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# EDIBLE COATINGS BASED ON BEESWAX AND SHELLAC EFFECTIVELY PRESERVE CHAYOTE (*Sechium edule* (Jacq.) Sw. var. *virens levis*) FRUITS DURING STORAGE

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## ABSTRACT

Edible coatings are used to maintain overall quality and extend the shelf-life of fruit after harvest. The objective of this research was to evaluate the effect of edible coatings based on beeswax and shellac on the postharvest quality of fresh chayote [*Sechium edule* (Jacq.) Sw. var. *virens levis*] stored for 0, 8, 16, 24, and 32 days at 7 °C. The experiment was conducted with a completely randomized design with mixed effects and three replicates. Physicochemical analyses were carried out for color, texture, acidity, pH, weight loss, and $CO_2$ concentration. The applied coatings stabilized the physicochemical properties and reduced the weight loss percentage (1.8 to 3.4 %) of the chayotes during the storage period without creating an adverse effect compared to the control (4.1 %). The most effective coating (treatment 6) had the highest concentration of beeswax and the lowest concentration of shellac, forming an effective barrier against gases and water vapor.

**Keywords:** color, weight loss, respiration rate, Hydroxypropyl methylcellulose.

## INTRODUCTION

Mexico is one of the world's leading exporting countries of chayote (*Sechium edule* (Jacq.) Sw.), along with Costa Rica, Brazil, and the Dominican Republic (Rojas-Sandoval, 2018). Veracruz is the Mexican state with the largest chayote production (156 519.53 Mg annually) (SIAP, 2016). The commercial exploitation of this fruit is affected by microorganisms, mechanical damage, and natural decay processes such as dehydration, weight loss, wilting, and sprouting symptoms (del Ángel-Coronel *et al.*, 2018). These factors lead to economic losses and increased prices for the fruit.

During postharvest, chayote fruits may present defects and undergo natural deterioration processes. Dehydration is reflected in weight loss and changes in

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appearance. To delay this, it is recommended to process at low temperatures ranging from 8 to 10 °C. However, temperatures below 7 °C can cause chilling injury, resulting in pitting, dark depressions in the skin, dehydration, and necrosis (Cadena-Iñiguez *et al*., 2006). Additionally, exposure to ethylene can promote vivipary and premature senescence (Khan *et al*., 2024). Common problems in fruit production include lack of color or sheen in the epidermis, white spots from shading, twin-fused fruit, bruising (mechanical damage), sunburn, improper shape and size, and leaf spotting (GISeM, 2011).

Chayote fruit is susceptible to rubbing, compression, and impact during postharvest and transport due to its thin epidermis. These wounds make the fruit vulnerable to attack by microorganisms such as *Didymella bryoniae*, *Fusarium oxysporum*, *F. solani*, and *Chaetomium globosum*, which cause rotting symptoms in the epidermis and mesocarp (Romero-Velazquez *et al*., 2015).

A common preservation technique in packing houses is to individually wrap chayote fruits in a polyethylene bag to prevent mechanical damage and extend their shelf-life. However, brokers have rejected the product due to the presence of fungal diseases caused by the high humidity conditions inside the plastic packaging. Furthermore, the use of this material significantly contributes to environmental pollution. An alternative to polyethylene bags is the use of edible coatings (ECs) that adhere to and wrap around the product, creating a semi-permeable barrier to gases ($O_2$ and $CO_2$) and water vapor (Mohamed *et al*., 2020).

After harvest, horticultural products undergo metabolic processes such as respiration, transpiration, growth, ripening, and senescence. Edible coatings can be used to partially or completely halt these processes, including the application of natural preservatives that do not harm the health of consumers (García-García and Searle, 2016) or the environment. These preservation techniques allow obtaining good-quality products and extending the shelf-life of the fruit. ECs are mainly based on proteins, lipids, and polysaccharides; these additives are biodegradable, food-grade products, and are considered safe for human consumption (Nawab *et al*., 2017).

Polysaccharides provide structure to the fruit (exocarp) and allow gas permeability ($O_2$ and $CO_2$). They are flexible film formers, do not emit odor, and are tasteless, colorless, biodegradable, and water-soluble. However, they are considered inefficient against fruit moisture (Arnon *et al*., 2014; Danalache *et al*., 2016). On the other hand, lipids confer resistance to water vapor and provide greater gloss in coated fruits (Nawab *et al*., 2017). Both compounds provide ECs with good functional properties for the product and contribute to extending the shelf-life of the fruits. Among the most commonly used ingredients for the production of ECs are beeswax and shellac; the former forms a good barrier against moisture, and the latter provides firmness and improves gas permeability (Byun *et al*., 2012).

