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# 1-Methylcyclopropene and lemongrass essential oil nanocoatings effect on the preservation of cold stored 'Rocha' pear

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## ARTICLE INFO

## ABSTRACT

The effects of coating 'Rocha' pear with alginate-based nanoemulsions enriched with lemongrass essential oil (LG) was evaluated and compared to the usual 1-MCP treatment. Fruit were treated with 1-MCP (312 nL L$^{-1}$) or coated with nanoemulsions: sodium alginate 2 % (w/w) + lemongrass essential oil 1.25 % (w/w) (LG 1.25 %) or lemongrass essential oil 2.5 % (w/w) (LG 2.5 %). Then, fruit were stored at 0 °C and 90–95 % relative humidity (RH), for eight months. Fruit samples were collected at harvest and after two, four, six and eight months of cold storage, and then transferred to shelf-life at 22 °C. Upon removal and after 7 d shelf-life, fruit symptoms of superficial scald and internal browning, ethylene production, color CIE (L*, hue), firmness, soluble solids content (SSC), titratable acidity (TA), weight loss, electrolytic leakage (EL), antioxidant activity and fatty acids of pear peel, microbial growth and sensory analyses were evaluated. Coatings and 1-MCP reduced fruit color evolution and preserved better firmness than control. Coatings and 1-MCP did not affect SSC and TA. Treatments did not influence the sensory quality. Microbial growth was within the safety limits in all treatments. Treatments with 1-MCP and LG-nanoemulsions were similarly efficient to reduce superficial scald, nevertheless the LG-nanoemulsions showed higher internal disorders after 8 months of storage and LG 2.5 % had higher decay at the same period, similar to control. 1-MCP treated fruit had the lowest softening rate after shelf-life up to 4 months and LG 2.5 % showed higher weight loss. Also, ethylene production was higher in control and LG 1.25 % up to 6 months plus shelf-life, while after 8 months there was no difference among treatments. This study suggests that 1-MCP is the most efficient for preserving quality of 'Rocha' pear for 8 months, while up to 6 months the best effect is obtained with LG 1.25 % nanocoatings.

## 1. Introduction

'Rocha' pear (*Pyrus communis* L.), a cultivar from the western region of Portugal, is the main produced in the country and widely consumed in several international markets (Fonseca et al., 2020). The fruit is harvested in August and its availability through the year is crucial to producers and consumers. Therefore, fruit metabolic processes should be reduced without compromising their postharvest quality. Methodologies as the traditional cold storage at around 0 °C, the use of 1-methyl-cyclopropene (1-MCP) and controlled atmosphere storage, have been used to extend the storage life of pear (Ekman et al., 2004; Lwin et al.,

2021; Saquet, 2019; Xie et al., 2014). Alternatively, it has been proposed recently the use of nanocoatings to preserve 'Rocha' pear with promising results (Gago et al., 2020). Alginate based coatings applied to raspberries, strawberries and plum fruit were effective to keep fruit quality during storage and shelf-life (Dhital et al., 2018; Gomes et al., 2017; Guerreiro et al., 2015; Valero et al., 2013).

It is widely known, that ethylene is involved in the ripening of climacteric fruit, promoting several fruit attributes, such as color, flavor, texture, and nutritional properties. However, it can also induce fast over-ripening reducing the shelf-life of fruit by the development of physiological disorders, senescence and increased pathogen

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susceptibility (Delong et al., 2004; Kader, 1997). For long term storage of 'Rocha' pear, 1-MCP, a competitive inhibitor of ethylene, has been largely used, nevertheless, with contradictory effect on pear fruit quality. In fact, 1-MCP prolongs storage and reduce superficial scald in fruit stored under normal atmosphere (Isidoro and Almeida, 2006), but, fruit show a ripening block, not allowing them to ripe properly in shell-life (Saquet, 2019). Furthermore, it is also reported an increase of internal disorders (Saquet and Almeida, 2017). Thereby, to find a treatment able to reduce superficial scald, and other possible disorders, without compromising the normal eating-ripe stage during shelf-life, still a challenge for the pear postharvest management.

The innovative use of lemongrass essential oil (LG) nanocoatings in 'Rocha' pear, reported by Gago et al. (2020) avoided superficial scald symptoms up to 6 months of cold storage and following shelf-life. The fruit still had a normal ripening process with a good consumer acceptance and without internal disorders when pears were coated with LG 1.25 % nanoemulsion, for up to 6 months storage. However, nothing is known on their effect for further storage, as well as compared with the usually used 1-MCP, or their influence on ethylene production and other chemical compounds related to scald development.

Some studies had related the superficial scald development with the formation and oxidation of α-farnesene into conjugated trienols (Gago et al., 2015; Lindo-García et al., 2021), which is largely supported by the fact that 1-MCP treatment, an ethylene inhibitor, prevent scald development in pears and apples (Lindo-García et al., 2021). Moreover, the oxidative nature of the scald disorder is also clear since treatments with synthetic antioxidants control the appearance of scald without altering ethylene biosynthesis (Karagiannis et al., 2018). Also, fatty acids, important structural and metabolic constituents of plant/fruit membranes, show a critical role on resistance against chilling injury (CI) (Marangoni et al., 1996; Saquet et al., 2003) and it was revealed a positive relationship between high unsaturated/saturated fatty acid ratio and cold tolerance (Gao et al., 2018).

The objective of this work is to compare the use of alginate-based nanoemulsions supplemented with lemongrass-essential oil (LG) of different concentrations as fruit coatings with the 1-MCP treatment or no treatment (control), in the preservation of 'Rocha' pear quality during long term cold storage.

## 2. Material and methods

### 2.1. Fruit and postharvest treatments

'Rocha' pear were harvested at optimal storage maturity stage [11.1 % soluble solids content (SSC) and 59 N firmness] from orchards in West Region of Portugal and immediately transported to the University of Algarve. Fruit were hand-sorted to select undamaged fruit and packed into plastic crates (60 fruits per crate) which were put in a cold room at 0 °C and 90–95 % relative humidity (RH). In the next day, six plastic crates were sealed into a big polyethylene (0.12 mm thick) bag and treated at the recommended commercial dose of 312 nL L$^{-1}$ of 1-MCP (SmarthFresh™, Agrofresh, Inc., Springhouse, PA, USA) for 20 h at 0 °C, according to the manufacturer's instructions and including the use of a small fan to assure air movement inside the bag.

Three more groups with the same number of fruit (360) were taken from the cold room, organized and, one was coated with sodium alginate 2 % (w/w) + lemongrass essential oil 1.25 % (w/w) (LG 1.25 %), other coated with sodium alginate 2 % (w/w) + lemongrass essential oil 2.5 % (w/w) (LG 2.5 %) and in the last group fruit were left as they come from the field, serving as control. The nanoemulsions used were produced according to Gago et al. (2020) with measured values of polydispersity, zeta potential and droplet size similar to those previously reported. The nanoemulsions were applied through all fruit surface by placing fruit on a moving belt net, by spraying with a paint gun (Dexter nozzle 1.5 mm, ADEO services, Ronchini - France) at a minimum distance of 20–30 cm, with a pression of 8 bars and the flow rate of 0.0025 m$^3$ s$^{-1}$ (Gago et al.,

2021). Then, using the same spray system, a 1 % (w/v) CaCl$_2$ solution was applied to fruit of the nanocoating treatments in order to form the nanocoating structure on the fruit surface (Gago et al., 2021). Then, fruit were left to dry at room temperature for 2 h. Following treatments, all fruit were stored at 0 °C and 90–95 % RH.

### 2.2. Fruit sampling

Measurements at harvest were done in fruit of control (fruit without any treatment). The other fruit were evaluated just after treatments application, then after the following 2, 4, 6 and 8 months in storage. At each date, fruit were removed from storage and evaluated in the same day, after reaching room temperature (22 °C and 70 % RH), and after 7 d of shelf-life. A total of 30 fruit per treatment were evaluated at each sampling date (in 3 replicates). At each sampling date, ethylene production and quality attributes were assessed. Also, two peel segments (1 mm thick) from each fruit within each treatment and replication were excised and immediately frozen in liquid N$_2$ and stored at − 80 °C for further chemical analyses, which aim to clarify the scald physiological disorder.

### 2.3. Assessment of superficial scald and internal disorders

Ten fruit from each replicate were visually examined for superficial scald and internal browning disorders as described in Gago et al. (2015). Scald incidence is the proportion of scalded fruit in each group, expressed as a percentage of the total fruit number. After that, the same fruit were cut lengthwise, and fruit with at least 1 cm diameter brown spot around core center was considered to have internal browning and its incidence was expressed as percentage of total fruit.

