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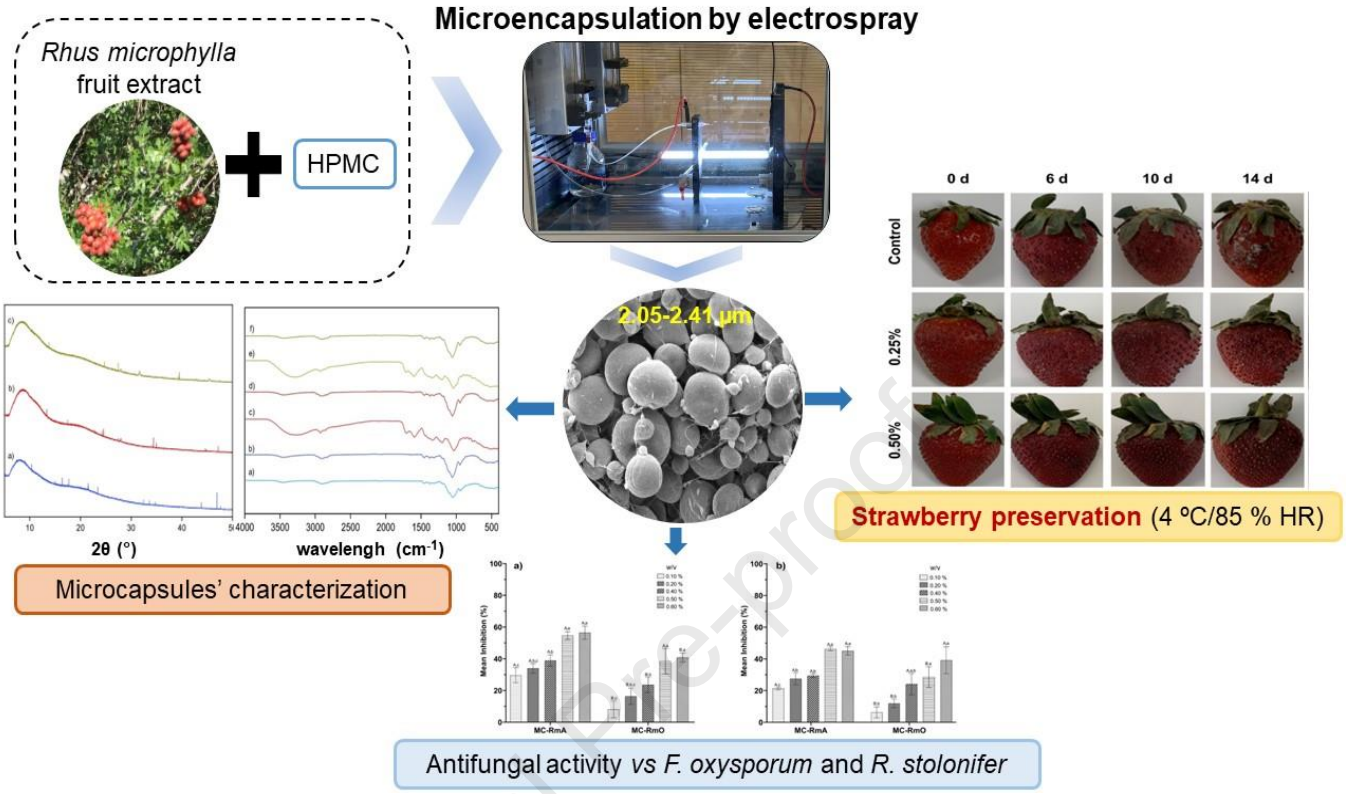
Graphical abstract



Electrosprayed hydroxypropyl methylcellulose microcapsules containing *Rhus microphylla* fruit extracts and their application in strawberry (*Fragaria* × *ananassa*) preservation

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Abstract

Encapsulation technology is used to incorporate a wide range of compounds, which is beneficial for protecting and improving the bioactivity of plant extracts. In this study, the objectives were to develop hydroxypropyl methylcellulose microcapsules containing two different extracts from *Rhus microphylla* fruit namely RmA (obtained by conventional agitation) and RmO (obtained by ohmic heating) using electrohydrodynamic processing. The microcapsules were then characterized through Scanning Electron Microscopy (SEM), ATR-Fourier transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), and thermogravimetric analysis (TGA). Additionally, the study aimed to evaluate their influence on strawberry quality. Spherical microcapsules with a particle size of 2.05-2.41 µm were successfully obtained, and FTIR analysis confirmed the proper incorporation of the extracts. The microcapsules containing RmA extract (MC-RmA) exhibited superior antioxidant and antifungal activities *in vitro*. Consequently, their efficacy in preserving the quality of strawberry fruits during storage at 4±1 °C and 85% relative humidity (RH) was evaluated at concentrations of 0.25% and 0.50% (w/v). After 14 days, the MC-RmA-treated fruits showed reduced weight loss, improved firmness, and unchanged color. Additionally, the gradual release of antifungal activity from MC-RmA suggests its potential as a novel solution to mitigate postharvest losses in strawberry fruits.

Keywords: *Rhus microphylla*; electrospraying; microcapsules; strawberry; shelf life

1. Introduction

Encapsulation is a process where a polymeric matrix surrounds another material, providing an enhancement and protection of its bioactivity, namely for compounds susceptible to degradation (Machado et al., 2019). It has been used in solids, liquids, and gaseous compounds (Papoutsis et al., 2018), mainly for the encapsulation of flavors (Dalmolin et al., 2016), aromas (Sanchez-Reinoso et al., 2017) and, recently, plant extracts (Pereira et al., 2018), demonstrating the versatility of this technology to be applied in various industries, such as: pharmaceutical, agri-food, among others. The size, shape, and functionality of the encapsulates strongly depend on the coating materials used, which can be mostly synthetic polymers (e.g., polycaprolactone and polyethylene glycol), gums (e.g., arabica gum and xanthan gum), proteins (e.g., zein and sodium caseinate) and polysaccharides (e.g., starch and maltodextrin) (Danafar, 2017; Sablania et al., 2018; Liu et al., 2019a). Also, the technique used has an important effect on the characteristics of the structures produced. Different techniques have been reported for the obtention of encapsulates, such as: spray-drying (Medina-Torres et al., 2019; Nunes et al., 2020), emulsification (Ishkeh et al., 2021), layer-by-layer (Pinheiro et al., 2015), coacervation (Ursache et al., 2018), and electrohydrodynamic processing (Bhushani et al., 2017), which differ in their mechanism and conditions of use, because there is no universal procedure that covers all core types and combinations of wall materials (Pellicer et al., 2019).

Electrohydrodynamic processing is a novel technique to produce capsules and fibers in micro and nanoscale and that can be used in two modes, electrospinning for the production of fibers and electrospraying to produce particles (Silva et al., 2022). Electrospraying presents some advantages comparing to others methods; for example, it is possible to encapsulate thermolabile compounds without affecting their integrity, it has a lower energy consumption, and it also provides greater homogeneity in the shape and particle size of the structures produced (Gómez-Mascaraque et al., 2017). During electrospraying process, the polymer solution containing the compounds of interest is atomized into a collector through a capillary employing a high electric field, where the electric energy promotes the atomization by a deformation of the droplet at the tip of the capillary nozzle, forming a structure known as Taylor cone (Silva et al., 2021). Proper atomization and formation of the Taylor cone is ensured by

employing electrical forces higher than the surface tension forces of the encapsulating solution (Nikoo et al., 2018). Electrospraying has been used for the microencapsulation of bioactive compounds such as anthocyanins (Atay et al., 2018), β-carotene (Gómez-Mascaraque et al., 2017), and curcumin (Gómez-Estaca et al., 2017), demonstrating its effectiveness to produce homogeneous structures using different wall materials and concentrations.

On the other hand, Mexico has a vast biodiversity of plants, being of great interest the plants that grow in arid and semi-arid zones, due to their phytochemical content (Vega-Ruiz et al., 2021), antioxidant (Santiago-Mora et al., 2017), antifungal (Charles-Rodríguez et al., 2020), and antiproliferative properties (López-Romero et al., 2018). Some extracts from *Larrea tridentata* and *Flourensia cernua* have shown noteworthy antifungal effects against *Rhizoctonia solani* (Castillo et al., 2010), while extracts from *Myrtillocactus geometrizans* showed interesting anti-hyperglycemic and anti-inflammatory activities i*n vitro* (Montiel-Sánchez et al., 2021). The genus *Rhus*, belonging to the family Anacardiaceae is composed of about 35 species (Yi et al., 2007). Extracts of some of these species have shown remarkable antioxidant (Bursal & Köksal, 2011; Wu et al., 2013; Liu et al., 2019b), antifungal (Jasso de Rodríguez et al., 2015; Charles-Rodríguez et al., 2020), and anticancer properties (Kim et al., 2019). Nonetheless, the use of crude plant extracts is limited because they tend to be highly susceptible to degradation under certain environmental conditions, such as extreme temperatures, humidity, and light (Muhoza et al., 2019; Al-Maqtari et al., 2021). In this context, encapsulation has proven to be an excellent tool to protect the integrity and activity of bioactive compounds (e.g., phenolic compounds) and plant extracts by the formation of micro- or nanocapsules that have been effective in extending the shelf life of some fruits, such as avocado (Correa-Pacheco et al., 2017), bell pepper (González-Saucedo et al., 2019), tomato (Gutiérrez-Molina et al., 2021), and strawberry (Hesami et al., 2021), among others.

Strawberry (*Fragaria* × *ananassa*) is a widely consumed and appreciated worldwide fruit for its flavor and multiple nutritional benefits (e.g., antioxidant, anti-aging, and anti-tumor properties), representing a valuable economic market, with Mexico being the third largest exporter of fresh strawberries (Müller et al., 2010; Morales-Mora et al., 2019; Li et al., 2020). However, strawberries are highly perishable during postharvest due to their sensitivity to injuries and fungal infections, which affect their quality (e.g., firmness, color, flavor),

thus causing important product losses (Chu et al., 2020). The application of new technologies, such as the development of encapsulates containing bioactive plant extracts through electrospraying, emerges as an alternative to improve the postharvest quality of fruits and vegetables. Therefore, the aims of the present study were to develop and characterize microcapsules containing *R. microphylla* fruit extracts using food-grade hydroxypropyl-methylcellulose (HPMC), by means of electrospraying, and to evaluate their effect on the postharvest decay of strawberries, as model fruit. It is noteworthy that this is the first report about the development of HPMC microcapsules through electrospray containing *R. microphylla* fruit extract and the study of their effect on strawberry preservation.

2. Materials and methods

2.1. Materials and reagents

Hydroxypropyl-methylcellulose (methoxyl 28-30 %, hydroxypropyl 7-12 %, viscosity 2 % aqueous solution, viscosity range of 40-60 mPa/s, at 20 °C, 90kDa, CAS 9004-65-3) was purchased from Alfa Aesar GmbH & Co KG (Karlsruhe, Germany). Folin-Ciocalteu reagent (FC), 2,2-diphenyl-1-picryl hydrazyl (DPPH, CAS 1898-66-4), 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt (ABTS, CAS 30931-67-0), 2,4,6-tri(2-pyridyl)-striazine (TPTZ, CAS 3682-35-7), iron (III) chloride hexa-hydrate (CAS 10025-77-1), ascorbic acid (AA, CAS 50-81-7), potassium persulfate ($K_2S_2O_8$, CAS 7727-21-1), sodium carbonate (Na_2CO_3, CAS 497-19-8) and gallic acid monohydrate (GA, CAS 5995-86-8) were purchased from Sigma-Aldrich (Steinheim, Germany). Absolute ethanol (>99.5%, CAS 64-17-5) was purchased from Honeywell (North Carolina, USA) and Sabouraud dextrose broth (SDB) was purchased from PanReac AppliChem (Darmstadt, Germany).

