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# Effect of coating on the maturation of jackfruit stored in simulated marketing condition

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## Abstract

The objective of this research was to evaluate the effect of coating on the maturation process and jackfruit quality. The fruits in physiological maturity were treated or not with two commercial coatings Natural Shine® 505-OR (40% v/v, R1) or Semperfresh™ (3% v/v, R2); were subsequently stored for 5 days at 8 or 13 °C simulating transportation to the United States of America and then stored at a temperature of 25 °C, simulating their commercialization. The witness fruits were stored at 25 °C until consumption maturity. Breathing speed (VR), ethylene production (VPE) and physical and chemical parameters were measured. The fruits stored at 25 °C presented the climatic peak and maximum VPE at 3 and 5 days of storage, respectively; however, the uncoated and coated fruits stored in refrigeration and then at room temperature, the apparition of the climatic peak and maximum VPE was delayed. The fruits stored for 5 days at 8 °C and coated with Semperfresh managed to extend the shelf life by 9 days relative to the fruits stored at 25 °C and 7 days with the fruits refrigerated at the same temperature, but without coating. It was concluded that the application of Semperfresh coating and storage at 8 °C for 5 days with subsequent storage at 25 °C may be an alternative to preserve the jackfruit for up to 17 days.

**Keywords:** coatings, jackfruit, maturation.

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## Introduction

Jackfruit (*Artocarpus heterophyllus* Lam.) is a tropical fruit of Asian origin, which has increased its world production to 3.7 million tons from 2015 to 2019 (FAO, 2019). In Mexico the state of Nayarit is the main producer nationwide with 22 192.83 t per year (SIAP, 2019). The main importers of Mexican jackfruit are USA and Canada (SIAP, 2019). However, the transport of jackfruit to these destinations is by land with a duration of 5 to 8 days between 8 and 13 °C, conditions in which the fruit arrives advanced in maturity and has 2 to 3 days to market it in markets close to landing (Mata-Montes de Oca *et al*., 2007). Therefore, it is necessary to combine technologies that allow to reduce the speed of fruits ripening and prolong their post-harvest life, to allow the Mexican jackfruit to have greater distribution margin.

The coatings to preserve fruits and vegetables fresh today are extensively researched, they are composed of natural biopolymers with specific properties with the function of providing a barrier to decrease the transfer of mass (gas or liquids) that delays maturation, prevent dehydration, and delay senescence due to the generation of a low microclimate in $O_2$ and high $CO_2$. Its effectiveness is dependent on the crop, coating type, and degree of maturity, mainly (Antunes *et al*., 2012).

The application of jackfruit coatings has been studied, mainly in the fruit bulbs and not in the whole fruit. Saxena *et al*. (2011) used additives as pretreated before applying chitosan to jackfruit bulbs, finding that the chitosan protected the sensory attributes of texture and flavor that influence the useful life of the pre-cut bulbs and that this was 46 to 48 days in controlled atmosphere (AC), so that the interactions of AC, pretreatment and the chitosan coating in synergy give microbial and physiological stability to the pre-cut product.

Teja *et al*. (2016) evaluated the effects of different coatings (*Aloe vera* gel and pectin) on the quality of jackfruit bulbs for 7 days stored at 6 °C, concluding that *Aloe vera* gel-coated bulbs significantly controlled weight loss and ascorbic acid, they have high caloric value, protein content and vitamin A and C, in addition to shelf life extended for seven days.

Vargas-Torres *et al*. (2017) applied potassium sorbate/calcium chloride with 1-methylcyclopropene (1-MCP) to jackfruit bulbs and applied edible coatings (xanthan gum, sodium alginate or gellan gum). Treatments combined and applying only coatings showed decreased maturation rate and reduced weight loss and breathing, compared to control. In addition, it increased the useful life up to 12 days without changes in sensory attributes, achieving high quality values in color, total soluble solids, titratable acidity and pH.

Natural Shine® 505-OR is a high gloss organic coating used on organically grown citrus fruits and is recommended for national export markets. This is a 100% organic product, biodegradable, approved under the regulations of the U.S. Department of Agriculture (USDA) and Organic Materials Review Institute (OMRI). It controls moisture loss, gives shine even after perspiration (Pace International, 2019). On the other hand, Semperfresh™ is a coating based on sucrose ester that inhibits water loss while allowing the exchange of gases between the fruit and its environment. It reduces weight loss and excess breathing, resulting in firmer cherries with fewer bites and their stems remain greener for longer, due to increased moisture retention, it also adds shine without leaving an oily or greasy film on the fruit. Its use in fresh pear reduces bruises, weight loss, preserves the green color, without modifying the normal maturation processes (Pace International, 2019).

So far, there are no reports on the effect of the commercial coatings mentioned for whole jackfruit preservation. The objective of the study was to evaluate the effect of jackfruit commercial coatings stored under simulated transfer conditions for export to the United States of America and storage under simulated marketing conditions.

## Materials and methods

In an orchard of El Llano, Municipality of San Blas, Nayarit, se harvested jackfruits of the vegetal material 'Agüitada' in physiological maturity, these presented a color of peduncle and light green shell slightly yellowish, the spines fully developed, separated and with recession, in addition the fruit when hitting with the fingers had a hollow sound (Mata-Montes de Oca *et al.*, 2007; Love and Paull, 2011; Luna-Esquivel *et al*., 2013).