### 2.4. Ethylene measurements

Three fruit from each replicate and treatment were placed in 1.5 L jars which were sealed for 1 h. Then, ethylene measurements were performed by withdrawing a 1 mL headspace gas sample from the jars with a syringe and injecting it into a Trace 1300 (Thermo Scientific) gas chromatograph, equipped with a TG-Bond Alumina (Na$_2$SO$_4$) 30 m × 0.53 mm × 10 mm (Thermo Scientific) at 60 °C and a flame ionization detector at 120 °C. The carrier gas was He at a flow rate of 5.83 10$^{-7}$ m$^3$ s$^{-1}$. Ethylene production rates were expressed as ng kg$^{-1}$ s$^{-1}$.

### 2.5. Skin color, flesh firmness, soluble solids content, titratable acidity, electrolyte leakage and weight loss

Skin color was measured in the CIE L* a* b* color space with a CR-300 colorimeter (CE Minolta, Japan) with a D65 light source and the observer at 10'. All measurements were performed on the widest part of the fruit, as a mean of 3 points. The a* and b* readings were converted to the vector coordinate' hue angle (h) using the equation h = arc tan b* / a* (McGuire, 1992).

Flesh firmness was measured on two opposite sides of each fruit, after peel removal, with a Chatillon Force TCD 200 and Digital Force Gauge DFIS 50 (Jonh Chatillon & Sons, Inc., U.S.A.), fitted with a convex probe of 8 mm diameter mounted on a standard drill press. Results are presented as the mean maximum force (N) required to push the probe 8 mm into the fruit flesh.

Electrolyte leakage (EL) was assessed as described by Gago et al. (2015), using an Orion 011007 conductivity meter (Thermo Scientific Orion StarTM, Beverly, USA).

A quarter of each fruit within each replication was combined to obtain a juice sample. SSC was measured in the juice with a digital refractometer (model PR-100, Atago Co., Tokyo, Japan). Titratable acidity was determined by titration of the juice with NaOH 0.1 mol L$^{-1}$ to the endpoint of pH 8.2 and expressed as concentration of malic acid equivalents.

Weight loss was calculated by weighing always the same sample of fruit (10 fruit for each replication, harvest date and treatment), and expressed as percentage of the initial weight.

## 2.6. Extraction and assay of α-farnesene, conjugated trienols, total phenols and antioxidant activity in pear peel

α-Farnesene and conjugated trienols of 'Rocha' pear were extracted from the frozen tissue. Peel segments (1 g) were extracted with 5 mL hexane (HPLC grade) for 10 min, under constant agitation, at $23 \pm 2°C$ (Isidoro and Almeida, 2006). Three separate extractions were performed on each of the three replicates. Extracts were assayed spectrophotometrically at 232 nm and in the range of 281–290 nm (Shimadzu, UV–Vis recording spectrophotometer, model UV-160 A, Shimadzu Corporation, Kyoto, Japan). To calculate the content of α-farnesene (μmol $kg^{-1}$) and conjugated trienols (μmol $kg^{-1}$) were used the extinction coefficients $\varepsilon_{232nm}= 27,740$ and $\varepsilon_{281-290nm}= 25,000$, respectively (Anet, 1972).

Extraction of total phenols and other active antioxidants was done in each sample, 1 g of pear peel was mix with 10 mL of distilled water and squeezed with an UltraTurrax T 18 (IKA, Staufen, Germany) for 2 min, then centrifuged 5 min at 2370$g$. The antioxidant activity of the extract was measured according to the modified method of Re et al. (1999) and expressed as Trolox equivalent (mol TE $kg^{-1}$). The total phenolic content (mg GAE $kg^{-1}$) was determined using the Folin–Ciocalteau reagent and gallic acid used as standard, as described by Slinkard and Singleton (1977).

## 2.7. Pear peel fatty acids

The fat fraction of pear' peel was extracted with $n$-hexane at room temperature with the aid of ultrasound (US). Briefly, 1.0 g of pear peel was placed in a 20 mL glass vial together with 5 mL of $n$-hexane. The extraction took place by means of an ultrasonic bath (Clifton DU-4; Clifton Ultrasonics Baths, North Somerset, United Kingdom) at 40 kHz for 15 min. This procedure was repeated three times, and the $n$-hexane phases were collected and evaporated under vacuum. The derivatization of fatty-acids (FAs) was optimized; the lipid extract obtained by $n$-hexane/US was exactly weighted (0.04–0.08 g). In the first step the collected FAs were resuspended in 2 mL of $n$-hexane and a transmetilation was carried out adding 1 mL of KOH / MeOH 2 mol $L^{-1}$ solution. The resulting mixture was then vortex-mixed for 30 s and kept at 70 °C for 2 min, followed by the addition of 1.2 mL HCl 1 mol $L^{-1}$. Then, a liquid-liquid extraction (LLE) was carried out by adding, 1 mL of $n$-hexane and vortex-mixing for 30 s. This process allows FAs derivatives collection in the form of methyl esters into the organic phase. A 0.6 mL of total extract were transferred into a 2.0 mL glass vial. The FAs analyses, in the form of methyl esters, were performed on a HP 6890 Series GC System with flame ionization detector (FID) and an automatic sampler injector, Agilent 7683 Series injector.

Chromatographic separation was achieved on a SP™-2380 capillary column (60 m × 0.25 mm i.d., 0.2 μm df) supplied by Supelco, Sigma-Aldrich, USA. The oven temperature program began at 140 °C hold for 5 min, raised at 4 °C $min^{-1}$ up to 240 °C and remaining at 240 °C for 10 min. Hydrogen was used as carrier gas at a flow rate of $2\ 10^{-8}\ m^3\ s^{-1}$ and the temperature of the injector and detector was set at 250 and 260 °C, respectively. 1 μL of each sample was injected with a 20:1 split ratio. Identification was carried out by comparison of the retention times of each peak with retention times of a Supelco™ 37 Component FAME Mix (Supelco, Bellefonte, PA) injected using the same conditions. Both data acquisition and processing were accomplished by software Clarity (DataApex, Prague).

The FAs peaks were identified by comparison with the retention times of FAs in a standard mixture and the amounts were calculated as a percentage of the total FAs and affluence was calculated by comparison of peak area as percentage. The unsaturated/saturated fatty acid ratio (UFA/SFA) was calculated by the formula: (18:1 + 18:2)/(16:0 + 18:0) where: 16:0 = Palmitic acid; 18:0 = Stearic acid; 18:1 = Oleic acid; 18:2 = Linoleic acid.

## 2.8. Microbial counts

The procedures for counts of aerobic mesophilic and psychrophilic bacteria and yeasts and molds were performed according to Guerreiro et al. (2015) and expressed as Log CFU $g^{-1}$ peel fruit. Fruit peel homogenates were prepared by using a masticator homogenizer classic/panoramic (IUL Instruments, Barcelona, Spain). Throughout cold storage and following shelf-life, in each treatment, the number of fruits showing visible symptoms of decay were examined.

## 2.9. Sensory evaluation

A taste panel, with 18 elements, did a sensory evaluation of pears, based on a 7-point hedonic scale (1 = dislike extremely, 4 = neither like nor dislike, 7 = like very much) for the sensory parameters: appearance, aroma, texture, taste, and overall acceptance according to Gol et al. (2013), with some modifications. Panelists consisted of Faculty students and staff members who were familiar with the characteristics of the fruit. All parameters were evaluated after 2, 4, 6 and 8 months of storage, and plus 7 d of shelf-life.

## 2.10. Statistical analysis

Data analysis was performed using IBM SPSS Statistic 27.0 software (IBM SPSS Inc., NY, USA) on an PC workstation (Intel(R) Core (TM) i7. The experimental design was a complete randomized design. Two-way analysis of variance (ANOVA) with postharvest treatments, storage time, and shelf-life as factors were done. Duncan's multiple-range test ($p < 0.05$) was used for comparing the means. The study of sensory data by one way analysis of variance (ANOVA) examines globally the difference in attributes between treatments at the 0.05 alpha level, with a subsequent multiple comparisons with Bonferroni test ($p < 0.05$). Kruskal-Wallis non-parametric ANOVA was performed to test the significant differences between the mean ranks among the four treatments, in four removals (2, 4, 6 and 8 months), and performed also a pairwise comparations to observe the differences. The panelists' questionnaire contains a several variables, which also agree with Homogeneity analysis, namely HOMALS, which it is a reduction method. This method makes complicated multivariate data accessible by displaying their main regularities in a scatter plots graphs that can easily be interpreted since they show the relationship between the categorical variables.

