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# Effect of Nano-Edible Coating Based on Beeswax Solid Lipid Nanoparticles on Strawberry's Preservation

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**Abstract:** Edible nano-coatings were applied in strawberry with the end goal of preserving quality by 21 days of storage at 4 °C. The beeswax solid lipid nanoparticles (BSLN) were prepared by high-energy homogenization, BSLN had a monomodal dispersion with average particle sizes of 214–227 nm and zeta potential of -30 mV. Four coatings were tested: 0, 10, 20, and 30 g/L of BSLN dispersion, all these edible coatings contained xanthan gum (XG) (3 g/L) and propylene glycol (5 g/L) and contrasted with strawberries without any treatment. The best behavior was achieved with 10 g/L of BSLN showing the lowest weight loss (6.1%), a decay index of (31%), loss of firmness (34%), and  $\Delta E = 11$ . It was established that a concentration of 30 g/L of BSLN caused physiological damage. Based on the findings found, it can be said that nano-coatings with 10 g/L of BSLN-XG are an excellent alternative in the conservation and to increase of shelf life of strawberry stored in refrigeration. In the present case, it was 10 g/L of BSL. Highlighting the importance to evaluate the best concentration in relation to the fruit characteristics.

Keywords: nanotechnology; xanthan gum; decay index; firmness; color

# 1. Introduction

Strawberry (*Fragaria ananassa*) it is a non-climacteric fruit with high consumer preference; however, it is a highly perishable product with a short post-harvest life, mainly due to its high metabolic activity and susceptibility to microbial growth, reasons indeed to seek alternative ways to increase shelf life [1].

Edible coatings reduce the respiration rate, retain firmness, and control microbial growth when used to preserve fruits, they are applied directly on the surface forming a thin membrane, invisible to the naked eye [2,3]. The development of edible coatings involves the use of polysaccharides, proteins, and lipids, or combinations of these [4,5]. These have been studied with the finality of increasing the shelf life of strawberries include carboxymethyl cellulose (CMC), pullulan, pectin, chitosan, some of them nanostructured with active substances like essential oils, propolis, aloe vera, etc. [6–11].

Xanthan gum (XG) is a natural microbial extracellular polysaccharide produced by *Xanthomonas campestris*, is stable to acid, salt, and extreme temperature conditions [12]. An approach to improving the water barrier properties of the films is to produce a composite film with lipid. Beeswax is a



complex mixture of saturated and unsaturated linear and complex monoesters, hydrocarbons, free fatty acid, free fatty alcohols, and other minor substances produced by the worker honeybee. Solid lipid nanoparticles (SLN) are the new generation of nanocarriers of active substances for controlled release and protective systems because they remain solid at room temperature [13]. SLN consist of the lipid phase dispersed and stabilized in a continuous water phase using surfactants.

Recently, their usefulness was tested as a coating for the preservation of guava fruit in a study which showed that the concentration of candelilla wax SLN added to a polysaccharide matrix is a key factor [14]. However, coatings containing SLN have not yet been explored in relation to strawberry preservation. The objective of this study was to evaluate the effect of beeswax SLN (BSLN) on the effectivity in the quality preservation of strawberries.

Among the recent findings in strawberry bioconservation with the use of edible coatings are coatings based on CMC (5%) and bacteriocins produced by Bacillus methylotrophicus strain BM47 (0.15 mg / mL) which led to a significant decrease in decomposition in addition to the effective decrease mushroom [15]. Technological advances where solid lipid nanoparticles are used in edible coatings were conducted by González-Reza et al. (2018) [16] in fresh cut guava where the coating based on xanthan gum (3 g/L) and SLN (5 g/L) improved the retention of firmness and decreased the browning index of the samples during 22 days of refrigerated storage.

Another application of SLNs in edible coatings is that carried out by Miranda-Linares et al. (2018) [17] in tomato 'Saladette'. The coating based on xanthan gum (3 g/L) and SLN (10 g/L) showed the most homogeneous changes in the firmness and concentration of lycopene, pH and °Bx during the storage time in refrigeration at 12 °C.