The fruits were washed with running water and thiabendazole (800 ppm) was applied as fungicide. The peduncle was then sealed with copper oxychloride (58% w/v) (Moon-Esquivel *et al*., 2013). The fruits were divided into seven batches of 50 fruits each, for seven treatments. Three lots were used as a witness: the first was jackfruit stored at 25 ±3 °C (absolute witness), the second and third lots were: jackfruit stored at 8 ±2 °C or 13 ±2 °C for 5 days, respectively, to simulate the transfer to the United States and transferred to 25 ±3 °C with 85-90% relative humidity (HR) until their maturity to simulate the market.

The fourth and fifth batch of fruits were treated with commercial immersion coatings taking care to completely cover the fruit with the coating solution: Natural Shine® 505-OR (40% v/v, R1), and Semperfresh™ (3% v/v, R2,) prepared with water, respectively, according to the manufacturer's instructions. They were left to dry at room temperature and later they were stored in cardboard boxes at 8 ±2 °C for 5 days, and then at 25 ±3 °C (8 °C 5D + AMB). The two remaining batches were applied the same coatings, but were stored 13 ±2 °C for 5 days, and then at 25 ±3 °C (13 °C 5D + AMB). The following variables were measured: respiration speed (VR) and ethylene production speed (VPE); physiological weight loss (PFP), firmness, pH, titrable acidity (AT), total soluble solids (OSH), and color.

### Methods of analysis

Respiration speed (VR) and ethylene production speed (VPE) were measured by the Mata-Montes de Oca *et al.* (2007) method where individual fruits were placed in airtight containers (of known volume) for one hour. It was obtained 1 mL of gas from headspace and was analyzed in a gas chromatograph (HP model 6890, USA) with an HP-PlotQ column (15 m x 0.53 mm and 40 µm film thickness), a flame ionization detector (FID) and a thermal conductivity detector (TCD). The temperature of the injection port and detectors was 250 °C. It was used $H_2$ (30 ml $min^{-1}$) and purified air (400 ml $min^{-1}$). The carrier gas was $N_2$ with a flow of 7 ml $min^{-1}$. The oven temperature had a ramp of 60 to 80 °C, which changed at a speed of 30 °C $min^{-1}$. An ultra-high purity calibration standard (5.0) Praxair® certified was used, containing 11.3 μmol $mol^{-1}$ ethylene, 2.01 cmol $mol^{-1}$ $CO_2$, 10.1 cmol $mol^{-1}$ $O_2$ and $N_2$ to balance the mixture.

$CO_2$ and ethylene concentrations were calculated considering the area and concentration of the standard, headspace, injection time, fruit weight and fruit volume. VR was expressed in ml $CO_2$ $kg^{-1}$ $h^{-1}$ and VPE in μl $kg^{-1}$ $h^{-1}$. Weight loss (PFP) was determined by weighing the fruits daily with a TORREY brand digital weight scale with a capacity of 20 kg and 0.5 g of precision, weight loss was expressed as a percentage of the initial weight of the fruit (Hernández-Lauzardo *et al*., 2007).

The firmness of whole fruits and bulbs were determined by a texturometer (Stable Micro Systems, TA-XT PlusC and United Kingdom) with a cylindrical strut 10 mm in diameter. The firmness of the whole fruits was measured directly at the upper, middle and low part of the fruit; and in nine bulbs (seedless) of each fruit. The data were expressed in Newtons(N).

Total soluble solids (SST) were determined in homogenized fresh pulp juice and they were measured in a refractometer (Atago, Model AD-13, Japan). Titrable acidity (AT) was determined by 942.15 volumetric method of the AOAC (2005) in homogenized pulp (5 g) with distilled water (25 ml) and it was titrated with NaOH 0.1N. The results were expressed as a percentage of citric acid.

The pH was measured in the homogenized pulp with a potentiometer (Jenco, Model 1671, Romania). The color of the shell and bulbs was measured on top, middle and low of the fruit with a Konica Minolta colorimeter, CR300 (Osaka, Japan) and the color was reported as an angle of tone °Hue.

### Statistical analysis

A two-factor design with random blocks was used with, where one factor to be evaluated was the coating, another the storage temperature and the blocks on the days of storage. The data was analyzed using an Anova, with comparisons of mean by the LSD test ($p \leq 0.05$), using the v. 10 statistical package (StatSoft, Tulsa, Oklahoma, USA).

## Results and discussion

### Respiration speed and ethylene production

The climatic peak of VR in the witness fruits at 25 °C was presented on the third day with 108.81 ml $CO_2$ $kg^{-1}$ $h^{-1}$ (Figure 1A). In uncoated fruits stored at 13 °C during five days and subsequent simulation of market at room temperature 25 °C (5D + AMB), had the climatic peak on day 7; however, in the fruits con R1 and R2, the maximum VR was presented at 8 and 10 days of storage, respectively (Figure 1B). In uncoated fruits and coated fruits R1 stored at 8 ±2 °C 5D + AMB (Figure 1C), the maximum VR was found at 9 days and 14 days for fruits coated with R2, with 179.22 and 115.85 ml $CO_2$ $kg^{-1}$ $h^{-1}$, respectively. VR increased dramatically when the fruits came out of refrigeration and were stored at room temperature, this coincides with Espinosa *et al.* (2013) who reported an acceleration in breathing metabolism when soursop fruits were stored in refrigeration and then at room temperature.