Receiver Operating Characteristic (ROC) analysis has become a popular method for assessing the accuracy of medical diagnostic systems. The most desirable property of ROC analysis is that the accuracy indices derived from this technique are not distorted by fluctuations caused using decision criteria. The concept of an ROC analysis is based on the notion of a decision variable. In this study, the treatment variable was considered in binary terms (1 = LG 1.25 % 0 = others; 1 = 2.5 % 0 = others; 1 = 1-MCP 0 = others and finally 1 = Control 0 = others) for the application of this procedure. This classification method should be taken with caution, as it is presented only as an accessory and complementary analysis tool.

## 3. Results and discussion

### 3.1. Physiological disorders

Superficial scald symptoms were present in control fruit just after 4 months of storage plus 7 d shelf-life and maintained a high incidence in this fruit until the end of the experiment. Scald symptoms appeared in 1-MCP-treated and in LG 1.25 % coated pears only after 8 months of storage and the subsequent shelf-life (Fig. 1 A), much lower than control.
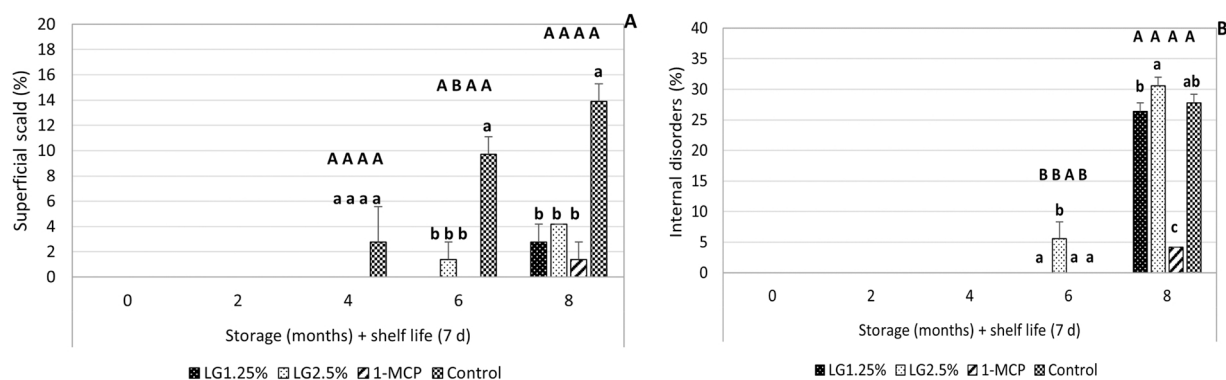
**Fig. 1.** Superficial scald (A) and internal disorders (B) of 'Rocha' pear fruit treated with 1-MCP (312 nL L$^{-1}$), nanoemulsions coatings [sodium alginate 2 % (w/w) + lemongrass essential oil 1.25 % (w/w) (LG 1.25 %) or sodium alginate 2 % (w/w) + lemongrass essential oil 2.5% (w/w) (LG 2.5 %)] and control (fruit as it comes from the field), after 0, 2, 4, 6 and 8 months of cold storage plus 7 d shelf-life. Bars with the same lower case in the same sampling date, and the same bar-treatment with the same upper case are not significantly different by Duncan's multiple range test, at $p < 0.05$.
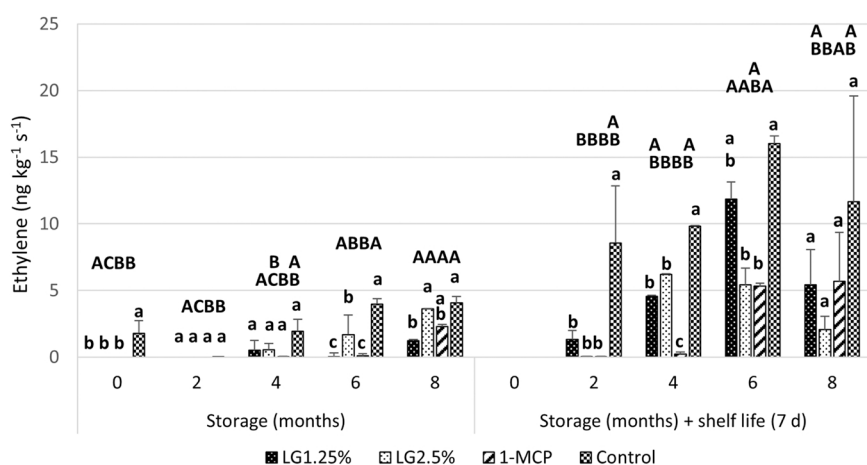


**Fig. 2.** Ethylene production of 'Rocha' pear treated with 1-MCP (312 nL L$^{-1}$), coatings with nanoemulsions [sodium alginate 2 % (w/w) + lemongrass essential oil 1.25 % (w/w) (LG 1.25 %) or sodium alginate 2 % (w/w) + lemongrass essential oil 2.5 % (w/w) (LG 2.5 %)] and control (fruit as it comes from the field), just after post-harvest treatment and after 2, 4, 6 and 8 months of cold storage and plus 7d shelf-life. Bars with the same lower case in the same sampling date, and the same bar-treatment with the same upper case are not significantly different by Duncan's multiple range test, at $p < 0.05$.

The effectiveness of 1-MCP in preventing or reducing superficial scald in 'Rocha' and other pear cultivars has been demonstrated (Argenta et al., 2003; Ekman et al., 2004; Gago et al., 2015; Isidoro and Almeida, 2006; Kubo et al., 2003). Recently, LG 1.25 % coated had demonstrated effectiveness in preventing scald symptoms up to 6 months of cold storage (Gago et al., 2020). The results presented herein suggest that the effectiveness of LG, particularly LG 1.25 %, is similar to that of 1-MCP against superficial scald in 'Rocha' pear.

The first symptoms of internal browning (IB) appeared after 6 months storage in pears coated with LG 2.5 % nanoemulsions (Fig. 1B). From 6–8 months storage, internal browning symptoms developed, reaching high incidence in control and LG-coated fruit. 1-MCP treated fruit showed slight incidence of internal browning in 'Rocha' pear. Effectively and according to Silva et al. (2010), 1-MCP reduced the incidence of IB during long-term storage at low temperature.

### 3.2. Ethylene production

Throughout cold storage, as climacteric fruit, control pears showed an increase in ethylene production (Fig. 2). Initially, ethylene production was present only in control fruit and the 1-MCP treatment was efficient in inhibiting ethylene production, as expected (Ekman et al., 2004; Lwin et al., 2021; Saquet, 2019; Xie et al., 2014). Interestingly, nanocoatings were also able to inhibit ethylene production as reported for other fruit (Guerreiro et al., 2017). Through storage there was a slight increase in ethylene which was higher in control after 6 months. In the other treatments the higher ethylene production occurred at the end of cold storage and with slightly lower values in fruit treated with 1-MCP

and LG 1.25 %.

During shelf-life, control fruit still increased ethylene production just after 2 months of cold storage. The ethylene peak occurred in shelf-life after six months (Fig. 2). Ethylene production in LG fruit, particularly in LG 1.25 % occurred from 4 months on, what may explain pear ripening during shelf-life as compared to 1-MCP treated fruit. After 8 months the ethylene production values were similar in all treatments.

The reduction of ethylene in 1-MCP treated pear was expected once 1-MCP is an effective inhibitor of ethylene action (Lurie and Watkins, 2012; Sisler and Serek, 1997). The lower ethylene production in LG coated pears as compared to control can be attributed to the reduction of gas exchange, creating an internal modified atmosphere, as already reported for alginate base edible coatings (Narsaiah et al., 2015; Tabassum and Khan, 2020).

### 3.3. Ripening behavior through storage and shelf-life

Initially, the color parameters (Table 1) did not show significant differences among treatments, but over the period of cold storage and the subsequent shelf-life there was a tendency of the L* values to rise and the hue values to decrease, with some differences among treatments. During storage, control fruit showed the highest values of L*, however, after shelf-life and particularly after 8 months of cold storage the control fruit had the lowest L* values, which may be due to the darkening of the fruit skin caused by advanced ripening.

