Aroma of mature-green and tree-ripe mangoes after refrigerated air or controlled atmosphere storage

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ABSTRACT: *Mango flavor is dependent on cultivar characteristics and postharvest handling procedures. Mangoes harvested with the ripening metabolism initiated develop better flavor than mangoes harvested at the mature-green stage. Different cultivars were harvested at both ripeness stages and evaluated to determine the effect of fruit ripeness, storage temperature and atmosphere on the volatiles present in aroma profiles. Mangoes of the cultivars Haden, Keitt and Tommy Atkins at distinct ripeness stages were stored in controlled atmospheres (CA) with 2, 5 or 21 kPa O_2 plus 0, 10 or 25 kPa CO_2 at 5, 8, 12 or 15 °C. Terpene concentrations of mangoes stored in air were higher than the concentrations in mangoes stored in CA. The sesquiterpene α-copaene did not present recognizable peaks in almost all elusion sequences. The same result was observed with the monoterpene β-pinene in cv. Haden and cv. Keitt mangoes while in 'Tommy Atkins' fruit β-pinene concentrations were below 1.06 µL·L⁻¹. Ethanol and acetaldehyde concentrations were significantly higher in mangoes from 2 kPa O_2 storage than those from air storage or the other CA treatments. Terpene synthesis in air or CA storage in all cultivars varied significantly, preventing generalizations as to what storage conditions favor or limit aroma components elution.*
Key words: *Mangifera indica L., terpenes, 3-carene, elevated CO_2, volatile compounds.*

Complexo aromático de mangas pré-climatéricas e maduras armazenadas em ar refrigerado ou atmosfera controlada

RESUMO: *O complexo aromático de mangas resulta das características de cada cultivar e do manejo pós-colheita dos frutos. Mangas colhidas em estádio de maturação mais avançado desenvolvem um aroma melhor que mangas colhidas no estádio pré-climetérico. Para o presente trabalho diferentes cultivares de mangas foram colhidas em ambos estádios de maturação e avaliadas para os efeitos destes estádios e da atmosfera de armazenagem nos compostos voláteis presentes no perfil de aroma. Mangas das cultivares Haden, Keitt e Tommy Atkins, em distintos estádios de maturação, foram armazenadas em ar refrigerado ou em atmosfera controlada (AC) com 2, 5 ou 21 kPa O_2 misturado a 0, 10, ou 25 kPa CO_2 com temperaturas de 8, 12 ou 15 °C. As concentrações de terpenos em mangas armazenadas em ar refrigerado foram mais elevadas que as concentrações determinadas em armazenagem em AC. O sesquiterpeno α-copaeno não apresentou picos reconhecíveis em nenhum dos cromatogramas de mangas dos diferentes tratamentos. O mesmo comportamento foi observado com o β-pineno nas cv. Haden e Keitt, enquanto que na cv. Tommy Atkins este monoterpeno apresentou picos de eluição abaixo 1.06 µL·L⁻¹. Concentrações de etanol e acetaldeído foram significativamente maiores em mangas armazenadas em AC de 2 kPa O_2 na comparação com armazenagem em ar e com as demais concentrações de AC. A biossíntese de terpenos em armazenagem, tanto em ar refrigerado como em AC, variou consideravelmente de modo que deve-se evitar generalizações sobre quais condições de armazenagem favorecem ou limitam a composição do complexo aromático em mangas.*
Palavras-chave: *Mangifera indica L., terpenos, 3-carene, elevado CO_2, compostos aromáticos.*

INTRODUCTION

Presence of tropical fruits, mangoes amongst those, on international markets is increasing yearly (MONACO et al., 2016). Mangoes are one of the most important tropical fruits in world trade (LI et al., 2017). Popularity outside of tropical areas has become a certainty because of continuous availability.

Mangoes´ unique flavor and production areas spread all over tropical and subtropical areas in the world have converted its status from that of a specialty fruit to a staple (SIVAKUMAR et al., 2011).

