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Articles

Cold damage to fruits of mango variety Ataulfo

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Abstract

Mangoes are one of the favorite fruits in the United States market, with annual imports of 120 million boxes. One of the challenges in delivering quality fruit is that shipping from countries of origin requires up to four weeks of transport, which causes overripeness and complications for distribution to wholesalers and retailers. Shipments are made in refrigerated sea containers, which slows down the ripening process. Nonetheless, mango fruits are susceptible to cold damage when stored at low temperatures. For all these reasons, the research aimed to quantify the effect of the degree of ripeness, temperature, and transport time on cold damage in Ataulfo mango fruits. The degree of ripeness (partially ripe and ripe), storage temperatures (7.5, 10 and 12.5 °C), and refrigerated transport (1, 2 or 3 weeks) were examined. The variables evaluated were external and internal damage, pulp firmness and color, and total soluble solids. It was found that the state of ripeness had no influence on the external and internal damage of the fruits. However, the temperature affected it significantly, the lower the temperature the greater the damage. Storage time significantly influenced external damage, pulp firmness and color, and total soluble solids. The longer the storage time, the greater the damage. In addition, it was observed that the combination of temperature and storage time was significant. The damage manifested itself from the first week of transport at 7.5 °C.

Keywords:

refrigerated transport, state of ripeness, temperature.

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Introduction

Mangoes are one of the favorite fruits in the United States market since, over the past three years, 120 million boxes have been imported, mainly from Mexico (65%), Peru (10%), Ecuador (9%), Brazil (7.1%), Guatemala (4.6%), and Haiti (2.3%) (USDA-FAS, 2020). The most demanded varieties for export are Tommy Atkins, Ataulfo, Kent, Keitt, and Haden (SAGARPA, 2020).

Most of the time, fruit quality at the consumer level is compromised as exporting countries face several challenges in the delivery of high-quality fruit (Brecht *et al*., 2017), since the transport of fruits from the largest exporting countries to the United States of America is carried out in refrigerated sea or land containers, requiring three to four weeks of transport (Osuna *et al*., 2019).

The mentioned above and the refrigeration temperature are the main problems for the transport of the fruit since, if there is not good handling, it can cause overripeness, complications for distribution at the wholesale and retail levels and CD (Osuna *et al*., 2019).

The severity of CD of fruits stored in refrigeration depends on the cultivar, state of ripeness, and time of exposure to a given temperature. The main symptoms of damage are irregular ripening, poor color and flavor development, peel pitting and discoloration, increased susceptibility to diseases and, in severe cases, pulp darkening (Lobo and Sidhu, 2017).

These symptoms are not evident while the fruit is refrigerated, they become visible until the fruit is exposed to warmer temperatures for ripening or during the marketing process. According to the literature, the optimal temperature for refrigerated mango storage is around 12-13 °C (Medlicott *et al*., 1990; Kader, 1992).

On the other hand, it is reported that the state of ripeness greatly influences the occurrence of CD. In general terms, unripe fruits are more susceptible than more ripe ones (Medlicott *et al*., 1990; Kader, 1997; Mohammed and Brecht, 2002). In addition, temperature and exposure time have a significant influence on the susceptibility of mango fruits to CD.

Fruits exposed to temperatures < 8 °C show symptoms of CD during the first week of storage, whereas those stored at the recommended temperature (12-13 °C), depending on the cultivar, express no damage or, at most, very slight damage (Chaplin, 1991; Phakawatmongkol *et al*., 2004; Luna *et al*., 2006; Miguel *et al*., 2011; Brecht *et al*., 2012).

According to Brecht *et al*. (2012), the critical information to avoid CD is the combination of times and temperatures, involving the maximum and minimum temperature at which CD is or is not detected. This study aimed to quantify the effects of the degree of ripeness at harvest, temperature, and refrigerated transport time on CD in Ataulfo mango fruits.

Materials and methods

The research was conducted during the 2019 season at the Naturamex S de RL de CV packing plant, located on state highway 54, at 1 200 in the locality of 5 de Mayo, municipality of Tepic, Nayarit, Mexico, where 62 fruits were obtained per treatment (2 boxes with 31 fruits each). The fruits were collected just after washing and already classified for the quarantine hydrothermal treatment of 75 or 90 min.

The fruits were then separated according to the degree of ripeness, considering partially ripe fruits (flat without filling of cheeks and shoulders below the peduncle insertion; pulp color values <2, and TSS content ≤6 °Bx) and ripe fruits (round in appearance with full filling of cheeks and shoulders raised above the peduncle insertion; pulp color values between 2 and 3, with an TSS content >6 °Bx).