1-MCP treated fruit maintained the highest hue values during cold storage (after 4 months) and the control fruit the lowest. This reflects the maintenance of green flesh color in fruit treated with 1-MCP and the

**Table 1**

Quality parameters (colour (L* and Hue), soluble solids content (SSC), titratable acidity and electrolytic leakage (EL)) of 'Rocha' pear treated with 1-MCP (312 nL L$^{-1}$), nanoemulsions coatings [sodium alginate 2% (w/w) + lemongrass essential oil 1.25% (w/w) (LG 1.25%) or sodium alginate 2% (w/w) + lemongrass essential oil 2.5% (w/w) (LG 2.5%)] and control (fruit as it comes from the field), just after postharvest treatment and after 2, 4, 6 and 8 months of cold storage and plus 7 d shelf-life. Values are mean ± standard error (SE). Values followed by the same lower-case letter, in the same column and parameter, and by the same upper case letter in the same row within storage dates or within shelf-life are not significantly different by Duncan's multiple range test, at $p < 0.05$.

| Parameter | Treatment | Storage (months) | | | | | Storage (months) + shelf-life (7 d) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 2 | 4 | 6 | 8 | 0 | 2 | 4 | 6 | 8 |
| L* | LG1.25% | 65.8 ± 0.3 aC | 67.22 ± 0.2 aC | 72.9 ± 0.4 abAB | 72.0 ± 0.6 abB | 74.2 ± 0.2 aA | 65.4 ± 0.8 aC | 66.0 ± 0.7 cC | 71.4 ± 0.0 bB | 72.7 ± 0.6 aAB | 73.9 ± 0.3 abA |
| | LG2.5% | 65.4 ± 0.2 aC | 66.8 ± 0.3 cC | 71.3 ± 0.3 bB | 71.0 ± 1.1 bB | 73.7 ± 0.2 aA | 65.7 ± 0.4 aC | 69.5 ± 0.9 bB | 72.2 ± 1.0 bA | 73.3 ± 0.5 aA | 71.8 ± 1.2 cA |
| | 1-MCP | 65.3 ± 0.2 aC | 68.9 ± 0.7 bB | 72.6 ± 0.7 abA | 70.3 ± 0.6 bB | 74.0 ± 0.7 aA | 65.8 ± 0.3 aC | 73.8 ± 0.2 aA | 74.5 ± 0.6 aA | 70.5 ± 1.1 bB | 74.8 ± 0.3 aA |
| | Control | 66.4 ± 0.6 aC | 72.7 ± 1.1 aB | 74.3 ± 0.4 aBC | 72.7 ± 0.9 aB | 74.5 ± 0.7 aA | 65.8 ± 1.4 aC | 65.5 ± 1.0 cC | 74.3 ± 0.1 aA | 70.1 ± 0.6 bB | 72.8 ± 0.5 bcA |
| Hue | LG1.25% | 110.4 ± 0.2 aA | 106.8 ± 0.2 aB | 97.1 ± 0.2 aC | 91.2 ± 1.0 abD | 88.8 ± 0.9 bE | 105.2 ± 0.5 aA | 103.1 ± 0.5 abA | 95.0 ± 0.5 aB | 92.0 ± 0.2 aB | 90.9 ± 0.4 aB |
| | LG2.5% | 110.7 ± 0.2 aA | 106.8 ± 0.9 aB | 95.2 ± 0.6 bC | 90.3 ± 0.9 bcD | 89.5 ± 0.6 bD | 108.9 ± 0.5 aA | 101.1 ± 0.5 bB | 90.9 ± 0.7 bC | 92.3 ± 0.4 aC | 90.5 ± 0.7 aC |
| | 1-MCP | 108.9 ± 0.5 bA | 104.6 ± 0.6 bB | 97.9 ± 0.7 aC | 93.1 ± 1.0 dD | 91.7 ± 0.4 aD | 108.9 ± 0.3 aA | 91.9 ± 0.4 cC | 94.0 ± 0.6 aB | 87.5 ± 1.1 bD | 88.4 ± 0.4 bD |
| | Control | 111.1 ± 0.3 aA | 100.5 ± 0.5 cB | 92.0 ± 0.1 cC | 88.6 ± 0.9 cD | 86.7 ± 0.6 cE | 110.2 ± 0.9 aA | 104.0 ± 1.4 aB | 86.8 ± 0.4 cC | 83.8 ± 0.3 cD | 86.0 ± 0.6 cC |
| SSC (%) | LG1.25% | 11.1 ± 0.4 aB | 12.8 ± 0.4 aA | 13.1 ± 0.1 aA | 14.3 ± 0.5 aA | 14.2 ± 0.6 aA | 12.6 ± 0.2 abC | 13.2 ± 0.3 aBC | 13.8 ± 0.1 aAB | 13.5 ± 0.2 bAB | 14.0 ± 0.2 aA |
| | LG2.5% | 11.6 ± 0.2 aD | 12.7 ± 0.0 abC | 12.6 ± 0.1 bBC | 13.3 ± 0.2 aAB | 13.8 ± 0.2 aA | 12.9 ± 0.1 aC | 12.8 ± 0.3 aC | 13.6 ± 0.2 aBC | 14.7 ± 0.5 aA | 13.9 ± 0.3 aAB |
| | 1-MCP | 11.7 ± 0.3 aB | 13.5 ± 0.5 aAB | 13.4 ± 0.2 aAB | 12.7 ± 1.2 aAB | 14.1 ± 0.1 aA | 12.2 ± 0.0 bD | 13.4 ± 0.1 aBC | 13.2 ± 0.2 aC | 14.3 ± 0.3 abA | 14.0 ± 0.2 aAB |
| | Control | 11.1 ± 0.3 aC | 12.6 ± 0.2 aB | 13.0 ± 0.2 aAB | 13.2 ± 0.3 aAB | 13.7 ± 0.3 aA | 12.9 ± 0.2 aB | 13.1 ± 0.3 aB | 13.4 ± 0.2 aAB | 14.0 ± 0.1 abA | 13.1 ± 0.2 bB |
| TA (g L$^{-1}$) | LG1.25% | 0.15 ± 0.0 aA | 0.15 ± 0.0 aA | 0.13 ± 0.0 abA | 0.13 ± 0.0 aA | 0.08 ± 0.0 aB | 0.15 ± 0.0 aA | 0.14 ± 0.0 abA | 0.09 ± 0.0 bB | 0.09 ± 0.0 bB | 0.10 ± 0.0 aB |
| | LG2.5% | 0.14 ± 0.0 aA | 0.14 ± 0.0 aA | 0.12 ± 0.0 abAB | 0.11 ± 0.0 aAB | 0.09 ± 0.0 aB | 0.15 ± 0.0 aC | 0.13 ± 0.0 abC | 0.10 ± 0.0 bB | 0.10 ± 0.0 bB | 0.09 ± 0.0 aB |
| | 1-MCP | 0.15 ± 0.0 aA | 0.13 ± 0.0 aA | 0.14 ± 0.0 aA | 0.12 ± 0.0 aAB | 0.10 ± 0.0 aB | 0.16 ± 0.0 aA | 0.15 ± 0.0 aAB | 0.12 ± 0.0 aAB | 0.12 ± 0.0 aAB | 0.10 ± 0.0 aC |
| | Control | 0.14 ± 0.0 aA | 0.13 ± 0.0 aAB | 0.11 ± 0.0 bAB | 0.12 ± 0.0 aAB | 0.10 ± 0.0 aB | 0.14 ± 0.0 aA | 0.12 ± 0.0 bA | 0.10 ± 0.0 bCD | 0.11 ± 0.0 abBC | 0.09 ± 0.0 aD |
| EL (%) | LG1.25% | 42.4 ± 1.8 aA | 36.1 ± 2.6 aB | 30.4 ± 1.3 bBC | 34.5 ± 1.1 bC | 39.8 ± 1.3 bAB | 51.4 ± 1.9 aA | 44.0 ± 1.4 bcBC | 35.1 ± 2.2 bcD | 40.1 ± 2.3 bCD | 48.6 ± 2.3 bAB |
| | LG2.5% | 39.8 ± 0.5 aA | 39.2 ± 3.1 aAB | 38.2 ± 1.1 aAB | 34.8 ± 1.6 bB | 37.6 ± 0.4 bcAB | 50.8 ± 1.0 aA | 45.4 ± 0.2 bBC | 41.1 ± 0.9 bD | 41.2 ± 3.0 bD | 49.8 ± 0.7 bAB |
| | 1-MCP | 41.4 ± 4.3 aA | 37.6 ± 3.3 aAB | 29.4 ± 1.5 bAB | 34.5 ± 0.7 bAB | 32.2 ± 1.7 cB | 52.2 ± 1.5 aA | 41.2 ± 2.7 cB | 31.5 ± 2.4 cC | 42.3 ± 2.2 bB | 49.0 ± 1.6 bA |
| | Control | 42.4 ± 0.7 aBC | 39.9 ± 1.2 aBC | 39.1 ± 1.5 aC | 43.4 ± 1.0 aB | 54.0 ± 0.7 aA | 51.2 ± 3.1 aB | 55.4 ± 1.7 aAB | 57.7 ± 4.8 aAB | 57.5 ± 1.1 aAB | 63.3 ± 2.4 aA |

progressive yellowing of control fruit during the storage period. According to Fonseca et al. (2020) the decrease of hue angle values reflects the yellowing of the skin through 'Rocha' pear ripening.