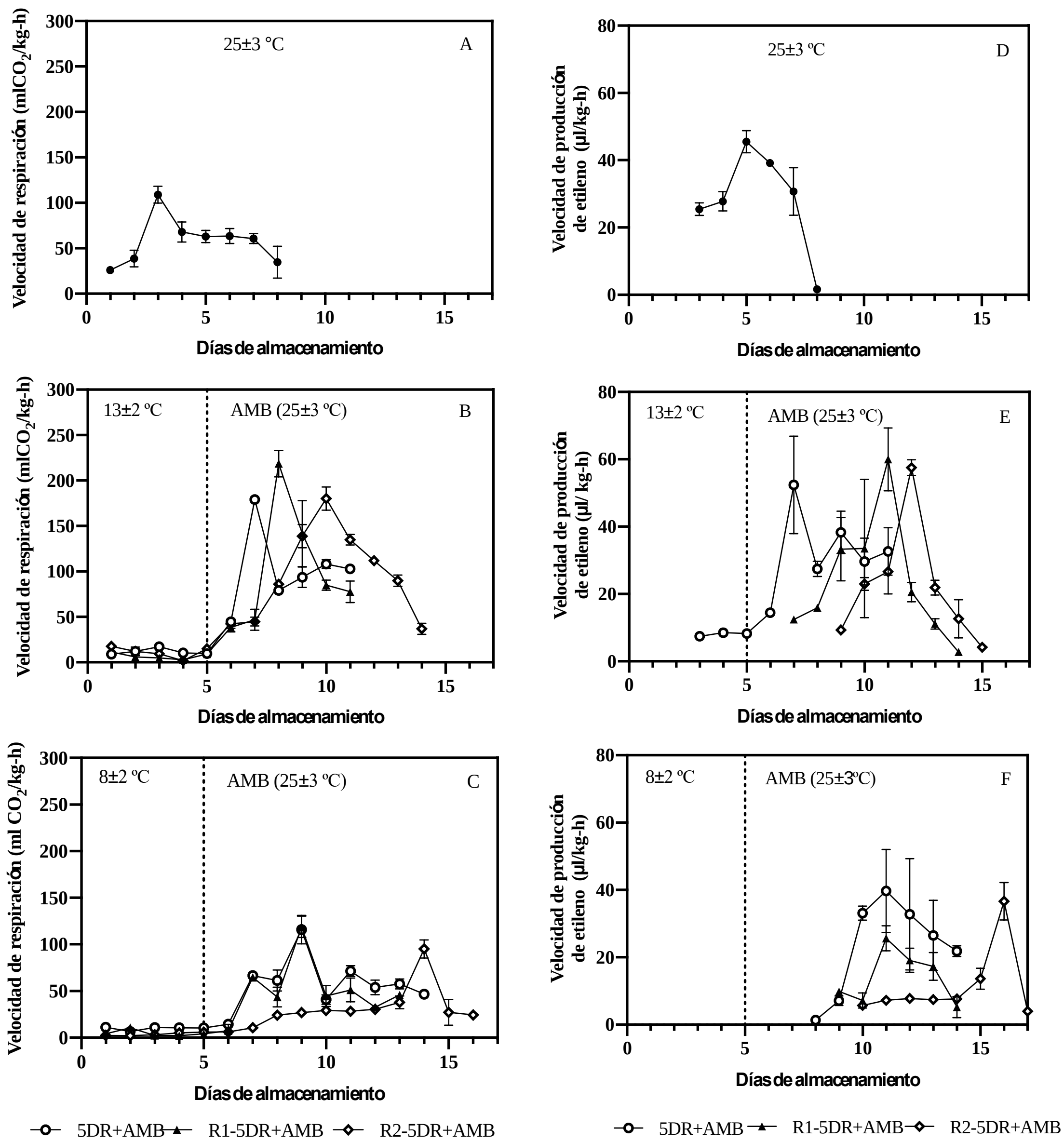


**Figure 1. Respiration speed (A, B, C) and ethylene production speed (D, E, F) in jackfruits. Fruits stored at room temperature (AMB, 25 ±3 °C) (A, D), fruits treated with coatings (R1 and R2) and uncoated with refrigeration for 5 days (5DR) at 13 ±2 °C (B, E) or 8 ±2 °C (C, F) and subsequent storage at room temperature until its consumption maturity.**

The significant effect ($p < 0.05$) of the cooling temperature for 5 days in VR was observed, since in the fruits stored at 8 °C 5D + AMB the VR was lower than the fruits that were stored at 13 °C 5D + AMB. Compared to the witness fruits, in the refrigerated fruits the maximum VR was delayed 4 and 5 days. Mathooko and Tsunashuma (2001) mention that cooling temperatures decrease the enzymatic activities involved in the complex breathing process and high temperatures increase enzymatic activity, therefore VR increased when jackfruits were stored at temperatures higher than refrigeration temperatures.

The VR of the jackfruits was affected by both the cooling temperature and the coatings used, as it was observed that the R1 coating had no significant effect, possibly because it is slightly hydrophobic according to the manufacturer; however, the Semperfresh$^{TM}$ (R2) coating decreased the VR attributing itself to mostly hydrophobic characteristics. This type of coating was able to create a modification of the internal atmosphere, as a result of the formation of a semi-permeable film on the surface of the fruit that reduces the oxygen available for plant tissue and decreases the breathing speed (Narsaiah *et al*., 2015).

