregano odor, Oregano flavor and Herbaceous smell were added as descriptors. The

fruits were evaluated according to the 1:10 scale of values, where the value 10 indicated maximum intensity and the value 1 indicated the absence of the descriptor. The samples were presented to the judges in randomized order and water was provided between tastings. On each sampling date, 5 boxes (3 fruits on each) CTR, EC1, EC2 fruit samples were also evaluated by each judge for the visual score. Visual appearance score resulted from the medium value of color, visible structural integrity, and visual appearance the different descriptors were quantified using a subjective 5–1 rating scale with 5 = very good, 4 = good, 3 = sufficient, 2 = poor (limit of edibility), and 1 = very poor (inedible) (Liguori et al., 2021).

2.10 Statistical analysis

An experimental randomization scheme was adopted for statistical analysis complete with 3 replications per treatment and for sampling date. The data were analyzed using one-way analysis of variance (ANOVA), and pairwise comparisons between the samples of control and treated fruits were evaluated using Tukey's test. The differences were considered significant for $p < 0.05$. The statistical analysis was carried out using Systat (Systat, Chicago, IL, United States).

3 Results and discussion

3.1 Balsamic time for oregano harvesting

The collected biomass was intended for the distillation of essential oils, so it was necessary to identify the time of complete flowering. The harvested plants belonged to local ecotypes characterized by considerable genotypic variability and non-uniform flowering. The harvest time of oregano depends on the commercial use of the product:

- beginning of flowering, for herb production.
- full blooming, when the oil content is at its maximum, for essential oil production.
- at maximum blooming (higher than 50%) and plant coverage (leaves and flowers), for food use (Comparetti et al., 2022).

The NDVI index is sensitive toward crop biophysical properties like nitrogen, chlorophyll, vigor, and biomass etc. The oregano was harvested when the NDVI values of most of the plants were equal to 0.58 and high flowering was evident from visual checks (Figure 3).

3.2 Chemical analysis of oregano essential oil

The volatile profile of OEO is graphically represented in Figure 4. A comprehensive analysis identified 27 volatile compounds belonging to six phytochemical groups: monoterpenes, monoterpenoids, sesquiterpenes, ethers, ketones, and alcohols.

The most abundant group are monoterpenoids representing 86% of the total composition of the essential oil, followed by monoterpenes (10%) and sesquiterpenes (3%). The least represented groups are ketones, alcohols, and sesquiterpenols, with total abundance values below 1%. However, the most representative compounds detected was

carvacrol, constituting an 83.42±3.5% of the total composition, establishing monoterpenoids as the prevailing class of VOCs in OEO. Based on the classification proposed by Fleisher and Sneer (1982), our analysis indicates that the OEO under investigation corresponds to the carvacrol oregano chemotype, primarily due to its substantial carvacrol content (~80%) and similar volatile composition was observed in oregano cultivated within the Mediterranean region

FIGURE 3
NDVI map of oregano on 15th June 2022.

(Morshedloo et al., 2018; Tsitlakidou et al., 2022). This suggests that the composition of oregano essential oil is primarily determined by the oregano variety rather than the specific cultivation region. In addition to contributing to the distinctive aroma of OEO, carvacrol exhibits a wide range of bioactive properties, including antioxidative effects, inhibition of antibiotic-resistant bacteria, suppression of microbial and fungal toxins, and potential anticarcinogenic activity (Karkabounas et al., 2006; Jayakumar et al., 2012). The inhibitory effects of carvacrol on fungal growth have been attributed to its ability to disrupt cell membranes, inhibit cellular respiration, and interfere with essential enzymatic processes (Hyldgaard et al., 2012; Nostro and Papalia, 2012; Gilling et al., 2014). Therefore, given the challenges associated with food preservation and the demand for natural alternatives to synthetic chemicals, carvacrol, a major component of OEO, has emerged as a promising candidate due to its reported antimicrobial properties (Hyldgaard et al., 2012).

3.3 Quality parameters: firmness, soluble solid content, titratable acidity, pH, color, and weight loss

The effect of edible coatings implemented with oregano essential oil should be positive, particularly regarding microbial growth, as demonstrated by Barreto et al. (2016).