SSC tended to increase over storage and subsequent shelf-life in all fruit, with small or no differences among treatments (Table 1). At the end of the experiment, all fruit reflected the advance of ripening, with the titratable acidity values decreasing during storage and ensuing shelf-life in all fruit (Table 1). However, pears treated with 1-MCP were less ripe, maintaining higher values of acidity and lower SSC.

The changes in electrolyte leakage (EL) can be used as indicator of cellular membrane integrity during storage and shelf-life, and usually increase gradually during ripening (Antunes and Sfakiotakis, 2008; Wade, 1995).

However, in our study, EL of pear peel decreased in the first 2 months and then slightly increased (Table 1). This variation in EL probably reflects structural changes and/or the reorganization of membrane components in response to cold and a slowdown in ripening, particularly in fruit treated with 1-MCP and LG-coatings, since control fruit presented

the highest EL values after 4 months until the end of cold storage. Wang et al. (2019), also suggest that membrane lipid metabolism plays an important role in cold stress response due to increase in EL and MDA as other related compounds, in chilled blueberries.

In shelf-life, where fruit were not subjected to cold, the EL values were similar in all treatments, except control which had the highest EL values. It seems that the combined action of low temperatures and treatments is necessary to slow down the ripening and maintain the structure and permeability of membranes. In the shelf-life periods following cold storage, 1-MCP treated fruit and LG-coated fruit showed lower EL values than the control, although after 6 months of storage the EL values started to rise progressively. Similar behavior was reported for 'Branquilla' pears treated with 1-MCP (Larrigaudière et al., 2004), suggesting that 1-MCP and LG-coatings promote cell wall maintenance.

The firmness remained constant in 1-MCP treated fruit during 8 months of storage at 0 °C, but significant softening occurred in the other pears' treatments, without significant differences between LG treatments and lower firmness in control (Fig. 3 A). Postharvest treatments
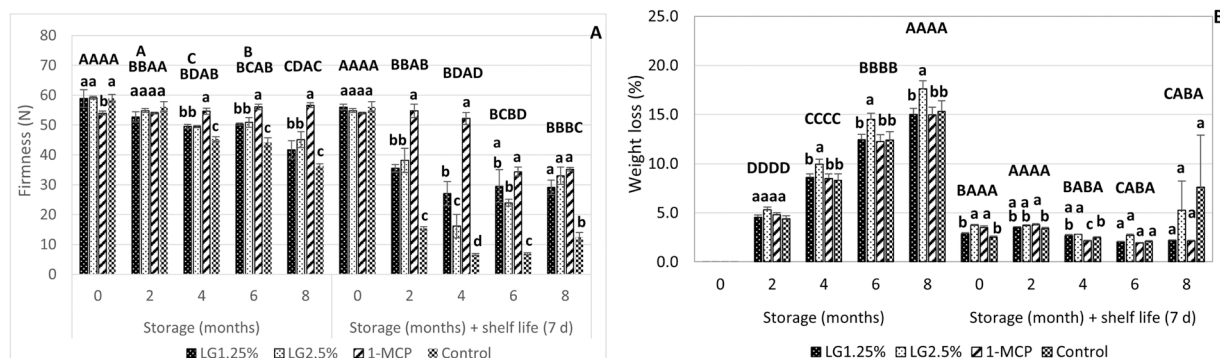
**Fig. 3.** Firmness (A) and weight loss (B) of 'Rocha' pear treated with 1-MCP (312 nL L$^{-1}$), nanoemulsions coatings [sodium alginate 2 % (w/w) + lemongrass essential oil 1.25 % (w/w) (LG 1.25 %) or sodium alginate 2 % (w/w) + lemongrass essential oil 2.5 % (w/w) (LG 2.5 %)] and control (fruit as it comes from the field). Firmness was measured after postharvest treatment and after 2, 4, 6 and 8 months of cold storage and plus 7 d shelf-life. The weight loss was calculated in the same fruit samples through storage, while for shelf-life was used the weight loss of the fruit that were removed from storage. Bars with the same lower case in the same sampling date, and the same bar-treatment with the same upper case are not significantly different by Duncan's multiple range test, at $p < 0.05$.
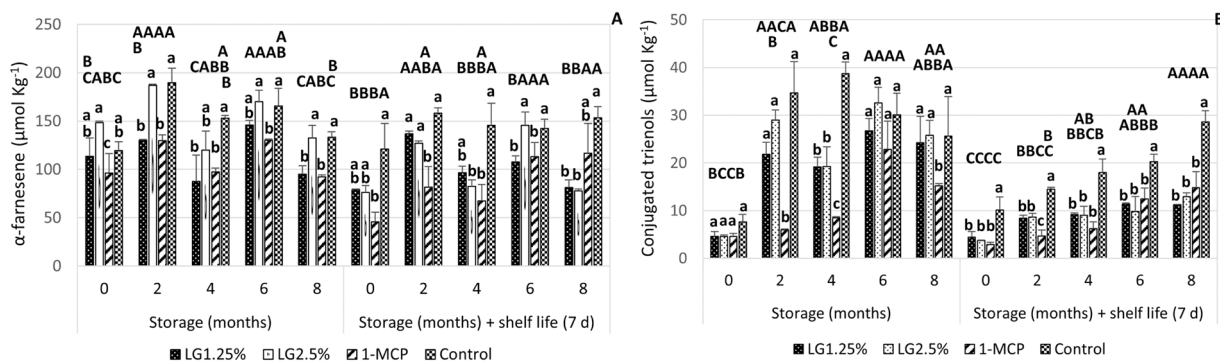
**Fig. 4.** α-farnesene (A) and conjugated trienols (B) of 'Rocha' pear treated with 1-MCP (312 nL L$^{-1}$), nanoemulsions coatings [sodium alginate 2 % (w/w) + lemongrass essential oil 1.25 % (w/w) (LG 1.25 %) or sodium alginate 2 % (w/w) + lemongrass essential oil 2.5 % (w/w) (LG 2.5 %)] and control (fruit as it comes from the field), just after postharvest treatment and after 2, 4, 6 and 8 months of cold storage and plus 7d shelf-life. Bars with the same lower case in the same sampling date, and the same bar-treatment with the same upper case are not significantly different by Duncan's multiple range test, at $p < 0.05$.

also affected the softening rate during subsequent self-life: 'Rocha' pear treated with 1-MCP and stored for 4 months did not soften after 7 d shelf-life contrarily to the other treatments; after 6 and 8 months of storage, all pears soften after 7 d in shelf-life, but LG coated fruit showed better eating-ripe firmness (≈24 N; Guerra et al., 2012) than 1-MCP-treated fruit, and control was overripe.

Weight loss of 'Rocha' pears is presented in Fig. 3B. Under the experimental conditions adopted, fruit coated with LG 2.5 % showed the highest weight loss during all storage period (≈18 %, at the end of storage), while the other treatments did not differ from each other (≈ 15 %, at the end of storage). Nevertheless, during shelf-life, although some differences were found among treatments, weight loss was less than 5 %, except at the end of the experiment.

### 3.4. α-farnesene, conjugated trienols, total phenols and antioxidant activity in pear peel

The most generally approved theory to explain scald development relates the appearance of the disorder to the production of α-farnesene and their oxidation into conjugated trienols (Farneti et al., 2015; Fonseca et al., 2020; Guerra et al., 2012; Mir et al., 1999; Rowan et al., 2001). Here, we found that α-farnesene and conjugated trienols contents were higher in control, followed by LG and 1-MCP treatments, particularly till 4 months (Fig. 4A, 4B), and more evident in conjugated trienols (Fig. 4B).

These findings agree with the lower scald values obtained in LG treated fruit and 1-MCP (Fig. 1A). After 6 and 8 months storage and shelf-life, LG treatments showed similar trienols with those of control, being those slightly lower in 1-MCP. This effect of 1-MCP is expected since it is an effective inhibitor of ethylene action, reducing scald by inhibiting α-farnesene synthesis and its oxidation product, the

conjugated trienols (Gapper et al., 2006; Xie et al., 2014). According to the observed incidence of superficial scald, this finding is consistent with the correlation between conjugated trienols and superficial scald demonstrated in previous studies (Isidoro and Almeida, 2006; Meir and Bramlage, 1988; Rowan et al., 2001).