Figure 1D shows the behavior of the witness fruit VPE, with the maximum VPE on the fifth day of storage with a value of 45.48 µl $kg^{-1}$ $h^{-1}$. In uncoated fruits stored at 13 °C 5D + WBA (Figure 1E), the appearance of the maximum VPE was the seventh day (52.34 µl $kg^{-1}$ $h^{-1}$), while on fruits coated with R1 and R2 a peak of ethylene is observed for days 11 (59.94 µl $kg^{-1}$ $h^{-1}$) and 12 (57.53 µl $kg^{-1}$ $h^{-1}$) of storage, respectively. For uncovered fruits and coated fruits with R1 stored at 8 °C 5D + AMB (Figure 1F), the presence of ethylene is observed when the fruits were stored at room temperature and from the ninth day, reaching the highest VPE on the eleventh day (39.69 and 25.67 µl $kg^{-1}$ $h^{-1}$, respectively), showing that the VPE was diminished by R1 effect; however, the fruits with R2 had lower VPE in the eleventh day and had maximum VPE until day 16 of storage (36.63 µl $kg^{-1}$ $h^{-1}$).

A significant effect ($p < 0.05$) of the storage temperature was observed in the VPE, in the refrigerated fruits at 13 or 8 °C the VPE was less than 25 °C during the refrigeration time, but this increased when coming out of refrigeration, being greater than 13 °C. It has been reported that storage at low temperatures decreases the self-catalytic production of ethylene because it may decrease the activity of amino cyclopropane carboxylate oxidase (ACC oxidase, enzyme involved in the synthesis of ethylene) during storage to these temperaturas; however, this can increase when the fruits are transferred to ripening conditions (Montalvo *et al*., 2007).

In addition, there was effect ($p < 0.05$) of the coatings on the decrease in VPE, R1 coating tends to decrease ethylene concentration and R2 coating decreased and delayed the maximum VPE. This is attributed to the that coatings were able to decrease internal oxygen availability, which is required by ACC oxidase to synthesize ethylene (Abeles *et al*., 1992), although the R2 coating was much more effective; which is attributed to this coating decreasing the respiration and diffusion of $CO_2$ and $O_2$ in the fruits, creating a modified atmosphere within the fruit tissues which is effective in delaying the maturation process (Narsaiah *et al*., 2015).

## Physiological weight loss

The witness fruits stored at 25 °C at day 8 had a physiological weight loss (PFP) of 11.9% (Figure 2A). Storage at 13 °C 5D + AMB caused a PFP of 11.38% (day 11); however, if coating is applied on the fruits, the percentage of loss is decreased by 17 to 20% for the same day of storage (day 11). As the coated fruits have a longer storage time at room temperature to reach their maturity (14 days), PFP was slightly higher 12.59% for fruits with R1 and 13.06% for fruits with R2 (Figure 2B). The perspiration of jackfruits is reflected in the loss of water and this in turn in physiological weight loss, this advances the ripening of the fruit (Mata-Montes de Oca *et al*., 2007).

When storing coated and uncoated fruits at 8 °C 5D + AMB (Figure 2C), on day 11 of storage the PFP was 10.09% for uncoated fruits and 8.33%-8.47% for coated fruits; that is, a reduction in weight loss of 11.33 and 27%, that the fruits stored at 13 °C 5D + AMB (Figure 2B) compared to fruits stored at 25 °C. The final PFP was 13.38% for uncovered fruits, 12.44% for fruits with R1 at 14 days of storage and 13.21% for fruits with R2 at 17 days of storage.

There was no significant effect ($p > 0.5$) per type of coating on the PFP, but it was less in the uncovered fruits. In addition, during refrigeration the PFP was lower, but once in conditions of market condition at room temperature (25 °C), it increases, although it is lower in the fruits that were at 8 °C.

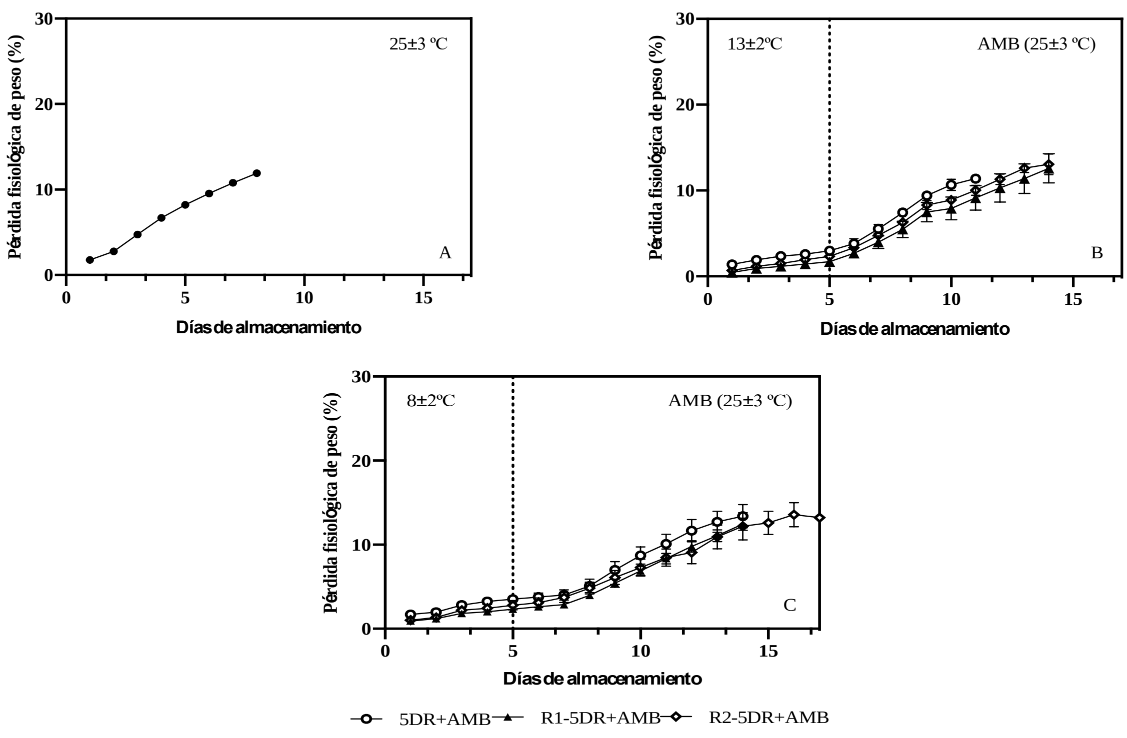


**Figure 2. Physiological weight loss of jackfruits stored at room temperature (25 ±3 °C) (A), uncoated fruits and coated fruits (R1 and R2) stored in refrigeration for 5 days (5DR) at 13 ±2 °C (B) or 8 ±2 °C (C) and subsequent storage at room temperature until their consumption maturity.**