The fruits had an excellent external appearance and were free of mechanical damage, pests, and/or diseases. Once the fruits were separated by state of ripeness and size, they were subjected to quarantine hydrothermal treatment according to the USDA-APHIS protocol. After this treatment, the fruits were stored at different temperatures (7.5 ±1 °C, 10 ±1 °C, and 12.5 ±1 °C) in commercial

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refrigerated storage chambers for up to three weeks with weekly transfers to marketing simulation (22 ±2 °C; 75 ±10% RH) until consumption ripeness.

The design used was factorial (2*3*3) (Table 1), considering the degree of ripeness, transport temperature, and duration of refrigerated transport, with five replications for each variable, generating the following treatments.

Table 1. Treatments generated by factorial (2*3*3).

Num.	Degree of ripeness	Transport temperature (°C)	Refrigeration time (week)
1	Partially ripe	7.5 ±1	1
2	Partially ripe	7.5 ±1	2
3	Partially ripe	7.5 ±1	3
4	Partially ripe	10 ±1	1
5	Partially ripe	10 ±1	2
6	Partially ripe	10 ±1	3
7	Partially ripe	12.5 ±1	1
8	Partially ripe	12.5 ±1	2
9	Partially ripe	12.5 ±1	3
10	Ripe	7.5 ±1	1
11	Ripe	7.5 ±1	2
12	Ripe	7.5 ±1	3
13	Ripe	10 ±1	1
14	Ripe	10 ±1	2
15	Ripe	10 ±1	3
16	Ripe	12.5 ±1	1
17	Ripe	12.5 ±1	2
18	Ripe	12.5 ±1	3

Sampling was carried out at the beginning and end of the refrigeration period and at consumption ripeness. The data was analyzed using the SAS statistical package (SAS, 2002).

Variables analyzed

Cold damage. The external symptoms of CD (lenticel darkening, peel pitting, scald-like discoloration, irregular ripening) were assessed throughout the storage period using a visual scale (Brecht *et al*., 2012), in which 1= severe damage (>50% of the fruit surface with damaged); 2= moderate damage (25-50% damage); 3= slight damage (max 25% CD); 4= traces (2-5% damage to the total surface of the fruit); 5= no apparent damage.

The internal symptoms of CD (pulp darkening and disease presence) were evaluated based on the following scale (Brecht *et al*., 2012): 0= no damage or presence of diseases; 1= slight damage (any damage no larger than – inch in diameter); 2= moderate damage (damage or presence of disease in diameters of – to 1½ inches); 3= severe damage (damage or presence of disease in diameters >1½ inches).

Pulp firmness. With a Chatillon DFE-050 penetrometer (Ametek Instruments, long, FL), adapted with a cylindrical punch of 8 mm diameter; the data were expressed in Newtons (N).

Pulp color. With a Konica Minolta C-R 10 portable colorimeter (Konica Minolta Sensing Americas, Inc., Ramsey, NJ, USA) with standard C lighting; the hue angle (Hue) was reported.

Total soluble solids (TSS). With a digital refractometer with Atago PAL temperature compensator calibrated with distilled water (AOAC, 1984).

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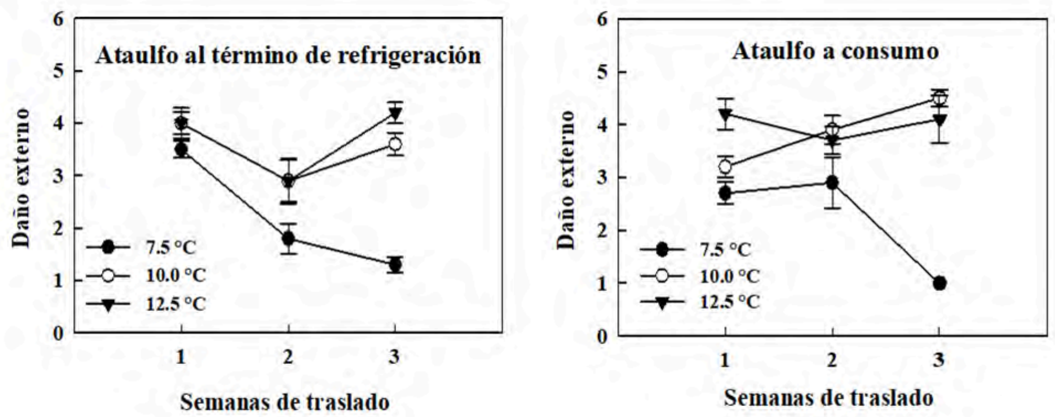
Results and discussion

External damage

It was observed that the degree of ripeness had practically no influence on the presence of external cold damage since no significant differences (p< 0.05) were detected between partially ripe and ripe fruits, which coincides with what was reported by Osuna *et al*. (2019) for Kent and Keitt varieties. However, the factors of temperature and duration of refrigerated storage did have a considerable impact on the fruits. The lower the temperature, the greater the damage; the longer the refrigeration time, the greater the deterioration (Figure 1).