Strawberries (*Fragaria* x *ananassa*) var. Festival were obtained from local market (Saltillo, Coahuila, Mexico), twelve hours after harvesting and immediately transported to the laboratory of the Universidad Autónoma Agraria Antonio Narro (UAAAN). Fruit with uniform color and size, without physical damage or fungal infection were selected.

In this work, two hydroalcoholic *R. microphylla* fruit (Rm) extracts obtained by conventional agitation (RmA) and ohmic heating (RmO) were used for encapsulation tests, selected based on their outstanding antioxidant and antifungal capacities determined in previous work (Guía-García et al., 2021).

2.2. Preparation of polymer solutions containing Rm extracts and electrospraying conditions

For the selection of the most appropriate encapsulation conditions, different amounts of extracts and ethanol concentrations were tested (Table 1). The HPMC concentration (3.0 %, w/v) was selected based on a preliminary study (Silva et al., 2021). The work solutions were prepared by dissolving the specific amount of extract in the ethanol solution, then, HPMC was slowly added and mixed.

The equipment used for the electrospraying process was a Fluidnatek® LE-50 (Bioinicia S.L, Valencia, Spain) equipped with a variable high voltage power supply (0-30 kV). The solutions were placed in 10 mL plastic syringes (TERUMO®, Leuven, Belgium) coupled to a digitally controlled syringe pump and connected by a polytetrafluoroethylene tube to a blunt stainless-steel needle with a diameter of 0.60 mm (20 ga, FISNAR®, Glasgow, United Kingdom). The electrospraying process was performed in horizontal mode with a temperature and relative humidity (RH) maintained in a range between 20-25 °C and 45-65 %, respectively. The flowrate and the distance between the needle and the collector were constant in all experiments based on preliminary tests (0.5 mL/h and 17 cm, data not shown). Voltage varied between 12-25 kV ensuring correct Taylor cone formation in all experiments.

2.3. Microcapsules characterization and bioactivity

2.3.1. Morphology and particle size of microcapsules

To select the best encapsulation conditions, the surface morphology of the particles obtained was examined by Scanning Electron Microscope (SEM) (Quanta FEG 650, FEI, USA). Briefly, 1.0-2.0 mg of sample were deposited on a double-sided conductive carbon tape, then analyzed at an acceleration voltage of 3.0 kV with a working distance of ~10 mm. After selecting the best treatment for each extract, 1.0-2.0 mg of specific samples were coated with gold under vacuum for 1 min (EM ACE200, Leica Microsystems Inc. Wetzlar, Germany) and analyzed in the SEM, with a voltage of 5 kV at the same working distance. The morphology of at least 150 microcapsules was analyzed using ImageJ software (version 1.53k, Maryland, USA), and

the particle size and the particle aspect ratio (PAR) were determined. PAR was calculated with the following equation:

$$PAR = \frac{Particle\ height}{Particle\ length} \quad (1)$$

2.3.2. ATR-Fourier transform infrared (FTIR) spectroscopy analysis

FTIR assay was employed to analyze the bonding arrangements and functional groups of the constituents present in free and encapsulated extracts to determine the possible interactions. For the analyses, a Bruker FT-IR VERTEX 80/ 80v (Boston, USA) in Attenuated Total Reflectance mode (ATR) with a platinum crystal was used to obtain the FTIR spectra. The measurements were recorded from 4000 to 400 cm^{-1} wavenumber range, at a resolution of 4 cm^{-1} and 32 scans.

2.3.3. X-Ray diffraction analysis (XRD)

XRD assay was performed to determine the presence of crystalline polymorphisms in the samples employing an X-Ray Diffractometer X Pert PRO MRD system (Malvern Panalytical Ltd., Royston, UK). The analyses were carried out at room temperature, and samples were observed at a voltage of 45 kV and 40 mA using angular scans from 5.0° to 50° (2θ) with a Cu source, X-ray tube (λ of 1.54056 Å). The information was collected during 174 s. For 2θ the fine calibration offset was -0.0372°.

2.3.4. Thermogravimetric analysis (TGA)

Measurements were performed using a simultaneous thermal analyzer and a differential scanning calorimeter (TGA/DSC 3+, Mettler Toledo, Columbus, USA). Each sample (2.5 mg) was placed in the equipment´s scale on an alumina crucible, and heated at rate of 5 °C/min. The heating was from 30 to 500 °C under a nitrogen atmosphere.

2.3.5. Extract release from microcapsules

To determine the extract release from the microcapsules (MC-RmA and MC-RmO), samples were treated using two treatments: ultrasound (U) or agitation (A). For the ultrasonic bath release, the methodology of Šturm et al. (2019) was followed with some modifications. Firstly, 10 mg of microcapsules were placed in 0.5 mL of mili-Q water and sonicated for 5 min. Then, the solutions were centrifuged at 13,300 rpm for 15

177 min. In the second method, the same concentration was used, but the solutions were kept in agitation for 1
178 h. The supernatant of the solutions was used for TPC, DPPH, ABTS, and FRAP assays.

179 *2.3.6. Total phenolic content (TPC) by Folin-Ciocalteu*

180 The TPC released from the microcapsules was determined using the Folin-Ciocalteu (FC) method, following
181 the methodology of Müller et al. (2010) with minor modifications. Twenty microliters of the supernatant were
182 mixed with 100 µL of diluted FC solution (1:10 v/v, in water) for 5 min in a 96-well microplate, and 75 µL of
183 Na_2CO_3 (7.5 % w/v) were added. The reaction was incubated for 5 min at 40 °C, cooled and kept at room
184 temperature for 30 min more under dark conditions. The absorbance was measured at 750 nm on a Sinergy
185 H1 Hybrid Reader microplate equipment (Biotek, Vermont, USA), and the values were compared with a GA
186 calibration curve (2.5-200 mg/L, R^2=0.9994). The results were expressed as mg GA equivalents per gram
187 of microcapsules (mg GA/g MC). All experiments were performed in quadruplicate.

188 *2.3.7. Radical scavenging capacity*

189 *2.3.7.1. DPPH radical scavenging activity*

190 The scavenging capacity for DPPH was measured according to the method described by Guía-García et
191 al. (2021), with minor modifications. Twenty-five microliters of the supernatant were placed in a 96-well
192 microplate and mixed with 200 µL of DPPH solution (150 µM, dissolved in absolute ethanol). The reaction
193 was incubated at room temperature for 30 min under dark conditions. The absorbance was measured at
194 520 nm in a Sinergy H1 Hybrid Reader microplate equipment (Biotek, Vermont, USA), using absolute
195 ethanol as control. The scavenging capacity was expressed as percentage of Radical Scavenging Activity
196 (%RSA), using the following equation:

197 $$RSA\ (\%) = \left(\frac{A_{control} - A_{sample}}{A_{control}}\right) x\ 100 \qquad (2)$$

198 where $A_{control}$= control absorbance and A_{sample}= sample absorbance. All assays were carried out in
199 quadruplicate.

200

201

2.3.7.2. ABTS radical scavenging activity

The ABTS assay was performed based on the method of Jesus et al. (2019), with minor modifications. The ABTS solution was prepared at concentration of 7 mM in milli-Q water and mixed with a potassium persulfate solution (2.45 mM) (1:1), the mixture was kept during 14-16 h at 4 °C under dark conditions to complete the reaction. Then, 10 µL of the supernatant were mixed with 200 µL of ABTS solution (adjusted with ethanol at 20 % to an absorbance of 0.700 ± 0.010 at 734 nm) in a 96-well microplate and incubated for 10 min under dark conditions at room temperature. The absorbance was measured at 734 nm in a Sinergy H1 Hybrid Reader microplate equipment (Biotek, Vermont, USA), using water as control. The results were expressed as %RSA as described in section 2.2.7.1 according to Equation 2. All experiments were conducted by quadruplicate.

2.3.7.3. Ferric reducing capacity by FRAP assay

The ferric reducing capacity of the microcapsules content was evaluated following the method described by Guo & Jauregi (2018), with minor modifications. In a microcentrifuge tube was added 5 µL of the supernatant and mixed for 15 s with 150 µL of FRAP reagent (83.33 % of acetate buffer (300 mM), 8.33 % of TPTZ (10 mM) in HCl 40 mM, and 8.33 % of ferric chloride hexahydrate aqueous solution (20 mM)). Then, 100 µL were transferred to a 96-well microplate and the absorbance was measured at 595 nm in a Sinergy H1 Hybrid Reader microplate equipment (Biotek, Vermont, USA). The results were expressed as ascorbic acid equivalents (AA), using an ascorbic acid standard curve (1.5-400 mg/L, R^2=0.9992). All assays were made by quadruplicate.

2.3.8. Antifungal properties

2.3.8.1. Fungal strains

The *Fusarium oxysporum* strain (NCBI, accession no. MT001892) was acquired by CICY (Yucatan Center for Scientific Research, Yucatan, Mexico) and *Rhizopus stolonifer* strain (CDBC accession no. 1384) was purchased from CINVESTAV (Center for Research and Advanced Studies of the National Polytechnic Institute, CDMX, Mexico).

2.3.8.2. Microdilution assay

The antifungal activity was made following the method report by Flores-López et al. (2016) with minor modifications. First, spore's suspensions of each strain were prepared by pouring a sterile Tween-80 solution (0.1%, w/w) onto a Petri dish containing 7-day-old fungi to release the spores. Then, the suspensions were mixed, and the spores were counted using a Neubauer chamber. Subsequently, sterile broth was added to the spore suspension to obtain the desired concentration of 10^4 spores/mL. After this, different amounts of microcapsules (0.10, 0.20, 0.30, 0.40, 0.50, and 0.60 %, w/v) were diluted with 100 µL of SDB and placed in a sterile 96-well microplate, followed by the addition of 100 µL of a spore's suspension of each strain. A positive control of 100 µL of SDB and 100 µL of spore's suspension was used. The samples were mixed and incubated at 25 ± 2 °C for 36 h, the fungal growth was measured by changes in the optical density (OD) at 530 nm in a Sinergy H1 Hybrid Reader microplate equipment (Biotek, Vermont, USA). The percentage of growth inhibition (%) was calculated through Equation 3:

$$Inhibition\ (\%) = \left(\frac{ODcontrol - ODsample}{ODcontrol}\right) x100 \qquad (3)$$

where $OD_{control}$, represents the optical density of the control and OD_{sample} represents the optical density of each treatment. All experiments were carried out in triplicate.

2.4. Effect of microencapsulated extracts on strawberry fruit decay

To evaluate the effect on strawberry fruit decay, only the microcapsules containing RmA were selected, as they presented the best *in vitro* results of antioxidant and antifungal activities.

A coating containing microcapsules (RmA) was prepared using a structured water vehicle, previously optimized for application in berries: 0.24 % (w/v) of lyophilized chia mucilage, 0.15 % (w/v) $CaCl_2$ and 0.05 % (w/v) glycerol (Charles-Rodríguez et al., 2021). Three treatments were evaluated: uncoated (control); coating with 0.25 % (w/v) and coating with 0.50 % (w/v) of microcapsules containing RmA, respectively. The treatments were applied on strawberry fruit by aspersion and left to dry in a convection oven at 25 °C for 25 min (Biobase Biodustry Shandong Co, Ltd., Jinan, SHG, China). For each treatment, three repetitions of 10 strawberries were evaluated (n=30, per treatment), the fruits were placed in

253 performed polypropylene plastic trays and stored at 4 ± 1 °C and 85 % RH for 14 d. Physicochemical and
254 decay evaluations were analyzed at regular intervals (0, 2, 4, 6, 8, 10, 12, and 14 d).

255 *2.5. Physicochemical analyses*

256 *2.5.1. Weight loss*

257 Weight loss of strawberries (n=30, per treatment) during storage was evaluated by means of the mass
258 changing every two days in each fruit using an analytical balance (Ohaus, New Jersey, USA), and the
259 results were expressed as percentage using the following equation:

260 $$Weight\ loss\ (\%) = \frac{W_0 - W_d}{W_0} x100 \qquad (4)$$

261 where W_0 is the initial weight, and W_d is the respective weight of every test day.