PFP decreases or increases with the storage temperature, which has an explanation in the respiratory metabolism of the fruits, in addition to the absence or presence of a coating, which would act as a barrier that prevents the gas exchange of the fruit with the external environment that surrounds it. The loss of water in the fruits is carried out by differences in the vapour pressure in the environment and the vapor pressure inside a fruit; however, it is also known that the application of coatings helps to decrease PFP and coating effectiveness depends on the characteristics of the fruit (cuticle type and perspiration speed), composition and storage conditions (Amarante and Banks, 2001). The application of the R2 coating delayed the PFP to a greater extent, due to its hydrophobic characteristics (Saberi *et al.*, 2018). González *et al.* (2014) reported that wax-based emulsions applied to soursop during postharvest decreased weight loss.

**Physicochemical parameters**

The jackfruit has the characteristic of having a thick shell that surrounds the pulp bulbs, which is porous and thick between 0.3 to 0.8 cm. The fruit in physiological maturity is difficult to penetrate, as it matures it loses moisture, appears to lose weight and become flexible, but it serves as protection to the pulp from external physical and biological damage for a longer time. Figure 3 shows the firmness behavior of whole fruits and jackfruit bulbs.

The initial firmness in all fruits was between 300 and 350 N, values similar to those reported by Mata-Montes de Oca *et al*. (2007) of 330 N, then firmness decreased. The loss of firmness during the maturation of climacteric fruits is related to the action of enzymes that degrade the cell wall such as polygalacturonase, pectinmethylesterase and ß-galactosidase among other (Montalvo *et al.*, 2009).

In whole fruits at 25 °C the firmness decreased to 239 N on day 8 (Figure 3A). In addition, in uncoated fruits stored at 5DR + 3AMB was 296.4 and 295 N respectively (Figure 3B and 3C), there was significant effect ($p < 0.05$) of the refrigeration temperature in maintain firmness; however, once the fruits are stored at room temperature in market simulation, it rapidly decreases firmness, but the effect of refrigeration is observed, as the fruits at 13 °C 5DR + 6AMB decreased to 235 N, while in the fruits stored at 8 °C 5DR+ 9 AMB reached a firmness of 216.7 N; that is, that the fruits are softened in a similar way as stored fruits at 25 °C, but refrigeration keeps them firm for longer time.

The firmness of whole fruits treated with coatings and stored at 13 °C 5DR + AMB (Figure 3B) or 8 °C 5DR + AMB (Figure 3C) it was not statistically different ($p > 0.05$), compared to uncovered fruits on most days of storage; it was only observed that in the fruits coated with R2, the firmness remained higher on the last day of storage. It also happened for the coated fruits stored at 8 °C, where the fruits with application of R2 maintained more firmness, but without significant differences. Probably no effect of the coating on the firmness was observed because the shell of the fruit when losing moisture becomes flexible and although to the touch it feels soft, when measuring the breaking force, this is not as low as would be expected in the rind of a ripe fruit, these data coincide with that reported by Mata-Montes de Oca *et al*. (2007).