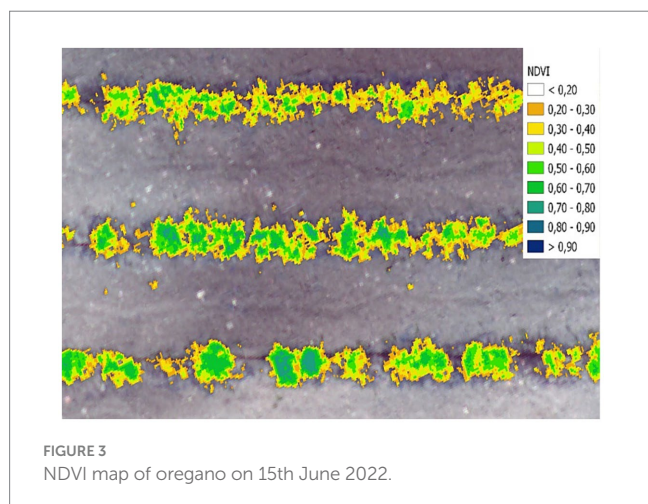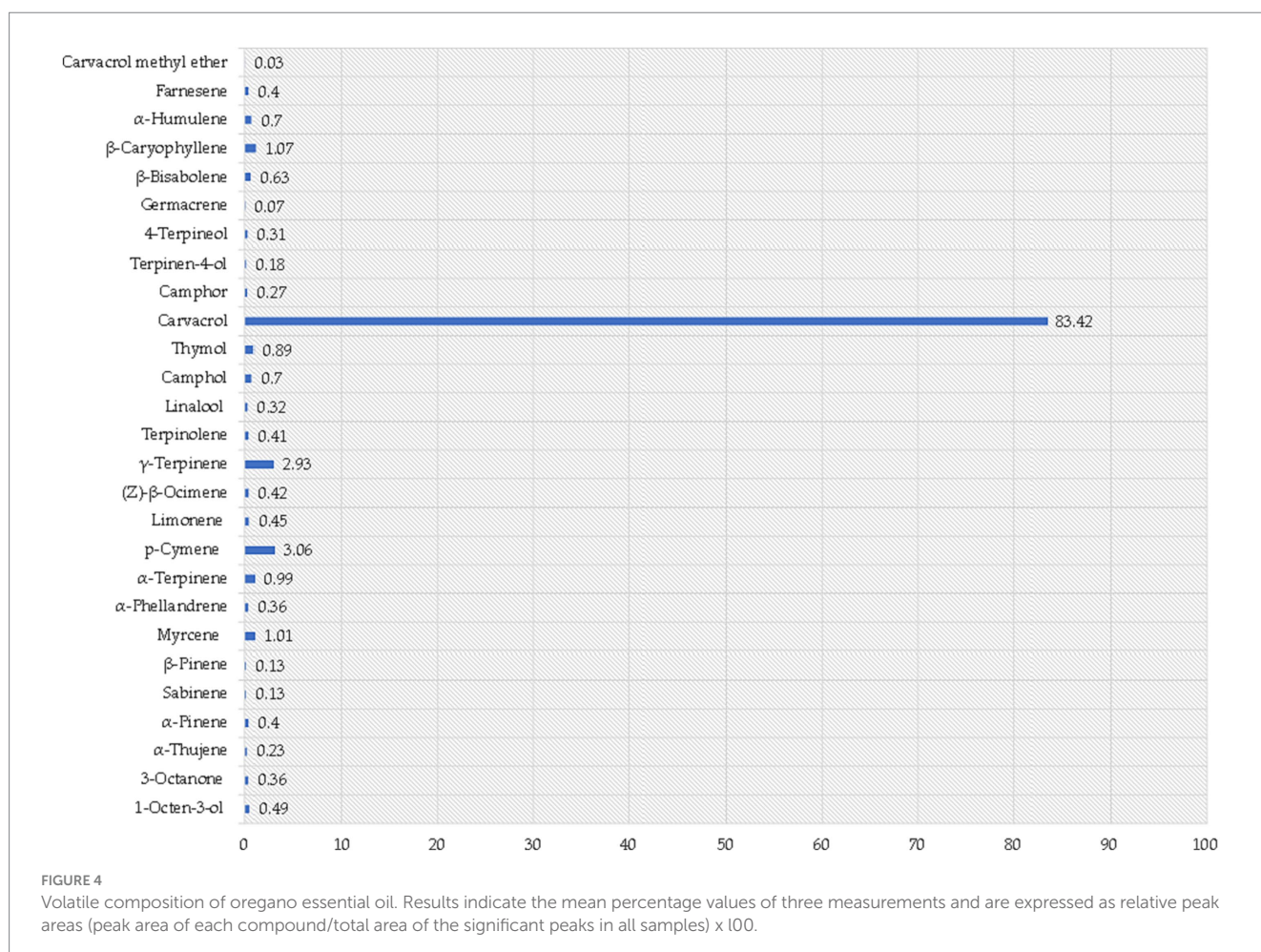FIGURE 4
Volatile composition of oregano essential oil. Results indicate the mean percentage values of three measurements and are expressed as relative peak areas (peak area of each compound/total area of the significant peaks in all samples) x l00.

The firmness of mandarin fruits (CTR; EC1; EC2) exhibited no significant changes throughout both the cold storage and shelf-life periods. Notably, during the third storage period (III shelf-life), treated fruits (EC1; EC2) maintained a slightly higher firmness compared to the control sample (CTR) (Table 1). Fruit texture, a crucial quality attribute in citrus fruits, is often affected by enzymatic reactions post-harvest, leading to rapid firmness losses. The incorporation of calcium chloride in coatings, as reported in other studies (Olivas and Barbosa-Cánovas, 2005; Brasil et al., 2012; Nguyen et al., 2020), has shown positive effects on preserving firmness. Similar findings were observed in gellan-based coated fresh-cut melon by Oms-Oliu et al. (2008).

Total Soluble Solids (TSS) remained unchanged during the initial storage period (I shelf-life). In the second storage period (II shelf-life), an increase in TSS was noted in EC1 and the control sample (CTR), whereas EC2 exhibited constant values. Additionally, on day 7 of the second storage period, TSS values were slightly lower in treated samples (EC1; EC2) compared to the control samples. No significant differences were observed during the third storage period (III shelf-life). The rise in water loss (fresh weight loss) tends to elevate TSS concentration in fresh fruits (Ali et al., 2020). Although not statistically significant, the control samples showed a greater increase in TSS compared to the treated samples, aligning with findings in other studies (Ali et al., 2021; Bhan et al., 2022).

Both treatments saw a slight increase in titratable acidity (TA). TSS and TA are pivotal indicators influencing the taste and acceptance of citrus fruits. In the first storage period (I shelf-life), EC2 experienced a slight increase in TA, while values remained constant in EC1 and control samples. No significant changes were recorded in the second and third storage periods (II shelf-life and III shelf-life). The results suggest that the application of edible coatings did not adversely impact the TSS content and TA of the fruits, in agreement with Arnon et al., (2014) findings.

Despite some significant differences in TSS, TA, and pH values, these variations may be attributed to several factors, as natural variability, growing conditions, and complex interactions among different fruit components. The pH, a crucial quality parameter reflecting potential spoilage, did not exhibit significant differences during the three storage periods (Table 1). Monitoring pH values during handling or processing is essential for predicting the microbial composition and maintaining fruit quality (Brackett, 1987).

One of the most important mandarin fruits quality parameters is peel color, because it determines consumers' visual perception, and influences their decision in purchases. The color of mandarin peel and pulp is principally governed by the content and composition of its carotenoid and apocarotenoid pigments (Rodrigo et al., 2013).

The color parameters L*, a*, and b* exhibited either minor or non-significant differences (Table 2). Despite a decrease in brightness over the storage period, small but significant variations were observed among the different treatments. However, these variations in color parameters could be linked to the ripening process of the fruits and field conditions, such as varying altitudes within the same orchard from which the fruits were harvested. Other research also reports that edible coatings did not affect tangerine fruit color (Gao et al., 2018).

Weight loss in the treated samples was lower during the cold storage period reaching a weight loss rate of 0.46 and 0.49% for EC1 and EC2, respectively (Figure 5). The lower weight loss of treated samples can be attributed to the barrier effect of edible coating, which limits gas exchange. In agreement with our results, several researchers showed that gellan-based coating formulation increased the water barrier properties of coated fresh-cut papaya (Sapper et al., 2019), melon (Olivas and Barbosa-Cánovas, 2005), pear (Oms-Oliu et al., 2008), and pineapple (Azarakhsh et al., 2014).