Another approach of an ethylene-independent regulation of scald has also been studied, since treatment with diphenylamine, a synthetic antioxidant, controls scald symptoms development in fruit, without inhibiting their ethylene biosynthesis (Giné-Bordonaba et al., 2020; Lindo-García et al., 2021). However, pear scald symptoms in the different treatments do not seem to be related to the antioxidant content of the peel, since they did not show significant differences in antioxidant content among treatments through storage and shelf-life (Table 2). This lack of a consistent pattern in peel antioxidant content during storage, has been observed previously for 1-MCP-treated 'Rocha' pear (Gago et al., 2015; Silva et al., 2010).

Although having an increase through storage, generally there was no evident significant differences among treatments in total phenolics content (Table 2).

### 3.5. Fatty acids content in pear peel

There were four major pear peel FAs identified, including two saturated FAs (SFA); palmitic acid (16:0) and stearic acid (18:0) and two unsaturated FAs (UFA); oleic acid (18:1) and linoleic acid (18:2) (Fig. 5A, B, C, D). The content (%) of FAs identified decreased for all pear treatments in storage and shelf-life period, except linoleic acid content which increased in all treatments but decreased in control fruit between 6 and 8 months of cold storage (Fig. 5A, B, C, D). Also, the ratio UFA/SFA increased consistently in all pear's postharvest treatments under cold storage and subsequent shelf-life (Fig. 5E). Between 6 and 8 months of

**Table 2**

Phenolic content and antioxidant activity in the peel of 'Rocha' pear treated with 1-MCP (312 nL L$^{-1}$), nanoemulsions coatings [sodium alginate 2% (w/w) + lemongrass essential oil 1.25% (w/w) (LG 1.25%) or sodium alginate 2% (w/w) + lemongrass essential oil 2.5% (w/w) (LG 2.5%)] and control (fruit as it comes from the field), just after postharvest treatment and after 2, 4, 6 and 8 months of cold storage and plus 7 d shelf-life. Values are mean ± SE. Values followed by the same lower-case letter, in the same column and parameter, and by the same upper-case letter in the same row within storage dates or within shelf-life are not significantly different by Duncan's multiple range test, at $p < 0.05$.

| Parameter | Treatment | Storage (months) | | | | | Storage (months) + shelf life (7 d) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 2 | 4 | 6 | 8 | 0 | 2 | 4 | 6 | 8 |
| Phenolic content (mol TE kg$^{-1}$) | LG1.25% | 3.82 ± 0.11 bC | 4.27 ± 0.28 abC | 4.31 ± 0.24 dC | 6.16 ± 0.10 aB | 7.60 ± 0.34 aA | 4.12 ± 0.27 aC | 6.35 ± 0.03 aB | 6.33 ± 0.12 aB | 6.80 ± 0.36 aAB | 7.17 ± 0.15 bA |
| | LG2.5% | 3.31 ± 0.20 bD | 4.10 ± 0.17 bC | 5.84 ± 0.04 bB | 4.28 ± 0.03 cC | 7.54 ± 0.25 aA | 5.25 ± 0.68 aB | 5.13 ± 0.10 dB | 5.86 ± 0.09 bB | 4.91 ± 0.14 cC | 7.61 ± 0.14 abA |
| | 1-MCP | 3.67 ± 0.20 bC | 5.17 ± 0.45 aB | 5.18 ± 0.11 cB | 5.81 ± 0.01 bB | 7.43 ± 0.25 aA | 4.99 ± 0.26 aC | 5.42 ± 0.13 cC | 6.52 ± 0.08 aB | 6.29 ± 0.28 abB | 7.68 ± 0.11 aA |
| | Control | 4.46 ± 0.06 aC | 3.91 ± 0.02 bD | 6.65 ± 0.15 aA | 5.66 ± 0.09 bB | 6.88 ± 0.23 aA | 4.58 ± 0.55 aC | 5.88 ± 0.03 bB | 5.54 ± 0.02 aB | 5.49 ± 0.32 bcBC | 7.56 ± 0.14 abA |
| Antioxidant activity (mg GAE kg$^{-1}$) | LG1.25% | 34.6 ± 3.7 aA | 28.4 ± 1.0 abA | 26.6 ± 1.5 aA | 31.1 ± 8.8 aA | 35.5 ± 5.3 aA | 33.2 ± 2.9 aA | 36.8 ± 5.7 aA | 32.2 ± 1.7 aA | 27.2 ± 0.6 bA | 30.9 ± 4.9 aA |
| | LG2.5% | 30.9 ± 2.3 aA | 30.3 ± 0.5 aA | 31.6 ± 1.7 aA | 28.4 ± 1.5 aA | 32.5 ± 5.1 aA | 36.6 ± 5.3 aA | 30.8 ± 1.3 aA | 33.6 ± 2.4 aA | 33.8 ± 2.4 aA | 31.2 ± 3.9 aA |
| | 1-MCP | 32.6 ± 0.9 aA | 29.7 ± 0.5 abA | 30.2 ± 2.8 aA | 32.0 ± 3.1 aA | 33.2 ± 5.2 aA | 34.1 ± 2.0 aA | 37.2 ± 1.7 aA | 34.7 ± 4.2 aA | 33.8 ± 2.9 aA | 34.0 ± 4.1 aA |
| | Control | 32.1 ± 1.8 aA | 27.6 ± 0.7 bA | 36.1 ± 5.3 aA | 30.2 ± 2,6 aA | 33.5 ± 5.1 aA | 30.6 ± 2.4 aA | 32.1 ± 0.1 aA | 332.6 ± 2.0 aA | 28.8 ± 0.4 abA | 32.8 ± 4.6 aA |
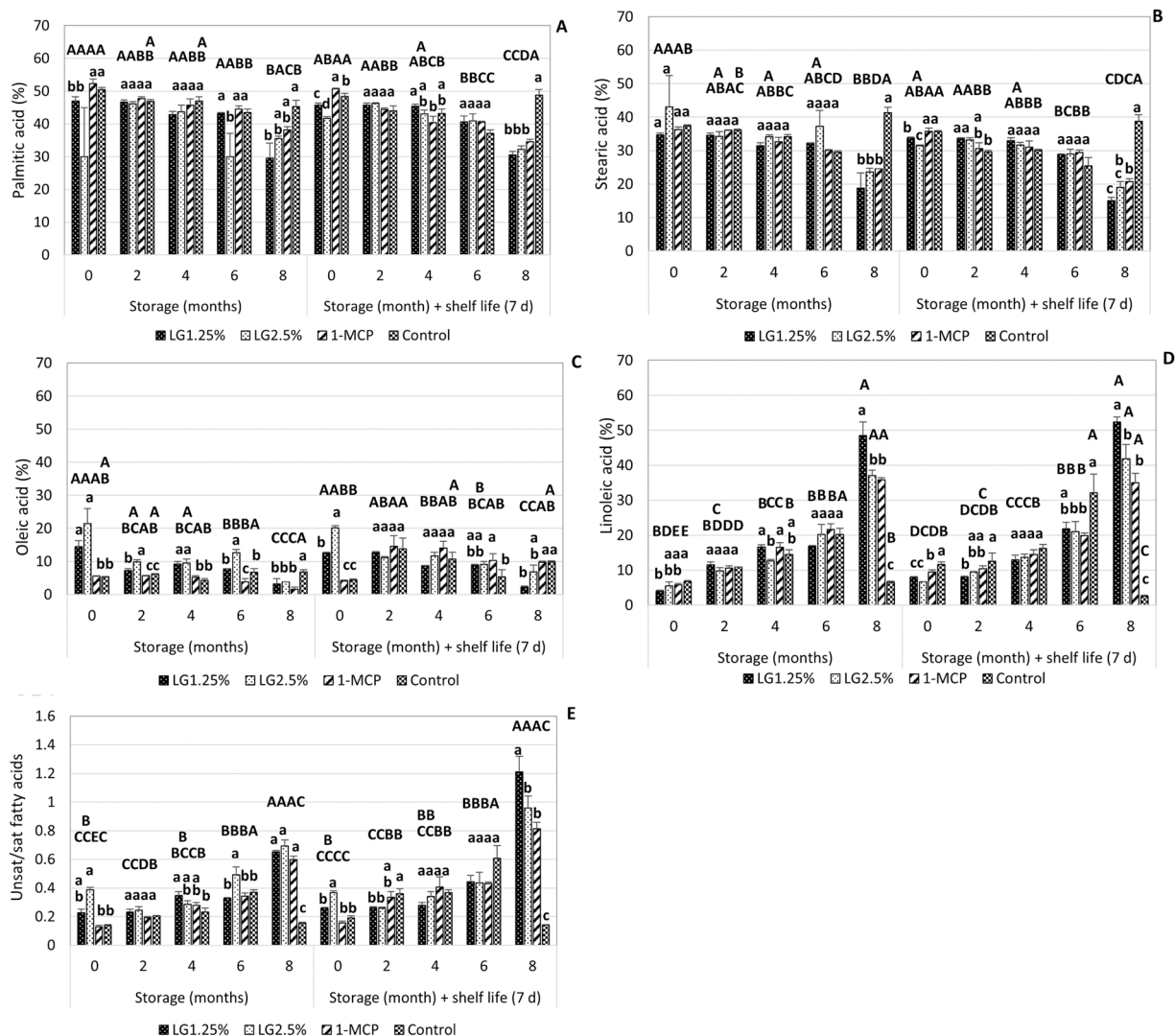
**Fig. 5.** Palmitic acid (A), stearic acid (B), oleic acid (C), linoleic acid (D) and ratio unsaturated/saturated fatty acids (E) in the peel of 'Rocha' pear treated with 1-MCP (312 nL L$^{-1}$), nanoemulsions coatings [sodium alginate 2 % (w/w) + lemongrass essential oil 1.25 % (w/w) (LG1.25 %) or sodium alginate 2 % (w/w) + lemongrass essential oil 2.5% (w/w) (LG 2.5 %)] and control (fruit as it comes from the field), just after postharvest treatment and after 2, 4, 6 and 8 months of cold storage and plus 7 d shelf-life. Bars with the same lower case in the same sampling date, and the same bar-treatment with the same upper case are not significantly different by Duncan's multiple range test, at $p < 0.05$.