Figure 1. External cold damage in Ataulfo mango fruits at the end of refrigeration and at consumption. Each point represents the mean of five observations ± the standard error. Scale 1= severe damage; 2= moderate damage; 3= slight damage; 4= traces; 5= no apparent damage.



In both the first and second week of storage at the end of refrigeration, the temperature of 7.5 °C caused slight to moderate damage, which increased at consumption as they reached values close to one, which represent moderate to severe damage to Ataulfo mango fruits. Other authors agree with these results as they observed CD at low temperatures, such as Vega-Álvarez *et al*. (2020), who report damage in the Keitt variety at 5 °C, Miguel *et al*. (2013), who report damage in the Palmer variety at 2 °C and 5 °C, and Chongchatuporn *et al*. (2013), who detected differences between the Nam Dok Mai and Choke Anan varieties when subjected to a temperature of 4 °C.

CD is a physiological disorder associated with cell membrane damage and increased production of reactive oxygen species (ROS). Cold storage reduces the ratio of unsaturated/saturated fatty acids in membranes, which become rigid and more susceptible to lipid peroxidation by ROS produced during cold stress. If this stress is prolonged, the membrane damage is irreversible and the fruit develops symptoms of CD (Sevillano *et al*., 2009).

Internal damage

In contrast, the internal cold damage (Figure 2), was practically negligible for Ataulfo mango fruits at the end of refrigeration and at consumption, without showing significant differences for degree of ripeness, temperature, and storage duration. The internal CD was lower because the refrigeration temperatures were not as extreme as those of other studies, where they used lower temperatures between 2 and 5 °C.

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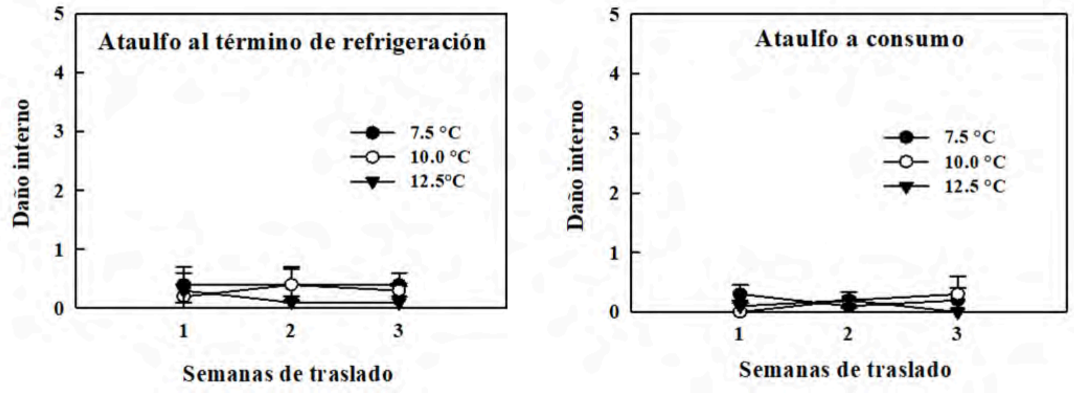
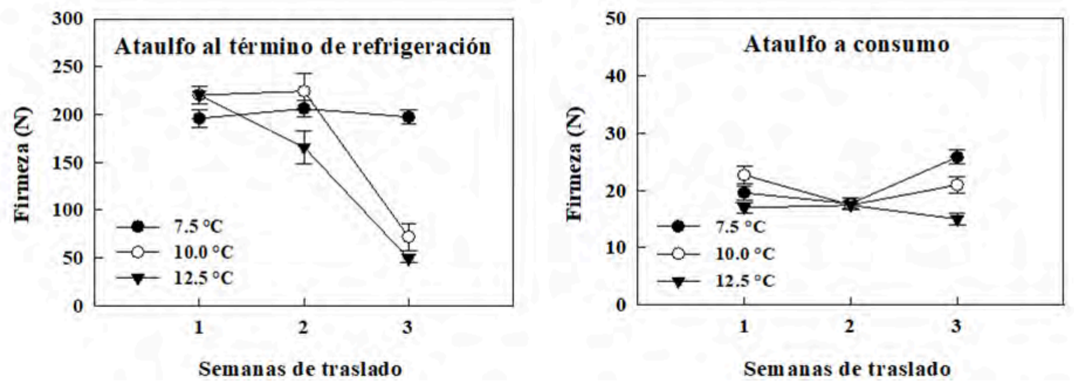
Figure 2. Internal cold damage to Ataulfo mango fruits at the end of refrigeration and at consumption. Each point represents the mean of five observations ± the standard error. Scale 0= no damage or presence of diseases; 1= slight damage; 2= moderate damage; 3= severe damage.



