

Validating Ideal Controlled Atmosphere Environmental Conditions to Protect Consumer Quality of Hot-Water-Treated Mangos at 12.5°C

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EXECUTIVE SUMMARY: *A controlled atmosphere (CA) treatment consisting of 10 or 20% carbon dioxide combined with $\geq 5\%$ oxygen slowed softening of hot-water-treated (HWT) mangos harvested at NMB-2 during simulated shipment at 12.5°C for 20 days. At 20 days, HWT ‘Tommy Atkins’ mangos softened more slowly under 10 or 20% carbon dioxide than mangos under air. There were no differences in softening between mangos stored under 20% or 10% CO₂. At 20 days, HWT ‘Ataulfo’ mangos softened more slowly under 20% carbon dioxide than mangos under 10% carbon dioxide or air. Mangos under 10% CO₂ were firmer than mangos under air, but softer than under 20% carbon dioxide. At 20 and 30 days, HWT ‘Keitt’ mangos softened more slowly under 20% carbon dioxide than mangos under 10% carbon dioxide or air. There were no differences in softening between mangos stored under 10% CO₂ or air, thus, 20% CO₂ should be used in ‘Keitt’. External and internal disorders were not observed in any of the treatments the same as for ‘off flavor’ development. CA did not influence rate of softening during warm display. However, mangos from the 20% CO₂ treatment remained firmer than mangos from other treatments during display because they started with higher firmness upon removal from CA. A controlled atmosphere facility was established in the CIAD in Culiacan, Mexico, for current and future work on mangos. Further work at the production areas on CA benefits on not-hot-water-treated (NHWT) mangos is encouraged. A commercial shipping demonstration of the benefits of CA for HWT mangos for trips lasting no more than 20 days will be performed as outreach education.*

Because some hot-water-treated mangos are imported over long distances, shippers currently use chilled temperatures and less mature mangos to assure the arrival of firm fruit that will tolerate handling at the destination. However, research over the past five years demonstrated that mangos shipped at chilling temperatures at low maturity have poor consumer acceptance due to low dry matter (sensory quality), chilling injury symptoms and other storage disorders. We hypothesize that using controlled atmosphere (CA) during shipment at 12.5°C (above chilling injury problems) should reduce softening and chilling injury development, providing consumers with high-quality mangos. Limited results using very low oxygen (O₂) balanced with N₂ and CO₂ on not-hot water-treated (NHWT) mangos indicated that mango storage/shipping postharvest life can be extended by CA storage conditions with high carbon dioxide and low oxygen. However, detailed recommendations based on validations of CA treatment (high carbon dioxide and/or low

oxygen concentrations) for hot-water-treated (HWT) mango cultivars are not available. A CA test using California NHWT mangos supported our hypothesis. We also demonstrated that mangos exposed to oxygen concentrations below 5% will acquire ‘off flavor’ due low anaerobic respiration during exposure. We proposed to develop an optimum CA treatment protocol for commercially harvested, HWT mangos, then, validate the new protocol using commercial shipments from cooperators. We believe CA will delay softening and reduce chilling injury damage on harvested mangos, increasing consumer satisfaction. The outcome of this proposed CA transportation protocol will benefit mango producers, handlers and consumers.

MATERIALS AND METHODS:

Objective 1: Hot-water-treated ‘Tommy Atkins’, ‘Keitt’, and ‘Ataulfo’ mangos collected in Mexico were used to determine the ideal oxygen (O₂) and carbon dioxide (CO₂) concentrations at 12.5°C for these three cultivars. These cultivars were harvested commercially and segregated into two maturities: Commercial (NMB-2: at least 90% of fruit at stage 2 or higher) and advanced maturity (NMB-3, most fruit at stage 3). Fruit were transported to CIAD in Culiacan, where they were exposed to two oxygen-carbon dioxide stress conditions (Table 1) for up to 30 days. We used 5% O₂ and two CO₂ concentrations with ethylene during storage-simulated transport at 12.5°C. Thus, six treatments (Air and two O₂-CO₂ combinations with two maturities) with three replications were used. The controlled atmosphere conditions were CA 1 = 5% O₂ and 10% CO₂ and CA 2 = 5% O₂ and 20% CO₂. Quality measurements were carried out after 20 and 30 days and during ripening after storage for six days at room temperature.

Table 1. Influence of maturity (NMB-2, NMB-3&4) and CA (oxygen (O₂) and carbon dioxide (CO₂) combinations) treatments on mango arrival quality after simulated transportation at 12.5°C.

Cultivar	Treatment	NMB-2		NMB-3	
		O ₂ (%)	CO ₂ (%)	O ₂ (%)	CO ₂ (%)
Ataulfo	Air	AIR	AIR	AIR	AIR
	CA 1	5	10	5	10
	CA 2	5	20	5	20
Keitt	Air	AIR	AIR	AIR	AIR
	CA 1	5	10	5	10
	CA 2	5	20	5	20
Tommy Atkins	Air	AIR	AIR	AIR	AIR
	CA 1	5	10	5	10
	CA 2	5	20	5	20

Objective 2: *Commercial shipment demonstration*

Commercial shipments to validate the impact of CA conditions during commercial shipment under real-world conditions are being organized. Discussions are underway with Carrier Europe, Hapag-Lloyd and DUREXPORTA (Ecuador).

Objective 3: Information Distribution

Besides developing and validating a CA protocol for important mango cultivars, this project includes training in postharvest technology for the groups involved. Our goal is to collect, summarize and distribute short semester interim reports and participate in outreach activities to disseminate the new handling protocol derived from these studies.

RESULTS

Tommy Atkins Softening during Storage: 0-30 days at 12.5°C.