storage and in subsequent shelf-life, the increase in UFA/SFA occurred for all treatments, except control (Fig. 5E). In this treatment the highest symptoms of superficial scald coincided with the lowest UFA/SFA. Cao et al. (2011) reported that the decrease of lipid unsaturation is associated with high levels of CI in loquat fruit. Cheng et al. (2015) found that increased unsaturated lipid content and membrane fluidity in 1-MCP treated fruit led to enhanced tolerance of pear fruit to chilling stress. In our work, the contents of linoleic acid and UFA/SFA were higher in all treated pears than in control (Fig. 5D, E). These results suggest that 1-MCP and the coatings tested might help in maintaining the normal function of membranes and reduced CI in peel pear fruit during cold storage.

### 3.6. Microbial evolution

The counts of aerobic mesophilic bacteria increased in all treatments until 4 months of cold storage, with 1-MCP and coated with LG 2.5 % fruit showing the lowest bacterial growth and control the highest (Table 3). During shelf-life, the growth of aerobic mesophilic bacteria in fruit peel, was similar among treatments, only at end of the experiment

control fruit showed higher counts of those microorganisms in comparison to the other treatments. No growth of psychrophilic aerobic bacteria was observed in any treatment.

Yeasts and molds population was very low in all treatments through storage and shelf-life (Table 3). Only at the beginning of the experiment was observed some yeast and mold growing, except in 1-MCP treatment.

Nevertheless, in all treatments, microbial counts were below the acceptance limit for the consumption of fruit products (6 Log CFU g$^{-1}$) (Bierhals et al., 2011).
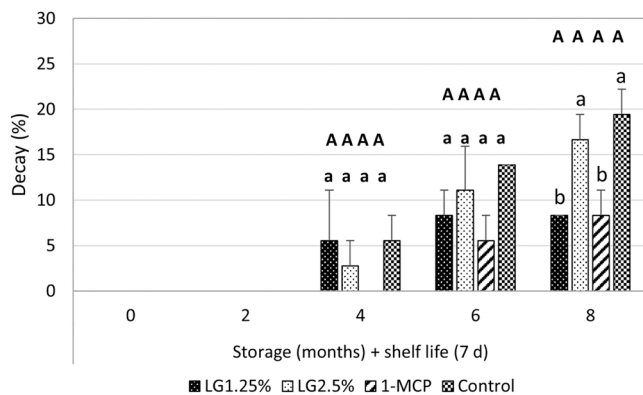
Decayed fruits were discarded as rots appeared, what started after 4 months storage in all treatments except in 1-MCP (Fig. 6). After 6 months fruit of all treatments showed some decay, and at the end of the experiment control and LG 2.5 % showed significantly higher percentage of fruit decay than LG 1.25 % and 1-MCP.

### 3.7. Sensory quality

For the variables analysed it was observed that fruit appearance, pulp appearance, aroma, and sweetness the results indicate significant differences among the four treatments ($p < 0.05$). In a subsequent step,

**Table 3**

Mesophilic bacteria and yeast and molds population developed in the peel of 'Rocha' pear treated with 1-MCP (312 nL L⁻¹), nanoemulsions coatings [sodium alginate 2% (w/w) + lemongrass essential oil 1.25% (w/w) (LG 1.25%) or sodium alginate 2% (w/w) + lemongrass essential oil 2.5% (w/w) (LG 2.5%)] and control (fruit as it comes from the field), just after postharvest treatment and after 2, 4, 6 and 8 months of cold storage and plus 7 d shelf-life. Values are mean ± SE. Values followed by the same lower-case letter, in the same column and parameter, and by the same upper-case letter in the same row within storage dates or within shelf-life are not significantly different by Duncan's multiple range test, at $p < 0.05$.

| Parameter | Treatment | Storage (months) 0 | 2 | 4 | 6 | 8 | Storage (months) + shelf-life (7 d) 0 | 2 | 4 | 6 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mesophilic (Log CFU g⁻¹) | LG1.25% | 1.5 ± 0.1 aC | 2.0 ± 0.6 aC | 3.0 ± 0.0 aC | 3.3 ± 0.2 abAB | 0.9 ± 0.1 abB | 1.9 ± 0.1 aA | 2.9 ± 0.1 aC | 3.6 ± 0.1 cC | 2.2 ± 0.2 bB | 2.1 ± 0.6 abA |
| | LG2.5% | 0.8 ± 0.4 aC | 0.6 ± 0.6 aC | 3.1 ± 0.0 cC | 3.0 ± 0.1 bB | 0.7 ± 0.1 bB | 1.1 ± 0.6 aA | 2.6 ± 0.0 aC | 3.6 ± 0.1 bB | 1.9 ± 0.3 aA | 2.4 ± 0.1 cA |
| | 1-MCP | 1.0 ± 0.5 aC | 1.3 ± 0.6 bB | 2.8 ± 0.3 bB | 2.1 ± 0.0 abA | 1.0 ± 0.5 aB | 1.1 ± 0.6 aA | 2.6 ± 0.1 aC | 3.6 ± 0.1 aA | 1.9 ± 0.3 aA | 2.4 ± 0.1 aA |
| | Control | 1.6 ± 0.0 aC | 2.0 ± 0.6 aB | 4.1 ± 0.0 aBC | 3.5 ± 0.0 aBC | 1.1 ± 0.4 aB | 1.9 ± 0.1 aA | 2.6 ± 0.1 cC | 3.6 ± 0.1 bB | 2.2 ± 0.1 bB | 3.1 ± 0.1 bcA |
| Yeasts and molds (Log CFU g⁻¹) | LG1.25% | 1.1 ± 0.7 aA | 0.0 ± 0.1 aB | 0.0 ± 0.0 aB | 0.0 ± 0.0 aC | 0.0 ± 0.0 abD | 1.9 ± 0.1 bE | 1.9 ± 0.1 aA | 0.0 ± 0.0 abA | 0.0 ± 0.0 aB | 0.4 ± 0.4 aB |
| | LG2.5% | 1.5 ± 0.9 aA | 0.8 ± 0.1 aA | 0.0 ± 0.0 aB | 0.0 ± 0.4 bC | 1.0 ± 0.0 bcD | 1.1 ± 0.0 bD | 1.7 ± 0.2 aA | 0.0 ± 0.0 bB | 0.0 ± 0.0 bC | 0.0 ± 0.0 aC |
| | 1-MCP | 0.0 ± 0.0 bA | 0.4 ± 0 aD | 0.0 ± 0.0 aB | 0.0 ± 0.4 aC | 0.3 ± 0.3 dD | 0.0 ± 0.0 aD | 0.8 ± 0.4 aD | 0.0 ± 0.0 aA | 0.0 ± 0.0 bD | 0.3 ± 0.3 bD |
| | Control | 1.8 ± 1.1 aA | 1.0 ± 0.1 aA | 0.0 ± 0.0 cB | 0.0 ± 0 cC | 0.0 ± 0.0 cD | 1.9 ± 0.1 cE | 2.1 ± 0.0 aB | 0.0 ± 0.0 cC | 0.0 ± 0.0 cD | 0.0 ± 0.0 cC |



**Fig. 6.** Percentage of decay in 'Rocha' pear treated with 1-MCP (312 nL L⁻¹), nanoemulsions coatings [sodium alginate 2 % (w/w) + lemongrass essential oil 1.25 % (w/w) (LG 1.25 %) or sodium alginate 2 % (w/w) + lemongrass essential oil 2.5 % (w/w) (LG 2.5 %)] and control (fruit as it comes from the field), just after postharvest treatment and after 2, 4, 6 and 8 months of cold storage and plus 7 d shelf-life. Bars with the same lower case in the same sampling date, and the same bar-treatment with the same upper case are not significantly different by Duncan's multiple range test, at $p < 0.05$.