## 2. Materials and Methods

#### 2.1. Materials

Polyvinyl alcohol (Mowiol<sup>®</sup> 4-88, Mw  $\approx$  31,000), xanthan gum from Xanthomonas campestris and Propylene glycol were obtained from Sigma-Aldrich (Estado de México, State of Mexico, Mexico). Beeswax (melting point 64–66.5 °C) was purchased at Multiceras<sup>®</sup>, S.A. de C.V. Distilled water was attained with MilliQ<sup>®</sup> equipment. All other chemical agents were analytical quality and used without further purification.

#### 2.2. Strawberries

A 30 kg lot of strawberries (Fragaria ananassa) cv. Camarosa was purchased in a local Central Market from Tultilán, State of Mexico, Mexico. The berries were at maturity stage 5 when the red color covered 75% of the fruit surface, the fruits selected had uniform maturity, shape, size, and color, and were free of mechanical damage and contamination by mold. They were washed and disinfected and then randomly separated into five batches, four with coatings, and a control sample.

#### 2.3. BSLN Preparation

BSLN were prepared using the hot high-stirring shear method [18]. The oily phase consisted of 100 g/L of beeswax melted at 75 °C. Separately, distilled water was heated to the same temperature. The stabilizer Mowiol<sup>®</sup> 4–88 (50 g/L) was added to the water. The oily phase was then dispersed into the aqueous phase under high stirring shear (IKA Ultra-Turrax T5; Klkalbor Technik, Königswinter, Germany, equipped with a disperser element S25N-25G) to obtain oil-in-water nanoemulsions at 1047.2 s<sup>-1</sup>/10 min for 3 cycles with 5 min of repose between cycles. Finally, solid lipid nanoparticles were obtained by cooling the dispersion at room temperature to allow formation.

#### *2.4.* Determination of Particle Size (PS), the Polydispersion Index (PDI), and Zeta Potential ( $\zeta$ )

PS and PDI were determined by the laser light scattering technique at a 90° fixed angle and temperature of 25 °C using a Z-sizer 4 (Zetasizer Nano Series Malvern Ltd., Grovewood Road, Malvern,

UK). The dispersions were diluted in Milli-Q<sup>®</sup> water according to the volume frequency histograms. The  $\zeta$  was estimated using a Z-sizer 4 at 90° (Zetasizer Nano Series Malvern Ltd., Grovewood Road, Malvern, UK). Values were normalized with polystyrene standard dispersion ( $\zeta = -55$  mV) and measurements were made at 25 °C in triplicate [19].

# 2.5. Scanning Electron Microscopy (SEM)

Morphological analysis of the BSLN was performed with one drop of the diluted suspension (0.1 mL to 10 mL) dried under vacuum conditions at room temperature. They were placed on stubs and coated (Coater<sup>®</sup> JFC-1100 JEOL, Tokyo, Japan) with gold (~20 nm thickness). Finally, the samples were observed under a scanning electron microscope (JSM-6400<sup>®</sup> SEM JEOL, Tokyo, Japan). For the observation of the nano-coatings on the strawberry, the methodology proposed by Zambrano-Zaragoza et al. (2014) [20]. Each portion with different BSLN treatments was placed on a slab and analyzed by SEM according to the technique described above.

## 2.6. Preparation of the Film-Forming Dispersions

All formulations contained 4 g/L of xanthan gum (XG) and 5 g/L of propylene glycol (PG), moreover, film-forming dispersions with beeswax solid lipid nanoparticles (BSLN) at different concentrations were prepared using 0 g/L of BSLN, 10 g/L of BSLN (10BSLN), 20 g/L of BSLN (20BSLN), and 30 g/L of BSLN (30BSLN).

# 2.7. Coating Application on Strawberries

The strawberries were coated by dipping in the film-forming dispersions for 1 min. They could drain for 15 min at room temperature and then packed in polyethylene clamshells. The packaged samples were refrigerated for 21 days at 4 °C and 85% relative humidity in clamshells with 15 strawberries each. All treatment was compared with samples control with any coating. All tests were performed in triplicate.