262 *2.5.2. Texture analyses*

263 The firmness of fruit was measured two times at different center region of seven fruit per replicate of each
264 treatment at day 0 and 14 of the experiment. A texture analyzer CT3 (Brookfield, USA), equipped with a 6
265 mm diameter size cylindrical probe was used. The conditions were the following: trigger force of 0.05 N,
266 penetration depth of 5.0 mm and test speed of 5.0 mm/s. The results were expressed in Newtons (N).

267 *2.5.3. Color*

268 The change in color parameters (*L**, *a** and *b**) of the strawberry surface was measured using a Minolta
269 colorimeter (CR-400, Minolta, Tokyo, Japan) every two days. The readings were made in two different
270 points on the fruit surface. The results were reported in function of chromaticity (*C**), hue angle (*H**) and
271 redness values (*a*/b**), calculated by the following equations (Quintana et al., 2021; Salas-Méndez et al.,
272 2019):

273 $$C^* = \sqrt{(a^{*2}) + (b^{*2})} \qquad (5)$$

274 $$H^* = tan^{-1}\left(\frac{b*}{a*}\right) \qquad (6)$$

275 $$Redness = \left(\frac{a*}{b*}\right) \qquad (7)$$

276 *2.5.4. Fungal decay*

277 For fungal decay evaluation, the stored strawberries (n=30) were visually inspected for the presence of
278 mold growth every 2 d, and any fruit with visible spoilage was considered affected. The following equation
279 was used to calculate the fungal decay percentage in each treatment (Quintana et al., 2021):

280 $$Fungal\ decay\ (\%) = \frac{Number\ of\ decay\ fruit}{Total\ number\ of\ fruit} x100 \qquad (8)$$

281 *2.6. Statistical analysis*

282 The results were expressed as means ± standard deviations. Minitab software version 17.0 (State College,
283 PA, USA) and GraphPad Prism version 8.0.1 (La Jolla California, USA) were used for data analyses. One-
284 way analyses of variance (ANOVA) were used to detect any significant differences followed by Tukey's
285 mean comparison test (p<0.05).

286 **3. Results and discussion**

287 *3.1. Morphology and particle size of microcapsules*

288 The ethanol and the extract amount were determining factors in the selection of the encapsulation
289 conditions; the use of 50 % ethanol did not allow a correct evaporation of the solvent, leading to droplets,
290 and the use of higher extract concentrations increased the presence of droplets in the samples (data not
291 shown). On the other hand, with a concentration of 75 % ethanol and 1 mg/mL of extract and voltage of 14
292 and 17 kV, the best structures were obtained for both the RmA and RmO extracts (T4 and T8, respectively).
293 Fig. 1 shows that these processing conditions allowed to produce homogeneous and spherical structures
294 with a smooth surface. This was confirmed by the PAR results (Table 2), where structures with values
295 closer to 1 are more closely related to spherical shapes for the encapsulates (Silva et al., 2021). On the
296 other hand, the particle size ranged from 2.05 to 2.41 µm as indicated in Table 2. This size range classifies
297 the samples as microcapsules, given that they fall within the typical range of 1-1000 µm (Shishir et al.,
298 2018). The significative differences in the particle size between MC-RmA and MC-RmO could be explained
299 by their components which can influence in the conductivity of the solutions and affect the particle size
300 (Bhushani et al., 2017). These results are in agreement with those obtained in the encapsulation of ferulic

acid, where spherical microcapsules were obtained through spray-drying using HPMC as wall material, having a suitable incorporation of phenolic acid within the structures (Yu et al., 2021).

3.2. ATR-FTIR analyses

In Fig. 2 is shown the FTIR spectra of HPMC powder, empty MC-HPMC, and the free (RmA and RmO) and encapsulated extracts (MC-RmA and MC-RmO). For the HPMC powder and MC-HPMC, the peak around 3460 cm^{-1} corresponds to the —OH stretching vibration, and the presence of —CH aliphatic stretching vibrations was confirmed by the absorption peak at 2908 cm^{-1}, while the two absorption peaks of 1454 and 1371 cm^{-1} could be attributed to the $—CH_3$ asymmetric vibrations (Sheng et al., 2021). Besides, it was observed a strong peak around 1060-1020 cm^{-1} corresponding to the —CO stretching vibrations in all the samples (Wang et al., 2021). On the other hand, for unencapsulated extracts (RmA and RmO), the region around 3270-3300 cm^{-1} indicated the —OH stretching vibrations from phenolic compounds and ethanol (extraction solvent), whereas the absorption peak of 2926 cm^{-1} corresponds to the symmetric aliphatic stretching vibrations ($—CH_2$) (Hu et al., 2019). The absorption peak at 1709 cm^{-1} is related to the —C=O stretching, and in the region of 1590 cm^{-1} the absorption peak corresponds to the aromatic ring stretching (Zhao et al., 2022). However, in the microcapsules containing RmA and RmO some minor changes in the spectra occurred, as the absorption peaks (1590-1700 cm^{-1}) of extracts were covered, indicating that extracts were correctly incorporated within the microcapsules (Sheng et al., 2021). Moreover, the intensity of the absorption peak around 3270-3330 cm^{-1} (presented in the extracts) decreased, and it was displaced to the spectral area of 3460 cm^{-1}. This could be explained by the hydrophobic interactions or hydrogen bonds formation between the polymer and the phenolic compounds from the extracts (Moreno et al., 2018). The FTIR results confirm the correct encapsulation of extracts inside the HPMC microcapsules produced by electrospray, providing protection, and reducing their susceptibility to environmental conditions.

3.3. XRD analyses

The XRD analysis is useful to identify the degree of crystallinity in samples, where a crystalline material exhibits specific and well-defined peaks in the diffractogram, while an amorphous material shows a rounded

and diffuse peak (Papoutsis et al., 2018). Amorphous materials have higher water-solubility and hygroscopicity compared with crystalline materials (Botrel et al., 2014).

Fig. 3A shows the X-ray diffractograms of the HPMC microcapsules and those containing RmA and RmO extracts. In general, all samples exhibited a diffuse peak around 2θ=8° and, according to the shape of the peak in the diffractograms (i.e., long and flattened), all samples also showed an amorphous structure. These results are in agreement with Yu et al. (2021) that encapsulated ferulic acid using HPMC by spray-drying, observing a single diffuse and broad peak, representative of amorphous materials. These types of structures are desirable, as amorphous structures usually have higher fluidity and solubility (Dalmolin et al., 2016); meanwhile, crystalline structures dissolve more slowly because only the surface exposed to the solvent tends to dissolve first (Ban et al., 2020).

3.4. *TGA analyses*

Commonly, the bioactive compounds present in plant extracts are thermally unstable; in specific, polyphenols are very sensitive to high temperatures, which can cause the breakdown of the glucosyl moiety of the aglycone present in these compounds, altering the bioactivity and bioavailability of the natural compound (Bedrníček et al., 2020).

Thermal analysis can provide information about the thermal stability of the samples and shows the amount of moisture and volatile compounds present in microparticles; and also, the thermal breakdown of the wall polymers (İnan & Özçimen, 2021). In Fig. 3B, the stage of major degradation occurred between 300-360 °C, and it is associated with the depolymerization and thermal breakdown of the polymer (Cho et al., 2019). The results demonstrated that the HPMC polymer can effectively protect the *R. microphylla* extracts from high temperatures, thereby preventing their thermal degradation.

3.5. TPC and antioxidant capacity of microcapsules

The different bioactive properties of microcapsules containing Rm extract depend on the effective release of the compounds from the polymeric matrix, since an unsuccessful release could cause a decrease in their bioactivity. Several works have reported the correlation between the TPC and the antioxidant capacity of plant extracts, as phenolic compounds present functional groups able to interact with the corresponding

molecules in each antioxidant assay (DPPH, ABTS, FRAP, etc.) (Xu et al., 2007; López-Romero et al., 2018).

Two treatments (ultrasound and agitation) were conducted to allow the release of the content of the microcapsules, and the results are presented in Table 3. In the case of MC-RmA, there were no significant differences between the treatments used for TPC and antioxidant capacity. However, for MC-RmO, the samples using only agitation presented a higher TPC and better antioxidant capacities (p<0.05) compared with the microcapsules treated with ultrasounds. This difference might be caused by the effect of sonication on phenolic compounds, because the cavitation may cause a slight degradation generating hydroxyl radicals (Aguilar-Villalva et al., 2021; Kaderides et al., 2019; Martins Strieder et al., 2019). In addition, MC-RmA showed the higher values of TPC and the highest RSA values for DPPH and ABTS assays. As previously reported by Guía-García et al. (2021), RmA extract is composed of a more complex structure (gallic acid, p-cumaric+epicatechin, catechin, ferulic acid, ellagic acid and resveratrol) than RmO (gallic acid and ellagic acid), which could partially explain the differences in release behavior.

3.6. Antifungal activity of microcapsules

Phytopathogenic fungi cause important losses in fruit and vegetables. *F. oxysporum* is an important fungus involved in preharvest losses in berries, causing the *Fusarium* wilt in strawberry crops, a disease that affects the whole plant system (Henry et al., 2017). In addition, *R. stolonifer* is a fastest-growing fungus and its invasion causes the development of a cottony mycelium with characteristic black spores in many fruits and vegetables during pre and postharvest stages, including the berries (Bautista-Baños et al., 2014). Plant extracts have recently been shown to successfully inhibit the development of phytopathogenic fungi, *in vitro* (Mahdi et al., 2021; Wang et al., 2018). The inhibition percentages of the microcapsules against *F. oxysporum* and *R. stolonifer* are shown in Fig. 4. The results evidenced that the MC-RmA had the best (p<0.05) antifungal activity against both fungi compared with MC-RmO, with inhibition percentages of 56.4±4.2 % and 46.3±1.2 % against *F. oxysporum* (Fig. 5a) and *R. stolonifer* (Fig. 5b), respectively. The two highest concentrations tested (0.50 and 0.60 %, w/v) did not show a significant difference in both cases. The higher antifungal effect of MC-RmA could be attributed to their antioxidant capacity previously reported, and a major number of phenolic compounds in the extract, both characteristics associated with the

promotion of antifungal activity (Jasso de Rodríguez et al., 2017). Since the MC-RmA exhibited higher antioxidant and antifungal properties, it was selected to evaluate its effect on the shelf life of strawberry fruit.

3.7. Effect of microcapsules containing RmA on strawberry fruit

3.7.1. Weight loss and firmness

Fruit weight loss is mainly associated with the respiration rate and the release of water into the environment (Yang et al., 2019). The effect of functionalized microcapsules on weight loss is presented in Fig. 5a. The highest weight loss (p<0.05) was in control fruit (uncoated) during all storage period. Besides, the uncoated fruit showed a significant difference (p<0.05) in weight loss on each day evaluated. At the end of the storage (14 d), the strawberries treated with 0.25 % (20.35±1.36 %) and 0.50 % (19.18±0.38 %) of MC-RmA had significantly (p<0.05) less weight loss than uncoated strawberries (40.86±1.64 %). This results confirm that the use of MC-RmA treatment provided a barrier capable to reduce the water loss by acting as a coating on the fruit surface (Salas-Méndez et al., 2019). On the other hand, there was no significant difference between the amount of MC-RmA used. These results are consistent with a previous study of Guerreiro et al. (2015), in which edible coatings containing 0.1 and 0.2 % eugenol did not show significant differences, but both were an effective barrier to water loss during the storage of strawberries for 14 d at 0.5 °C. In addition, the use of HPMC as an encapsulating agent in synergy with the use of chia mucilage based coating as vehicle, could favor the formation of a semi-permeable matrix (Gol et al., 2013; Urbizo-Reyes et al., 2020). Gol et al. (2013) reported a lower weight loss in strawberries treated with an HPMC edible coating at day 12 of storage at 11 ± 1 °C, associating this effect to the formation of the barrier on the surface of the fruit.