3.4 Bioactive compounds (total phenolic content) and radical scavenging activity

The total phenolic content showed significant variations influenced by both storage time and treatment (Figure 6). A gradual decrease in total phenolic content was observed from the time of harvest to the last day of storage, regardless of treatment. The control sample exhibited the most notable decline, with a reduction of 55.68% from harvest to the last storage day (III SHELF LIFE). In contrast, the treated samples showed lower rates of decrease, with reductions of 24.52 and 20.51%, respectively, (Figure 6). Notably, during the period from day 0 to day 14 at $6 \pm 1°C + 7$ days at $15 \pm 1°C$, the total phenolic content decreased by 37.8% in the control sample, while in the treated samples, it decreased by 15.2% (EC1) and 8.79% (EC2).

Essential oils inherently contain natural antioxidant compounds, and their incorporation into coatings has the potential to enhance their functional properties, making them more effective in protecting fruits and vegetables. Numerous studies have explored the impact of edible coatings enriched with antioxidants, including essential oils, on the quality and preservation of both fresh and fresh-cut fruits and vegetables (Yousuf et al., 2021).

The radical scavenging activity, assessed using DPPH, exhibited a decline over the storage periods for both treated (EC1 and EC2) and untreated (CTR) fruits. The control sample experienced the most significant decrease, with a rate of 47.70% during 24 days at 6°C plus 7 days at $15 \pm 1°C$ (Figure 7). Notably, the DPPH radical scavenging rate in EC2 (39.11%) surpassed that in EC1 (37.32%) (Figure 7). Furthermore, during the period of 24 days at 6°C plus 7 days at $15 \pm 1°C$, the DPPH rate decreased by 18.70% in EC2 and by 22.76% in EC1 (Figure 7). Previous studies (Robles-Sánchez et al., 2013) have demonstrated that gellan gum edible coatings can enhance antioxidant capacity. Oregano essential oil, as indicated by Jouki et al. (2014), has also shown the capability to augment the antioxidant capacity of food.

The ascorbic acid content (AAC) in mandarin fruits underwent notable variations influenced by the applied treatments. At day $7 \pm 1°C$ plus 7 days at $15 \pm 1°C$, a substantial increase of approximately 15% in ascorbic acid content was observed in both treated and untreated fruits, initiating a subsequent decline from day 14 at 6°C plus 7 days at $15 \pm 1°C$. By day 14 at 6°C plus 7 days at $15 \pm 1°C$, the ascorbic acid content decreased by 2.08% in the control samples compared to day 0. In contrast, the treated samples exhibited an increase of 11.56% in EC1 and 9.12% in EC2 compared to day 0. On day 24 at 6°C plus 7 days at $15 \pm 1°C$, the increase in ascorbic acid in EC2 was 5.77%, in EC1 it was 0.93% compared to day 0, whereas a decrease of 10.4% was noted in CTR.

The initial surge in ascorbic acid levels may be associated with biosynthesis processes, while subsequent declines could result from degradation or conversion. If biosynthesis processes predominate over degradation during cold storage, an increase in ascorbic acid levels is plausible (Dzah et al., 2023). The observed tendency for the ascorbic acid content in mandarin fruits to decrease with increasing storage days aligns with findings in other studies, such as Ladaniya (2011).

TABLE 1 Changes in firmness, total soluble solids (TSS) titratable acidity (TA), pH content in mandarin fruits control samples (CTR), treated mandarin fruit samples (EC1; EC2) at the harvest, during the cold storage (7, 14 and 24 days at 6 ± 1°C) and during the shelf-life (I shelf-life: 7 days at 6 ± 1°C plus 7 days at 15 ± 1°C; II shelf-life: 14 days at 6 ± 1°C plus 7 days at 15 ± 1°C and III shelf-life: 24 at 6 ± 1°C plus 7 days at 15 ± 1°C).

Storage Time (Days)	Treatments	Firmness (N)	TSS (°Brix)	TA % citric acid	pH (%)
HARVEST	CTR	3.14 ± 1.12 aA	11.95 ± 0.87 Aa	1.92 ± 0.28 aA	4.07 ± 0.25 Aa

I SHELF LIFE 7 days at 6 ± 1 °C + 7 days at 15 ± 1°C					
Storage Time (days)	Treatments	Firmness (N)	TSS (°Brix)	TA % citric acid	pH (%)
0	CTR	2.75 ± 0.70 aA	11.84 ± 0.87 ns	1.90 ± 0.28 aA	4.22 ± 0.17 ns
3	CTR	2.44 ± 0.67 aA	11.80 ± 2.03 ns	1.86 ± 0.06 aA	4.42 ± 0.16 ns
7	CTR	2.53 ± 0.56 aA	11.82 ± 1.12 ns	1.77 ± 0.07 aA	4.34 ± 0.07 ns
0	EC1	2.91 ± 1.12 aA	11.78 ± 0.87 ns	1.89 ± 0.28 aA	4.27 ± 0.25 ns
3	EC1	2.79 ± 1.03 bA	11.62 ± 1.09 ns	1.87 ± 0.02 aB	4.41 ± 0.14 ns
7	EC1	2.70 ± 1.03 bA	11.70 ± 1.09 ns	1.83 ± 0.02 aB	4.35 ± 0.04 ns
0	EC2	2.85 ± 1.12 aA	11.75 ± 0.87 ns	1.91 ± 0.28 aA	4.24 ± 0.25 ns
3	EC2	2.55 ± 0.62 aB	11.52 ± 1.01 ns	2.13 ± 0.16 bA	4.35 ± 0.08 ns
7	EC2	2.63 ± 0.35 aB	11.64 ± 1.06 ns	2.03 ± 0.06 bA	4.40 ± 0.10 ns