The mango industry did not develop a handling procedure for its own use, but rather adapted the practices of the deciduous fruit industry by harvesting the fruit at the pre climacteric ripeness

stage (*i.e.*, mature green) and using temperature management and exclusion of ethylene to delay the onset of ripening until after the fruit have reached destination markets.

The mango industry has settled on harvesting the fruit at less ripe stages to extend shelf life, thus, facilitating supply of distant markets even though there are negative consequences for flavor (BALOCH & BIBI, 2012). Mango flavor is dependent on cultivar characteristics, but is also affected by ripeness stage at harvest. Postharvest handling procedures may also affect internal fruit quality (SIVAKUMAR et al., 2011; BRECHT, 2020). LEBRUN et al. (2008) confirmed that mangoes harvested at the tree-ripe stage (*i.e.*, with ripening initiated) develop better flavor than mangoes harvested at the mature-green stage.

There have been studies with different approaches to characterize mango flavor components. By the combination of three analytical methods ENGEL & TRESSL (1983), characterized 114 components in two of the most important Asian cultivars: Alphonso and Baladi. Similarly, MacLEOD & SNYDER (1985) evaluated the cultivars Tommy Atkins and Keitt at different ripeness stages and found great variation in aroma profiles, especially with respect to the major monoterpenes. BARTLEY & SCHWEDE (1987) concluded that as mangoes ripen in storage the increase in concentrations of higher esters is noteworthy.

LALEL et al. (2003) concluded that ripe cv. Kensington Pride mangoes exhibited higher amounts of aroma volatiles than mangoes harvested at a less ripe stage. LEBRUN et al. (2008) corroborated that statement with three mango cultivars harvested at two ripeness stages. PANDIT et al. (2009) analyzed fruit of 'Alphonso' mangoes at five ripeness stages and concluded that during the transition from unripe to ripe qualitative and quantitative compound changes contribute to unique volatile signatures. MUNAFO et al. (2016) identified 34 aroma compounds in tree-ripe mangoes previously linked to high flavor dilution factors.

Despite all the work on mango aroma profiles, there have not been many studies to evaluate the effect of different storage conditions on individual components of the mango aroma profile beyond our previous research with mature-green and tree-ripe cv. Tommy Atkins mangoes stored in CA at 8 °C or 12 °C (BENDER et al., 2000a). LALEL et al. (2003) determined that storage of mature-green 'Kensington Pride' mangoes in 2 kPa O_2 combined with CO_2 up to 9 kPa at 13 °C reduced total aroma

volatiles, monoterpenes, sesquiterpenes and aromatic compounds after fruit ripening. ULLAH et al. (2010) indicated that fully ripe cv. Alphonso mangoes stored in 3 kPa O_2 plus 6 kPa CO_2 for 3 weeks at 10 °C had better flavor as indicated by sensory panelists in comparison to air storage or higher CO_2 partial pressures. GOSWAMI & RAVINDRA (2013) observed that mature-green cv. Amrapali mangoes stored in CO_2 partial pressures as high as 8 kPa presented limited volatile production, especially hydrocarbons and esters after storage at 12 °C plus 5 days of ripening at 21 °C.

Therefore, aroma volatiles from different mango cultivars, harvested at different ripeness stages, that had been stored for up to 3 weeks in various combinations of temperature and CA storage conditions were evaluated in order to determine the effect of fruit ripeness stage, storage temperature, and storage atmosphere on the production of the most predominant volatiles present in mango aroma profiles.

MATERIALS AND METHODS

The determination of aroma volatiles was performed on fruit from 'Keitt', 'Tommy Atkins' and 'Haden' mango cultivars of different ripeness stages that had been stored under different atmospheres and at different storage temperatures. 'Keitt' mangoes at the tree-ripe stage were harvested from Gulf Island Grove at Pine Island/Fort Myers, Florida. Mature green and tree ripe 'Tommy Atkins' mangoes were harvested from a grove of Brooks Tropicals, Homestead, Florida. Selection for harvest and ripeness stage was based on ground color and on fruit shape, *i.e.* the outgrowing of the shoulders as described in MILLER et al. (1986): mature-green corresponds to hard fruit, well-formed and with totally green skin ground color (RS1) and tree-ripe fruit are firm, well-formed and with some yellow ground color development (RS3).