The strawberries' firmness is an important quality parameter for consumers, and its decrease is related to the loss of cell wall strength caused by the degradation of the middle lamella of cortical parenchyma cells, and also by the loss of turgidity due to the activity of degrading enzymes (e.g., pectinamethylesterase and polygalacturonase) (Oliveira et al., 2021). In this study, the fruits treated with MC-RmA showed a significant less decrease of their initial firmness (MC-RmA 0.25%: 5.26±1.10% of decrease; MC-RmA 0.50%: 6.98±1.14% of decrease) in comparison with uncoated strawberries (64.17±0.61% of decrease) at the end

406 of storage, being consistent with the results of weight loss. Similarly, Li et al. (2020) reported that the active
407 film of microcapsules containing oregano essential oil allowed the highest firmness values in strawberries
408 due to the decrease in the moisture content surrounding the fruit surface. In addition, the coatings act as a
409 barrier to O_2 uptake and metabolic activity is slowed down (Sogvar et al., 2016). The MC-RmA showed to
410 have a positive effect on fruit firmness, resulting in improved fruit quality by reducing their softness during
411 the storage.

412 *3.7.2. Color*

413 Color significantly influences the acceptability of strawberry fruits, and it is related to their ripening process
414 (Gol et al., 2013). Color change in fruits was monitored by means of chroma, Hue angle, and redness
415 values (Fig. 6). For chroma and redness there was a significant reduction from day 0 to day 14 in all
416 treatments (p<0.05), which results in a loss of fruit brightness and changes in the fruit color. Nevertheless,
417 treated fruit showed no significant changes compared to untreated fruit in terms of C^*, H^* and redness on
418 each day of evaluation. Similarly, Guerreiro et al. (2015) found no differences between untreated
419 strawberries and those treated with a pectin coating containing essential oils. This phenomenon is also
420 reported in other studies, where slight changes in fruit color are considered a natural occurrence due to
421 factors such as loss of freshness, oxidative processes, and microbial contamination during storage (Fan et
422 al., 2009; Liguori et al., 2021; Pinzon et al., 2020; Valenzuela et al., 2015). These results are important
423 because significant changes in fruit color induced by the treatments could affect consumer acceptability;
424 and, in this study it is demonstrated that it is possible to incorporate the bioactive properties of MC-RmA
425 without negatively altering the color of the fruit.

426

427 *3.7.3. Fungal decay*

428 Decay in strawberries is mainly caused by their high susceptibility to postharvest fungal attack, mainly by
429 *R. stolonifer*, *Botrytis cinerea*, *Penicillium* spp., and *Colletotrichum* spp. (Feliziani & Romanazzi, 2016). The
430 results of fungal decay are shown in Fig. 5b, and it can be observed that after day 8, the coated fruit started
431 to show a significant less fungal decay compared with uncoated fruits and during the following days, the

decay was faster and more significant in the control treatment. This behavior demonstrates the particularity of MC-RmA to gradually release their content (Kittitheeranun et al., 2015). Besides, a concentration-dependent effect was observed at 14 d of storage, as the fruits treated with 0.25 % MC-RmA presented a higher (p<0.05) fungal decay compared to those treated with 0.50 %. Likewise, Fan et al. (2019) reported that a higher amount of lotus leaf extract incorporated in coatings significantly reduces decay in goji berries due to the presence of a higher amount of bioactive compounds.

Fig. 7 shows the visual evolution of the strawberry fruits during the storage period, in which it can be observed that fungal development was faster in the control group. A similar behavior was previously reported by Liu et al. (2021), as coated strawberries (containing asparagus waste extract) showed better control of *P. italicum,* than uncoated fruit after 8 d of storage at 25 °C and 80% RH. Other works have also reported interesting results on the antifungal effect of coatings or microcapsules containing plant extracts on strawberry fruits (Sangsuwan et al., 2016; Oliveira et al., 2021; Saleh & Abu-Dieyeh, 2022), which is an indicator of the potential of these technologies to extend the shelf life of these fruits. These results prove that the use of MC-RmA effectively reduces the decay of strawberry fruits due to their bioactive compounds with antifungal properties, besides, the encapsulation provides a slow release of its content, thus extending their activity.

4. Conclusions

Microcapsules containing extracts from *R. microphylla* fruit were developed using electrospray technique and HPMC as encapsulating agent, which showed a spheric shape and particle size between 2.05-2.41 µm. With both concentrations of MC-RmA evaluated (0.25 and 0.5 %, w/v), the treated fruits showed a decrease in weight loss, fungal decay, and firmness, compared with the uncoated fruits. Therefore, the effectiveness of MC-RmA in extending the shelf life of strawberry fruits under the test storage conditions (4 °C for 14 d and 85 % HR) was confirmed. The results are promising and demonstrate the positive effect of the functionalized microcapsules on the quality of strawberries. They provide a novel biorational alternative for use in the postharvest stage, where the use of synthetic product is avoided due to the proximity of the final product to the consumer. This technology could help to reduce the product losses while maintaining quality

458 attributes. However, it is important to evaluate feasible application methods, as well as to design appropriate
459 vehicles to improve the use of this technology.

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464 **References**

465 Aguilar-Villalva, R., Molina, G. A., España-Sánchez, B. L., Díaz-Peña, L. F., Elizalde-Mata, A., Valerio, E.,
466 Azanza-Ricardo, C., & Estevez, M. (2021). Antioxidant capacity and antibacterial activity from
467 Annona cherimola phytochemicals by ultrasound-assisted extraction and its comparison to
468 conventional methods. *Arabian Journal of Chemistry*, *14*(7), 1–17.
469 https://doi.org/10.1016/j.arabjc.2021.103239

470 Al-Maqtari, Q. A., Mohammed, J. K., Mahdi, A. A., Al-Ansi, W., Zhang, M., Al-Adeeb, A., Wei, M., Phyo,
471 H. M., & Yao, W. (2021). Physicochemical properties, microstructure, and storage stability of
472 Pulicaria jaubertii extract microencapsulated with different protein biopolymers and gum arabic as
473 wall materials. *International Journal of Biological Macromolecules*, *187*, 939–954.
474 https://doi.org/10.1016/J.IJBIOMAC.2021.07.180

475 Atay, E., Fabra, M. J., Martínez-Sanz, M., Gomez-Mascaraque, L. G., Altan, A., & Lopez-Rubio, A.
476 (2018). Development and characterization of chitosan/gelatin electrosprayed microparticles as food
477 grade delivery vehicles for anthocyanin extracts. *Food Hydrocolloids*, *77*, 699–710.
478 https://doi.org/10.1016/J.FOODHYD.2017.11.011

479 Ban, Z., Zhang, J., Li, L., Luo, Z., Wang, Y., Yuan, Q., Zhou, B., & Liu, H. (2020). Ginger essential oil-
480 based microencapsulation as an efficient delivery system for the improvement of Jujube (Ziziphus
481 jujuba Mill.) fruit quality. *Food Chemistry*, *306*, 125628.
482 https://doi.org/10.1016/J.FOODCHEM.2019.125628

Bautista-Baños, S., Bosquez-Molina, E., & Barrera-Necha, L. L. (2014). Rhizopus stolonifer (Soft Rot). In S. Bautista-Baños (Ed.), *Postharvest Decay: Control Strategies* (1st ed., pp. 1–44). Elsevier. https://doi.org/10.1016/B978-0-12-411552-1.00001-6

Bedrníček, J., Jirotková, D., Kadlec, J., Laknerová, I., Vrchotová, N., Tříska, J., Samková, E., & Smetana, P. (2020). Thermal stability and bioavailability of bioactive compounds after baking of bread enriched with different onion by-products. *Food Chemistry*, *319*. https://doi.org/10.1016/j.foodchem.2020.126562

Bhushani, J. A., Kurrey, N. K., & Anandharamakrishnan, C. (2017). Nanoencapsulation of green tea catechins by electrospraying technique and its effect on controlled release and in-vitro permeability. *Journal of Food Engineering*, *199*, 82–92. https://doi.org/10.1016/J.JFOODENG.2016.12.010

Botrel, D. A., de Barros Fernandes, R. V., Borges, S. V., & Yoshida, M. I. (2014). Influence of wall matrix systems on the properties of spray-dried microparticles containing fish oil. *Food Research International*, *62*, 344–352. https://doi.org/10.1016/J.FOODRES.2014.02.003

Bursal, E., & Köksal, E. (2011). Evaluation of reducing power and radical scavenging activities of water and ethanol extracts from sumac (Rhus coriaria L.). *Food Research International*, *44*(7), 2217–2221. https://doi.org/10.1016/j.foodres.2010.11.001

Castillo, F., Hernández, D., Gallegos, G., Mendez, M., Rodríguez, R., Reyes, A., & Aguilar, C. N. (2010). In vitro antifungal activity of plant extracts obtained with alternative organic solvents against Rhizoctonia solani Kühn. *Industrial Crops and Products*, *32*(3), 324–328. https://doi.org/10.1016/J.INDCROP.2010.05.013

Charles-Rodríguez, A. V, Padierna-Araiza, T., Genisheva, Z., Guía-García, J. L., Robledo-Olivo, A., Martínez-Vazquez, D. G., Rangel Ortegan, S., Peña-Ramos, F., Hernández-González, M., & Flores-López, M. L. (2021, September). Edible coating based on black chia (Salvia hispanica L.) seed mucilage containing Myrtillocactus geometrizans fruit phenolic extracts. Poster session presentation at the 32nd Anual Meeting-AAIC. Association for the Advancement of Industrial Crops. Bologna, Italy.

Charles-Rodríguez, A. V, Rivera-Solis, L. L., Martins, J. T., Genisheva, Z., Robledo-Olivo, A., González-Morales, S., López-Guarin, G., Martínez-Vázquez, D., Vicente, A., & Flores-López, M. L. (2020). Edible films based on Black Chia (Salvia hispanica L.) seed mucilage containing Rhus microphylla fruit phenolic extract. *Coatings*, *10*(326), 1–15.