II SHELF LIFE 14 days at 6 ± 1 °C + 7 days at 15 ± 1°C					
Storage Time (days)	Treatments	Firmness (N)	TSS (°Brix)	TA % citric acid	pH (%)
0	CTR	2.67 ± 0.71 aA	11.02 ± 1.66 aA	1.31 ± 0.28 aA	4.32 ± 0.16 aA
3	CTR	3.40 ± 2.00 aA	11.71 ± 0.82 aA	1.32 ± 0.16 aA	4.70 ± 0.11 aB
7	CTR	3.10 ± 0.78 aA	12.32 ± 1.23 aA	1.29 ± 0.15 aA	4.31 ± 0.11aAB
0	EC1	2.74 ± 0.68 aA	10.89 ± 1.40 aA	1.21 ± 0.09 aA	4.66 ± 0.10 aA
3	EC1	3.24 ± 0.76 aA	10.99 ± 0.72 aA	1.12 ± 0.05aAB	4.59 ± 0.08 aA
7	EC1	2.84 ± 0.41 aA	11.39 ± 0.79 bA	1.31 ± 0.04 aA	4.35 ± 0.10 aB
0	EC2	2.90 ± 0.38 aA	11.38 ± 1.00 aA	1.21 ± 0.12 aA	4.32 ± 0.16 aA
3	EC2	3.69 ± 1.12 aB	11.45 ± 0.73 bA	1.27 a 0.02 aA	4.83 ± 0.12 bB
7	EC2	3.16 ± 0.41 aB	11.10 ± 1.06 aA	1.38 ± 0.12 aA	4.48 ± 0.07aAB

III SHELF LIFE 24 days at 6 ± 1 °C + 7 days at 15 ± 1°C					
Storage Time (days)	Treatments	Firmness (N)	TSS (°Brix)	TA % citric acid	pH (%)
0	CTR	2.13 ± 0.29 aA	11.09 ± 0.94 aA	1.22 ± 0.02 aA	4.07 ± 0.05 aA
3	CTR	2.89 ± 0.86 aA	11.40 ± 0.86 aA	1.26 ± 0.12 aA	4.46 ± 0.06 aB
7	CTR	2.80 ± 0.95 aA	11.91 ± 1.11 aA	1.32 ± 0.10 aA	4.35 ± 0.07 aB
0	EC1	2.29 ± 0.59 aA	10.85 ± 0.84 bA	1.19 ± 0.06 aA	4.17 ± 0.17 aA
3	EC1	2.85 ± 0.45 aB	10.72 ± 1.17 aA	1.07 ± 0.02 aB	4.63 ± 0.13 aB
7	EC1	2.94 ± 0.66 aB	11.45 ± 0.78 aA	1.22 ± 0.04 aA	4.37 ± 0.03 aAB
0	EC2	2.28 ± 0.40 aA	10.93 ± 1.19 bA	1.19 ± 0.17 aA	4.21 ± 0.11 aA
3	EC2	3.06 ± 0.47 aB	11.67 ± 1.32 aA	1.13 ± 0.08 aA	4.44 ± 0.14 aA
7	EC2	2.76 ± 0.59 aB	11.66 ± 1.24 aA	0.98 ± 0.07 bA	4.47 ± 0.06 aA

Data are the mean ± S.D. Different lowercase letters indicate significant differences at $p \leq 0.05$ between the treatments on each sampling date. Uppercase letters indicate significant differences at $p \leq 0.05$ between the different storage period on each sampling treatment.

TABLE 2 Changes in Brightness (L*), Red/Green value (a*), Blue/Yellow value (b*) Chroma (c*), Hue (H) and ∆e in mandarin fruits control samples (CTR), treated mandarin fruit samples (EC1; EC2) at the harvest, during the cold storage (7, 14 and 24 days at 6 ± 1°C) and during the shelf-life (I shelf-life: 7 days at 6 ± 1°C plus 7 days at 15 ± 1°C; II shelf-life: 14 days at 6 ± 1°C plus 7 days at 15 ± 1°C and III shelf-life: 24 at 6 ± 1°C plus 7 days at 15 ± 1°C).

I SHELF LIFE at 7 days at 6 ± 1 °C + 7 days at 15 ± 1°C							
Storage time (Days)	Treatments	CieLab					
		L*	a*	b*	c*	hue	∆e
HARVEST		68.17 ± 2.07 aA	19.39 ± 2.1 aA	72.08 ± 3.87 ns	74.66 ± 4.00 ns	0.26 ± 0.02 ns	-

I SHELF LIFE at 7 days at 6 ± 1 °C + 7 days at 15 ± 1°C							
Storage Time (Days)	Treatments	CieLab					
		L*	a*	b*	c*	hue	∆e
0	CTR	68.37 ± 1.96 aA	19.41 ± 21.58 aA	71.85 ± 3.46 ns	74.43 ± 3.65 ns	0.26 ± 0.03 ns	-
3	CTR	67.92 ± 1.91 aA	19.79 ± 1.98 aA	70.46 ± 1.20 ns	73.21 ± 1.28 ns	0.27 ± 0.03 ns	4.46 ± 2.44 ns
7	CTR	68.60 ± 1.35 aB	22.52 ± 1.85 aB	70.58 ± 1.90 ns	74.11 ± 1.97 ns	0.31 ± 0.02 ns	3.87 ± 2.09 ns
0	EC1	68.26 ± 1.92 aA	19.58 ± 2.35 aA	72.15 ± 3.64 ns	74.76 ± 3.85 ns	0.26 ± 0.03 ns	-
3	EC1	67.65 ± 1.74 bAB	20.36 ± 1.93 aB	71.52 ± 1.25 ns	73.34 ± 1.16 ns	0.28 ± 0.03 ns	4.68 ± 2.35 ns
7	EC1	68.52 ± 1.38 aB	21.24 ± 1.59 aB	70.47 ± 1.54 ns	73.60 ± 1.50 ns	0.29 ± 0.02 ns	3.41 ± 1.31 ns
0	EC2	68.47 ± 1.7 aA	19.46 ± 1.49 aA	72.37 ± 3.26 ns	74.94 ± 3.21 ns	0.26 ± 0.02 ns	-
3	EC2	67.77 ± 1.91 aB	19.91 ± 1.87 aA	71.13 ± 1.20 ns	73.06 ± 1.28 ns	0.27 ± 0.03 ns	4.35 ± 2.66 ns
7	EC2	68.33 ± 1.46 aA	21.60 ± 1.30 aB	70.41 ± 1,72 ns	73.65 ± 1.64 ns	0.30 ± 0.02 ns	3.00 ± 2.09 ns