The fruit were placed into 10.05-L glass jars, four fruit per jar, upon arrival at the laboratory. Three treatments, with three replicate jars per treatment, were exposed via the flow-through system to 5 kPa O_2 plus either 10 kPa or 25 kPa CO_2 or an air control. The tree ripe 'Tommy Atkins' mangoes were stored for 21 days at 8 °C or 12 °C while the mature green mangoes were only stored at 12 °C. The tree ripe 'Keitt' mangoes were stored at 8 °C or 5 °C also for 21 days. After the period of CA storage, fruit of both cultivars were maintained for 3 days in air at 20 °C.

'Haden' mangoes were imported from Peru and 'Tommy Atkins' from Brazil by Brooks

Tropicals in Homestead, Florida and transported to Gainesville by refrigerated truck. These mangoes were harvested at the mature-green ripeness stage and handled at the origin under normal commercial conditions, treated with 46.1 °C water for 60 minutes for insect disinfestation, and coated with a commercial formulation of carnauba wax prior to marine shipment to Florida. After arrival at the Postharvest Laboratory/ Horticultural Sciences Department, University of Florida, the mangoes were selected for freedom from defects, and immediately placed in glass jars and transferred to storage rooms.

'Haden' mangoes were held in 1.75-L glass jars, one fruit/jar, with either air or CA applied in a flow-through system for 14 days at 15 °C, with six replicate jars per treatment. Air, delivered by a compressor, was mixed with nitrogen (N_2) from a cylinder to produce treatments of 2 kPa and 5 kPa O_2. Control treatment was air in the flow-through system. A treatment of 25 kPa CO_2 was obtained by combining air with CO_2 delivered by a cylinder. The same CA treatments were applied to 'Tommy Atkins' mangoes for 21 days at 12 °C. In this experiment, there were four fruit per 10.05-L glass jar and four replicate jars per treatment.

Mesocarp tissues of mature green and tree-ripe 'Tommy Atkins' and tree-ripe 'Keitt' mangoes were homogenized after the three-days at 20 °C ripening period. Tissues of the imported mature-green 'Haden' and 'Tommy Atkins' mangoes were homogenized upon retrieval from CA storage. A 50% (w/v) homogenate was prepared by mixing equal amounts of tissue and deionized water. The diluted samples were stored at -20 °C until used for volatile determinations.

Volatile components were quantified based on the procedure of BALDWIN et al. (1991) and modified by MALUNDO et al. (1997) using a Perkin-Elmer GC (Foster City, CA), model 8500, equipped with a model HS-6 headspace sampler, a flame ionization detector and a 0.53x3000 mm polar Durowax column (J & W Scientific, Folsom, CA). The concentrations of the volatiles were calculated using regression equations fitted to peak height calibration curves as described in MALUNDO et al. (1997) except for acetaldehyde, ethanol and hexanal, for which there were no calibration curves prepared. Those compounds are presented as peak heights.

Data were analyzed via analysis of variance (ANOVA) and correlation coefficients determined using SAS for PC (SAS Inst., Cary, NC). The experiments were conducted in completely randomized designs and averages separated at a P < 0.05 by Tukey´s multiple range test.

RESULTS AND DISCUSSION

The components determined in the present research with cv. Keitt and Tommy Atkins and Haden mangoes were predominantly monoterpenes and sesquiterpenes, confirming the conclusions of MacLEOD & SNYDER (1985), who also worked with 'Tommy Atkins' and 'Keitt' mangoes. MacLEOD & PIERIS (1984), likewise, identified terpenes as the most abundant volatiles in cv. Jaffna, cv. Parrott and cv. Willard mangoes and PANDIT et al. (2009), in trials with cv. Alphonso mangoes at different ripeness stages corroborated the conclusions on terpenes in mango aroma profiles.