## 2.8. Oxygen Consumption

The effect of the coatings on the O<sub>2</sub> consumption rate was determined by the static method [21]. Briefly, strawberries of known weight were placed inside 170 mL glass bottles and the bottles were sealed. Samples of headspace gas were drawn with a needle inserted into a septum placed in the top of the container and connected to an oxygen analyzer (Quantek<sup>®</sup> Instruments model 905, Magil Drive Grafton, MA, USA). This behavior was monitored every third day at 21 days. The O<sub>2</sub> consumption rate (RO<sub>2</sub>) was expressed as,

$$RO_{2} = \frac{(y_{i}O_{2} - yO_{2})}{(t - t_{i})} * \frac{V_{f}}{W}$$
(1)

where  $y_iO_2$  and  $y_O2$  are, respectively, the  $O_2$  concentration in the gas mixture at time  $t_i$ —any time except time zero expressed in hours—while  $RO_2$  is the respiration rate; W is the weight of the strawberries (kg), and  $V_f$  is the free volume inside the container.

## 2.9. Skin Color Development

A colorimeter (Model CR-300, Konica Minolta Corp, Tokyo, Japan) was used to measure the apparent color of the samples in terms of  $L^*$ ,  $a^*$ , and  $b^*$ . The color was recorded on two different equatorial sides during the storage period in triplicate to measure hue angle, chroma, and total color difference ( $\Delta E$ ). Parameters were calculated using the equations,

$$h^{\circ} = \frac{180}{\pi} * \tan^{-1} \left( \frac{a^*}{b^*} \right) \tag{2}$$

$$C = \sqrt{(a^{*2} + b^{*2})}$$
(3)

$$\Delta E^{*} = \sqrt{\left(L^{*} - L_{0}^{*}\right)^{2} + \left(a^{*} - a_{0}^{*}\right)^{2} + \left(b^{*} - b_{0}^{*}\right)^{2}}$$
(4)

where  $h^{\circ}$  is the hue angle (in degrees), C is the chroma value,  $a^*$  is the change from redness to greenness, and  $b^*$  the change from yellowness to the blueness of the sample.

#### 2.10. Firmness Measurement

The firmness of the strawberries was measured every third day up to day 21, using an INSTRON 4411 equipped with a 50-N load cell, with a fixed, 6 mm-thick (Instron, Mass., Norwood, MA, USA). Five fruits were longitudinally divided into two equal parts before the test. Each sample was fractured by a downward motion using a velocity of 150 mm/min to measure the maximum force required to penetrate 5 mm into the fruit. This measurement was taken to represent the firmness index [1]. These tests were performed in quintuplicate.

#### 2.11. Physical and Chemical Changes

The weight loss percentage relative to initial weight was calculated by monitoring samples every 3 days in triplicate. The juice from five strawberries was extracted from the containers for each sample and used to measure total soluble solids (TSS) using an ABBE refractometer (Spectronic, Inc., Mobil, AL, USA). Titratable acidity was ascertained by titration with 0.1 N NaOH at pH 8.1 and expressed as ascorbic acid (mg).

#### 2.12. Juiciness

Juiciness was determined by extracting the juice from five strawberries, weighing it and measuring the volume by using a pipette to obtain a volume-weight ratio according to the following relation [22].

Juiciness : 
$$\left(\frac{\text{g juice} - \text{mL juice}}{\text{mL juice}}\right)$$
 (5)

#### 2.13. Decay Index

Each strawberry was visually examined at 3-day intervals throughout the storage period. Surface mycelia development and bacterial lesions were considered signs of decay. A 1–5 scale was applied to each treatment group as follows: 1 = normal (no decay on fruit surface); 2 = trace (up to 5% of fruit surface with decay); 3 = slight (5–20% of fruit surface with decay); 4 = moderate (20–50% of fruit surface with decay); and 5 = severe (>50% of fruit surface with decay). Results were expressed as the fungal decay index [9].

$$DI = \frac{\sum (\text{degree of damage}) * (\text{no.of fruits with this degree})}{\text{total number of fruits}}$$
(6)

#### 2.14. Statistical Analysis

Results were analyzed using the statistical analysis software MINITAB<sup>®</sup> Release 17 to determine the effect of the SLN concentrations on the coating composition and average particle droplets, decay index, firmness, and juiciness. Differences among treatments were measured as a function of variation with respect to the mean by performing an ANOVA and Tukey tests ( $\alpha = 0.05$ ).

