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Aroma Volatiles of Mature-green and Tree-ripe 'Tommy Atkins' Mangoes after Controlled Atmosphere vs. Air Storage

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***Abstract*. To determine the effects of fruit maturity, storage temperature, and controlled atmosphere (CA) on aroma volatiles, mature-green (MG) and tree-ripe (TR) 'Tommy Atkins' mangoes *(Mangifera indica* L.) were stored for 21 days in air or in CA (5% O_2 plus 10% or 25% CO_2). The MG fruit were stored at 12 °C and the TR fruit at either 8 or 12 °C. Homogenized mesocarp tissue from fruit that had ripened for 2 days in air at 20 °C after the 21-day storage period was used for aroma volatile analysis. The TR mangoes produced much higher levels of all aroma volatiles except hexanal than did MG fruit. Both MG and TR mangoes stored in 25% CO_2 tended to have lower terpene (especially p-cymene) and hexanal concentrations than did those stored in 10% CO_2 and air-stored fruit. Acetaldehyde and ethanol levels tended to be higher in TR mangoes from 25% CO_2 than in those from 10% CO_2 or air storage, especially at 8 °C. Inhibition of volatile production by 25% CO_2 was greater in MG than in TR mangoes, and at 8 °C compared to 12 °C for TR fruit. However, aroma volatile levels in TR mangoes from the 25% CO_2 treatment were in all cases equal to or greater than those in MG fruit treatments. The results suggest that properly selected atmospheres, which prolong mango shelf life by slowing ripening processes, can allow TR mangoes to be stored or shipped without sacrificing their superior aroma quality.**

Intensified international trade in recent years has promoted mangoes to higher ranks of popularity (Gourgue et al., 1992; Subrahmanyam, 1990). Continuous availability on the market has changed the status of mango from that of a specialty fruit with unique flavor (Engel and Tressl, 1983) to a standard item in produce departments. This has been made possible by adoption of postharvest handling practices that enable the movement of larger volumes of fruit (Medlicott et al., 1986; Tucker and Seymour, 1991). Harvest of mature-green (MG) mangoes prolongs shelf life (Thomas and Joshi, 1988), but also negatively affects flavor characteristics, as has already been demonstrated for apple (*Malus ×domestica* Borkh.) (Streif and Bangerth, 1988; Willaert et al., 1983).

Lakshminarayana (1980) determined that mangoes harvested at the MG stage and then ripened at temperatures above 15 °C had better flavor than those held below 15 °C. Several attempts have been made to characterize mango flavor components (Bartley and Schwede, 1987; Engel and Tressl, 1983; Koulibaly et al., 1992; MacLeod and Snyder, 1985). Engel and Tressl (1983) identified the monoterpenes as an important class of volatiles contributing to mango flavor in New World varieties, in contrast to Old World varieties, which have more oxygenated volatile compounds like esters, furanones, and lactones. The terpene hydrocarbons are considered to be important contributors to the flavor of Florida (New World) mango varieties such as 'Keitt', 'Kent', and 'Tommy Atkins' (Malundo et al., 1996, 1997). The only oxygenated volatile compounds found in those varieties were ethanol, acetaldehyde, and hexanal (MacLeod and Snyder, 1985; Malundo et al., 1997).

Despite the extensive work conducted to identify the more than 150 volatile compounds found in various mango varieties, there has been no evaluation of changes in mango aroma profiles resulting from different storage conditions. Therefore, the objective of this study was to determine if temperature and ripeness stage could significantly influence the production of aroma volatiles by 'Tommy Atkins' mangoes held in air or controlled atmosphere (CA) storage.

Materials and Methods

Mature-green and tree-ripe (TR) 'Tommy Atkins' mangoes were harvested from a grove in Homestead, Fla., stored overnight at 12 °C, then transported by car to Gainesville and placed in a flow-through CA system at 8 (TR) or 12 °C (MG and TR) with the following treatments: 1) air; 2) 5% O_2 plus 10% CO_2 (= 10% CO_2); and 3) 5% O_2 plus 25% CO_2 (= 25% CO_2). Each treatment was replicated three times, with each replicate consisting of four fruit in a 10.05-L sealed glass jar with inlet and outlet tubes for gas flow. Ripeness stages for the MG and TR fruit corresponded to RS1 (fruit hard, well formed, with totally green skin ground color) and RS3 (fruit firm, well formed, with some yellow ground color development), respectively, as described in Miller et al. (1986).