The terpenes that were quantified in the present research probably are, according to MALUNDO et al. (1997), the most critical for mango flavor, even though WILSON et al. (1990) concluded that a characteristic component for mango flavor can not be determined, considering the complexity of the mixture of components in a mango volatile profile. ADEDEJI et al. (1992) reiterated this conclusion. PANDIT et al. (2009), SINGH & SAINI (2014), LI et al. (2017) and ZAFAR & SIDHU (2017) add further that the variability in the mango aroma complex and chemical and nutritional profiles also depend on growing conditions, rootstock, ripeness stage at harvest, and storage atmosphere composition.

In the samples of 'Keitt' mangoes stored for 21 days at 5 °C or 8 °C, then analyzed after 3 days in air at 20 °C, the fruit stored in the 25 kPa CO_2 atmosphere at 5 °C had significantly higher levels of α-pinene, 3-carene, limonene and myrcene (Table 1). The terpinolene contents (Table 2) was also significantly higher in mangoes of the 25 kPa CO_2 atmosphere when compared with air storage or 10 kPa CO_2 and the initial values determined prior to storage. In contrast, *P*-cymene was completely absent in the mangoes from the 25 kPa CO_2 storage atmosphere and caryophyllene synthesis apparently is not influenced by the elevated CO_2 atmospheres. The component that has been determined to be the most abundant in 'Tommy Atkins', 'Keitt' and 'Kent', the three Florida-type mangoes examined by MALUNDO et al. (1997) is 3-carene, a monoterpene hydrocarbon (ADEDEJI, 1992), which was also confirmed in our experiments.

In the experiments with mature-green 'Haden' and 'Tommy Atkins' mangoes in which the response to the reduction of O_2 partial pressures was tested, there were differences in volatile elution from mesocarp tissue when sampled on the day of

Table 1 - Aroma compounds, in µL·L⁻¹, in mesocarp tissues of tree ripe cv. Keitt mangoes at beginning of storage and after 3 days in air at 20 °C following a 21-day storage in CA (5 kPa O₂ plus 10 kPa or 25 kPa CO₂) or air at 5 °C or 8 °C.

	α-pinene	3-carene	Limonene	P-cymene	Myrcene
Initial value	0.0303	3.945	0.0630	0.0037	0.4571
Air-5°C	0.0327 b[1]	3.153 b	0.0527 b	0.0046 b	0.3296 b
Air-8°C	0.0410 b	3.984 b	0.0672 b	0.0098 a	0.3792 b
10 kPa CO₂ 5°C	0.0260 b	3.578 b	0.0583 b	0.0061 b	0.3374 b
25 kPa CO₂ 5°C	0.1725 a	6.569 a	0.0959 a	0.0000 c	0.6167 a
CV[2]	110.21	35.87	30.88	73.69	33.35

[1]Averages followed by the same letter in columns do not differ statistically at Tukey´s multiple range test (P < .05)
[2]CV= variation coefficient.

transfer to air at 20 °C after 14 or 21 days of storage (Table 3). 'Haden' had higher levels of 3-carene as well as limonene, P-cymene and, to some extent, myrcene than did 'Tommy Atkins'. According to the observations of BANDYOPADHYAY & GHOLAP (1973) this difference could be a consequence of the higher storage temperature (15 °C) used for 'Haden' fruit compared with 'Tommy Atkins' (12 °C). But then, α-pinene, also a terpenoid hydrocarbon (IDSTEOM & SCHREIER, 1985), and therefore, supposedly derived from the same general pathway of 3-carene as indicated by their high partial correlation coefficient (0.963), was considerably higher in 'Tommy Atkins' than in 'Haden'. These observations indicate that cultivar differences are also major factors concerning the differences in aroma compounds, though that

observation does not hold through for caryophyllene and terpinolene, which varied in about the same range in both cultivars (Table 4).