On Day 0 (harvest), prior to being placed in storage (simulated transportation), ‘Tommy Atkins’ NMB-2 mangos had an average firmness of 36.4 lbf. Mangos were placed in each treatment at 12.5°C for 20 and 30 days (**Figure 1**). Softening occurred in all treatments during simulated transportation, but at different rates. After 20 days, ‘Tommy Atkins’ stored in either CA treatment were firmer (~7.0 lbf) than mangos stored in air (2.4 lbf). By 30 days, there were no significant differences in mango firmness among treatments, mangos under the CA 2 treatment had firmness of 4.0 lbf followed by CA 1 and Air with ~3.0 lbf.

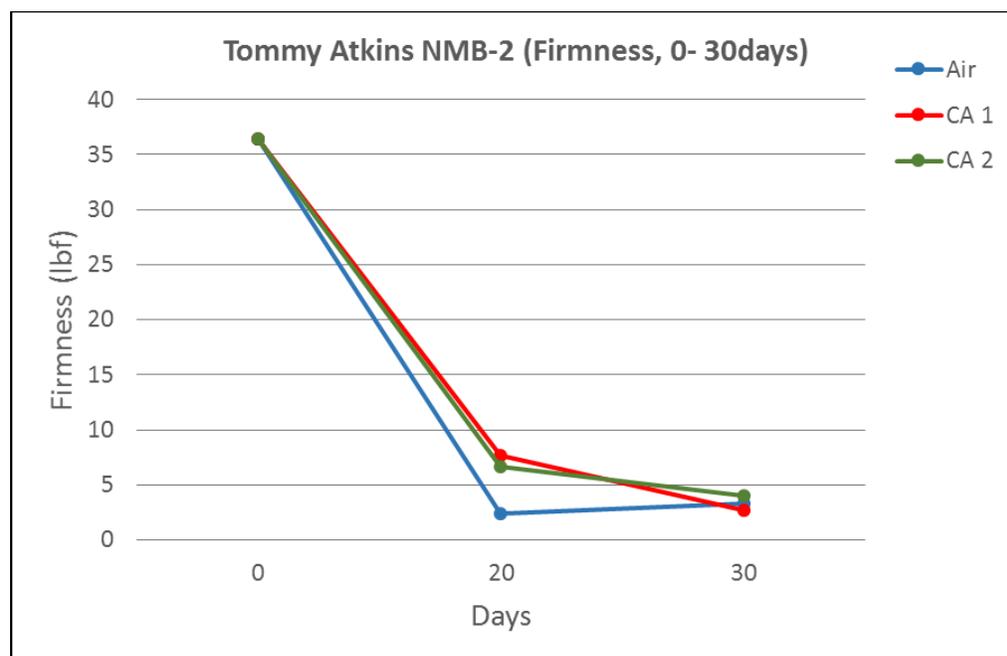


Figure 1. Softening of ‘Tommy Atkins’ mangos harvested at NMB-2 during 30 days storage at 12.5°C under three atmospheric conditions.

CA treatments did not affect softening during 30 days simulated transportation of ‘Tommy Atkins’ mangos harvested at advanced maturity stages (NMB-3). By 20 or 30 days, mango firmness was no different among treatments. For example, by 20 days mango firmness was ~2.5 lbf in all treatments (**Figure 2**) and by 30 days storage, ~2.0 lbs. At both evaluation dates, mangos were too soft to tolerate retail handling.

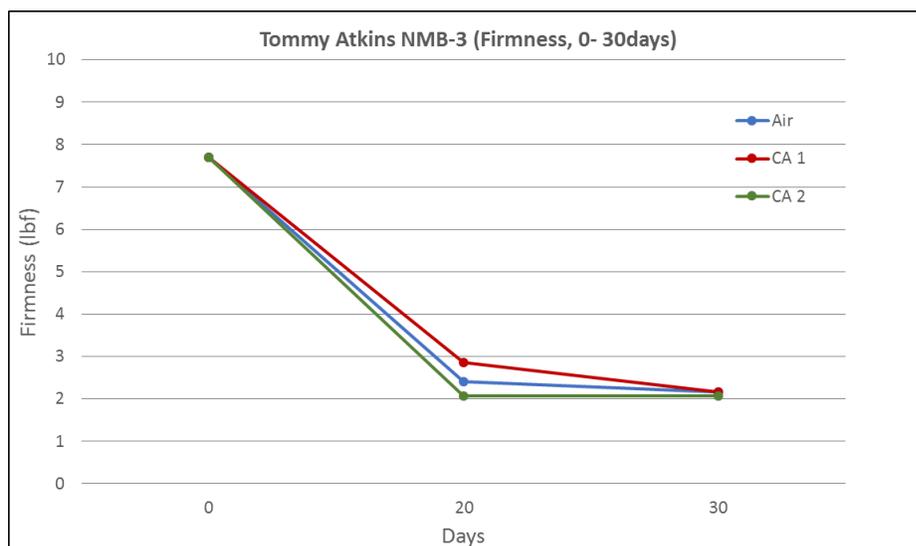


Figure 2. Softening of ‘Tommy Atkins’ mangos harvested at NMB-3 during 30 days storage at 12.5°C under three atmospheric conditions.

‘Tommy Atkins’ softening during display: 20 to 26 days at room temperature.

After 20 days storage, mangos were displayed for six days at room temperature and firmness measured every two days (at two, four, and six days). ‘Tommy Atkins’ NMB-2 mangos stored in CA 1 and CA 2 softened significantly throughout the six days of display, while air-treated mangos had low firmness after 20 days and experienced little change during the display period (**Figure 3**). Mangos stored in CA 1 had a firmness of 1.5 lbf after six display days, CA 2 mangos had a firmness of 2.3 lbf, and air-treated mangos were 1.5 lbf. This was a decrease of 6.2 lbf in CA 1, 4.4 lbf in CA 2, and 0.9 lbf for air over six days at ambient temperature.