The objective of this study was to evaluate the effect of edible coatings based on beeswax-shellac on the postharvest quality of fresh chayote (*S. edule* var. *virens levis*). The hypothesis is that edible coatings based on beeswax and shellac will effectively stabilize the physicochemical properties of fresh chayote and reduce weight loss during cold storage, with higher concentrations of beeswax providing better preservation of quality and shelf-life by forming a more effective barrier against gas exchange and water vapor loss.

## MATERIALS AND METHODS

Chayote (*Sechium edule* (Jacq.) Sw. var. *virens levis*) samples were collected from the producing area of the municipality of Coscomatepec, Veracruz, Mexico. The criteria for selecting fruit samples were uniformity in maturity, green color, and size, in accordance with the NMX-FF-047-SCFI-2003 Standard (DOF, 2003). The fruits were stored in a refrigerator with a transparent glass door at 7 °C and 60 % relative humidity, indirectly exposed to natural light.

United States Pharmaceutical (USP) grade beeswax, USP grade oleic acid, E-904 shellac, USP grade glycerol, and sugarcane alcohol were obtained from "Droguería Cosmopolita S.A." (Mexico City, Mexico). Hydroxypropyl methylcellulose (HPMC) was donated by "Química Carayani S.A. de C.V." (Mexico City, Mexico). Food-grade reagents were used.

### Coating formulations

The edible coating (EC) treatments were formulated using glycerol and oleic acid as a plasticizer and emulsifier, respectively. The beeswax-shellac ratios were 3:1 and 1:3 (dry basis) (Table 1), while the remaining ingredients were kept constant throughout

**Table 1.** Formulations of edible coatings based on beeswax and shellac applied to chayote fruits (*Sechium edule* (Jacq.) Sw. var. *virens levis*).

| Treatment (T)- coating formulation | Beeswax (BW) (% w/w) | Shellac (S) (% w/w) | Solids content (SC) (%) |
|---|---|---|---|
| T1- without coating (control) | - | - | - |
| T2- polyethylene bag | - | - | - |
| T3- 1:3 BW-S_2 % SC | 1 | 3 | 2 |
| T4- 1:3 BW-S_4 % SC | 1 | 3 | 4 |
| T5- 3:1 BW-S_2 % SC | 3 | 1 | 2 |
| T6- 3:1 BW-S_4 % SC | 3 | 1 | 4 |

the treatments. The aqueous solutions were prepared using beeswax and shellac at 2 and 4 % solids content (v/v), respectively, following the Fagundes *et al*. (2014) method with some modifications. HPMC was hydrated in hot water at 90 °C for 15 min, then cooled to 20 °C before adding beeswax, shellac, glycerol, oleic acid, and alcohol. The solutions were heated again to 90 °C with stirring.

To successfully mix the shellac with the other ingredients, the Byun *et al*. (2012) technique was used, which involves dissolving shellac in alcohol and stirring for 24 h. The mixture was then filtered using Whatman® #5 filter paper and mixed for 1 min at 12 000 rpm, followed by 3 min at 22 000 rpm using an Ultra Turrax® dispersing instrument (IKA® T10 basic, China). The samples were then cooled to 30 °C for 25 min with gentle stirring to ensure complete hydration. Finally, the ECs were stored at 5 °C for one day to verify the stability of the formulations.

## Coating application

The application of each coating formulation (Table 1) was carried out by immersion for 1 min (Moalemiyan and Ramaswamy, 2012). Distilled water was used as a control solution, and a batch of uncoated fruits was left placed inside a polyethylene bag. All treated fruits were cold-stored at 7 °C for 0, 8, 16, 24, and 32 d (Poverenov *et al*., 2014). At the end of each storage period, the corresponding physicochemical analyses were carried out in triplicate. Each treatment involved a total of 63 chayote fruits.

## Fruit evaluation

### Color

Color was measured using a KONICA MINOLTA® colorimeter (model CR-400, Japan), where L*, a*, and b* values were obtained on the CIELAB scale. Each measurement was taken at three different sites in each chayote fruit, and data were reported as chroma (C*), lightness (L*), and color index (CI) (Moalemiyan and Ramaswamy, 2012).