II SHELF LIFE 14 days at 6 ± 1 °C + 7 days at 15 ± 1°C							
Storage Time (days)	Treatments	CieLab					
		L*	a*	b*	c*	hue	∆e
0	CTR	68.62 ± 1.77 aA	21.72 ± 2.61 ns	70.42 ± 1.93 aA	73.75 ± 1.55 aA	0.30 ± 0.04 ns	-
3	CTR	69.11 ± 1.44 aA	21.70 ± 1.57 ns	70.21 ± 2.43 aB	73.50 ± 2.17 aA	0.30 ± 0.02 ns	3.61 ± 1.53 aA
7	CTR	67.57 ± 1.92 aB	23.59 ± 2.34 ns	72.29 ± 2.37 aAB	76.55 ± 2.17 aB	0.31 ± 0.03 ns	5.75 ± 2.00 aB
0	EC1	68.62 ± 1.60 bA	22.52 ± 1.72 ns	71.19 ± 2.03 aA	74.67 ± 1.61 aA	0.31 ± 0.03 ns	-
3	EC1	69.02 ± 0.98 bA	22.01 ± 1.59 ns	70.29 ± 1.45 aB	73.66 ± 1.53 bA	0.30 ± 0.02 ns	3.73 ± 1.45 aA
7	EC1	68.03 ± 1.62 aA	22.60 ± 1.73 ns	73.66 ± 1.87 aB	77.05 ± 2.00 bB	0.30 ± 0.02 ns	4.81 ± 2.12 aA
0	EC2	67.04 ± 1.37 bA	23.68 ± 1.27 ns	68.57 ± 1.98 bA	72.54 ± 1.89 aA	0.33 ± 0.02 ns	-
3	EC2	67.47 ± 1.21 bA	22.36 ± 2.20 ns	67.81 ± 3.03 bB	71.40 ± 2.90 aA	0.32 ± 0.03 ns	4.51 ± 2.59 aA
7	EC2	67.28 ± 1.80 aA	23.00 ± 1.81 ns	74.01 ± 2.42 aB	77.50 ± 2.28 bB	0.30 ± 0.03 ns	7.53 ± 2.77 bA

III SHELF LIFE 24 days at 6 ± 1 °C + 7 days at 15 ± 1°C							
Storage Time (days)	Treatments	CieLab					
		L*	a*	b*	c*	hue	∆e
0	CTR	68.22 ± 2.48 aA	23.42 ± 2.30 ns	71.08 ± 2.54 aA	75.07 ± 2.53 aA	0.32 ± 0.03 ns	-
3	CTR	67.19 ± 1.37 aA	23.11 ± 1.20 ns	68.20 ± 2.20 aB	72.03 ± 1.97 aB	0.33 ± 0.02 ns	5.32 ± 2.04 aA
7	CTR	67.42 ± 1.13 aA	23.54 ± 1.78 ns	68.90 ± 2.14 aB	72.83 ± 2.28 aB	0.33 ± 0.02 ns	3.70 ± 1.61 aB
0	EC1	68.52 ± 1.6 aA	22.61 ± 2.86 ns	72.56 ± 1.66 aA	76.00 ± 1.77 aA	0.30 ± 0.04 ns	-
3	EC1	66.21 ± 1.59 aB	22.71 ± 2.76 ns	66.89 ± 2.19 aB	70.64 ± 2.33 bB	0.33 ± 0.04 ns	7.63 ± 2. bA
7	EC1	66.56 ± 1.17 aB	23.97 ± 1.40 ns	67. 80 ± 1.46 aB	71.91 ± 1.33 aB	0.34 ± 0.02 ns	4.04 ± 2.23 aB
0	EC2	67.67 ± 1.28 aA	22.24 ± 2.21 ns	70.35 ± 2.07 bA	73.78 ± 2.21 abA	0.31 ± 0.03 ns	-
3	EC2	67. 00 ± 1.37 aA	23.44 ± 1.57 ns	67.19 ± 2.01 aB	71. 16 ± 1.91 aB	0.34 ± 0.02 ns	4.49 ± 2.00 aA
7	EC2	66.82 ± 1.43 aA	22.90 ± 1.63 ns	67.48 ± 1.59 aB	71.26 ± 1.64 aB	0.33 ± 0.02 ns	3.73 ± 2.56 aA

Data are the mean ± S.D. Different lowercase letters indicate significant differences at $p \leq 0.05$ between the treatments on each sampling date. Uppercase letters indicate significant differences at $p \leq 0.05$ between the different storage period on each sampling treatment.
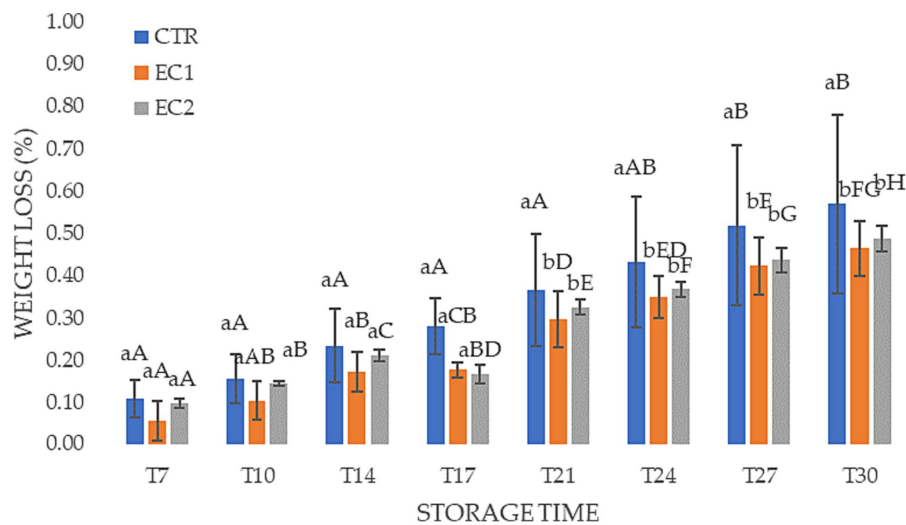
FIGURE 5
Changes in weight loss (%) in mandarin fruits control samples (CTR), treated mandarin fruit samples (EC1; EC2) during the cold storage at $6 \pm 1°C$ Different lowercase letters indicate significant differences at $p \leq 0.05$ between the treatments on each sampling date. Uppercase letters indicate significant differences at $p \leq 0.05$ between the different survey on the same treatment on each sampling treatment. Data are the mean $\pm$ S.D.
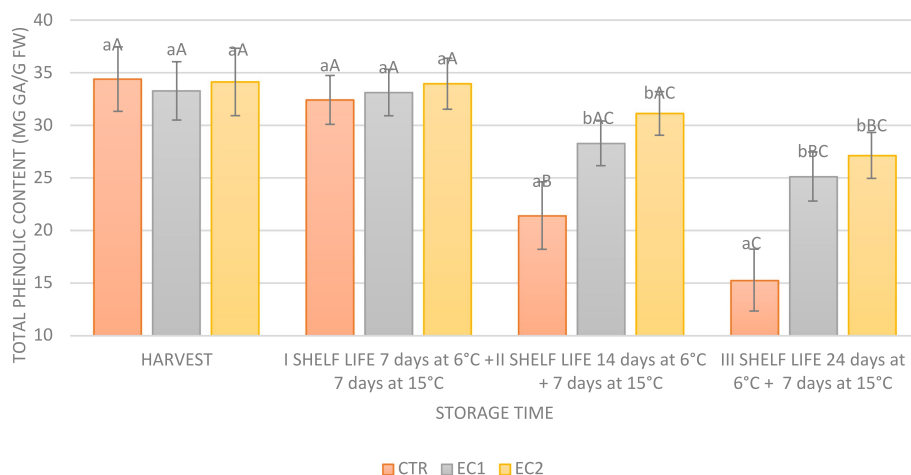