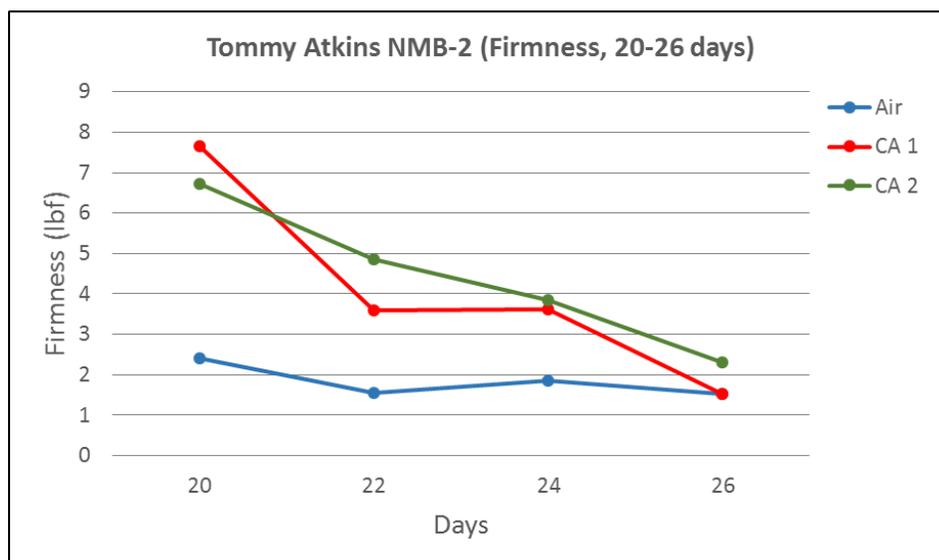


Figure 3. Softening of ‘Tommy Atkins’ mangos harvested at NMB-2 during six days display at 20°C after 20 days storage under three atmospheric conditions.

‘Tommy Atkins’ NMB-3 mangos displayed for six days at room temperature after 20 days storage showed reduced firmness in CA 1 and air-treated mangos (**Figure 4**). CA 1 treated mangos decreased in firmness by 1.2 lbf to an average 1.6 lbf after six display days and air-

treated mango firmness decreased by 0.2 lbf to 2.2 lbf after six display days. CA 2 treated mangos increased in firmness after six display days, from 2.1 lbf to 2.85 lbf at 26 days.

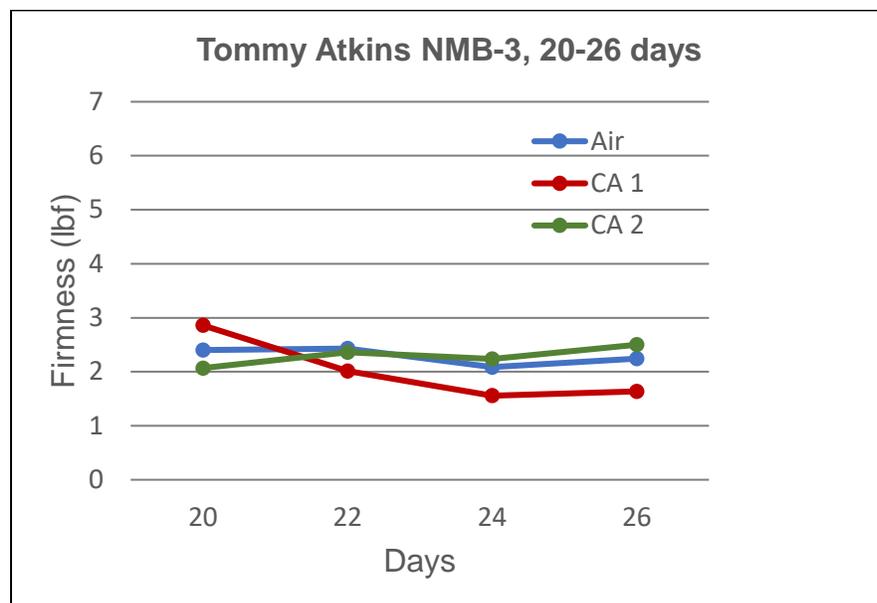


Figure 4. Softening of 'Tommy Atkins' mangos harvested at NMB-3 during six days display at 20°C after 20 days storage under three atmospheric conditions.

'Tommy Atkins' softening during display: 30 to 36 days at room temperature.

After 30 days in storage and six days display at room temperature, 'Tommy Atkins' NMB-2 mango firmness decreased by 2.0 (CA 2), 1.2 (CA 1) of 2.3 lbf (air) (**Figure 5**). The final firmness of the three treatments after 30 days storage and six days display was 3.5 lbf (CA 2), 1.5 lbf (CA 1) or 1.lbf (air).

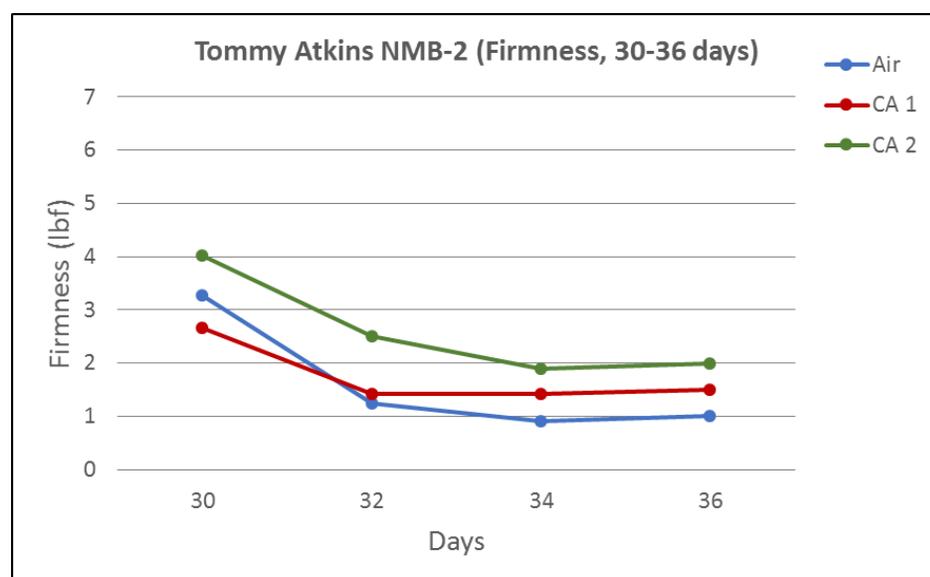


Figure 5. Softening of 'Tommy Atkins' mangos harvested at NMB-2 during six days display at 20°C after 30 days storage under three atmospheric conditions.