# 3. Results and Discussion

# 3.1. Characterization of SLN with Beeswax

SLN dispersions used in the nano-edible coatings had nanometric sizes with values between 214 and 227 nm. The distribution of the BSLN in the polymer dispersion results in a slight decrease in particle size but the effect was not statistically significant ( $\alpha = 0.05$ ) of 227 ± 10 to 214 ± 3 nm.  $\zeta$  not showing a statistically significant difference was found by adding XG to the formulation, with values of  $-29.73 \pm 0.51$  at  $-33.86 \pm 3.30$  mV. The negative charge is attributed to the functional groups present in the Mowiol<sup>®</sup> 4-88. Based on the potential values obtained for all coatings, it is possible to assume that the dispersions are stable systems with no effect on BSLN content in the film-forming dispersion and no apparent aggregation due to the change in the surface charge [14,23].

# 3.2. Morphological Studies

Figure 1 shows the micrographs taken of the initial BSLN suspension and 10 g/L of BSLN applied to the fruit surface. Figure 1a reveals the presence of spherical nanoparticles with a particle size that matches the light scattering method. It was difficult to observe individual particles because, apparently, the sample preparation provoking aggregation. Figure 1b presents the distribution of the 10 g/L of BSLN coating on the tissue surface, showing that it was uniform with no aggregation in the film.



**Figure 1.** Micrographs of BSLN: (**a**) dispersion of 100 g/L BSLN, and (**b**) dispersion 10 g/L of BSLN on the fruit surface.

# 3.3. Respiration Rate as Function Treatment

The strawberries coated with the suspension 10 g/L of BSLN showed the lowest consumption oxygen rate after 21 days of  $12.92 \pm 1.56$  mL O<sub>2</sub>/kg h. The second-lowest respiration rate was observed for the strawberries coated with 20 g/L of BSLN, with rates of  $14.83 \pm 0.98$  mL O<sub>2</sub>/kg h. The strawberries coated with 30 g/L of BSLN had the highest O<sub>2</sub> consumption ( $16.45 \pm 1.12$  mL O<sub>2</sub>/kg h) while the control samples and XG showed no statistically significant difference in their behavior during the storage period with  $20.29 \pm 1.58$  mL O<sub>2</sub>/kg h. Generally, changes in the respiration rate of strawberries has been attributed to the changes found due to a modified atmosphere. Barrios et al. (2014) [24], reporting values of 18.6 mL O<sub>2</sub>/kg h in strawberries at  $10 \,^{\circ}$ C, and 8.45 mL O<sub>2</sub>/kg h in a modified environment, causing a reduction of 54.56% in the respiration rate. In our study, the reduction was 57.04% when the BSLN coating was used, highlighting the effectiveness of the 10 g/L of BSLN. Also, Eshghi et al. (2014) [25] studied the effect of chitosan nano-coatings with and without copper and found maximum respiration values of 4 mL/kg h after 8 days when the product was not covered, and 40 mL/kg h after

21 days when it had the chitosan coating, regardless of the addition of copper. It can be assumed that adding BSLN forms a modified atmosphere on the fruit's surface, while lipid phase permeability modifies the surface properties, and the submicron size helps promote a considerable slowing of the respiration rate.

# 3.4. Color Development

Figure 2a shows minimal changes in the hue angle for strawberries treated with 10 g/L of BSLN, but a significant decrease beginning on day 15. This rate indicates an increase in red of 8.3% at day 15, 28% on day 18, and 32.7% at the end of storage. The color of the strawberries coated with a dispersion containing 20 g/L of BSLN remained constant until 6 days of storage and a decrease of 36.68% after 12 days, suggesting that this coating was less effective in preserving the color of the strawberries and exhibited a more intense red tone associated with a loss in color quality for a total change of 75% in color compared to the initial condition [26].