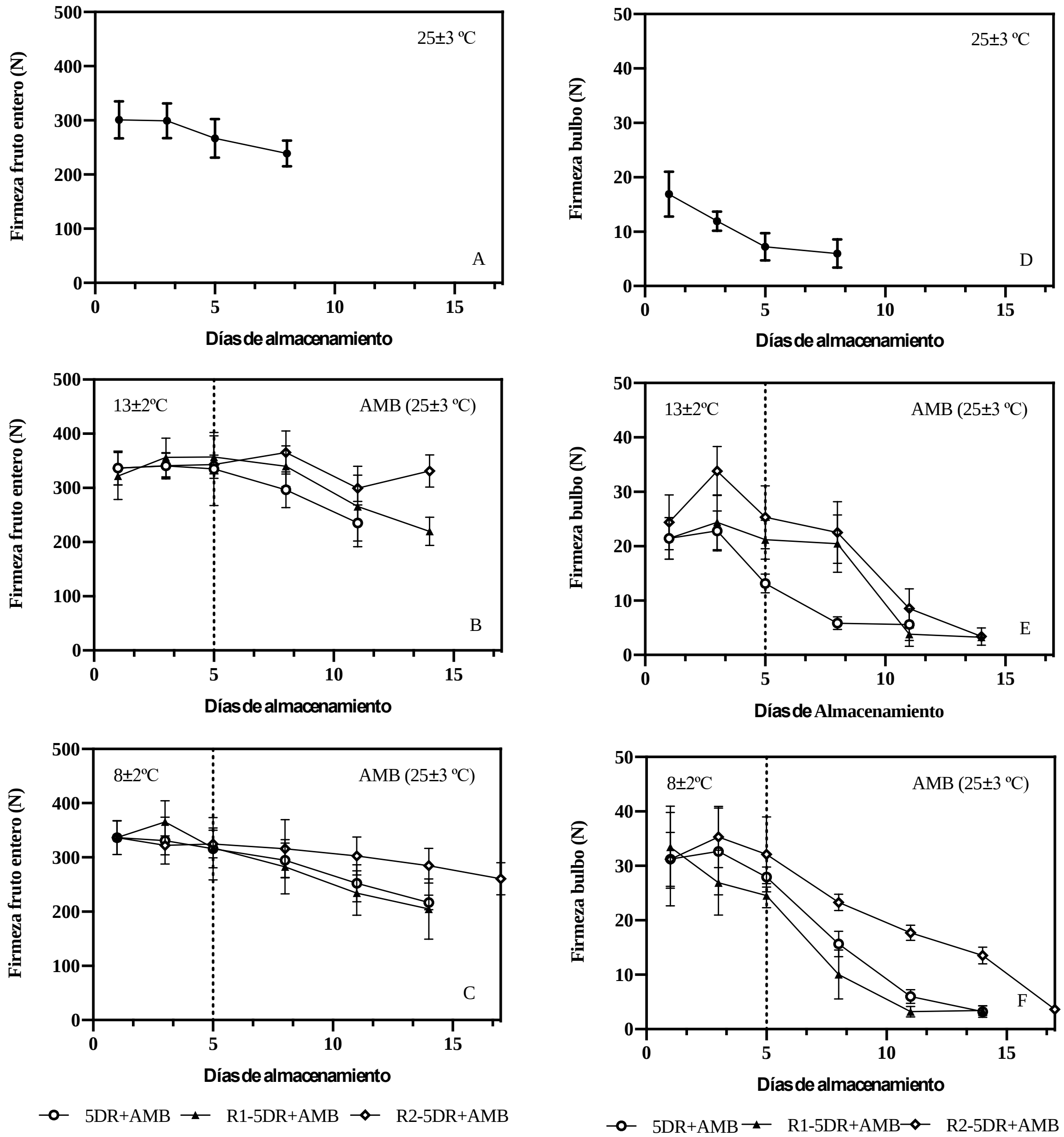


**Figure 3. External firmness (A, B, C) and internal (D, E, F) of jackfruits. Fruits stored at room temperature (A, D), fruits treated with coatings (R1 and R2) and uncoated with refrigeration for 5 days (5DR) at 13 ±2 °C (B, E) or 8 ±2 °C (C, F) and subsequent storage at room temperature until its consumption maturity.**

On the other hand, the bulbs of the fruits stored at 25 °C had an initial firmness of 16 N, reaching values of 6 N once the fruits were ripe (Figure 3D). The bulbs of the fruits treated with the coatings and stored at 13 °C 5DR+AMB (Figure 3E) had more firmness during the refrigeration time and the 5 more days of storage at room temperature compared to the bulbs of the uncoated fruits under the same storage conditions.

In Figure 3F, it is observed that the fruit bulbs with the R1 coating and stored at 8 °C 5DR + AMB showed no significant difference in firmness with respect to the refrigerated bulbs to 8 °C 5DR + AMB without coating unlike fruit bulbs with R2 that maintained greater firmness during storage time, reaching a firmness between 3 N until day 17.

The difference in the decreased firmness behavior between the shell and the bulbs of the fruits when mature, is due to the structural composition of each tissue. On the other hand, refrigeration temperatures can decrease the activity of enzymes that degrade the cell wall, such as cellulases, polygalacturonase and β-galactosidase, however, the proportion in enzymatic decrease depends on the storage temperature (Jeong *et al*., 2002; Montalvo *et al*., 2009).

It is indisputable that the combination of refrigeration temperature and Semperfresh coating helped extend the shelf life of the jackfruit up to 17 days for the refrigeration case at 8 °C for five days and subsequent market simulation. The results found coincide with those reported by Kumar *et al*. (2018) in plum fruits treated with Semperfresh, which reduced the loss of firmness during the storage period, for its part Vargas-Torres *et al*. (2017), reported that coated jack bulbs were firmer than uncoated fruits.

It coincided that VPE was lower (Figure 1F) in R2-coated fruits and stored for 5 days at 8 °C, so it is possible that the activity of enzymes that degrade the cell wall was slower, due to the effect of temperature and coating (Montalvo *et al*., 2009). SST increases during the maturation process (Tables 1 and 2). Initially, the harvested fruits had between 7.23 and 8.33 °Brix.

**Table 1. Total soluble solids, titratable acidity, pH and internal color of jackfruits stored at room temperature (AMB, 25 ±3 °C), fruits stored in refrigeration for 5 days at 13 ±2 °C and then stored at room temperature (5D 13 °C+AMB), fruits treated with NaturalShine505-OR® (R1) and SemperFresh® (R2) coatings, stored in refrigeration for 5 days at 13 ±2 °C and then stored at room temperature.**

| Storage days | 25 ±3 °C | 5DR 13 °C +AMB | R1-5DR 13°C +AMB | R2-5DR A 13 °C +AMB |
|---|---|---|---|---|
| | | Total soluble solids (°Brix) | | |
| 1 | 8.33 ±1.53a | 8.3 ±0.14a | 7.23 ±0.26a | 7.23 ±0.26a |
| 5 | 27.05 ±0.95a | 25 ±0.23b | 13.63 ±0.33c | 13.92 ±1.67c |
| 8 | 29.55 ±3.52a | 30.13 ±2.41a | 20.15 ±2.09c | 20.6 ±4.8c |
| 11 | | 29.85 ±1.12a | 29.13 ±0.9a | 26.38 ±0.57b |
| 14 | | | 33.48 ±0.78 | nm |
| 16 | | | | 31.08 ±1.49 |
| | | Titratable acidity (% citric acid) | | |
| 1 | 0.17 ±0.05a | 0.14 ±0.03a | 0.18 ±0.03a | 0.15 ±0.02a |
| 5 | 0.24 ±0.06a | 0.55 ±0.13b | 0.25 ±0.04a | 0.28 ±0.01c |