The final firmness of the three treatments of Tommy Atkins NMB-3 mangos after 30 days storage and six days display at room temperature was 2.0 lbf (CA 2), 1.2 lbf (CA 1), and 1.1 lbf (air) (**Figure 6**). The CA 1 mangos decreased in firmness by 1 lbf and air by 1.1 lbf. CA 2 increased in average firmness by 0.7 lbf. This increase in firmness is not significant and likely due to differences in the initial maturity of the mangoes tested at two, four and six days.

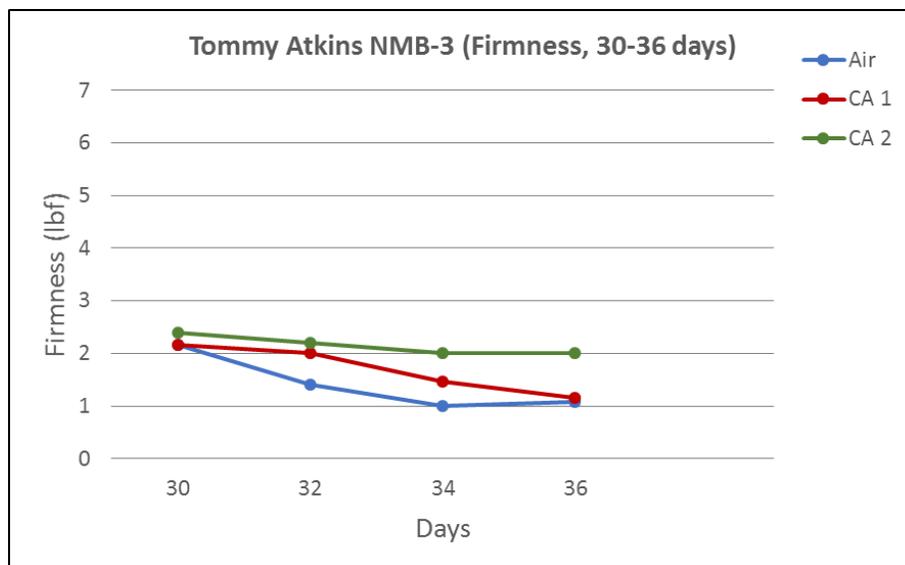


Figure 6. Softening of ‘Tommy Atkins’ mangos harvested at NMB-3 during six days display at 20°C after 30 days storage under three atmospheric conditions.

‘Ataulfo’ softening during storage: 0-30days at 12.5°C.

Before being placed in the three storage treatments at 12.5°C, ‘Ataulfo’ mangos at NMB-2 had an average firmness of 26.7 lbf (**Figure 7**). After 20 days, mangos stored in CA 2 were firmest (6.5 lbf) followed by those stored in CA 1 (4.6 lbf) and air (1.6 lbf). After 30 days storage, the CA 2 mangos remained firmest (2.5 lbf), followed by CA 1 (1.9 lbf) and air (1.2 lbf).

The NMB-3 ‘Ataulfo’ mangos had an average firmness of 15.8 lbf before storage (**Figure 8**). The firmest treatment after 20 days was CA 2 (2.4 lbf), followed by CA 1 (2.0 lbf) and air-treated (1.3 lbf). After 30 days storage, CA 2 mangos remained the firmest (2.9 lbf), followed by CA 1 (1.4 lbf) and air-treated (1.1 lbf).

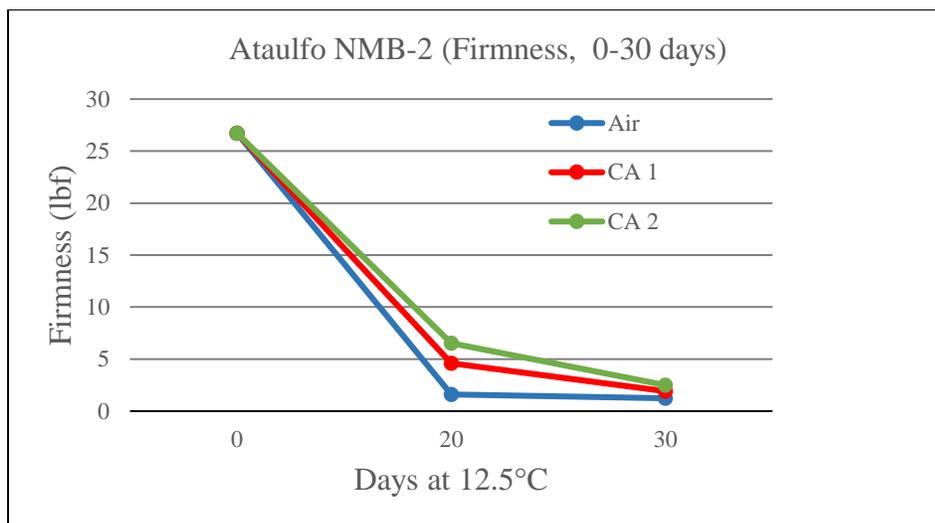


Figure 7. Softening of ‘Ataulfo’ mangos harvested at NMB-2 during 30 days storage at 12.5°C under three atmospheric conditions.