On the other hand, the samples coated with the 30 g/L of BSLN had a considerable color change after 6 days of storage. This showed that the use of 30 g/L of BSLN does not contribute to preserving product quality. These results indicate that particle size and the concentration of the polysaccharide supporting BSLN are important since their aggregation and formation significantly modify the atmosphere on the product's surface. Chromaticity for the different treatments, demonstrating that strawberries coated with 10BSLN remained more vividly-colored as the chroma presented no statistically-significant differences ( $\alpha = 0.05$ ) after 12 days of refrigerated storage, according to the ANOVA performed on storage time, though values decreased 21 days later.

Figure 2b shows the total color difference for the treatments. Strawberries coated with 10BSLN had minor changes as  $\Delta E$  was <5 up to 12 days of storage. This is indicative of minimal changes in the fruit, though change increased after 12 days, with  $\Delta E > 11$  at until the end. The samples with 20 g/L of BSLN and 30 g/L of BSLN showed greater variation in  $\Delta E$  from the beginning of storage, which rose to >6 after 3 days. The effectiveness of coatings on strawberries was studied by Nadim et al. (2015) [9], who reported that  $\Delta E$  did not increase beyond 7 units using CMC at a concentration of 3%. This suggests that the use of a coating with 10 g/L of BSLN contributes to decreasing  $\Delta E$  during storage. Moreover, [26] reported  $\Delta E$  values of 6–7 units for strawberries coated with chitosan and mentioned that these values are within the range of color tolerance. In another study where an emulsion containing whey protein isolate and maltodextrin, was applied to strawberries and was found that  $\Delta E$  of control was found 16.02, while dip-coated samples were between 2.84 and 11.09 and electrospray-coated samples were between 13.51 and 20.14 similar to control samples at 5 days of storage [6]. In this study, the changes like control were found after 12 days of storage, indicating that this is achieved by increasing the shelf-life of product.



**Figure 2.** Changes in color parameters of strawberries at 4 °C: (**a**) changes in hue angle; (**b**) Total color difference ( $\Delta$ E). Control,  $\Rightarrow$  XG,  $\approx$  10BSLN,  $\Rightarrow$  20BSLN,  $\Rightarrow$  30BSLN. Error bars represent the standard deviation of the triplicate results.

#### 3.5. Firmness and Decay Index

Figure 3a shows variations in firmness. At the beginning of the study, observations showed that samples needed an average of 16.6 N and that this was not affected by the composition of the coating. Puncture force decreased by 49.6% in the samples coated with 30 g/L of BSLN, indicative of a negative effect on fruit quality. Control samples had the highest loss of firmness with 38.37% at 6 days. After that, they presented a variable trend until moisture loss caused an increase in hardness. In contrast, the samples coated with XG had the lowest resistance after 15 days, when they had lost 65% of their strength. At that point, firmness increased due to the hydrophilic nature of the xanthan gum and its ability to foster mold development. The samples with the best firmness were those coated with 10 g/L of BSLN, with a loss of 34.93% after 21 days. The behavior of the samples with 10 g/L of BSLN was similar to that reported by Eshghi et al. (2014) [25], who observed that the use of chitosan nanocoatings with copper added on strawberries, had a loss in texture of 33.3% after 21 days of storage; suggesting that the use of submicron-size systems contributes to controlling firmness with the advantages that BSLN are natural ingredients.

Figure 3b shows the rate of decay of the strawberries due to the fungal growth. Controls had a rapid decay with 40% decay after 6 days, while the samples treated with 10 g/L of BSLN had the lowest rate of decay (21%) after 21 days, showed that using of BSLN contribute to decrease the fungal contamination compared with other studies that used aloe vera- and starch-chitosan as coatings obtaining control the decay (20%) at 14 days [27]. The strawberries coated with XG failed to increase storage time in relation to the decay rate because this treatment generated an environment that contributed to mold development, which significantly reduced product quality. In this regard, we can suggest that the concentration of BSLN influences surface changes. These are due to the interaction of the lipid with the cell wall of the fruit that produces an antimicrobial effect [8].