### Acidity and pH

The titratable acidity (TA) was determined according to Montecinos-Pedro *et al*. (2019), with slight modifications. Juice was extracted from the fruits of each treatment. Then, 15 mL were taken from each sample and titrated with 0.1 N NaOH using two drops of phenolphthalein as an indicator. TA was expressed as % of citric acid per L. The pH of the juice was determined using a potentiometer (Thermo Scientific®, Orion Star, Singapore) (Islam *et al*., 2018).

### Weight loss

Weight loss was determined gravimetrically using an analytical balance (OHAUS® RANGER, Germany) (Poverenov *et al*., 2014), and the results were expressed as a percentage of weight loss compared to the initial weight of the fresh fruit:

$$\%\ \textit{Physiological weight loss} = \left(\frac{Pi - Pf}{Pf}\right) * 100$$

where $Pi$ = initial weight of the fresh fruit; and $Pf$ = final weight of the coated fruit.

**Firmness**

Firmness was determined using a texture analyzer (SHIMADZU® EZ-S 500 N, Japan) equipped with a 3 mm diameter cylindrical punch. Results were expressed as the maximum force (N) needed to penetrate the fruit with skin (penetration) and without skin (puncture), as described by Aung *et al*. (1996) with some modifications. The distance traveled for both determinations was 10 mm at a speed of 5 mm $s^{-1}$.

**Respiration rate**

The respiration rate was determined as described by Márquez *et al*. (2009). Two fruits from each treatment were weighed and placed in hermetically sealed containers for 24 h. Data was collected using a $CO_2$ sensor (MQ-135 gas sensor, OKstar brand, Guangdong, China) and expressed as $\mu g$ of $CO_2$ $kg^{-1}$ $h^{-1}$.

## Statistical analysis

The experiment was conducted using a completely randomized design with mixed effects and three replicates. The treatment followed a 6 x 5 factorial structure. The sample size consisted of 63 chayote units per treatment. The distribution of chayotes, according to the response variables measured, was as follows: for color, acidity, pH, and firmness, 45 chayotes were used per treatment across five time points (nine for each time); for the respiration variable, 10 chayotes were used; and for the weight loss variable, eight chayotes were used. The statistical model of the experiment was as follows:

$$y_i k_j = \mu + \alpha_i + \beta_j + (\alpha \beta)_{ij} + e_{ijk}$$

with $i$ = 1, 2, 3, 4, 5, 6; $j$= 1, 2, 3, 4, 5 and $k$ = 1, 2, 3

where $y_{ijk}$ is the response variable of the $i$th treatment at the $j$th time and the $k$th replicate; $\mu$ is the global mean; $\alpha_i$ is the fixed effect of the $i$th treatment; $\beta_j$ is the random effect of the $j$th time; $(\alpha\beta)_{ij}$ is the combined effect of the interaction of the $i$th treatment with the $j$th time; and $e_{ijk}$ is the random experimental error, which is assumed to be independent, identically, and normally distributed with zero mean and variance $\sigma^2_{\alpha\beta}$. The analysis was carried out with the GLIMMIX procedure of the SAS version 9.4 statistical package (SAS Institute, Cary, NC, USA). Means were compared using the Tukey test.

# RESULTS AND DISCUSSION

## Color

The values of C*, L*, and CI remained constant after day 8 in all treatments. No significant difference was found among treatments (Table 2). All treatments exhibited

**Table 2.** Color parameters of chayote fruit (*Sechium edule* (Jacq.) Sw. var. *virens levis*) stored at 7 °C for 32 days, evaluated with and without coatings.

| Treatments | Color index | Lightness (L*) | Chroma (C*) |
|---|---|---|---|
| T1- without coating (control) | -8.45 ± 0.36 a | 60.23 ± 1.98 a | 39.00 ± 1.21 a |
| T2- polyethylene bag | -9.22 ± 0.36 a | 57.28 ± 1.98 a | 37.60 ± 1.21 a |
| T3- 1:3 BW-S_2 % SC | -9.22 ± 0.36 a | 54.44 ± 1.98 a | 35.30 ± 1.21 a |
| T4- 1:3 BW-S_4 % SC | -9.20 ± 0.36 a | 55.46 ± 1.98 a | 36.82 ± 1.21 a |
| T5- 3:1 BW-S_2 % SC | -9.38 ± 0.36 a | 55.84 ± 1.98 a | 35.88 ± 1.21 a |
| T6- 3:1 BW-S_4 % SC | -9.35 ± 0.36 a | 55.55 ± 1.98 a | 36.04 ± 1.21 a |

Means with the same letters are not statistically different ($p \leq 0.05$). BW: beeswax; S: shellac; SC: solids content.

a decrease in color over time. These findings show that none of the coatings had an adverse effect on the color of the chayote fruit.