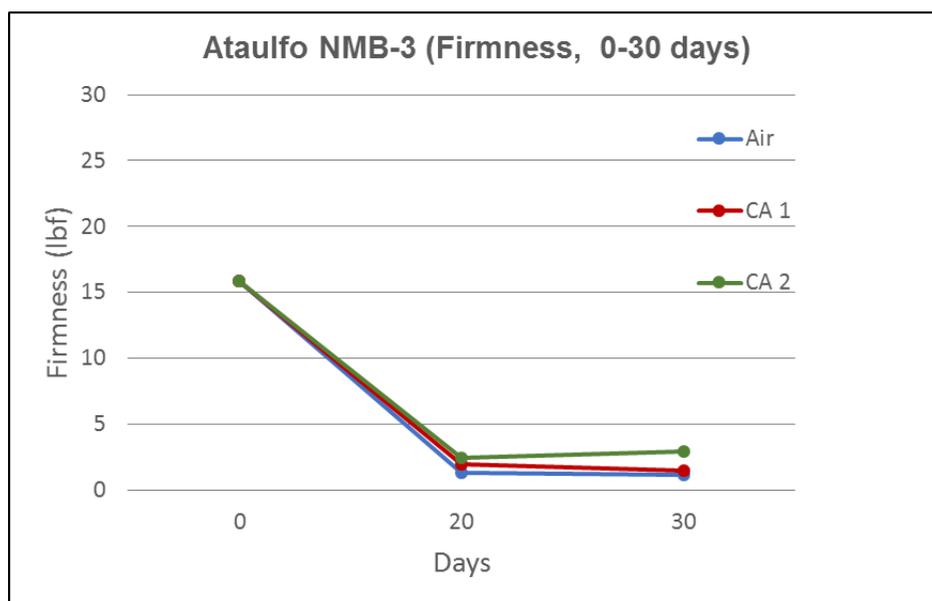


Figure 8. Softening of ‘Ataulfo’ mangos harvested at NMB-3 during 30 days storage at 12.5°C under three atmospheric conditions.

‘Ataulfo’ softening during display: 20 to 26 days at room temperature.

‘Ataulfo’ NMB-2 mangos stored in CA 1 or CA 2 had significant decreases in firmness after 20 days storage and six days display at room temperature (**Figure 9**). Mangos stored in CA 2 decreased in firmness by 4.7 lbf during display to an average of 1.9 lbf after six days. ‘Ataulfo’ mangos stored in CA 1 dropped 2.91 lbf to 1.7 lbf at six days. Air-treated ‘Ataulfo’ mangos had an average firmness of 1.6 lbf after 20 days storage and lost 0.3 lbf during six display days, with a final average firmness of 1.3 lbf.

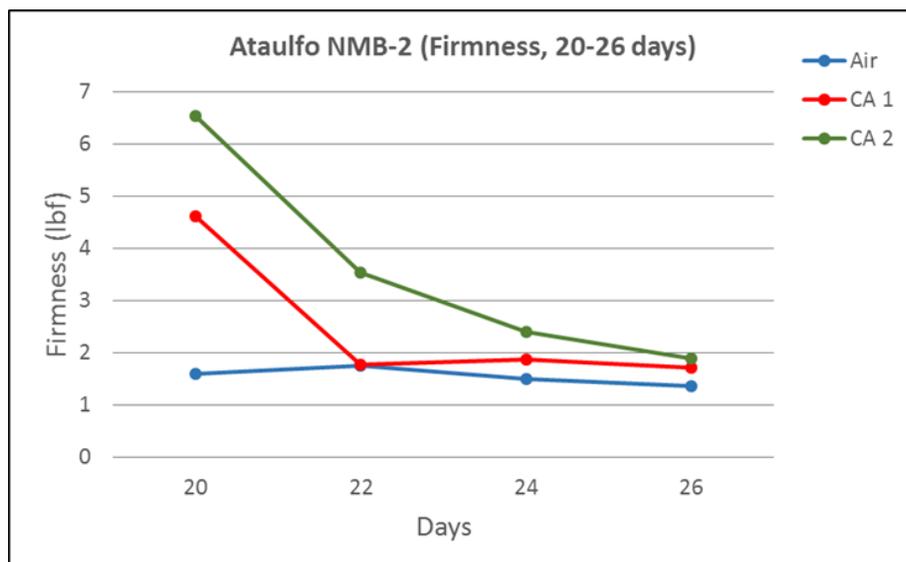


Figure 9. Softening of ‘Ataulfo’ mangos harvested at NMB-2 during six days display at 20°C after 20 days storage under three atmospheric conditions.

After 20 days storage and six days display at room temperature, ‘Ataulfo’ NMB-3 mangos stored at CA 1 were the firmest at 2.2 lbf, an increase of 0.3 lbf gained during display (**Figure 10**). This is likely due to different initial maturity at storage and variance in firmness after storage removal in the mangos tested at two-day intervals. CA 2 mangos had a firmness of 1.7 lbf, dropping 0.7 lbf in six days. Air-treated ‘Ataulfo’ NMB-3 mangos decreased 0.16 lbf, to 1.18 lbf after six days display.

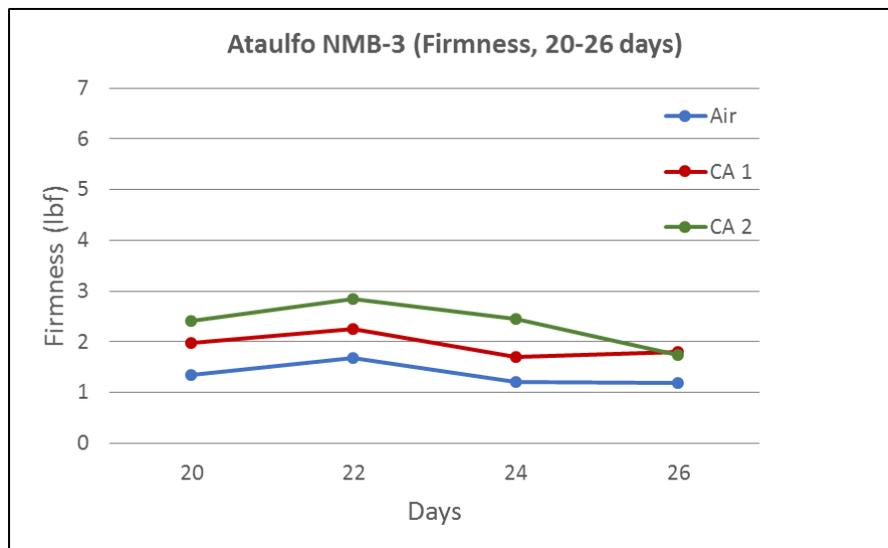


Figure 10. Softening of ‘Ataulfo’ mangos harvested at NMB-3 during six days display at 20°C after 20 days storage under three atmospheric conditions.