**Figure 3.** Changes in of strawberries during storage as a function of coating with respect to control (a) firmness; 10 g/L of BSLN, 20 g/L of BSLN, 30 g/L of BSLN, Control, XG; and (b) decay index Control, XG, T10BSLN, 20BSLN, 30BSLN. Error bars represent the standard deviation of the triplicate results.

# 3.6. Physicochemical Changes

Table 1 summarizes the results for physicochemical changes during storage. It highlights that the control samples had a weight loss of 20% at the 21 days of storage, while the coating with the lowest weight loss was 10 g/L of BSLN with losses below 7% at 21 days. This concentration contributed greatly to improving the parameters associated with environmental conditions on the fruit surface due to the incorporation of a solid lipid phase of submicron size and the use of a polysaccharide matrix that exerts a synergistic effect. The use of a XG coating helped reduce weight loss compared to control samples. Gol et al. (2013) [28] reported weight losses in strawberries of 6.89–9.38% after 12 days of storage at 1 °C when a coating based on CMC, chitosan, or a combination of the two.

Coating	Days	Weight Loss (%)	Juiciness (%)	pН	SSC	TTA (%)
10BSLN	0	$0.00 \pm 0.00$	$59.58 \pm 1.84$	$3.83 \pm 0.06$	$7.97 \pm 0.64$	$0.29 \pm 0.05$
	3	$0.89 \pm 0.038$	$59.72 \pm 1.56$	$3.70\pm0.10$	$7.67 \pm 0.51$	$0.22 \pm 0.03$
	9	$1.96 \pm 0.034$	$60.61 \pm 2.69$	$3.87 \pm 0.12$	$7.70\pm0.98$	$0.20\pm0.09$
	15	$3.53 \pm 0.03$	$56.94 \pm 3.05$	$3.43 \pm 0.06$	$7.40 \pm 0.39$	$0.25\pm0.03$
	21	$6.15 \pm 0.57$	$32.33 \pm 2.22$	$3.43 \pm 0.06$	$8.47 \pm 0.29$	$0.19\pm0.02$
20BSLN	0	$0.00 \pm 0.00$	$64.44 \pm 4.57$	$3.33 \pm 0.15$	$7.20 \pm 1.04$	$0.25\pm0.04$
	3	$2.22 \pm 0.22$	$60.45 \pm 1.81$	$3.67 \pm 0.06$	$7.60\pm0.45$	$0.23\pm0.04$
	9	$3.38 \pm 0.59$	$54.79 \pm 1.79$	$3.80 \pm 0.10$	$7.37 \pm 0.55$	$0.24\pm0.06$
	15	$6.44 \pm 0.41$	$43.03 \pm 4.06$	$3.60 \pm 0.26$	$8.33 \pm 0.06$	$0.26 \pm 0.02$
	21	$9.71 \pm 0.21$	$25.31 \pm 1.96$	$3.37 \pm 0.06$	$8.43 \pm 0.45$	$0.26\pm0.02$
30 BSLN	0	$0.00\pm0.00$	$61.94 \pm 2.17$	$3.20\pm0.10$	$6.67\pm0.12$	$0.28\pm0.07$
	3	$2.20 \pm 0.25$	$51.98 \pm 8.10$	$3.83 \pm 0.26$	$8.43 \pm 0.81$	$0.30\pm0.06$
	9	$4.28 \pm 1.08$	$37.55 \pm 13.51$	$3.70 \pm 0.06$	$8.50\pm0.44$	$0.30\pm0.01$
	15	$13.33 \pm 2.13$	$28.97 \pm 5.02$	$3.97 \pm 0.10$	$8.57 \pm 0.25$	$0.31 \pm 0.03$
	21	$17.21 \pm 0.35$	$24.32 \pm 1.18$	$3.10\pm0.12$	$8.47\pm0.15$	$0.43 \pm 0.02$
CONTROL	0	$0.00 \pm 0.00$	$61.30 \pm 5.80$	$3.10 \pm 0.10$	$7.40\pm0.12$	$0.42\pm0.08$
	3	$3.41 \pm 1.27$	$59.87 \pm 3.95$	$3.03\pm0.15$	$7.83 \pm 0.72$	$0.30\pm0.02$
	9	$2.78\pm0.19$	$34.53 \pm 2.61$	$3.87\pm0.06$	$8.00\pm0.98$	$0.24\pm0.04$
	15	$11.54 \pm 3.21$	$23.02 \pm 1.73$	$3.70\pm0.06$	$8.20\pm0.10$	$0.16\pm0.02$
	21	$19.85 \pm 2.23$	$24.36 \pm 3.70$	$3.70 \pm 0.25$	$8.17\pm0.06$	$0.14\pm0.03$
XG	0	$0.00 \pm 0.00$	$59.24 \pm 0.97$	$3.57 \pm 0.06$	$7.33 \pm 0.70$	$0.30\pm0.08$
	3	$1.62 \pm 0.35$	$53.05 \pm 1.21$	$3.67\pm0.10$	$8.50 \pm 1.04$	$0.32\pm0.03$
	9	$7.89 \pm 0.41$	$49.35 \pm 1.57$	$3.10\pm0.10$	$8.33 \pm 0.58$	$0.44 \pm 0.02$
	15	$13.78\pm0.49$	$35.24 \pm 2.40$	$3.60\pm0.06$	$8.90 \pm 0.36$	$0.25\pm0.03$
	21	$16.73 \pm 1.98$	$25.85 \pm 1.09$	$3.53\pm0.06$	$8.13 \pm 0.21$	$0.26\pm0.04$