Cultivar differences were also observed in relation to β-pinene and α-copaene. Whereas in 'Haden' and 'Keitt' mangoes elution sequences scarcely presented β-pinene peaks, in 'Tommy Atkins' mesocarp homogenates β-pinene concentrations varied from 0.10 to 0.23 ± 0.072 µL·L⁻¹. The α-copaene concentrations in 'Keitt' mangoes ranged from 0.034 to 0.127 ± 0.075 µL·L⁻¹ after 21 days at 5 °C or 8 °C plus 3 days in air at 20 °C. In contrast, in 'Haden' and 'Tommy Atkins' fruit α-copaene was not detected after retrieval from storage.

Peak heights of hexanal for 'Haden' were generally much greater than for 'Tommy Atkins'

Table 2 - Aroma compounds in mesocarp tissues of tree ripe cv. Keitt mangoes at beginning of storage and after 3 days in air at 20 °C following a 21-day storage in CA (5 kPa O₂ plus 10 kPa or 25 kPa CO₂) or air at 5 °C or 8 °C.

	Caryophyllene	Terpinolene	Acetaldehyde	Ethanol	Hexanal
	------------------(µL·L⁻¹)------------------		-------------------------------(Peak height in mm)----------------------------		
Initial value	0.3409	0.0731	593.21	762.74	112.77
Air-5°C	1.4650 a[1]	0.0612 b	1,270.46 b	2,872.98 b	293.02 a
Air-8°C	0.3462 b	0.0686 b	1,471.63 b	4,323.68 b	303.50 a
10 kPa CO₂-5°C	0.2689 b	0.0462 b	808.40 b	2,233.54 b	161.02 b
25 kPa CO₂-5°C	0.2648 b	0.1227 a	18,270.63 a	186,948.5 a	64.49 c
CV[2]	100.33	41.27	145.53	169.18	54.9

[1]Averages followed by the same letter in columns do not differ statistically at Tukey´s multiple range test (P < .05).
[2]CV= variation coefficient.

Table 3 - Aroma compounds, $\mu L^{.}L^{-1}$, in mesocarp tissue of harvested mature-green cv. Haden and Tommy Atkins mangoes at transfer to 20 °C from air storage or in CA of 5 kPa O_2 plus 10 kPa or 25 kPa CO_2 for 2 weeks at 15 °C or 3 weeks at 12 °C, respectively.

	α-pinene	3-carene	Limonene	P-cymene	Myrcene
--'Haden'---					
Air	0.29 a [1]	31.5 a	0.549 a	0.088 ns	2.98 a
2 kPa O_2	0.14 ab	17.4 ab	0.291 ab	0.049	1.50 ab
5 kPa O_2	0.07 b	8.2 b	0.129 b	0.031	0.51 b
25 kPa CO_2	0.13 ab	16.7 ab	0.296 ab	0.093	1.48 ab
CV [2]	82.22	91.63	79.63	85.76	82.98
--'Tommy Atkins'--					
Air	1.49 ns [3]	9.80 ns	0.154 ns	0.019 ns	0.85 ns
2 kPa O_2	1.65	8.88	0.180	0.015	1.00
5 kPa O_2	0.97	6.31	0.111	0.004	0.59
25 kPa CO_2	1.19	8.86	0.152	0.015	0.80
CV [3]	47.35	68.58	67.29	122.85	68.7

[1] Averages followed by the same letter in columns for each cultivar do not differ statistically at Tukey´s multiple range test (P < .05).

[2] CV= variation coefficient.

[3] ns= differences in averages not statistically significant.