Cho, Y. J., Getachew, A. T., Saravana, P. S., & Chun, B. S. (2019). Optimization and characterization of polysaccharides extraction from Giant African snail (Achatina fulica) using pressurized hot water extraction (PHWE). *Bioactive Carbohydrates and Dietary Fibre*, *18*, 100179. https://doi.org/10.1016/J.BCDF.2019.100179

Chu, Y., Gao, C. C., Liu, X., Zhang, N., Xu, T., Feng, X., Yang, Y., Shen, X., & Tang, X. (2020). Improvement of storage quality of strawberries by pullulan coatings incorporated with cinnamon essential oil nanoemulsion. *LWT - Food Science and Technology*, *122*, 109054. https://doi.org/10.1016/j.lwt.2020.109054

Correa-Pacheco, Z. N., Bautista-Baños, S., Valle-Marquina, M. Á., & Hernández-López, M. (2017). The Effect of Nanostructured Chitosan and Chitosan-thyme Essential Oil Coatings on Colletotrichum gloeosporioides Growth in vitro and on cv Hass Avocado and Fruit Quality. *Journal of Phytopathology*, *165*(5), 297–305. https://doi.org/10.1111/jph.12562

Dalmolin, L. F., Khalil, N. M., & Mainardes, R. M. (2016). Delivery of vanillin by poly(lactic-acid) nanoparticles: Development, characterization and in vitro evaluation of antioxidant activity. *Materials Science and Engineering: C*, *62*, 1–8. https://doi.org/10.1016/J.MSEC.2016.01.031

Danafar, H. (2017). Study of the composition of polycaprolactone/poly (ethylene glycol)/polycaprolactone copolymer and drug-to-polymer ratio on drug loading efficiency of curcumin to nanoparticles. *Jundishapur Journal of Natural Pharmaceutical Products*, *12*(1), e34179. https://doi.org/10.5812/jjnpp.34179

Fan, X.-J., Zhang, B., Yan, H., Feng, J.-T., Ma, Z.-Q., & Zhang, X. (2019). Effect of lotus leaf extract incorporated composite coating on the postharvest quality of fresh goji (Lycium barbarum L.) fruit. *Postharvest Biology and Technology*, *148*, 132–140.

https://doi.org/10.1016/J.POSTHARVBIO.2018.10.020

Fan, Y., Xu, Y., Wang, D., Zhang, L., Sun, J., Sun, L., & Zhang, B. (2009). Effect of alginate coating combined with yeast antagonist on strawberry (Fragaria × ananassa) preservation quality. *Postharvest Biology and Technology*, *53*(1–2), 84–90. https://doi.org/10.1016/j.postharvbio.2009.03.002

Feliziani, E., & Romanazzi, G. (2016). Postharvest decay of strawberry fruit: Etiology, epidemiology, and disease management. *Journal of Berry Research*, *6*(1), 47–63. https://doi.org/10.3233/JBR-150113

Flores-López, M. L., Romaní, A., Cerqueira, M. A., Rodríguez-García, R., Jasso de Rodríguez, D., & Vicente, A. A. (2016). Compositional features and bioactive properties of whole fraction from Aloe vera processing. *Industrial Crops and Products*, *91*, 179–185. https://doi.org/10.1016/j.indcrop.2016.07.011

Gol, N. B., Patel, P. R., & Rao, T. V. R. (2013). Improvement of quality and shelf-life of strawberries with edible coatings enriched with chitosan. *Postharvest Biology and Technology*, *85*, 185–195. https://doi.org/10.1016/j.postharvbio.2013.06.008

Gómez-Estaca, J., Balaguer, M. P., López-Carballo, G., Gavara, R., & Hernández-Muñoz, P. (2017). Improving antioxidant and antimicrobial properties of curcumin by means of encapsulation in gelatin through electrohydrodynamic atomization. *Food Hydrocolloids*, *70*, 313–320. https://doi.org/10.1016/J.FOODHYD.2017.04.019

Gómez-Mascaraque, L. G., Perez-Masiá, R., González-Barrio, R., Periago, M. J., & López-Rubio, A. (2017). Potential of microencapsulation through emulsion-electrospraying to improve the bioaccesibility of β-carotene. *Food Hydrocolloids*, *73*, 1–12. https://doi.org/10.1016/J.FOODHYD.2017.06.019

González-Saucedo, A., Barrera-Necha, L. L., Ventura-Aguilar, R. I., Correa-Pacheco, Z. N., Bautista-Baños, S., & Hernández-López, M. (2019). Extension of the postharvest quality of bell pepper by applying nanostructured coatings of chitosan with Byrsonima crassifolia extract (L.) Kunth. *Postharvest Biology and Technology*, *149*(April 2018), 74–82.

https://doi.org/10.1016/j.postharvbio.2018.11.019

Guerreiro, A. C., Gago, C. M. L., Faleiro, M. L., Miguel, M. G. C., & Antunes, M. D. C. (2015). The use of polysaccharide-based edible coatings enriched with essential oils to improve shelf-life of strawberries. *Postharvest Biology and Technology*, *110*, 51–60. https://doi.org/10.1016/j.postharvbio.2015.06.019

Guía-García, J. L., Charles-Rodríguez, A. V., López-Romero, J. C., Torres-Moreno, H., Genisheva, Z., Robledo-Olivo, A., Reyes-Valdés, H. M., Ramírez-Godina, F., García-Osuna, H. T., & Flores-López, M. L. (2021). Phenolic Composition and Biological Properties of Rhus microphylla and Myrtillocactus geometrizans Fruit Extracts. *Plants*, *10*(10), 2010. https://doi.org/https://doi.org/10.3390/plants10102010

Guo, Y., & Jauregi, P. (2018). Protective effect of β-lactoglobulin against heat induced loss of antioxidant activity of resveratrol. *Food Chemistry*, *266*(May), 101–109. https://doi.org/10.1016/j.foodchem.2018.05.108

Gutiérrez-Molina, J., Corona-Rangel, M. L., Ventura-Aguilar, R. I., Barrera-Necha, L. L., Bautista-Baños, S., & Correa-Pacheco, Z. N. (2021). Chitosan and Byrsonima crassifolia-based nanostructured coatings: Characterization and effect on tomato preservation during refrigerated storage. *Food Bioscience*, *42*(April). https://doi.org/10.1016/j.fbio.2021.101212

Henry, P. M., Kirkpatrick, S. C., Islas, C. M., Pastrana, A. M., Yoshisato, J. A., Koike, S. T., Daugovish, O., & Gordon, T. R. (2017). The population of Fusarium oxysporum f. sp. fragariae, cause of fusarium wilt of strawberry, in California. *Plant Disease*, *101*(4), 550–556. https://doi.org/10.1094/PDIS-07-16-1058-RE

Hesami, G., Darvishi, S., Zarei, M., & Hadidi, M. (2021). Fabrication of chitosan nanoparticles incorporated with Pistacia atlantica subsp. kurdica hulls' essential oil as a potential antifungal preservative against strawberry grey mould. *International Journal of Food Science and Technology*, *56*, 4215–4223. https://doi.org/10.1111/ijfs.15110

Hu, Y., Kou, G., Chen, Q., Li, Y., & Zhou, Z. (2019). Protection and delivery of mandarin (Citrus reticulata

587 Blanco) peel extracts by encapsulation of whey protein concentrate nanoparticles. *LWT - Food*
588 *Science and Technology*, *99*, 24–33. https://doi.org/10.1016/j.lwt.2018.09.044

589 İnan, B., & Özçimen, D. (2021). Preparation and characterization of microalgal oil loaded alginate/poly
590 (vinyl alcohol) electrosprayed nanoparticles. *Food and Bioproducts Processing*, *129*, 105–114.
591 https://doi.org/10.1016/j.fbp.2021.07.008

592 Ishkeh, S. R., Shirzad, H., Asghari, M. R., Alirezalu, A., Pateiro, M., & Lorenzo, J. M. (2021). Effect of
593 chitosan nanoemulsion on enhancing the phytochemical contents, health-promoting components,
594 and shelf life of raspberry (Rubus sanctus schreber). *Applied Sciences (Switzerland)*, *11*(5), 1–16.
595 https://doi.org/10.3390/app11052224

596 Jasso de Rodríguez, D., Salas-Méndez, E. de J., Rodríguez-García, R., Hernández-Castillo, F. D., Díaz-
597 Jiménez, M. L. V., Sáenz-Galindo, A., González-Morales, S., Flores-López, M. L., Villarreal-
598 Quintanilla, J. A., Peña-Ramos, F. M., & Carrillo-Lomelí, D. A. (2017). Antifungal activity in vitro of
599 ethanol and aqueous extracts of leaves and branches of Flourensia spp. against postharvest fungi.
600 *Industrial Crops and Products*, *107*, 499–508. https://doi.org/10.1016/j.indcrop.2017.04.054

601 Jasso de Rodríguez, D., Trejo-González, F. A., Rodríguez-García, R., Díaz-Jimenez, M. L. V., Sáenz-
602 Galindo, A., Hernández-Castillo, F. D., Villarreal-Quintanilla, J. A., & Peña-Ramos, F. M. (2015).
603 Antifungal activity in vitro of Rhus muelleri against Fusarium oxysporum f. sp. lycopersici. *Industrial*
604 *Crops and Products*, *75*, 150–158. https://doi.org/10.1016/j.indcrop.2015.05.048

605 Jesus, M. S., Genisheva, Z., Romaní, A., Pereira, R. N., Teixeira, J. A., & Domingues, L. (2019).
606 Bioactive compounds recovery optimization from vine pruning residues using conventional heating
607 and microwave-assisted extraction methods. *Industrial Crops and Products*, *132*, 99–110.
608 https://doi.org/10.1016/j.indcrop.2019.01.070

609 Kaderides, K., Papaoikonomou, L., Serafim, M., & Goula, A. M. (2019). Microwave-assisted extraction of
610 phenolics from pomegranate peels: Optimization, kinetics, and comparison with ultrasounds
611 extraction. *Chemical Engineering and Processing - Process Intensification*, *137*, 1–11.
612 https://doi.org/10.1016/j.cep.2019.01.006

Kim, M. S., Lee, C. W., Kim, J. H., Lee, J. C., & An, W. G. (2019). Extract of Rhus verniciflua Stokes Induces p53-Mediated Apoptosis in MCF-7 Breast Cancer Cells. *Evidence-Based Complementary and Alternative Medicine*, *2019*, 1–9. https://doi.org/10.1155/2019/9407340

Kittitheeranun, P., Sajomsang, W., Phanpee, S., Treetong, A., Wutikhun, T., Suktham, K., Puttipipatkhachorn, S., & Ruktanonchai, U. R. (2015). Layer-by-layer engineered nanocapsules of curcumin with improved cell activity. *International Journal of Pharmaceutics*, *492*, 92–102. https://doi.org/10.1016/J.IJPHARM.2015.06.040

Li, L., Song, W., Shen, C., Dong, Q., Wang, Y., & Zuo, S. (2020). Active packaging film containing oregano essential oil microcapsules and their application for strawberry preservation. *Journal of Food Processing and Preservation*, *44*(10), 1–13. https://doi.org/10.1111/jfpp.14799

Liguori, G., Gaglio, R., Settanni, L., Inglese, P., D'Anna, F., & Miceli, A. (2021). Effect of Opuntia ficus-indica Mucilage Edible Coating in Combination with Ascorbic Acid, on Strawberry Fruit Quality during Cold Storage. *Journal of Food Quality*, *2021*, 1–8. https://doi.org/10.1155/2021/9976052

Liu, C., Jin, T., Liu, W., Hao, W., Yan, L., & Zheng, L. (2021). Effects of hydroxyethyl cellulose and sodium alginate edible coating containing asparagus waste extract on postharvest quality of strawberry fruit. *LWT*, *148*, 111770. https://doi.org/10.1016/j.lwt.2021.111770

Liu, Q., Jing, Y., Han, C., Zhang, H., & Tian, Y. (2019). Encapsulation of curcumin in zein/caseinate/sodium alginate nanoparticles with improved physicochemical and controlled release properties. *Food Hydrocolloids*, *93*, 432–442. https://doi.org/10.1016/J.FOODHYD.2019.02.003

Liu, T., Li, Z., Li, R., Cui, Y., Zhao, Y., & Yu, Z. (2019). Composition analysis and antioxidant activities of the Rhus typhina L. stem. *Journal of Pharmaceutical Analysis*, *9*(5), 332–338. https://doi.org/10.1016/j.jpha.2019.01.002

López-Romero, J. C., González-Ríos, H., Peña-Ramos, A., Velazquez, C., Navarro, M., Robles-Zepeda, R., Martínez-Benavidez, E., Higuera-Ciapara, I., Virués, C., Olivares, J. L., Domínguez, Z., & Hernández, J. (2018). Seasonal Effect on the Biological Activities of Litsea glaucescens Kunth Extracts. *Evidence-Based Complementary and Alternative Medicine*, *2018*, 1–11.

https://doi.org/10.1155/2018/2738489

Machado, A. R., Pinheiro, A. C., Vicente, A. A., Souza-Soares, L. A., & Cerqueira, M. A. (2019). Liposomes loaded with phenolic extracts of Spirulina LEB-18: Physicochemical characterization and behavior under simulated gastrointestinal conditions. *Food Research International*, *120*, 656–667. https://doi.org/10.1016/J.FOODRES.2018.11.023

Mahdi, A. A., Al-Maqtari, Q. A., Mohammed, J. K., Al-Ansi, W., Cui, H., & Lin, L. (2021). Enhancement of antioxidant activity, antifungal activity, and oxidation stability of Citrus reticulata essential oil nanocapsules by clove and cinnamon essential oils. *Food Bioscience*, *43*, 101226. https://doi.org/10.1016/j.fbio.2021.101226