‘Aaulfo’ softening during display: 30 to 36 days at room temperature.

After 30 days storage and six days display at room temperature, ‘Aaulfo’ NMB-2 mangos stored either treatment reached an average firmness of 1.0 lbf (**Figure 11**). CA 2 mangos decreased in firmness by 1.0 lbf over six days display, and air treated mangos remained near 1.0 lbf after storage removal.

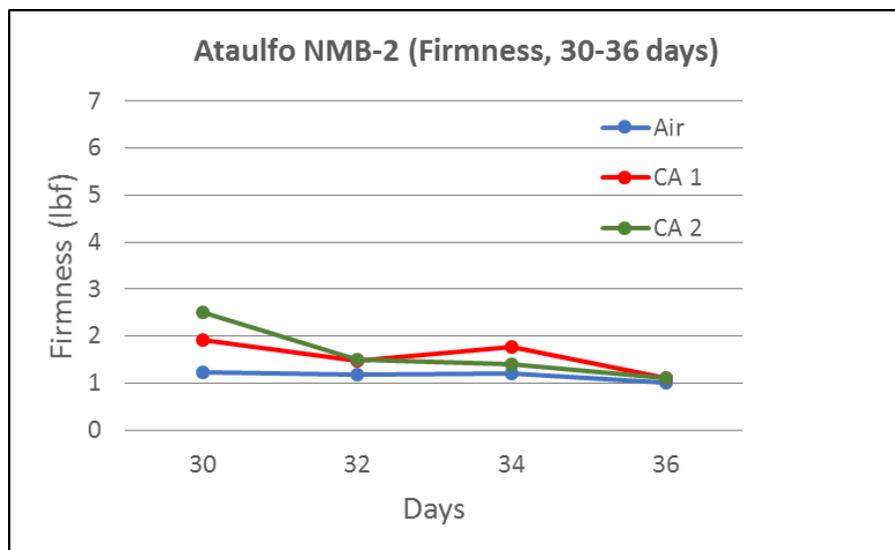


Figure 11. Softening of ‘Aaulfo’ mangos harvested at NMB-2 during 30 days storage at 12.5°C under three atmospheric conditions.

Aaulfo NMB-3 mangos had an average firmness of 1.5 lbf (CA 2), 1.4 lbf (CA 1) and 1.1 lbf (air) after 30 days storage and six days display at ambient temperature (**Figure 12**). CA 2 treated mangoes decreased in firmness by 1.4 lbf over six days display, and the firmness of CA 1 and air-treated mangos did not change.

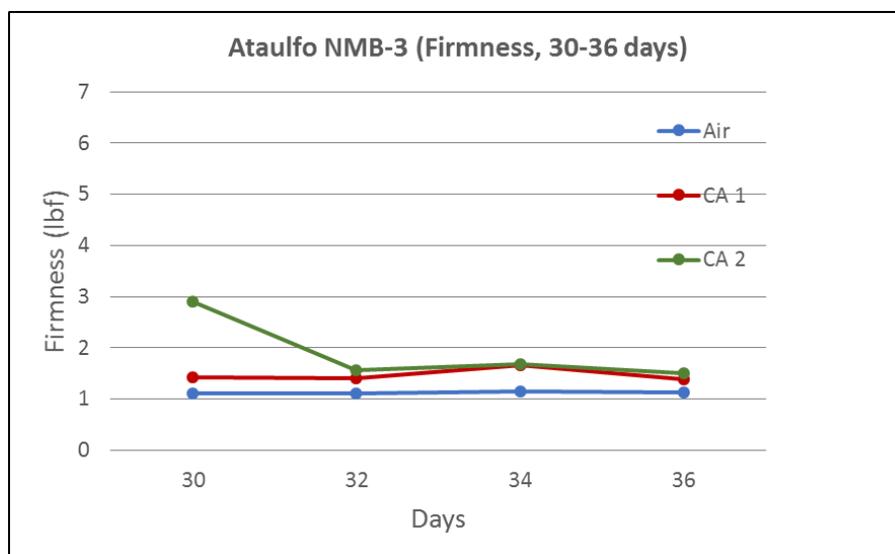


Figure 12. Softening of ‘Aaulfo’ mangos harvested at NMB-3 during 30 days storage at 12.5°C under three atmospheric conditions.

'Keitt' Softening during Storage

Not-Hot-Water-Treated (NHWT) 'Keitt' (California)

Based on previous CA studies, we selected 5% O₂ and 10% CO₂ to test the benefits of this storage-transportation technique on fresh-harvested NHWT mangos at 12.5°C. This treatment was chosen primarily because it did not significantly affect 'off flavor' perception in previous evaluations. Mangos were sourced from a commercial farm in the Coachella Valley in Southern California. Fruit harvested at NMB-2 were stored under air or CA (5% O₂ + 10% CO₂) in 330 L metallic boxes, at 12.5°C with 85% relative humidity, for up to 30 days, following the same procedure described above. Fruit were removed after 10, 20 and 30 days storage and examined for changes in fruit firmness, flesh color, titratable acidity, soluble solids concentration, visual appearance, and flavor. These CA conditions effectively reduced fruit softening rate, acidity degradation, and flesh color changes from green-yellow to yellow of 'Keitt' mangos without affecting sugar metabolism and 'off flavor' development during 30 days storage (Table 2). In general, average fruit firmness loss during 30 days was reduced by CA to a rate of 0.1 lbf/day, down from 0.2lbf/day in air. During the first 10 days of storage, when fast softening occurred, mangos stored in air lost 0.35lbf/day of firmness compared to 0.16lbf/day) in mangos under CA. Flesh color changes from green-yellow to yellow were also delayed in mangos under CA rather than air. As with flesh color, titratable acidity changed less under CA than air.