FIGURE 6
Total phenolic content during harvest (day 0) and during the shelf-life I shelf-life: harvest plus 7 days at $15 \pm 1°C$; II shelf-life: 14 days at 6°C plus 7 days at $15 \pm 1°C$ and III shelf-life: 24 days at 6°C plus 7 days at $15 \pm 1°C$. Data are the mean $\pm$ S.D. Different lowercase letters indicate significant differences at $p \leq 0.05$ between the treatments on each sampling date. Uppercase letters indicate significant differences at $p \leq 0.05$ between the different storage period on each sampling treatment.

The primary cause of ascorbic acid reduction during storage, often attributed to oxidation, has been documented in various fruits and vegetables (Lee and Kader, 2000). Additionally, the protective role of edible coatings in mitigating the loss of ascorbic acid by limiting exposure to oxygen has been highlighted in studies such as Ali et al. (2021) (Figure 8).

3.5 Evolution of microbiological parameters on mandarin fruits

Mandarin fruits are susceptible to many postharvest diseases mainly determined by spoilage filamentous fungi (molds) (Zhu et al., 2019). Therefore, one effective method to increase their shelf-life is based to the application of antibacterial edible coatings. In this study, edible coating samples, control (CTR), and treated (EC1 and EC2) mandarin fruits were analyzed by culture-dependent approach for the presence of the main undesired microorganisms commonly associated with foods (Jay et al., 2009). The microbiological analysis performed on the two edible coatings did not reveal the presence of any of the microorganisms object of investigation, confirming their suitability for food applications. The presence of spoilage microorganisms (pseudomonads and yeasts), responsible to the microbial decay of horticultural products (Passafiume et al., 2023) was never found in CTR, EC1 and EC2 mandarin fruit samples. These results confirmed what previously
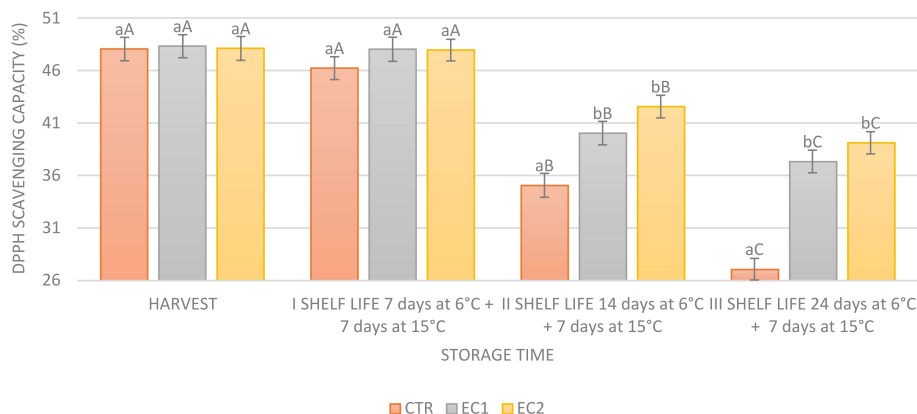
FIGURE 7
DPPH radical scavenging rate during harvest (day 0) and during the shelf-life I shelf-life: 7 days $\pm 1°C$; at 6 plus 7 days at $15 \pm 1°C$; II shelf-life: 14 days at 6°C plus 7 days at $15 \pm 1°C$ and III shelf-life: 24 days at 6°C plus 7 days at $15 \pm 1°C$. Data are the mean $\pm$ S.D. Different lowercase letters indicate significant differences at $p \leq 0.05$ between the treatments on each sampling date. Uppercase letters indicate significant differences at $p \leq 0.05$ between the different storage period on each sampling treatment.
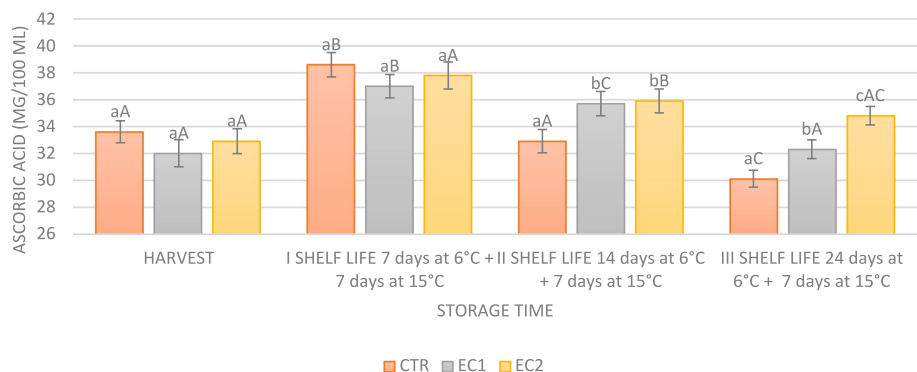

FIGURE 8
Ascorbic acid rate during harvest (day 0) and during the shelf-life I shelf-life: harvest plus 7 days at $15 \pm 1°C$; II shelf-life: 14 days at 6°C plus 7 days at $15 \pm 1°C$ and III shelf-life: 24 days at 6°C plus 7 days at $15 \pm 1°C$. Data are the mean $\pm$ S.D. Different lowercase letters indicate significant differences at $p \leq 0.05$ between the treatments on each sampling date. Uppercase letters indicate significant differences at $p \leq 0.05$ between the different storage period on each sampling treatment.

reported by Schena et al. (2011) that bacteria and yeasts are not able to determine postharvest diseases in mandarin fruits. No foodborne pathogens such as *E. coli*, CPS, *L. monocytogenes* and *Salmonella* spp., associated with the consumption of fruit commodities (Leff and Fierer, 2013) developed from the cell suspensions of all mandarin fruit samples analyzed. The absence of these microorganisms is undoubtedly due to the respect of high-quality standards during the pre-and postharvest operations (Liguori et al., 2023). Significant differences ($p < 0.05$) were found, after 7 d at 6°C plus 7 d at $15°C \pm 1°C$, only for the levels of molds among trials (Figure 9).