Martins Strieder, M., Keven Silva, E., & Angela A. Meireles, M. (2019). Specific Energy: A New Approach to Ultrasound-assisted Extraction of Natural Colorants. *Food and Public Health*, *9*(2), 45–52. https://doi.org/10.5923/j.fph.20190902.02

Medina-Torres, L., Núñez-Ramírez, D. M., Calderas, F., González-Laredo, R. F., Minjares-Fuentes, R., Valadez-García, M. A., Bernad-Bernad, M. J., & Manero, O. (2019). Microencapsulation of gallic acid by spray drying with aloe vera mucilage (aloe barbadensis miller) as wall material. *Industrial Crops and Products*, *138*, 111461. https://doi.org/10.1016/J.INDCROP.2019.06.024

Montiel-Sánchez, M., García-Cayuela, T., Gómez-Maqueo, A., García, H. S., & Cano, M. P. (2021). In vitro gastrointestinal stability, bioaccessibility and potential biological activities of betalains and phenolic compounds in cactus berry fruits (Myrtillocactus geometrizans). *Food Chemistry*, *342*(October 2020), 128087. https://doi.org/10.1016/j.foodchem.2020.128087

Morales-Mora, L. A., Martínez-Salgado, S. J., De Ita, M. A. V., Andrade-Hoyos, P., Silva-Rojas, H. V., & Romero-Arenas, O. (2019). First report of leaf spot and anthracnosis caused by pestalotiopsis sp. On strawberry in puebla, Mexico. *Plant Disease*, *103*(10). https://doi.org/10.1094/PDIS-05-19-1010-PDN

Moreno, M. A., Gómez-Mascaraque, L. G., Arias, M., Zampini, I. C., Sayago, J. E., Ramos, L. L. P., Schmeda-Hirschmann, G., López-Rubio, A., & Isla, M. I. (2018). Electrosprayed chitosan

665 microcapsules as delivery vehicles for vaginal phytoformulations. *Carbohydrate Polymers*,
666 *201*(March), 425–437. https://doi.org/10.1016/j.carbpol.2018.08.084

667 Muhoza, B., Xia, S., Cai, J., Zhang, X., Duhoranimana, E., & Su, J. (2019). Gelatin and pectin complex
668 coacervates as carriers for cinnamaldehyde: Effect of pectin esterification degree on coacervate
669 formation, and enhanced thermal stability. *Food Hydrocolloids*, *87*, 712–722.
670 https://doi.org/10.1016/J.FOODHYD.2018.08.051

671 Müller, L., Gnoyke, S., Popken, A. M., & Böhm, V. (2010). Antioxidant capacity and related parameters of
672 different fruit formulations. *LWT - Food Science and Technology*, *43*, 992–999.
673 https://doi.org/10.1016/J.LWT.2010.02.004

674 Nikoo, A. M., Kadkhodaee, R., Ghorani, B., Razzaq, H., & Tucker, N. (2018). Electrospray-assisted
675 encapsulation of caffeine in alginate microhydrogels. *International Journal of Biological*
676 *Macromolecules*, *116*, 208–216. https://doi.org/10.1016/J.IJBIOMAC.2018.04.167

677 Nunes, R., Pereira, B. D. A., Cerqueira, M. A., Silva, P., Pastrana, L. M., Vicente, A. A., Martins, J. T., &
678 Bourbon, A. I. (2020). Lactoferrin-based nanoemulsions to improve the physical and chemical
679 stability of omega-3 fatty acids. *Food and Function*, *11*(3), 1966–1981.
680 https://doi.org/10.1039/c9fo02307k

681 Oliveira, S. S., Braga, G. C., Cordeiro, N. K., Stangarlin, J. R., & Alves, H. J. (2021). Green synthesis of
682 silver nanoparticles with Euphorbia tirucalli extract and its protection against microbial decay of
683 strawberries during storage. *Journal of Food Science and Technology*, *59*, 2025–2034.
684 https://doi.org/10.1007/s13197-021-05217-y

685 Papoutsis, K., Golding, J. B., Vuong, Q., Pristijono, P., Stathopoulos, C. E., Scarlett, C. J., & Bowyer, M.
686 (2018). Encapsulation of citrus by-product extracts by spray-drying and freeze-drying using
687 combinations of maltodextrin with soybean protein and ι-carrageenan. *Foods*, *7*(7), 1–12.
688 https://doi.org/10.3390/foods7070115

689 Pellicer, J. A., Fortea, M. I., Trabal, J., Rodríguez-López, M. I., Gabaldón, J. A., & Núñez-Delicado, E.
690 (2019). Stability of microencapsulated strawberry flavour by spray drying, freeze drying and fluid

bed. *Powder Technology*, *347*, 179–185. https://doi.org/10.1016/J.POWTEC.2019.03.010

Pereira, M. C., Oliveira, D. A., Hill, L. E., Zambiazi, R., Borges, C. D., Vizzotto, M., Mertens-Talcott, S., Talcott, S., & Gomes, C. L. (2018). Effect of nanoencapsulation using PLGA on antioxidant and antimicrobial activities of guabiroba fruit phenolic extract. *Food Chemistry*, *240*, 396–404. https://doi.org/10.1016/j.foodchem.2017.07.144

Pinheiro, A. C., Bourbon, A. I., Cerqueira, M. A., Maricato, É., Nunes, C., Coimbra, M. A., & Vicente, A. A. (2015). Chitosan/fucoidan multilayer nanocapsules as a vehicle for controlled release of bioactive compounds. *Carbohydrate Polymers*, *115*, 1–9. https://doi.org/10.1016/J.CARBPOL.2014.07.016

Pinzon, M. I., Sanchez, L. T., Garcia, O. R., Gutierrez, R., Luna, J. C., & Villa, C. C. (2020). Increasing shelf life of strawberries (Fragaria ssp) by using a banana starch-chitosan-Aloe vera gel composite edible coating. *International Journal of Food Science and Technology*, *55*(1), 92–98. https://doi.org/10.1111/ijfs.14254

Quintana, S. E., Llalla, O., García-Risco, M. R., & Fornari, T. (2021). Comparison between essential oils and supercritical extracts into chitosan-based edible coatings on strawberry quality during cold storage. *Journal of Supercritical Fluids*, *171*(September 2020), 105198. https://doi.org/10.1016/j.supflu.2021.105198

Sablania, V., Bosco, S. J. D., Rohilla, S., & Shah, M. A. (2018). Microencapsulation of Murraya koenigii L. leaf extract using spray drying. *Journal of Food Measurement and Characterization*, *12*(2), 892–901. https://doi.org/10.1007/s11694-017-9704-1

Salas-Méndez, E. de J., Vicente, A., Pinheiro, A. C., Ballesteros, L. F., Silva, P., Rodríguez-García, R., Hernández-Castillo, F. D., Díaz-Jiménez, M. de L. V., Flores-López, M. L., Villarreal-Quintanilla, J. Á., Peña-Ramos, F. M., Carrillo-Lomelí, D. A., & Jasso de Rodríguez, D. (2019). Application of edible nanolaminate coatings with antimicrobial extract of Flourensia cernua to extend the shelf-life of tomato (Solanum lycopersicum L.) fruit. *Postharvest Biology and Technology*, *150*, 19–27. https://doi.org/10.1016/j.postharvbio.2018.12.008

Saleh, I., & Abu-Dieyeh, M. (2022). Novel Prosopis juliflora leaf ethanolic extract coating for extending

postharvest shelf-life of strawberries. *Food Control*, *133*(PB), 108641. https://doi.org/10.1016/j.foodcont.2021.108641

Sanchez-Reinoso, Z., Osorio, C., & Herrera, A. (2017). Effect of microencapsulation by spray drying on cocoa aroma compounds and physicochemical characterisation of microencapsulates. *Powder Technology*, *318*, 110–119. https://doi.org/10.1016/J.POWTEC.2017.05.040

Sangsuwan, J., Pongsapakworawat, T., Bangmo, P., & Sutthasupa, S. (2016). Effect of chitosan beads incorporated with lavender or red thyme essential oils in inhibiting Botrytis cinerea and their application in strawberry packaging system. *LWT - Food Science and Technology*, *74*, 14–20. https://doi.org/10.1016/j.lwt.2016.07.021

Santiago-Mora, P. D., Cardador-Martinez, A., Tellez-Perez, C., Montejano-Gaitan, J. G., & Martin del Campo, S. T. (2017). In-Vitro Antioxidant Capacity and Bioactive Compounds Preservation Post-Drying on Berrycacti (Myrtillocactus geometrizans). *Journal of Food Research*, *6*(4), 121. https://doi.org/10.5539/jfr.v6n4p121

Sheng, K., Zhang, G., Kong, X., Wang, J., Mu, W., & Wang, Y. (2021). Encapsulation and characterisation of grape seed proanthocyanidin extract using sodium alginate and different cellulose derivatives. *International Journal of Food Science and Technology*, *56*(12), 6420–6430. https://doi.org/10.1111/ijfs.15299

Shishir, M. R. I., Xie, L., Sun, C., Zheng, X., & Chen, W. (2018). Advances in micro and nano-encapsulation of bioactive compounds using biopolymer and lipid-based transporters. *Trends in Food Science and Technology*, *78*, 34–60. https://doi.org/10.1016/j.tifs.2018.05.018

Silva, P.M., Prieto, C., Lagarón, J. M., Pastrana, L. M., Coimbra, M. A., Vicente, A. A., & Cerqueira, M. A. (2021). Food-grade hydroxypropyl methylcellulose-based formulations for electrohydrodynamic processing: Part I – Role of solution parameters on fibre and particle production. *Food Hydrocolloids*, *118*, 106761. https://doi.org/10.1016/j.foodhyd.2021.106761

Silva, Pedro M., Torres-Giner, S., Vicente, A. A., & Cerqueira, M. A. (2022). Management of Operational Parameters and Novel Spinneret Configurations for the Electrohydrodynamic Processing of

743 Functional Polymers. *Macromolecular Materials and Engineering*, 2100858.
744 https://doi.org/10.1002/mame.202100858

745 Sogvar, O. B., Koushesh Saba, M., & Emamifar, A. (2016). Aloe vera and ascorbic acid coatings maintain
746 postharvest quality and reduce microbial load of strawberry fruit. *Postharvest Biology and*
747 *Technology*, *114*, 29–35. https://doi.org/10.1016/J.POSTHARVBIO.2015.11.019

748 Šturm, L., Osojnik Črnivec, I. G., Istenič, K., Ota, A., Megušar, P., Slukan, A., Humar, M., Levic, S.,
749 Nedović, V., Kopinč, R., Deželak, M., Pereyra Gonzales, A., & Poklar Ulrih, N. (2019).
750 Encapsulation of non-dewaxed propolis by freeze-drying and spray-drying using gum Arabic,
751 maltodextrin and inulin as coating materials. *Food and Bioproducts Processing*, *116*, 196–211.
752 https://doi.org/10.1016/J.FBP.2019.05.008

753 Urbizo-Reyes, U., San Martin-González, M. F., Garcia-Bravo, J., & Liceaga, A. M. (2020). Development of
754 chia seed (Salvia hispanica) mucilage films plasticized with polyol mixtures: Mechanical and barrier
755 properties. *International Journal of Biological Macromolecules*, *163*, 854–864.
756 https://doi.org/10.1016/J.IJBIOMAC.2020.07.023

757 Ursache, F. M., Andronoiu, D. G., Ghinea, I. O., Barbu, V., Ioniţă, E., Cotârleţ, M., Dumitraşcu, L., Botez,
758 E., Râpeanu, G., & Stănciuc, N. (2018). Valorizations of carotenoids from sea buckthorn extract by
759 microencapsulation and formulation of value-added food products. *Journal of Food Engineering*,
760 *219*, 16–24. https://doi.org/10.1016/j.jfoodeng.2017.09.015