Aroma volatiles were measured in mango mesocarp tissue after 2 d in air at 20 °C following a 21-d storage period at 8 or 12 °C. Mesocarp tissue was homogenized with equal parts of deionized water and the diluted homogenate was stored at –20 °C until used for volatile determinations. Volatile components were quantified based on the headspace analysis procedure of Baldwin et al. (1991) as modified by Malundo et al. (1997) for mangoes. Analysis was conducted with a Perkin-Elmer model 8500 FID gas chromatograph with model HS-5 headspace sampler (Perkin-Elmer; Foster City, Calif.), and a 0.53 × 3000 mm polar Durowax column (J&W Scientific, Folsom, Calif.) The concentrations of the hydrocarbon terpene volatiles (α-pinene, 3-carene, limonene, and p-cymene) were calculated as $\mu L \cdot L^{-1}$ using regression equations fitted to peak height calibration curves as described in Malundo et al. (1997). Data for acetaldehyde, ethanol, and hexanal levels are presented as peak heights.

The experiment was conducted twice with 'Tommy Atkins' and once each with 'Haden' and 'Keitt' mangoes (data not shown) with similar results. The experimental design was completely randomized, with MG fruit stored in three atmosphere treatments at 12 °C and TR fruit stored in the same atmospheres at either 8 or 12 °C. Data were analyzed [analysis of variance (ANOVA) and least significant difference (LSD)] using SAS for PC (SAS Inst., Cary, N.C.). The results for MG and TR fruit stored at 12 °C and for TR fruit held at 8 and 12 °C were analyzed as separate data sets and the overall LSD values were calculated at $P \leq 0.05$ for comparisons of the treatments.

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Results and Discussion

The concentrations of all four of the terpene volatiles measured were influenced by initial ripeness stage, with MG fruit from all atmosphere treatments stored at 12 °C having lower concentrations than did TR mangoes stored at the same temperature (Table 1). However, there was no significant temperature effect on the levels of the terpene volatiles α-pinene, 3-carene, and limonene for TR mangoes stored at 8 or 12 °C (Table 1). The only terpene in TR fruit that was significantly affected by the storage temperature was p-cymene, which was present at higher levels after 12 °C storage than after 8 °C storage. Terpene concentrations also seemed to be influenced by CO_2 concentration (Table 1). There was a tendency for the concentrations of the terpenes to be lower with increasing CO_2 concentration in the storage atmosphere at both temperatures and for both ripeness stages. CA storage, especially the 25% CO_2 treatment, seemed to reduce terpene biosynthesis regardless of ripeness stage. However, the terpene aroma volatile levels in TR mangoes from the 25% CO_2 treatment at 12 °C, while lower than the levels in the 10% CO_2 or air treatments at 12 °C, were still significantly greater than those in MG fruit stored in either air or CA at 12 °C.

Based on subjective evaluations, Engel and Tressl (1983) concluded that monoterpenes are important components of mango flavor, especially for Florida varieties. Wilson et al. (1990) also suggested that, because of the complexity of mango flavor, there is no typical flavor component for mangoes. As for the metabolic processes leading to volatile biosynthesis, lipid components have been considered to be the main precursors of volatiles in mangoes and in fruits in general via their breakdown to fatty acids in the mevalonate and isoprenoid pathways (Gholap and Bandyopadhyay, 1980; Koulibaly et al., 1992; Selvaraj et al., 1989).

Gholap and Bandyopadhyay (1980) identified significant changes in fatty acid ratios in ripening mangoes. The authors suggested that these fatty acid components might have a significant metabolic function in ripening. Therefore, the effects of storage atmospheres on 'Tommy Atkins' aroma components could be related to the effects of CO_2-mediated ripening retardation, resulting in delay of onset of ripening in MG and reduced rate of ripening in TR mangoes.

Despite the relatively high acetaldehyde and ethanol levels in TR mangoes from the 25% CO_2 treatment at 12 °C compared with those in both TR and MG mangoes at 12 °C, acetaldehyde and ethanol levels did not differ significantly in TR vs. MG fruit treatments (Table 1). This reflected the great variability in acetaldehyde and ethanol levels among the replicates in the TR 10% and 25% CO_2 treatments, which was probably related to differences in initiation of acetaldehyde and ethanol synthesis among the individual fruit. Acetaldehyde and ethanol levels were significantly higher in the TR mangoes from the 25% CO_2 treatment at 8 °C than in the other TR fruit at 8 °C or in the TR fruit at 12 °C (Table 1). Pyruvate decarboxylase and alcohol dehydrogenase apparently were stimulated in the higher CO_2 atmosphere, as observed by Ke et al. (1995) in avocados (*Persea americana* Mill.) stored under CO_2 stress. Acetaldehyde and ethanol were highly correlated with "fermented" off-flavors in other fruits stored in stress levels of O_2 and CO_2 (Ke et al., 1994; Ke and Kader, 1990). Nevertheless, informal tasting of the mangoes from the present study did not indicate that the acetaldehyde and ethanol levels encountered had negatively affected the flavor of these fruit. Both acetaldehyde and ethanol are present in mango fruit at the beginning of ripening and before storage, and their levels normally increase during ripening, even in air (Bender, 1996).