(Table 4) and 'Keitt' (Table 2) mangoes. TAMURA et al. (2001) indicated that cultivar differences are the major factor for those differences in terpenes and oxygenated aroma compounds such as hexanal. Nonetheless, the elevated CO_2 atmospheres might have an influence on the synthesis of these C_6 hydrocarbons as they probably derive, according to BANDYOPADHYAY & GHOLAP (1973) from fatty acid lipid peroxidation. Lipid components and their breakdown to fatty acids have been considered to be the main precursors of volatiles in mangoes and in fruits in general (SELVARAJ et al., 1989). It is generally recognized that the sesquiterpene hydrocarbons are derived from acetyl-CoA through the mevalonic acid (MVA) pathway in the cytosol (SHARON-ASA et al., 2003; YU et al., 2015).

In addition to differences between cultivars, there was also a significant difference in acetaldehyde peak height among the storage atmosphere treatments. Both 'Haden' mangoes stored for 14 days at 15 °C and 'Tommy Atkins' mangoes stored for 21 days at 12 °C in the 2 kPa O_2 atmosphere had the highest acetaldehyde peaks for each cultivar (Table 4). Fruit from the 2 kPa O_2 treatment for both cultivars also had the highest ethanol production rates as already previously observed (BENDER et al., 2000b) with 'Tommy Atkins' having much higher ethanol levels than 'Haden'. This is an indication that reduction of the O_2 partial pressure in the storage atmosphere for mangoes affects fermentative metabolism not only by stimulating alcohol dehydrogenase, but also pyruvate decarboxylase, as observed by KE et al. (1993) in strawberries and by KE et al. (1995) in avocados.

MacLEOD & SNYDER (1985), when examining aroma profiles of 'Keitt' mangoes, questioned whether ethanol and, consequently, acetaldehyde are true components of mango flavor. It seems, though, that these components are, in fact, components of mango aroma considering that acetaldehyde and ethanol were determined at the beginning of ripening and before storage of cv. Keitt mangoes (Table 2) contrasting with the statement of MacLEOD & SNYDER (1985) that only stored or overripe mangoes produce ethanol. Furthermore, data from mature green cv. Kent (not discussed in the present paper) indicated the presence of acetaldehyde and ethanol at the beginning of storage.

In addition to oxygen partial pressure in the storage atmosphere, storage temperature also influences anaerobic metabolism. As described in BENDER et al. (2000a), there is a significant

Table 4 - Aroma compounds in mesocarp tissue of harvested mature-green cv. Haden and Tommy Atkins mangoes at transfer to 20 °C air from storage or in CA of 5 kPa O_2 plus 10 kPa or 25 kPa CO_2 for 2 weeks at 15 °C or 3 weeks at 12 °C, respectively.

Caryophyllene ($\mu L \cdot L^{-1}$)		Terpinolene	Acetaldehyde	Ethanol	Hexanal
		----------------------($\mu L \cdot L^{-1}$)----------------------		--------------(peak height, in mm)------------	
--'Haden'--					
Air	0.77 a [1]	0.69 a	1,132.9 b	510.3 b	942.2 ns [2]
2 kPa O_2	0.27 bc	0.15 b	3,371.7 a	11,737.0 a	1,281.4
5 kPa O_2	0.02 c	0.06 b	718.7 b	2,979.4 a	1,390.6
25 kPa CO_2	0.37 bc	0.28 ab	713.0 b	370.4 b	1,078,8
CV	64.0	91.38			
--'Tommy Atkins'--					
Air	0.24 ns	0.14 ns	1,757.3 c	7,495.6 c	337.7 a
2 kPa O_2	0.38	0.25	16,385.4 a	356,159.8 a	390.5 a
5 kPa O_2	0.21	0.14	8,111.8 b	121,772.1 b	218.8 ab
25 kPa CO_2	0.30	0.18	1,359.7 c	13,675.1 c	129.4 b
CV [3]	54.82	71.85	33.96	38,26	30,52

[1] Averages followed by the same letter in columns for each cultivar do not differ statistically at Tukey´s multiple range test (P < .05)

[2] ns= differences in averages not statistically significant.