**Table 4**

Kruskal-Wallis test for fruit postharvest treatments at four taste panel evaluation removals (2, 4, 6, 8 months plus 7d shelf-life).

| Null Hypothesis | 2 Sig.[a,b] | 4 Sig.[a,b] | 6 Sig.[a,b] | 8 Sig.[a,b] |
|---|---|---|---|---|
| The distribution of **Fruit appearance** is the same across categories of treatment. | .400 | .271 | **.014** | **.016** |
| The distribution of **Pulp appearance** is the same across categories of treatment. | .199 | .750 | .107 | .601 |
| The distribution of **Aroma** is the same across categories of treatment. | .106 | **.035** | .797 | .916 |
| The distribution of **Texture** is the same across categories of treatment. | .986 | .511 | **.013** | .737 |
| The distribution of **Sweetness** is the same across categories of treatment. | **.001** | **.010** | .386 | .683 |
| The distribution of **Acidity** is the same across categories of T treatment. | .147 | .324 | .376 | .982 |
| The distribution of **Overall liking** is the same across categories of treatment. | **.015** | .106 | .174 | .994 |

the multiple comparisons with Bonferroni test, indicate among which treatments these differences can be found. The appearance of the whole fruit shows worst score in control than in the other treatments. The scores for the appearance of the pulp are also the worst for control treatment although this just significantly differs from 1-MCP. The score for sweetness reveals worse scores for 1- MCP and do not differ from the fruit with LG 1.25 % or LG 2.5 % treatment.

In order to understand the results of the sensory panel, a Kruskal-Wallis Test was conducted to examine the differences on tasters' variables according to the treatment taken and separated along time (four removals). Those are reported in Table 4. Significant differences for sweetness (p = 0.001) and overall liking (p = 0.015) were found among the four treatments at the 2nd month. For sweetness, 1-MCP reveals the minimum values and overall liking shows that Control is similar to LG 1.25 % but higher than the other treatments (1-MCP and LG 2.5 %). At this time, control fruit had a more yellow color (Table 1, < Hue) which may explain the panelists' assessment.

At the 4th month, significant differences for aroma (p = 0.035) and sweetness (p = 0.01) were found among treatments with control with superior values, what matches with fruit nore ripe. In the 6th month, significant differences in fruit appearance (p = 0.014) and texture (p = 0.013) were found among the four treatments, with control having inferior values. Finally, at the 8th month, significant differences in fruit
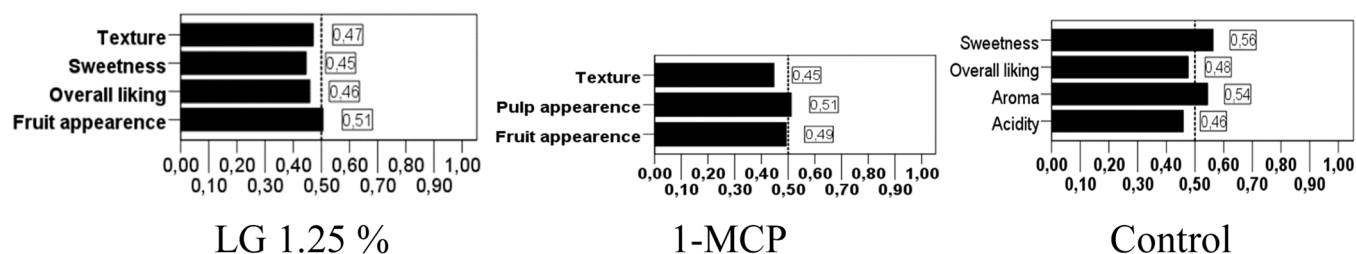
**Fig. 7.** Model quality for ROC curve analysis with tasters' variables according to treatment.
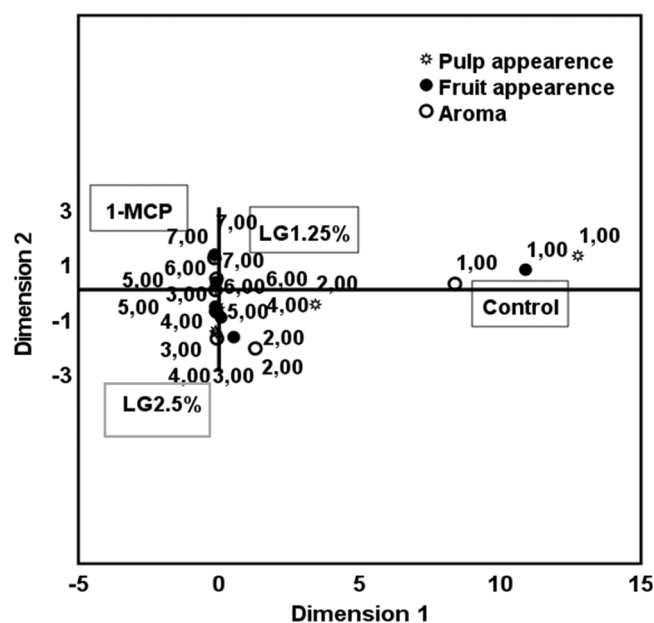


**Fig. 8.** HOMALS (homogeneity analysis) Biplot Graph for pulp appearance, fruit appearance and aroma variables according to treatment.

appearance (p = 0.016) were found among the four treatments with control with inferior values. Thus, in these last two sensory evaluation dates, superficial scald incidence (Fig. 1A) may have influenced the panelists' scores, as the fruit with the highest incidence of scald (control) were the worst classified in fruit appearance.

Performing a ROC analysis, were done models for each treatment and in LG 1.25 % fruit appearance was the variable that respond with better scores, in 1-MCP the main variable was pulp appearance and in Control sweetness and aroma provide the best scores. In LG 2.5 % there is no specific variable with important scores (Fig. 7).

It is known that taster evaluation of pulp and fruit appearance can be affected by the presence of symptoms of internal disorders and superficial scald, respectively. Also, the use of essential oils can modify natural aroma of fruit what is mentioned as one of the inconveniences for its use in edible coatings (Gago et al. 2019). However, the use of a Homals analysis for pulp fruit appearance and aroma showed that the lowest scores for those parameters are associated with the control and the highest scores were obtained in LG 1.25 % and 1-MCP treated fruit (Fig. 8), attesting the effectiveness of these treatments in maintaining fruit quality during storage and shelf-life.

## 4. Conclusion

LG nancoatings and 1-MCP reduced fruit color evolution and preserved better firmness than control but 1-MCP treated fruit showed reduced softening in shelf-life up to 4 months. Coatings and 1-MCP did not affect SSC and TA as compared to control. However, their influence

on sensory quality was positive, showing the LG 1.25 % and 1-MCP fruit higher scores in aroma and fruit appearance. These two treatments also did not show scald symptoms until 6 months of storage. LG 1.25 % treatment was similar in reducing scald symptoms with 1-MCP but had higher internal browning and rot at the end of storage. Nevertheless, control had the highest values.

Mainly due to the effect of 1-MCP in reducing scald latter in long term storage (8 months) as compared to LG treatments without significant effect on firmness, it can be considered that 1-MCP is the most efficient for preserving quality of 'Rocha' pear for late consume up to 8 months. For up to 6 months, LG 1.25 % nanocoating shall be considered since preserves quality and reduces physiological disorders without compromising the normal eating ripen process during shelf-life.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgements and funding

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