| Storage days | 25 ±3 °C | 5DR 13 °C +AMB | R1-5DR 13°C +AMB | R2-5DR A 13 °C +AMB |
|---|---|---|---|---|
| 8 | 0.19 ±0.02a | 0.33 ±0.04b | 0.37 ±0.04b | 0.26 ±0.05b |
| 11 | | 0.33 ±0.03a | 0.5 ±0.07b | 0.32 ±0.08a |
| 14 | | | 0.43 ±0.19 | nm |
| 16 | | | | 0.3 ±0.01 |
| | | pH | | |
| 1 | 5.88 ±0.4a | 6.05 ±0.1a | 6.06 ±0.13a | 6.06 ±0.13a |
| 5 | 4.83 ±0.05b | 4.46 ±0.21b | 5.21 ±0.03a | 4.90 ±0.13a |
| 8 | 5.46 ±0.28a | 4.9 ±0.08b | 5.05 ±0.11b | 4.87 ±0.32b |
| 11 | | 5.17 ±0.02b | 5.05 ±0.12a | 5.08 ±0.07a |
| 14 | | | 5.29 ±0.03 | nm |
| 16 | | | | 5.36 ±0.14 |
| | | °Hue (*h*) | | |
| 1 | 80.5 ±10.73a | 69.1 ±1.42a | 72 ±2.32a | 72 ±2.32a |
| 5 | 64.86 ±2.62a | 70.91 ±1.94b | 72.72 ±1.68b | 72.54 ±3.23b |
| 8 | 64.06 ±4.48a | 68.25 ±1.59a | 72.41 ±1.94b | 73.09 ±4.46b |
| 11 | | 63.5 ±4.17a | 69.77 ±1.99a | 73.09 ±4.46a |
| 14 | | | 67.86 ±2.77 | nm |
| 16 | | | | 69.66 ±2.12 |

Means with equal letters per line are statistically equal ($p \leq 0.05$).

**Table 2. Total soluble solids, titratable acidity, pH and internal color of jackfruits stored at room temperature (AMB, 25 ±3 °C), fruits stored in refrigeration for 5 days at 8 ±2 °C and then stored at room temperature (5D 8 °C + AMB), fruits treated with NaturalShine505-OR® (R1) and SemperFresh® (R2) coatings, stored in refrigeration for 5 days at 8 ±2 °C and then stored at room temperature.**

| Storage days | 25 ±3 °C | 5DR 8 °C +AMB | R1-5DR 8 °C +AMB | R2-5DR 8 °C +AMB |
|---|---|---|---|---|
| | | Total soluble solids (°Brix) | | |
| 1 | 8.33 ±1.53a | 8.33 ±1.53a | 5.9 ±0.58a | 5.9 ±0.58a |
| 5* | 27.05 ±0.95a | 13.38 ±0.25b | 20.38 ±4.57b | 14.73 ±0.78b |
| 8 | 29.55 ±3.52a | 17.85 ±2.48b | 23.1 ±2.14c | 16.73 ±2.36c |
| 11 | | 28.95 ±0.52a | 29.6 ±1.17a | 20.78 ±1.65a |
| 14 | | 26.63 ±0.89a | 28.63 ±1.25a | nm |
| 17 | | | | 29.6 ±4.79 |

| Storage days | 25 ±3 °C | 5DR 8 °C +AMB | R1-5DR 8 °C +AMB | R2-5DR 8 °C +AMB |
|---|---|---|---|---|
| | | Titratable acidity (% citric acid) | | |
| 1 | 0.17 ±0.05a | 0.17 ±0.05a | 0.17 ±0.01a | 0.14 ±0.01a |
| 5* | 0.26 ±0.07a | 0.26 ±0.07a | 0.48 ±0.08b | 0.31 ±0.03b |
| 8 | 0.19 ±0.02a | 0.19 ±0.02a | 0.37 ±0.09b | 0.27 ±0.04b |
| 11 | | 0.36 ±0.06a | 0.51 ±0.11b | 0.32 ±0.04a |
| 14 | | 0.24 ±0.02a | 0.4 ±0.08b | nm |
| 17 | | | | 0.28 ±0.06 |
| | | pH | | |
| 1 | 5.88 ±0.40a | 5.88 ±0.14a | 5.86 ±0.15a | 5.86 ±0.15a |
| 5* | 4.83 ±0.05a | 4.89 ±0.09a | 4.66 ±0.17a | 4.89 ±0.08a |
| 8 | 5.46 ±0.28a | 5.53 ±0.18a | 5.06 ±0.45a | 4.91 ±0.07b |
| 11 | | 5.01 ±0.11a | 5.29 ±0.06a | 5.1 ±0.04a |
| 14 | | 5.21 ±0.01a | 5.26 ±0.04a | nm |
| 17 | | | | 5.28 ±0.05 |
| | | °Hue (*h*) | | |
| 1 | 80.5 ±10.73a | 78.6 ±11.71a | 77.73 ±3.45a | 77.73 ±3.45a |
| 5* | 64.86 ±2.62a | 71.17 ±2.12b | 70.05 ±3.89b | 75.39 ±2.19b |
| 8 | 64.06 ±4.48a | 73.75 ±3.81b | 75.66 ±2.84b | 77.05 ±4.16b |
| 11 | | 63.94 ±9.54a | 65.07 ±2.92a | 72.94 ±1.51b |
| 14 | | 69.96 ±5.61a | 66.31 ±0.83a | nm |
| 17 | | | | 64.68 ±2.51 |

Means with equal letters per line are statistically equal ($p \leq 0.05$). * = last day in refrigeration; nm= not measured.