These microorganisms were found at about 10^4 CFU/g in the CTR and EC1 productions and remained constant for all shelf-life trials. Interestingly, molds were detected only after 24 d at 6°C plus 7 d at $15°C \pm 1°C$ in EC2 treated mandarin fruits and their final levels were 2 Log cycles lower than those estimated in CTR and EC1 fruits. These differences are mainly imputable to the high concentration of carvacrol contained in the OEO used in the formulation of edible coating of the EC2 trial. Therefore, our data confirmed the antifungal

properties of OEO (Leyva-López et al., 2017) even after their inclusion in edible coating formulations.

3.6 Sensory analysis and visual score

Data from sensory evaluation and visual scoring are crucial because they provide us about potential customers probable preferences for a product once they have purchased it. Mandarin fruits of all treatments (CTR; EC1; EC2) were subjected to sensory evaluation. No significant differences were found in the three treatments at the harvest, during the cold storage and during the shelf-life. The panelists rated all samples from the three case studies positively, giving a slightly higher liking rating in the treated fruits (Figures 10A–C). The following descriptors oregano odor, oregano flavor, and herbaceous hint were included in EC2 to allow the incidence of oregano essential oil to be evaluated. (Figure 10C). The "sweet" parameter was evaluated positively by the panelists; in fact, the sweetness of the fruits remained constant in all samples, and at the last
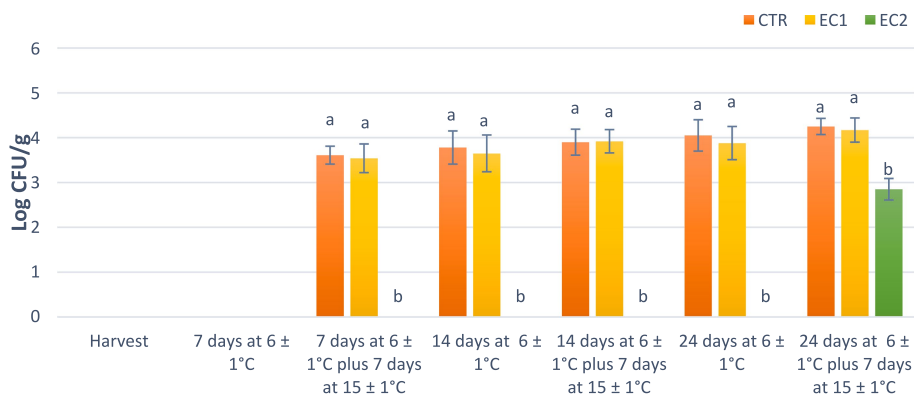
FIGURE 9
Cell densities of molds on control and treated mandarins fruit samples. Histograms followed by different lowercase letters are significantly different according to Tukey's test ($p < 0.05$).
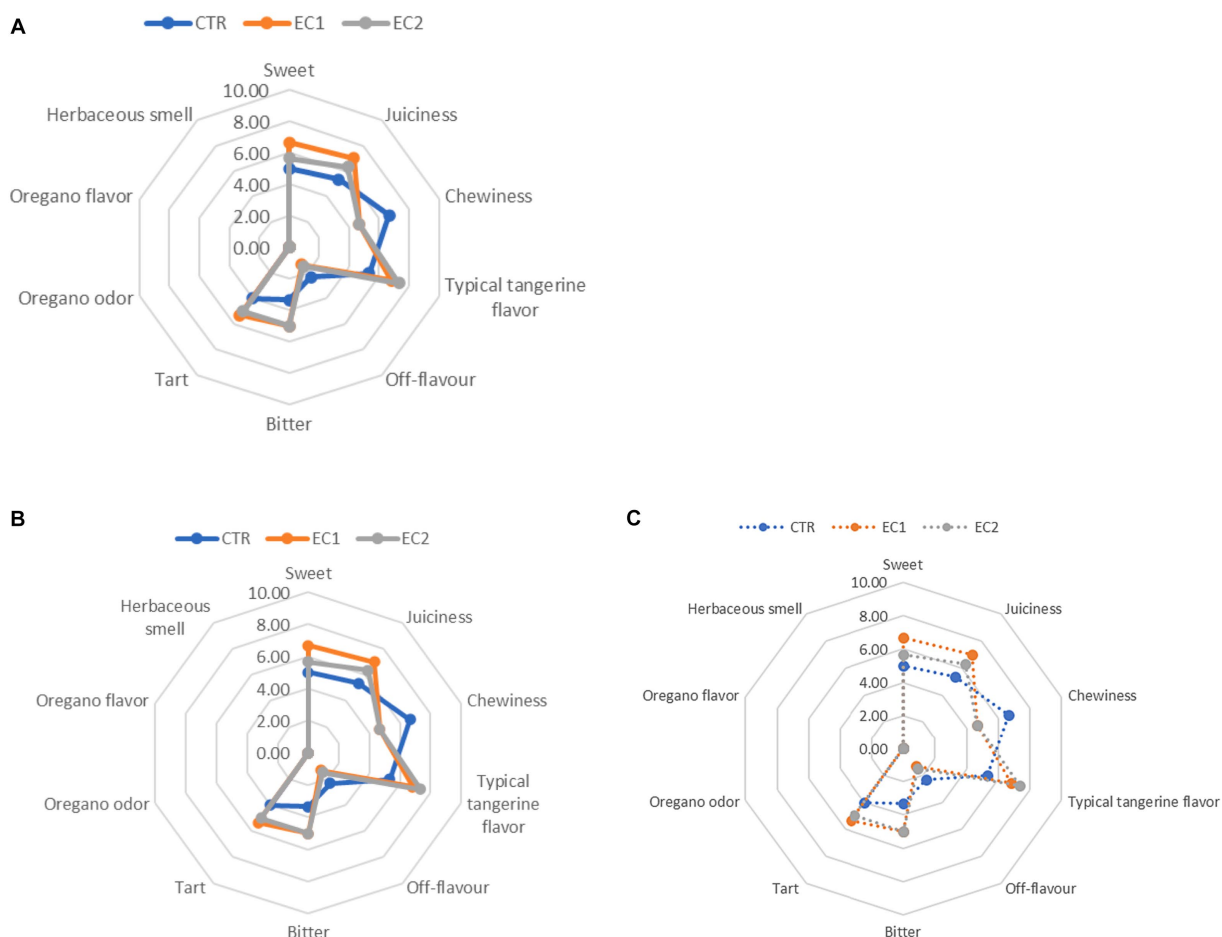