The 5% O₂ and 10% CO₂ CA conditions at 12.5°C benefitted 'Keitt' mangos by reducing fruit softening, flesh color and acidity changes without negative impact on visual appearance or flavor. This validates previous studies that CA storage helps maintain fruit firmness and extends shelf life of horticultural crops by inhibiting ethylene production and activities of fruit softening enzymes. The establishment of this CA treatment during storage and/or long term shipment for up to 30 days can maintain the quality of mangos.

Table 2. Fruit quality attributes of not-hot-water-treated California 'Keitt' mangos harvested at NMB-2 during simulated shipment at 12.5°C in 5% O₂ and 10%CO₂ controlled atmosphere (CA) conditions or air.

Storage at 12.5°C (Days)	Treatments					
	Firmness (lbf)		Flesh Color (Hue)		Titratable Acidity (%)	
	Air	CA	Air	CA	Air	CA
0	9.1	9.1	87.6	87.6	0.6	0.6
10	5.6	7.5	89.4	88.0	0.6	0.7
20	4.8	6.8	95.2	93.4	0.5	0.7
30	2.4	4.9	116.6	90.9	0.4	0.6

Hot-water-treated (HWT) 'Keitt' Softening during Storage (Sinaloa, Mexico): 0-30 days at 12.5°C.

Because only one maturity stage was available, 'Keitt' mangos at NMB-2 were stored in the three atmospheric treatments at 12.5°C for 20 days. The average firmness of the mangos after harvest and prior to storage was 23.4 lbf (Figure 13). After 20 days storage, the mangos stored in CA 2 were the firmest (13.3 lbf), followed by air (10.0 lbf) and CA 1 (8.0 lbf). By 30 days, mangos under CA 2 remained firmer (~5.0lbf) than mangos from the other treatments, although all mangos were soft.

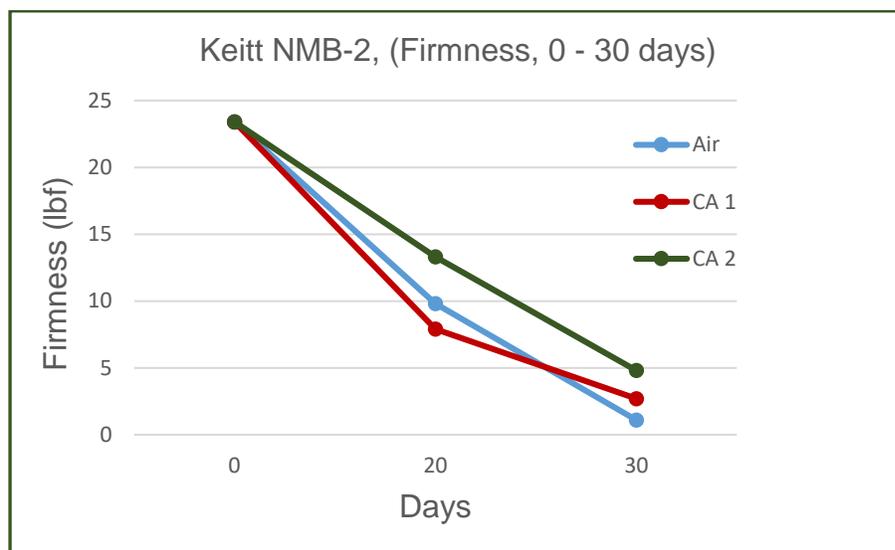


Figure 13. Softening of 'Keitt' mangos harvested at NMB-2 stage during 30 days storage at 12.5°C under three atmospheric conditions.

‘Keitt’ softening during display: 20 to 26 days at room temperature.

After 20 days storage, mangoes were displayed for six days at room temperature and firmness was measured every two days. ‘Keitt’ NMB-2 mangos stored in CA 1, CA 2 and air softened during the six days of display (**Figure 14**), ending with an average of 1.8 lbf by day six.