Hexanal levels tended to be lower in TR mangoes in air or CA storage at 12 °C than in MG fruit stored in the same atmospheres (Table 1). Hexanal levels were also lower in TR mangoes stored at 8 °C than at 12 °C. Hexanal and C-6 aldehydes impart a green flavor character to preclimacteric apples (Flath et al., 1967; Willaert et al, 1983) and to fruit in general (Bauer et al, 1990). The higher concentrations of hexanal in the MG than in TR mangoes at 12 °C are in agreement with those reports. However, the lower hexanal concentrations in TR mangoes stored at 8 °C than at 12 °C, is not in agreement with the observation that this flavor component is present in higher concentrations in less ripe fruit. If that were so, higher hexanal concentrations would be expected in the TR mangoes from 8 °C storage, which were less ripe following storage than those stored at 12 °C. However, in contrast with the situation reported for apples, hexanal levels increase during ripening of tomato (*Lycopersicon esculentum* Mill.) fruit (Baldwin et al., 1991).

Conclusions

Except for hexanal, aroma volatile levels after storage were greater in mangoes picked at the TR stage than in MG mangoes, regardless of storage atmosphere. Storing mangoes in a CA containing 10% CO_2 had little effect on aroma volatile levels compared with air storage, but an atmosphere containing 25% CO_2 reduced terpene levels in both MG and TR fruit and increased acetaldehyde and ethanol levels in TR fruit. This sensitivity to high CO_2 was greater in MG fruit than in TR fruit, and in TR fruit from 8 °C storage than in those from 12 °C storage. While TR mangoes stored in 25% CO_2 produced elevated levels of acetaldehyde and ethanol, indicating that anaerobic metabolism was induced by the CA, their flavor was not impaired. In fact, aroma volatile levels were always higher in TR mangoes from both CA treatments than in either air- or CA-stored MG mangoes. The results show that CA storage, which prolongs mango shelf life by slowing the ripening processes, thus allowing TR mangoes to be successfully handled, also allows TR mangoes to be stored or shipped without sacrificing their superior aroma quality compared with MG fruit.

Table 1. Concentrations ($\mu L \cdot L^{-1}$) or peak heights of volatiles in the headspace for mesocarp tissue from mature-green (MG) and tree-ripe (TR) 'Tommy Atkins' mangoes stored for 21 d in air or CA at 8 or 12 °C plus 2 d in air at 20 °C.

Atmosphere	α–Pinene ($\mu L \cdot L^{-1}$)	3–Carene ($\mu L \cdot L^{-1}$)	Limonene ($\mu L \cdot L^{-1}$)	p–Cymene ($\mu L \cdot L^{-1}$)	Acetaldehyde (pk. ht in mm)	Ethanol (pk. ht in mm)	Hexanal (pk. ht in mm)
			MG mangoes at 12 °C				
Air	2.56	18.6	0.30	0.03	1,322	780	361
5% O_2 + 10% CO_2	2.35	12.7	0.28	0.03	1,308	1,356	261
5% O_2 + 25% CO_2	0.76	5.4	0.12	0.00	1,314	725	213
			TR mangoes at 12 °C				
Air	7.92	63.3	1.32	0.09	1,498	2,822	165
5% O_2 + 10% CO_2	6.67	58.4	1.04	0.15	2,178	7,921	158
5% O_2 + 25% CO_2	5.73	52.6	0.86	0.08	11,803	45,687	120
			TR mangoes at 8 °C				
Air	7.21	58.7	0.90	0.04	1,459	653	92
5% O_2 + 10% CO_2	5.86	53.5	1.03	0.04	1,577	1,249	29
5% O_2 + 25% CO_2	2.06	14.8	0.34	0.00	67,554	79,124	48
			LSD ($P \leq 0.05$)				
MG and TR at 12 °C[z]	3.12	25.3	0.48	0.06	NS	NS	104
TR at 8 °C and 12 °C[y]	NS	NS	NS	0.07	27,447	49,474	84

[z]Overall LSD at $P \leq 0.05$ for comparison of atmosphere treatments for MG and TR mangoes at 12 °C.
[y]Overall LSD at $P \leq 0.05$ for comparison of atmosphere treatments for TR mangoes at 8 and 12 °C.
[NS]Nonsignificant at $P \leq 0.05$.

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