FIGURE 10
(A) Sensorial analysis of mandarin fruits control samples (CTR-A), treated mandarin fruit samples (EC1-B; EC2-C) at I shelf-life: 7 days at 6°C plus 7 days at 15°C; (B) Sensorial analysis of mandarin fruits control samples (CTR-A), treated mandarin fruit samples (EC1-B; EC2-C) at II shelf-life: 14 days at 6°C plus 7 days at 15°C; (C) Sensorial analysis of mandarin fruits control samples (CTR-A), treated mandarin fruit samples (EC1-B; EC2-C) at III shelf-life: 24 days at 6°C plus 7 days at 15 ± 1°C.

shelf-life EC1 samples had one point more than the CTR and EC2 ones. The juiciness parameter remained similar in all three theses during the storage periods; as well as for chewiness. The parameter "typical tangerine flavor "had the higher score in EC2 at 24 days at 6 ± 1°C plus 7 days at 15 ± 1°C. Starting from the third storage period, the treated samples were preferred by the panelists showing 2 points
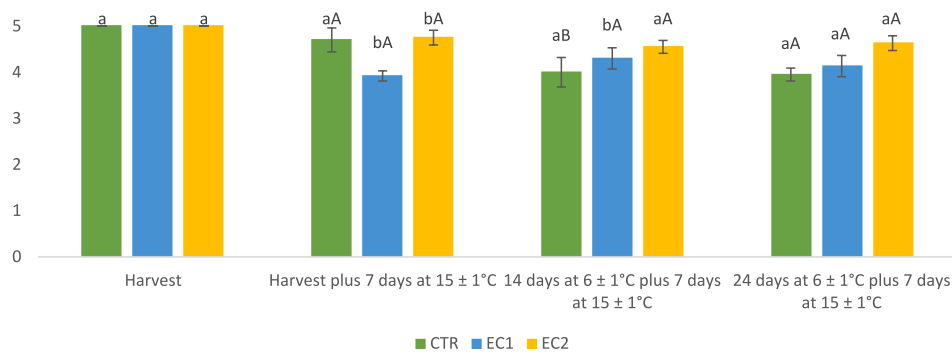
FIGURE 11
Visual score of mandarin fruits control samples (CTR), treated mandarin fruit samples (EC1; EC2) at the harvest, during the shelf-life (I shelf-life: harvest plus 7 days at $15 \pm 1°C$; II shelf-life: 14 days at 6°C plus 7 days at $15 \pm 1°C$ and III shelf-life: 24 days at 6°C plus 7 days at $15 \pm 1°C$).

more in EC2 on 24 days at $6 \pm 1°C$ plus 7 days at $15 \pm 1°C$ than the CTR samples. Bitter and sour parameters were similarly evaluated during the storage periods by the panelists.

"Oregano odor," "Oregano flavor" and "herbaceous smell" remained persistent until 3rd day of the second storage period (II shelf-life), following a slight increase in these descriptors between 3rd day and 7th day of the first storage period (Figure 10C). There was a similar evaluation at harvest (0 days) and 3rd day of the second storage period (II shelf-life) until these descriptors were not detected from 7th day of the second storage period (II shelf-life).

These descriptors were completely absent during the third storage period (III shelf-life 24 days at $6 \pm 1°C + 7$ days at $15 \pm 1°C$) (Figure 10C).

During the three storage periods, all treatments samples showed scores above the marketability threshold (Figure 11). Only treated samples maintained a score above 4 during the three storage periods.

4 Conclusion

The analysis of multispectral images acquired through UAVs offers the potential to identify the optimal collection time. Specifically, for harvested oregano intended for essential oil extraction, the balsamic time was determined when the NDVI values of most plants reached 0.58.

This study marks the first evaluation of the impact of a coating composed of gellan, glycerol, and calcium chloride enriched with essential oils of oregano featuring high carvacrol content on the shelf life of mandarin fruits. Our findings suggest that the application of edible coatings maintained the quality parameters of the fruits without inducing quality decay. Leveraging its barrier effect, the edible coating resulted in reduced weight loss of the treated fruits, a crucial aspect for preserving product quality. Additionally, the edible coatings demonstrated the ability to better preserve nutritional and nutraceutical attributes throughout the storage periods.

Notably, carvacrol exhibited inhibitory effects for 24 days at $6 \pm 1°C$ plus 7 days at $15 \pm 1°C$, preventing the occurrence of green and blue mold, which are responsible for rendering the product unsuitable for commercialization. This underscores the significant value of the treatments in safeguarding the quality parameters of mandarin fruits and mitigating food waste arising from non-marketability.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

GL: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Validation, Writing – original draft, Writing – review & editing. GGr: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Writing – original draft, Writing – review & editing. GS: Data curation, Formal analysis, Investigation, Writing – original draft. GGa: Formal analysis, Investigation, Writing – original draft. RG: Data curation, Investigation, Methodology, Software, Writing – original draft, Writing – review & editing. MB: Formal analysis, Investigation, Writing – original draft. CG: Data curation, Investigation, Project administration, Resources, Writing – original draft. SO: Data curation, Formal analysis, Investigation, Resources, Writing – original draft. GF: Funding acquisition, Project administration, Resources, Writing – review & editing. MM: Funding acquisition, Project administration, Resources, Writing – original draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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