761 Valenzuela, C., Tapia, C., López, L., Bunger, A., Escalona, V., & Abugoch, L. (2015). Effect of edible
762 quinoa protein-chitosan based films on refrigerated strawberry (Fragaria × ananassa) quality.
763 *Electronic Journal of Biotechnology*, *18*(6), 406–411. https://doi.org/10.1016/j.ejbt.2015.09.001

764 Vega-Ruiz, Y. C., Hayano-Kanashiro, C., Gámez-Meza, N., & Medina-Juárez, L. A. (2021). Determination
765 of chemical constituents and antioxidant activities of leaves and stems from jatropha cinerea
766 (Ortega) müll. arg and jatropha cordata (ortega) müll. arg. *Plants*, *10*(2), 1–13.
767 https://doi.org/10.3390/plants10020212

768 Wang, Y., Bian, W., Ren, X., Song, X., & He, S. (2018). Microencapsulation of clove essential oil

improves its antifungal activity against Penicillium digitatum in vitro and green mould on Navel oranges. *The Journal of Horticultural Science and Biotechnology*, *93*(2), 159–166. https://doi.org/10.1080/14620316.2017.1345332

Wang, Z., Zhou, Z., Fan, J., Zhang, L., Zhang, Z., Wu, Z., Shi, Y., Zheng, H., Zhang, Z., Tang, R., & Fu, B. (2021). Hydroxypropylmethylcellulose as a film and hydrogel carrier for ACP nanoprecursors to deliver biomimetic mineralization. *Journal of Nanobiotechnology*, *19*(1), 1–15. https://doi.org/10.1186/s12951-021-01133-7

Wu, T., McCallum, J. L., Wang, S., Liu, R., Zhu, H., & Tsao, R. (2013). Evaluation of antioxidant activities and chemical characterisation of staghorn sumac fruit (Rhus hirta L.). *Food Chemistry*, *138*(2–3), 1333–1340. https://doi.org/10.1016/j.foodchem.2012.10.086

Xu, G., Ye, X., Chen, J., & Liu, D. (2007). Effect of heat treatment on the phenolic compounds and antioxidant capacity of citrus peel extract. *Journal of Agricultural and Food Chemistry*, *55*(2), 330–335. https://doi.org/10.1021/jf062517l

Yang, Z., Zou, X., Li, Z., Huang, X., Zhai, X., Zhang, W., Shi, J., & Tahir, H. E. (2019). Improved Postharvest Quality of Cold Stored Blueberry by Edible Coating Based on Composite Gum Arabic/Roselle Extract. *Food and Bioprocess Technology*, *12*(9), 1537–1547. https://doi.org/10.1007/s11947-019-02312-z

Yi, T., Miller, A. J., & Wen, J. (2007). Phylogeny of Rhus (Anacardiaceae) based on sequences of nuclear Nia-i3 intron and chloroplast trnC-trnD. *Systematic Botany*, *32*(2), 379–391. https://doi.org/10.1600/036364407781179635

Yu, J. Y., Roh, S. H., & Park, H. J. (2021). Characterization of ferulic acid encapsulation complexes with maltodextrin and hydroxypropyl methylcellulose. *Food Hydrocolloids*, *111*, 106390. https://doi.org/10.1016/j.foodhyd.2020.106390

Zhao, W., Liu, Z., Liang, X., Wang, S., Ding, J., Li, Z., Wang, L., & Jiang, Y. (2022). Preparation and characterization of epigallocatechin-3-gallate loaded melanin nanocomposite (EGCG @MNPs) for improved thermal stability, antioxidant and antibacterial activity. *LWT*, *154*, 112599.

795 https://doi.org/10.1016/J.LWT.2021.112599

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Figures Captions

Fig. 1. SEM images of the developed microcapsules and their particle diameter distribution. A) MC-HPMC (T2); b) MC-RmA (T4); and c) MC-RmO (T8).

Fig. 2. FTIR spectra of free extracts and encapsulated extracts. a) HPMC powder; b) MC-HPMC; c) RmA; d) MC-RmA; e) RmO; f) MC-RmO.

Fig. 3. X-ray diffractograms (A) and TGA curves (B) of developed microcapsules. a) MC-HPMC; b) MC-RmA; and c) MC-RmO.

Fig. 4. Mean inhibition percentage of microcapsules containing RmA and RmO against (a) *F. oxysporum* and (b) *R. stolonifer*. Different uppercase letters indicate statistical differences between treatments in each concentration (p<0.05). Different lowercase letters indicate statistical differences between concentrations in each treatment (p<0.05).

Fig. 5. Influence of MC-RmA at different concentrations on strawberry fruits stored at 4±1 °C and 85 % HR. (a) Weight loss percentage, and (b) fungal decay percentage. Different uppercase letters indicate statistical differences between days for each treatment (p<0.05). Different lowercase letters indicate statistical differences between treatments in each day (p<0.05).

Fig. 6. Changes in color parameters of control (uncoated) and treated strawberries with MC-RmA at different concentrations and stored at 4±1 °C and 85 % HR. a) Chroma, b) Hue angle, c) redness.

Fig. 7. Appearance changes of strawberries treated with HPMC microcapsules containing RmA (0.25 and 0.50 %, w/v) and control, stored at 4±1 °C and 85 % HR.

Tables

Table 1.

Electrospraying testing conditions.

Treatment	Extract	Extract concentration (mg/mL)	Ethanol concentration (%, v/v)	Voltage (kV)
T1	Blank (HPMC)	3.0 %	50	10
T2	Blank (HPMC)	3.0 %	75	10
T3	RmA	1.0	50	16
T4	RmA	1.0	75	14
T5	RmA	2.5	50	18
T6	RmA	2.5	75	15
T7	RmO	1.0	50	19
T8	RmO	1.0	75	17
T9	RmO	2.5	50	25
T10	RmO	2.5	75	**

** The extract could not be solubilized.

Table 2.

Particle size and particle aspect ratio of selected samples.

Sample	Particle Size (μm)	PAR
MC-HPMC	2.31±0.62[a]	1.10±0.08[a]
MC-RmA	2.41±0.57[a]	1.08±0.07[a]
MC-RmO	2.05±0.50[b]	1.08±0.06[a]

Different letters in the same column indicate statistical differences (p<0.05).

Table 3.

Total phenolic content (TPC) and antioxidant capacity of HPMC microcapsules with and without RmA and RmO.

Assay	Treatment	Sample		
		MC-RmA	MC-RmO	MC-HPMC
TPC (mg GA/g MC)	Ultrasound	3.08±0.30[a]	0.51±0.08[b]	n.d.
	Agitation	2.94±0.39[a]	1.45±0.21[a]	n.d.
DPPH (mg/mL, %RSA)	Ultrasound	17.15±0.36[a]	3.61±0.77[b]	n.d.
	Agitation	16.52±0.39[a]	10.46±0.62[a]	n.d.
ABTS (mg/mL, %RSA)	Ultrasound	16.20±0.82[a]	2.87±0.74[b]	n.d.
	Agitation	15.24±1.35[a]	7.23±0.93[a]	n.d.
FRAP (mg AA/g MC)	Ultrasound	4.04±0.17[a]	0.52±0.09[b]	n.d.
	Agitation	3.99±0.92[a]	1.30±0.16[a]	n.d.

Different uppercase letters in the same row indicate statistical differences (p<0.05) between release treatments for each assay.

n.d. not detected.

Figures

Fig. 1.

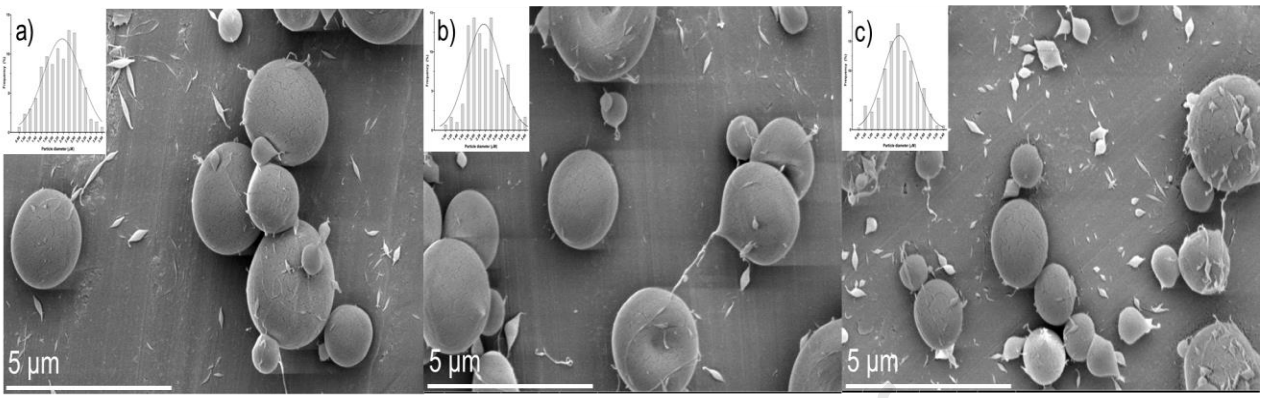


Fig. 2.