In the ripened fruits at 25 °C, 29.6 °Brix was reached at day 8 and in the fruits that were refrigerated to 13 °C or 8 °C DR + AMB without coatings, very similar values were achieved, but on day 11 and 14, respectively. This shows the effect of refrigeration temperature on delay in SST development for 6 days.

On the other hand, there were significant differences ($p < 0.05$) in the SST content between the fruits with both coatings and stored at 13°C + AMB, as the fruits with R1 developed the highest SST content, on day 14 with 33.48 °Brix and the fruits with R2 had 31.08 °Brix on day 16.

In the fruits refrigerated at 8 °C with coatings, a similar behavior was observed in the SST, reaching values between 26.6 and 28.6 °Brix on days 11-14 the fruits coated with R1, but in the fruits coated with R2 its maturity was extended until day 17 (5DR + 12AMB) with 29.60 °Brix. R2 had a greater effect in retarding the development of soluble solids, reaching the expected values at consumption maturity 8 or 7 days longer than those stored at room temperature 3 and 5 days relative to uncoated refrigerated and between 2 and 3 days compared to the R1 coating.

SST increase according to jackfruit ripens and this is due to the degradation of polysaccharides (Vargas-Torres *et al*., 2017). Coatings also have an important effect on this parameter; Velickova *et al*. (2013) reported that, in coated strawberries this behavior is due to slower metabolization of carbohydrates during storage time.

The barrier properties of the R2 coating and storage temperature of 8 °C, decreased the production of ethylene, so the increase in SST was delayed more days in the fruits with these treatments. SST found in this experiment are within the range reported by Shamsudin *et al.* (2009) between 19.03-32.53 °Brix in jackfruit bulb juice stored at room temperature of 27 °C.

The titratable acidity and pH are shown in Table 1 and 2. In all bulbs, a slight tendency to increase of the AT was observed and consequently the pH to decrease. Vargas-Torres *et al*. (2017) and Mata-Montes de Oca *et al*. (2007) reported a different behavior from AT and pH in coated jackfruit bulbs, as the AT decreases and pH decreases, this may be due to the difference in raw material, since in this experiment a plant material not previously studied was used.

It is observed that only in fruits that were stored at 13 °C or 8 °C DR + AMB with coatings, the change in AT and pH with respect to the witness fruits was slightly delayed ($p< 0.05$). Edible coatings have barrier properties that reduce the surface permeability of the fruits to $O_2$ and $CO_2$, which generates an increase in $CO_2$ concentration in fruit tissues and adecrease in $O_2$ concentration that delays ripening (of Wild *et al.*, 2005), this allows to conclude that the delay in VR and VPE also delay the evolution of AT and pH in this treatment.

Regarding the color, the jack bulbs changed from a light yellow to intense orange color in all treatments. The light-yellow hue in bulbs in state of physiological maturity has °Hue values of 72.01-80.50 and decreases to average values of 63.50-69.66, which is the characteristic yellow-orange color in the jackfruit pulp, in all bulbs of the evaluated fruits.

The color change of the bulbs was dependent on each treatment, the bulbs stored at 25 °C were the ones that changed first from light yellow to orange followed, of the fruit bulbs stored at 13 °C 5DR + AMB uncoated and coated, at 8 °C 5DR + AMB uncoated and coated; therefore, significant differences ($p< 0.05$) were observed in color development due to the storage and coating condition.

Vargas-Torres *et al*. (2017) reported that the value of °Hue for mature jackfruit bulbs (yellow) is 82.52-87.87. On the other hand, Mata-Montes de Oca *et al*. (2007) mention that the color of the jackfruit bulbs is yellow (92-93 °Hue) in the immature state and changes to a color yellow-orange when they mature (75 °Hue). The aforementioned authors do not report what type of plant material they used. These results do not coincide whit those found in this work because the color of mature jackfruit bulbs may vary depending on the genotype.

Ethylene regulates the synthesis of enzymes involved in carotenoid biosynthesis, if ethylene biosynthesis is delayed or inhibited, carotenoid synthesis slows or stops (Mustilli *et al*., 1999). Therefore, the effect of refrigeration at 8 °C and application of the R2 coating on the slow development of color in bulbs may be related to the evolution of VPE, as there was probably a decrease in the activity of enzymes that synthesize carotenoids.

## Conclusions

The jackfruit fruits of the plant material 'Agüitada' ripen between 6-7 days when they are stored at room temperature. When the jackfruit fruits are refrigerated at 13 °C or 8 °C for 5 days and then they ripen at room temperature, their shelf life is 9-10 and 11-12, days respectively, although in the fruits stored at 8 °C for 5 days there is a slight cold damage.

The application of Natural Shine coatings in combination with cold storage for 5 days and subsequent marketing condition, did not extended the shelf life of the fruits, although a decrease in weight loss was observed. The application of the Semperfresh coating in combination with the cooling temperatures (8 and 13 °C for 5 days) decreased the respiration speed, ethylene production, weight loss and delayed evolution of physicochemical parameters, extending the shelf life of jackfruit between 13 and 15 days, respectively, for marketing.

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