The color index is considered a quality control variable. The evolution in the ripening of the chayote fruits was measured by the color index (CI), and it was also used to describe the color of the chayote epicarp. In most cases, skin color changes as the fruit ripens or matures, making it a useful ripening index for producers to establish the harvest date. Color charts are available for different cultivars for this purpose (FAO, 2003).

The CI ranges from -8.45 to -9.38 (Table 2). According to Machado-Molina *et al*. (2015), this indicates that the colors go from deep green to yellowish green. Fagundes *et al*. (2014) reported that the use of HPMC and beeswax in different concentrations reduces the respiration rate, leading to a slight increase in the color of some fruits, but with the treatments used in this research, this increase was not achieved. Similar results were observed by Li *et al*. (2018), who applied commercial wax to pineapple fruits and found no significant differences compared to the control.

## Acidity and pH

The pH and TA variables (expressed as the percentage of citric acid) were determined for all coated and uncoated treatments stored at 7 °C (Table 3). The TA and pH values ranged from 0.21 to 0.36 % and 6.5 to 6.7, respectively. However, the control (T1) had small differences, showing from day 16 a progressive decrease in TA, while pH levels remained constant throughout the study period. Andrade *et al.* (2013) and Fagundes *et al.* (2014) point out that the TA and pH parameters are not usually affected by ECs because the internal quality of the fruit depends not only on the coating, but also on the harvest process, the ripening index, the variety, and the weather conditions.

These results coincide with those reported by Li *et al*. (2018), who found that the higher the amount of wax, the higher the TA inhibition. Wax maintains the respiration rate and therefore limits the excessive consumption of citric acid with respiration. Cadena-

**Table 3.** Acidity and pH of chayote fruit (*Sechium edule* (Jacq.) Sw. var. *virens levis*) with and without coating, stored at 7 °C for 32 days.

| Treatments | pH | Acidity (% of citric acid per L) |
|---|---|---|
| T1- without coating (control) | 6.47±0.06 b | 0.28±0.02 ab |
| T2- Polyethylene bag | 6.50±0.06 b | 0.36±0.02 a |
| T3- 1:3 BW-S_2 % SC | 6.58±0.06 ab | 0.29±0.02 ab |
| T4- 1:3 BW-S_4 % SC | 6.63±0.06 ab | 0.28±0.02 ab |
| T5- 3:1 BW-S_2 % SC | 6.65±0.06 ab | 0.24±0.02 b |
| T6- 3:1 BW-S_4 % SC | 6.70±0.06 a | 0.21±0.02 b |

Means with the same letters are not statistically different ($p \leq 0.05$). BW: beeswax; S: shellac; SC: solids content.

Iñiguez *et al*. (2006, 2011) found values between 0.039 and 0.041 % of citric acid at different temperatures, and there were no significant differences between treatments. It is thus confirmed that the use of beeswax-shellac-based ECs improved the citric acid percentage and stabilized pH values in chayote fruits.

All ECs applied to the fruits were effective in maintaining the metabolic process during the storage period. According to Nawab *et al*. (2017), citric acid and malic acid are the substrates involved in the respiration process of climacteric fruits, so a decrease during the storage period is to be expected, but these authors observed that the amount of TA and pH in the different treatments remained constant during the test period. Fagundes *et al*. (2014), on the other hand, observed a relationship between pH increase and citric acid loss, whereas in the present investigation the results obtained for TA remained constant during the analysis period, as did pH.

## Weight loss

The weight loss percentage of the different treatments, with and without coating, ranged from 1.8 to 3.4 % and 2.6 to 4.1 %, respectively (Figure 1A). In relation to the T3, T4, T5, and T6 treatments (with coating) and the T2 treatment (polyethylene bag), no significant differences were found. In general, the treatment that created the best barrier against moisture was the 3:1 BW-S coating with 4 % SC (T6). This treatment significantly reduced the weight loss of the coated chayote fruits during storage compared to the control.