Firmness

Regarding the pulp firmness for Ataulfo mango fruits (Figure 3), no significant differences ($p< 0.05$) were detected at the end of one week of refrigerated transport. Nonetheless, at the end of the second week, the recommended temperature (12.5 °C) was not enough to maintain the firmness of the fruits. After three weeks of refrigeration, the effect of the colder temperature (7.5 °C) managed to significantly preserve ($p< 0.05$) the firmness of the pulp. At lower temperatures, the firmer the pulp was observed.

Figure 3. Firmness in Ataulfo mango fruits at the end of refrigeration and at consumption. Each point represents the mean of five observations ± the standard error.



Nevertheless, it was also evident that the temperature of 7.5 °C caused external damage to the mango fruits. This is consistent with what was reported by Vega-Álvarez *et al*. (2020), who observed that the temperature of 5 °C maintained the firmness of the Keitt variety fruits since, at the end of the 20-day cold storage, the firmness of the fruit decreased significantly; likewise, they were able to observe CD in the fruits due to the temperature used.

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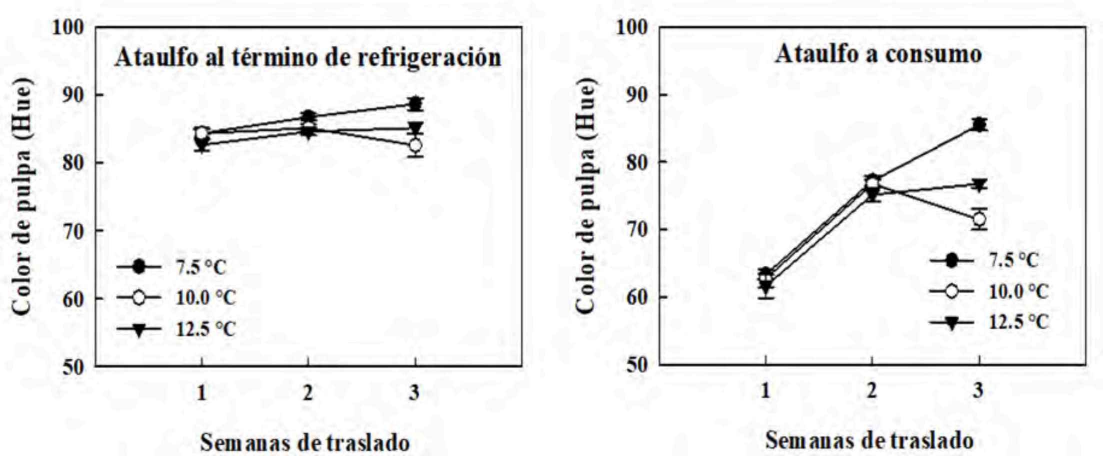
On the other hand, Osuna *et al*. (2019) reported that the temperature of 7.5 °C maintained the firmness of Kent and Keitt fruits during three weeks of storage; however, this temperature caused CD in both varieties.

Regarding the firmness of the fruits at the time of consumption, it is important to mention that the longer the refrigerated transport time, the shorter the time required to reach the ready-to-eat fruit state (20 to 40 N firmness). After a week of refrigeration, the fruits required 12 days to reach consumption ripeness, after two weeks, they only required nine days, and after three weeks, they reached the ideal point in just seven days after the end of refrigeration.

Pulp color

Regarding the pulp color of the Ataulfo mango fruits (Figure 4), it was observed that at a lower temperature or with a longer storage time, the intensity of the pulp color was delayed. There were no significant differences at the end of one week of refrigeration. Nevertheless, at the end of two weeks, a significant difference was found between the fruits, with those fruits that were refrigerated at 7.5 °C showing a decrease in color development. A similar trend was observed at the end of the three weeks of refrigeration.

Figure 4. Pulp color (Hue) in Ataulfo mango fruits at the end of refrigeration and at consumption. Each point represents the mean of five observations ± the standard error.