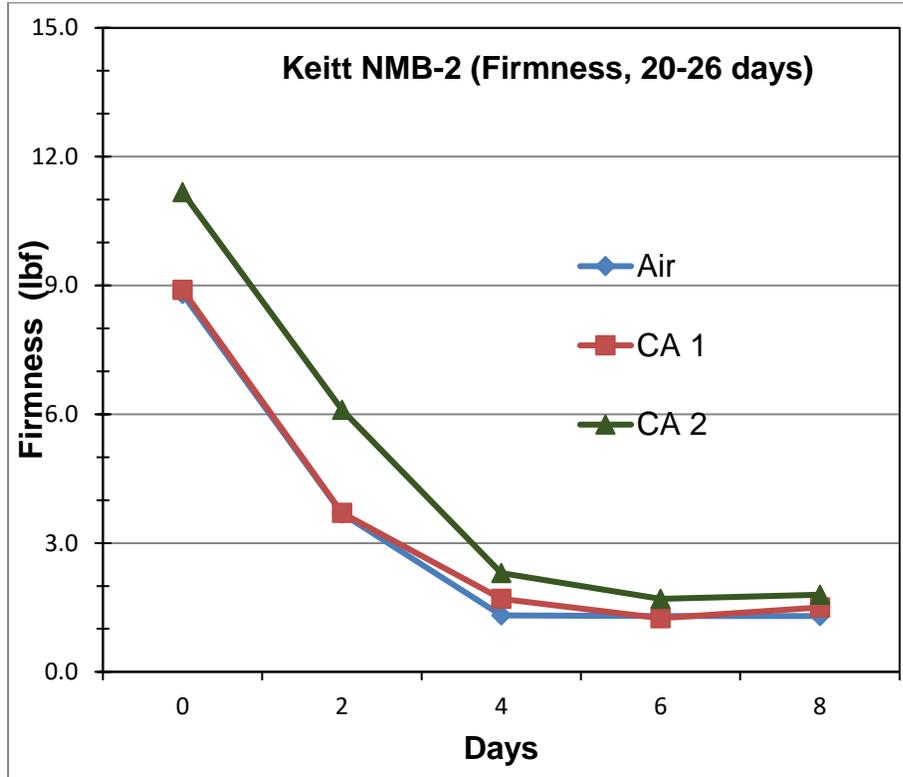


Figure 14. Softening of ‘Keitt’ mangos harvested at NMB-2 during six days display at 20°C after 20 days storage under three atmospheric conditions.

‘Keitt’ softening during display: 30 to 36 days at room temperature.

After 30 days storage and six days display at room temperature, ‘Keitt’ NMB-2 mangos stored in air had an average firmness of 1.1 lbf, while those stored in CA 1 and CA 2 had an average firmness of 4.0 lbf, ending with ~2.0 lbf by day six (**Figure 15**).

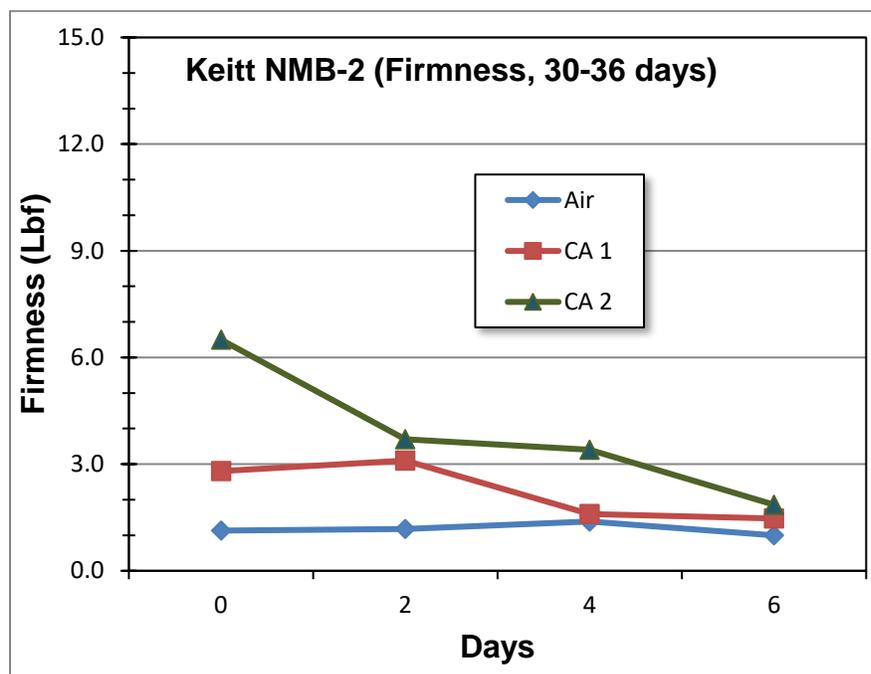


Figure 15. Softening of ‘Keitt’ mangos harvested at NMB-2 during six days display at 20°C after 30 days storage under three atmospheric conditions.

Mango Quality during Simulated Transportation and Room Display: External and internal disorders were not observed in any fruit stored at 12.5°C upon arrival and during the warm display. Also, flavor was not affected by any of the treatments (data not shown).

CONCLUSIONS

A controlled atmosphere (CA) treatment consisting of high carbon dioxide combined with oxygen ($\geq 5\%$) slowed softening of hot-water-treated (HWT) mangos harvested at the NMB-2 maturity stage during simulated shipment at 12.5°C during 20 days.

External and internal disorders were not observed in any of the treatments the same as for ‘off flavor’ development.

At 20 days, HWT ‘Tommy Atkins’ mangos softened more slowly under 10 or 20% carbon dioxide than mangos under air. There were no differences in softening between mangos stored under 20% or 10% CO₂.

At 20 days, HWT ‘Ataulfo’ mangos softened more slowly under 20% carbon dioxide than mangos under 10% carbon dioxide or air. Mangos under 10% CO₂ were firmer than mangos under air, but softer than under 20% carbon dioxide.

At 20 and 30 days, HWT 'Keitt' mangos softened more slowly under 20% carbon dioxide than mangos under 10% carbon dioxide or air. There were no differences in softening between mangos stored under 10% CO₂ or air, thus, 20% CO₂ should be used in 'Keitt'.

After 30 days stored at 12.5°C, CA did not control softening of mangos picked at the NMB-2 stage, ending as soft as mangos maintained under air. Except on 'Keitt'.

CA did not control softening at any time during storage of any HWT mangos picked at an advanced maturity stage (NMB-3).

CA did not influence rate of softening during warm display. However, mangos from the 20% CO₂ treatment remained firmer than mangos from other treatments during display because they started with higher firmness upon removal from CA.

Our comparison of CA benefits on softening between HWT and NHWT 'Keitt' indicate a high potential for NHWT mangos. However, as mangos were harvested in different locations and yearly conditions vary, further exploration of CA benefits of not-hot-water-treated (NHWT) mangos is encouraged.

A controlled atmosphere facility was established in the CIAD, Culiacan, Mexico, for current and future work on mangos.

A commercial shipping demonstration of the benefits of CA for hot-water-treated (HWT) mangos during storage and shipping within 20 days of harvest will be carried out as outreach education.