However, the coatings with the addition of beeswax prevented weight loss of the chayote fruits to a lesser extent than the control treatment (T1) but still presented more significant weight loss than the 3:1 BW-S coating with 4 % SC (T6) (Figure 1A). This indicates that the weight loss percentage decreased as the content of hydrophobic compounds increased. This coincides with Navarro-Tarazaga *et al*. (2008), who report that an increase in beeswax content creates a more effective barrier to weight loss by providing greater resistance to water movement through the fruit epicarp.

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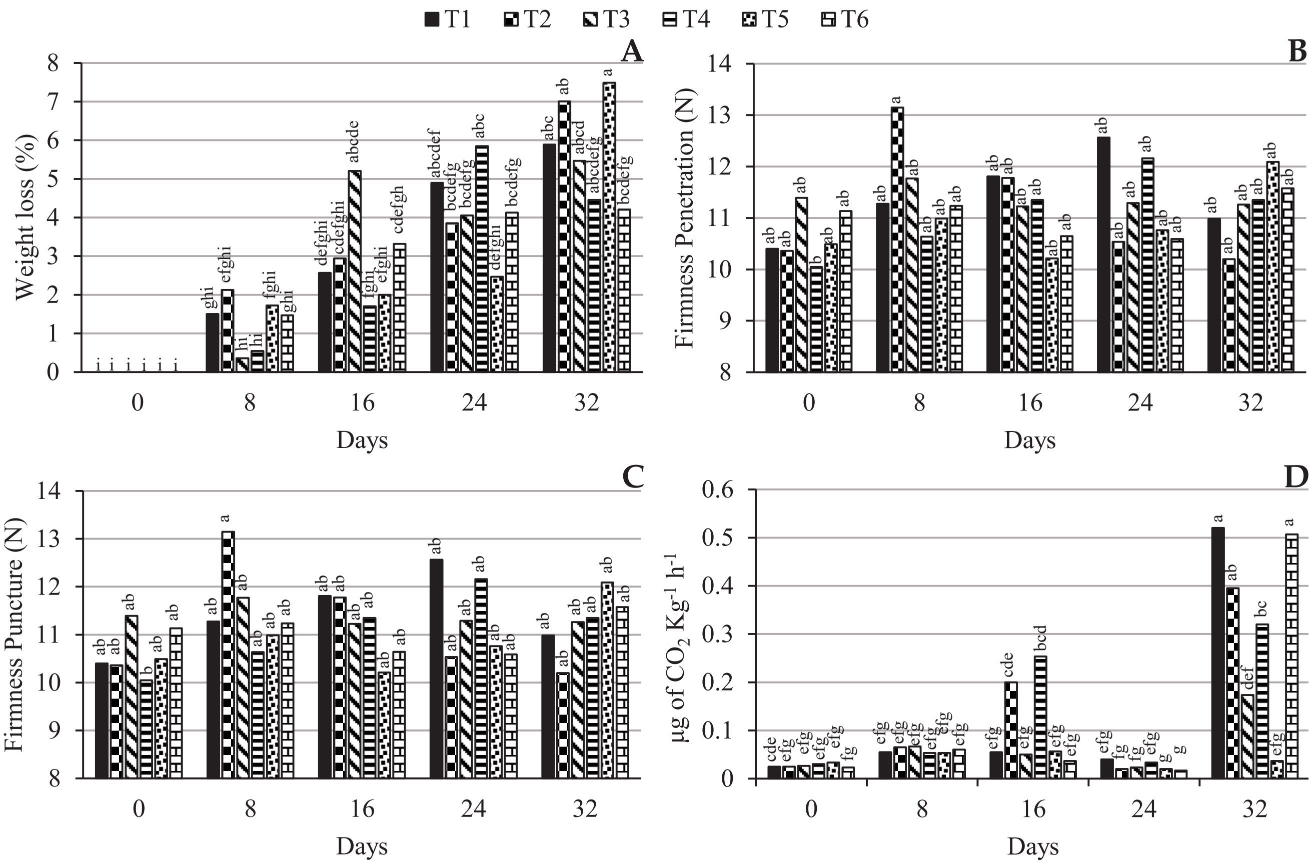


**Figure 1.** Fruit parameter values in chayote fruits with and without edible coatings stored at 0, 8, 16, 24, and 32 days at 7 °C. A: Weight loss; B: peel firmness (penetration); C: pulp firmness (puncture); D: respiration rate. Means with the same letters are not statistically different ($p \leq 0.05$). T1: control, fruits without any coating; T2: polyethylene bag; T3: 1:3 BW-S_2 % SC; T4: 1:3 BW-S_4 % SC; T5: 3:1 BW-S_2 % SC; T6: 3:1 BW-S_4 % SC.