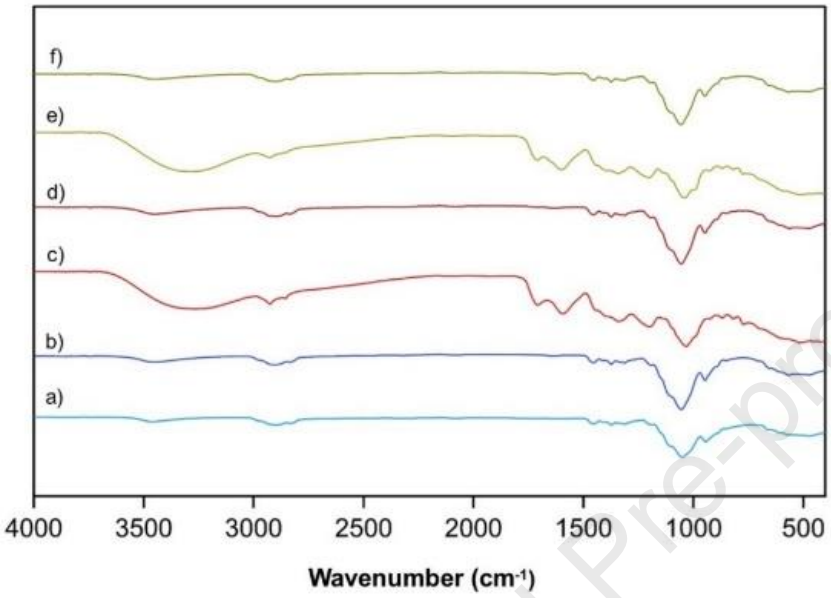
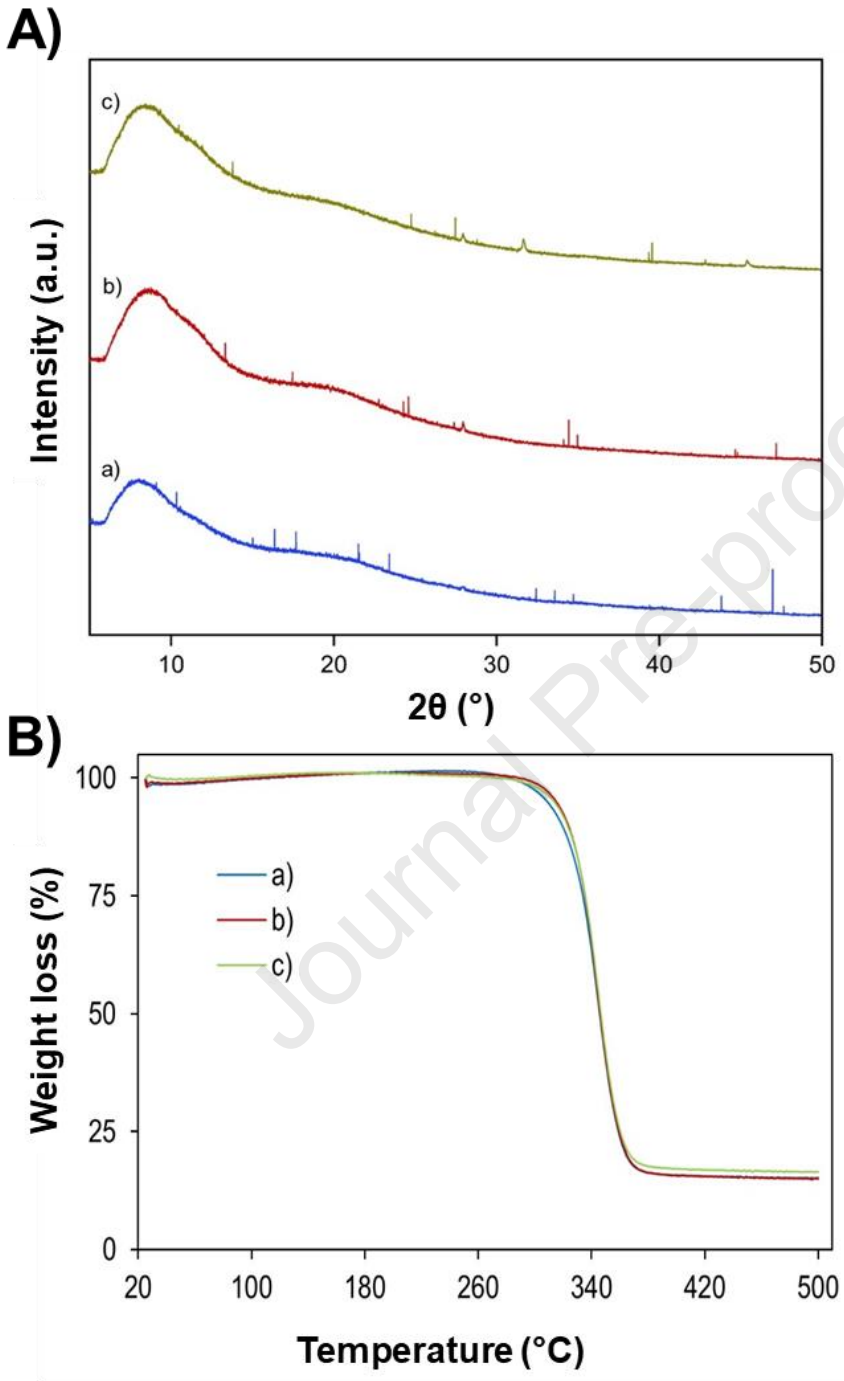


Fig. 3.



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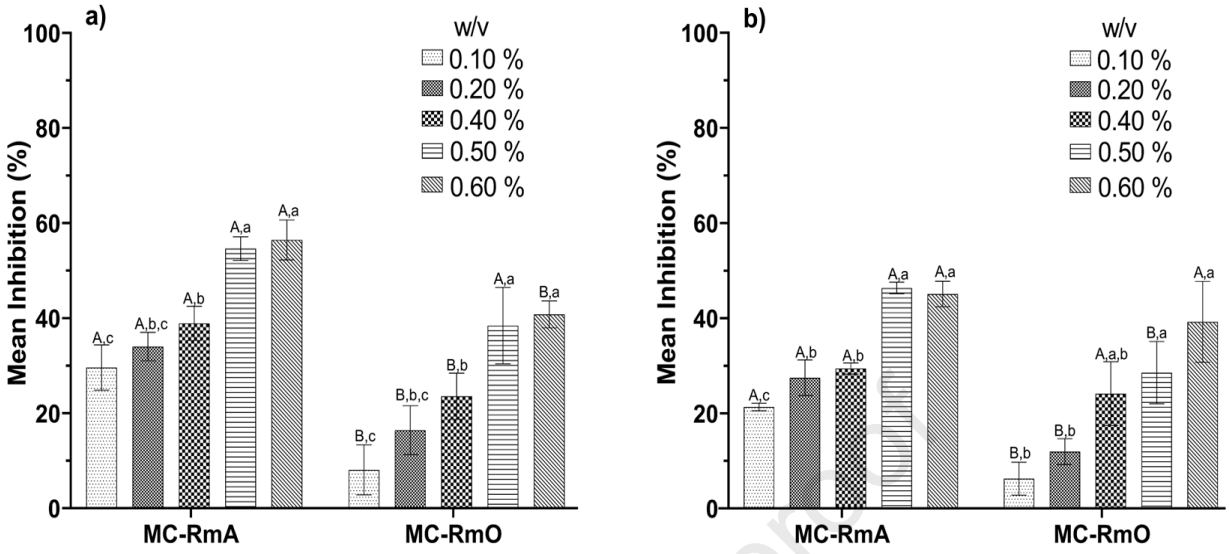

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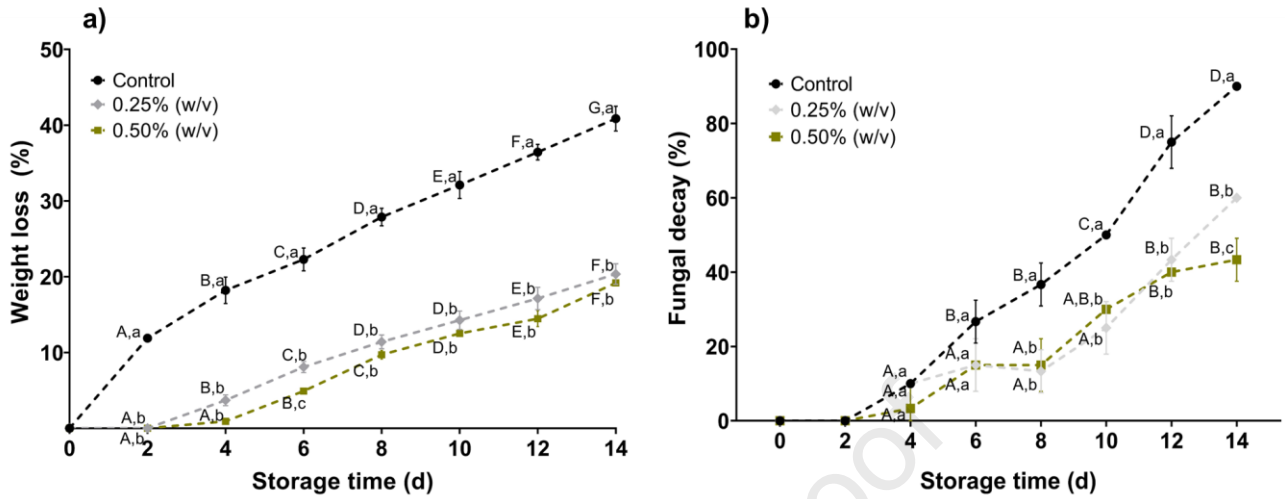


Fig. 6.

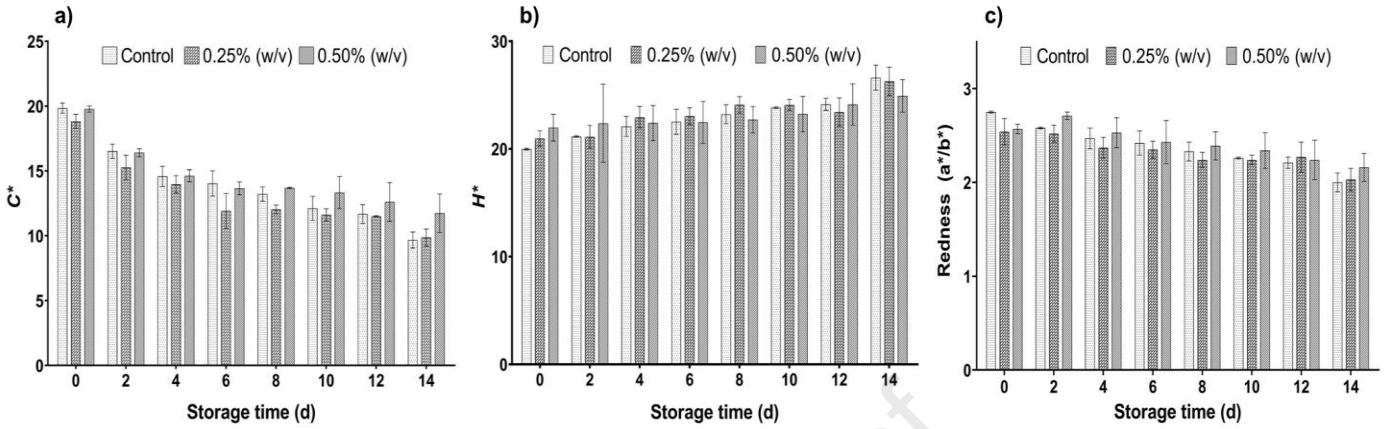
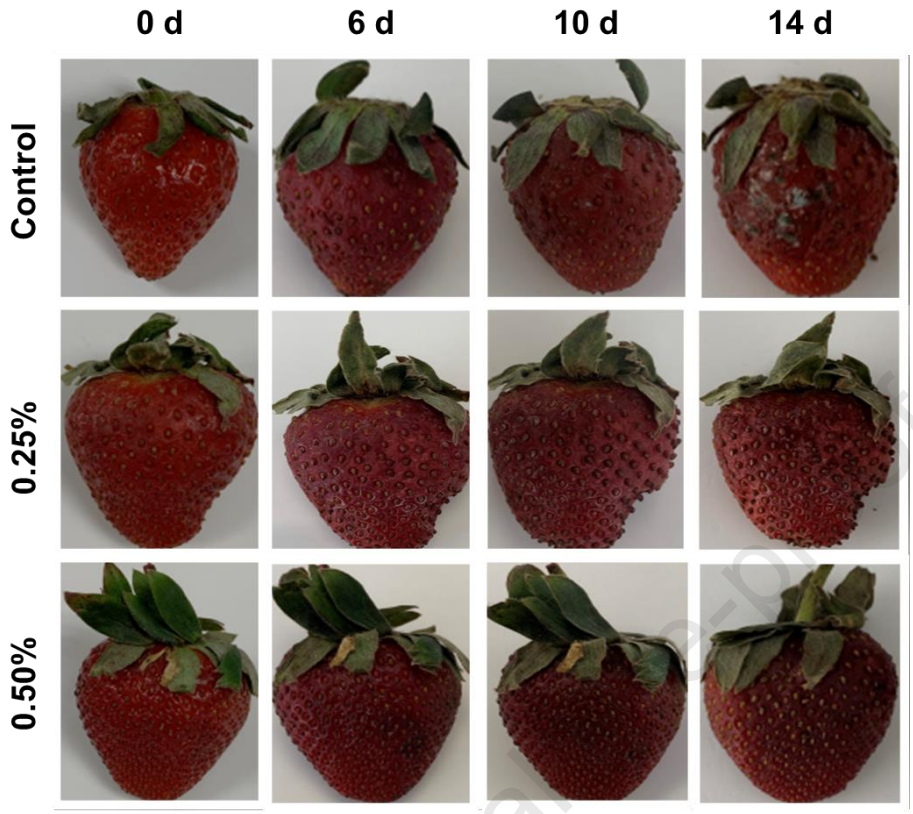


Fig. 7.



Highlights

- Spherical-microcapsules with *R. microphylla* extracts were obtained by electrospray
- HPMC and electrospray enabled extract incorporation into microcapsules
- Functionalized microcapsules delay fungal decay and weight loss in strawberries
- Microcapsules with *R. microphylla* extracts are a novel postharvest technology

Conflict of Interest Statement

The authors declare that there is no conflict of interest.