[3] CV= variation coefficient.

increase in acetaldehyde production rates of tree-ripe 'Tommy Atkins' mangoes during storage for 3 weeks at 8 °C in comparison to a 12 °C-storage. Moreover, in that paper tree-ripe 'Tommy Atkins' fruit stored at 12 °C had acetaldehyde production rates similar to mature-green fruit stored under the same storage conditions.

Biosynthesis of some terpenes in mangoes stored in elevated CO_2 atmospheres was not altered in mature green or tree ripe cv. Tommy Atkins mangoes stored at either 8 °C or 12 °C (Table 5) and tree ripe cv. Keitt mangoes stored at 5 °C or 8 °C (Tables 1 and 2). In the paper BENDER et al. (2000a) and under the same storage procedures, we concluded that the 5 kPa O_2 plus 25 kPa CO_2 treatment seemed to have different effects on the biosynthesis of aroma compounds, such as α-pinene and 3-carene, depending on the ripeness stage of the fruit. In the early stages of ripening (*i.e.*, mature-green fruit), exposure to the higher CO_2 storage atmosphere might have a greater effect on the synthesis of certain volatile compounds than exposure at later stages, which could lead to poor flavor after transfer to air. With tree-ripe fruit, the same atmosphere in association with the 5 °C storage temperature might prevent the breakdown and also the synthesis of a few other compounds, like *P*-cymene (Tables 1 and

2), which could impart an uncharacteristic flavor to the mangoes stored under those conditions.

Nevertheless, there is still much left to investigate in terms of specific pathways leading to important compounds for the aroma of mangoes. How each one is regulated and responds to CA and low temperatures needs further investigation dependent on the elucidation of the pathways.

CONCLUSION

Terpene synthesis by 'Keitt', 'Haden' and 'Tommy Atkins' mangoes in air or CA storage varied significantly, preventing generalizations as to what storage conditions favor or limit aroma components elution. The component that has been determined to be the most abundant in these cultivars is 3-carene. Among the aroma compounds analyzed, *P*-cymene biosynthesis in 'Keitt' mangoes seemed to be most sensitive to storage in the injurious 25 kPa CO_2 atmosphere. The 25 kPa CO_2 treatment at 5°C had the most pronounced effect on the aroma profile of 'Keitt' mangoes, which suggested that this treatment causes damage that severely impairs mango ripening after transfer to air. Storage of mature-green 'Haden' and 'Tommy Atkins' fruit in 2 kPa O_2 resulted in elevated fermentative metabolism.

Table 5 - Aroma compounds (μL.L-1) in mesocarp tissue of mature green (MG) or tree ripe (TR) cv. Tommy Atkins mangoes after 2 days in air at 20 °C following a 21-day storage in CA (5 kPa O2 plus 10 kPa or 25 kPa CO2) or air at 8 °C or 12 °C.

	Caryophyllene	β-pinene	Myrcene	Terpinolene
--MG at 12 °C--				
Air	0.377 ns/1	0.250 ns	1.393 ns	0.280 ns
10 kPa CO2	0.713	0.287	1.530	0.353
25 kPa CO2	0.277	0.100	3.933	0.170
--TR at 12 °C--				
Air	1.403	0.887	7.447	1.907
10 kPa CO2	0.720	0.597	5.250	1.080
25 kPa CO2	1.767	1.060	6.097	1.257
--TR at 8 °C--				
Air	0.640	0.677	4.530	1.040
10 kPa CO2	0.597	0.590	5.410	1.417
25 kPa CO2	0.663	0.287	1.927	0.533
CV/2	74.3	84.69	83.41	85.15

/1ns= differences in column averages not statistically significant.

/2 CV = coefficient of variation.

DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

RJB and JKB conceived and designed experiments. RJB performed the experiments, carried out the lab analyses and performed statistical analyses of experimental data. RJB prepared the draft of the manuscript. JKB and EZB critically revised the manuscript and approved of the final version.

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