Similar results were reported by Cadena-Iñiguez *et al*. (2006), who used ECs and commercial waxes and found weight loss values of 3.7 to 13.6 %. Also, the Interdisciplinary Research Group on *S. edule* in Mexico (GISeM, 2011) reported that the weight loss of fresh uncoated chayotes of the *virens levis* variety ranged between 8 and 10 % after harvest. Aung *et al*. (1996) indicated that the weight loss percentage in chayote fruits covered with edible films ranged from 0.02 to 40 %. It is thus confirmed that the use of beeswax and shellac as additives creates a more effective barrier against moisture loss in chayote fruits compared to commercial waxes. Additionally, seed germination did not occur at any point during the experiment, as the storage temperature of 7 °C prevented sprouting.

### Firmness

The penetration (Figure 1B) and puncture tests (Figure 1C) in chayote fruit samples with and without EC indicated that all treatments maintained the firmness of the samples during the storage period. There were no significant differences among treatments with and without EC, since the coatings used did not affect the fruit epicarp over time. Similar results were found by Aung *et al*. (1996), who reported a pulp (puncture) value of 12.8 N and a skin firmness (penetration) of 19 N. In our research, the firmness of the chayote peel ranged from 12.7 to 13.5 N and the firmness of the pulp varied from 10.8 to 11.8 N; the little difference from our texture values not only depends on the EC applied but also on other factors such as the chayote variety, weather conditions, and storage time. Fagundes *et al*. (2014) indicated that ECs based on beeswax and shellac show high water vapor permeability during storage time due to the permanence of a saturated internal atmosphere, which controls enzymatic activities that improve fruit firmness.

### Respiration rate

According to the classification proposed by GISeM (2011), chayote is a fruit with a low respiration rate, having values of 5–10 mg $CO_2$ $kg^{-1}$ $h^{-1}$ (1.389 μg $CO_2$ $kg^{-1}$ $h^{-1}$) at 5 °C. The results obtained show that, until day 24, all treatments stored at 7 °C kept the emitted $CO_2$ levels stable, that is, the metabolic activity of the chayote fruit remained stable. However, on day 32, it was observed that all treatments drastically increased $CO_2$ levels except for T5 (3:1 BW-S_2 % SC), which, in addition to stabilizing $CO_2$ levels throughout the analysis period, also showed a significant difference compared to the other treatments (Figure 1D).

Cadena-Iñiguez *et al.* (2006) reported $CO_2$ values between 0.86 and 1.3 μg $kg^{-1}$ $s^{-1}$ of $CO_2$ (3096 and 4680 μg $kg^{-1}$ $h^{-1}$ of $CO_2$) in chayotes coated with commercial waxes and plastic films and stored at 10 °C for 28 days. For comparison, in our results, the respiration rate of chayote fruits with and without EC was 0.006 to 0.014 and 0.007 to 0.144 μg $kg^{-1}$ $s^{-1}$ (21.6 to 50.4 and 25.2 to 518.4 μg $kg^{-1}$ $h^{-1}$), respectively.

Based on these results, the EC formulations applied to chayote fruits were effective in reducing the respiration rate. Degradation of organic reserves (proteins, carbohydrates, and fats) leads to the release of metabolic energy from the fruits. The formulations based on beeswax and shellac modified the internal atmosphere of the fruits, slowing the senescence process, respiration, and transpiration of the coated fruits. Chitravathi *et al*. (2014) reported that fruits with low gas emissions reduce enzymatic activities that cause deterioration of fruit tissues, thereby retaining firmness during storage.

## CONCLUSIONS

The physicochemical properties of chayote fruits were retained after the application of edible coatings, and no adverse effects were observed compared to the control group. All of the edible coatings reduced the weight loss percentage of the fruits while maintaining stable titratable acidity and pH. The T5 coating, which consisted of a 3:1 mixture of beeswax and shellac with 2 % solids content, was the most effective in reducing the respiration rate. The T6 coating (3:1 beeswax-shellac with 4 % solids content) was the most effective, creating a barrier against gases and water vapor due to its high proportion of beeswax and low amount of shellac. Edible coatings formulated with beeswax-shellac can preserve chayote fruits without compromising their quality.

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