**Table 1.** Physicochemical changes in strawberries stored at 4 °C as a function of SLN content on the coating with a continuous matrix of xanthan gum.

Table 1 also shows changes in the juiciness of the strawberries. Samples with 10 g/L of BSLN kept their juiciness with no statistically significant difference (p < 0.05) during 15 days of storage. Samples coated with 30 g/L of BSLN and control samples had the highest loss of juiciness. The XG contributed to reducing the loss of juiciness up to 9 days of storage compared to controls. This effect is intensified when BSLN are incorporated. Hussain et al. (2012) [29], reported weight losses between 3% and 7% after 12 days of storage in strawberries coated with different concentrations of CMC also treated with gamma radiation; while in our study the results were achieved without additional treatment and Martínez-González et al. (2020) [30], achieved a control of weight loss over 8 days when employing nanoparticles of chitosan and propolis with a weight loss of 9.7%, which shows that possible to agree that the use of a small proportion of BSLN (10 g/L) was more effective. Changes in pH, SSC, and acidity are associated with weight loss in all systems. The samples that showed the smallest variations were 10 g/L of BSLN. pH decreased slightly in all treatments, consistent with the study by [31], who reported a pH of 3.86–3.27 during the storage of strawberries coated with chitosan. The slight decrease that occurred in SSC was attributed to the respiration process [28].

# 4. Conclusions

The BSLN obtained by the rotor/stator method were sub-micron size, spherical in shape, stable, and compatible with xanthan gum. The coating with 10 g/L of BSLN, 4 g/L of xanthan gum, and 5 g/L of propyleneglycol contributed positively to preservation while also decreasing decay rates; reflected in less fungal growth, weight loss, and physiological damage to the end of storage. The strawberries with 30 g/L of BSLN suffered physiological damage due to the modified atmosphere that formed and limited oxygen diffusion and water loss through transpiration that, in turn, caused an accumulation of beeswax that limited respiration.

The use of sub-micron size systems with larger surface areas has a positive effect on preserving product quality and is a key issue in determining the optimum concentration, which is dependent on such attributes as the respiration rate, water content, and physicochemical structure of individual fruits.

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