In general, the development of pulp color was delayed by lower temperatures. Other studies indicate browning in the pulp of the fruits of the Nam Dok Mai and Choke Anan varieties when exposed to temperatures of 4 and 12 °C (Chongchatuporn *et al*., 2013), whereas Vega-Álvarez *et al*. (2020) observed that fruits of the Keitt variety presented significant color changes between storage conditions, with inhibition of color when the fruits were stored at 5 °C for 20 days.

Subsequently, the fruits were stored for seven days at 21 °C and they took on a more reddish hue. Likewise, Osuna *et al*. (2019) mention that, at lower temperatures (7.5 °C and 10 °C), the intensity of pulp color was delayed in the Kent and Keitt varieties. On the other hand, the recommended temperature (12.5 °C) showed the highest intensity of the pulp color, which indicates that, at this temperature, the ripening process of the fruits does not stop.

This is consistent with what was reported by Dea *et al*. (2010), where fruits of the Kent variety stored at 12 °C had a more orange hue than fruits stored at 5 °C, which showed a more yellow hue. This phenomenon is probably due to the continuation of the ripening process at the highest temperature.

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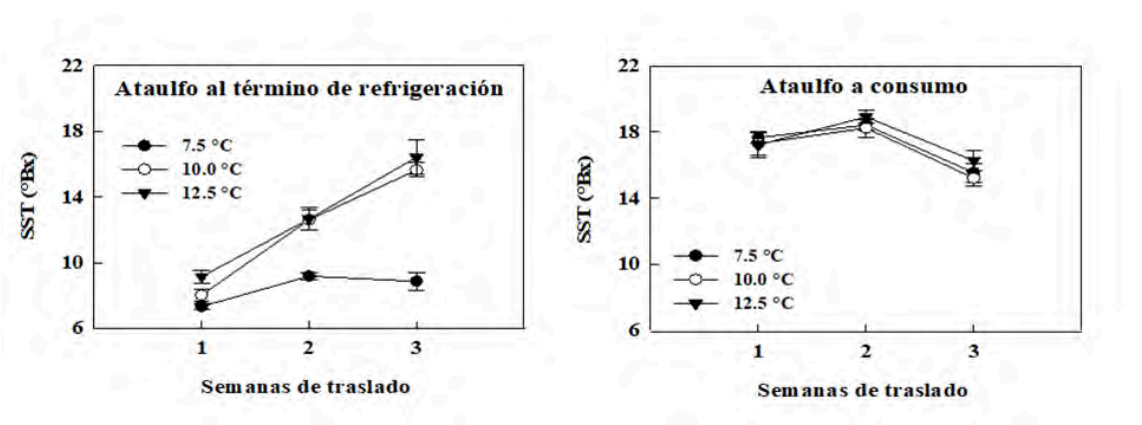
Total soluble solids (TSS)

For the TSS content of Ataulfo mango fruits (Figure 5), there was a significant difference between temperatures at the end of two and three weeks of refrigeration, with a lower content in the fruits stored at 7.5 °C. The lower the temperature, the lower the development of the TSS content, which reflects a delay in the ripening process.

Figure 5.Total soluble solids in Ataulfo mango fruits at the end of refrigeration and at consumption. Each point represents the average of five observations ± the standard error.



After two weeks of marketing simulation, the fruits kept at the recommended temperature (12.5 °C) showed the highest TSS content, suggesting a more accelerated ripening process. This is consistent with what was reported by Dea *et al*. (2010), who point out that Kent fruits stored at 12 °C had lower acidity, higher pH, and higher TSS content compared to fruits stored at 5 °C, indicating faster ripening at higher temperatures.

On the other hand, Vega-Álvarez *et al*. (2020) observed that TSS content gradually increased in Keitt fruits during storage, with a lower percentage when the fruits were stored at 5 °C for 20 days. In contrast, when the fruits were stored at 21 °C for seven days, they showed a significant increase in the percentage of TSS content. Similarly, Osuna *et al*. (2019) reported that the lower the storage temperature (7.5 °C), the lower the development of TSS content.

Conclusions

Mango fruits of the Ataulfo variety were susceptible to CD, with external damage being more significant than internal damage. The factors that influenced the most were temperature and refrigeration time. It was observed that, at lower temperatures and with a longer refrigerated storage time, the damage was more pronounced. In addition, at lower temperatures, the fruits were firmer, whereas a longer storage time resulted in less firmness. For practical purposes, it is recommended that Ataulfo mango fruits be transported at 12.5 °C and never at 7.5 °C to avoid CD.

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