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Harvest Maturity and Concentration and Exposure Time to Acetylene Influence Initiation of Ripening in Mangos

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Abstract. The effects of acetylene at 0, 0.1, 0.2, 0.4, 0.8, or 1.6 ml-liter⁻¹ and exposures of 4, 8, 12, or 24 hours on ripening initiation in mangos (*Mangifera indica* L.) harvested at three stages of maturity were investigated: Ripeness was assessed before and after treatment in 'Tommy Atkins', 'Ruby', and 'Amelie' mangos by analysis of texture, peel, and pulp color development, soluble solids concentration, and pH. The initiation of ripening depended on the acetylene concentration, exposure time to acetylene, the physiological maturity of the fruit at harvest, and on the cultivar. Changes that can occur during ripening had different sensitivities to acetylene gas. Acetylene treatment of 0.1 or 0.2 ml-liter⁻¹ for 24 hours at 25C initiated softening, but had no effect on the other ripening processes measured. All the ripening changes measured were initiated with a 24-hour exposure to 0.4 ml-liter⁻¹ in 'Tommy Atkins', while 0.8 ml-liter⁻¹ was required with 'Ruby' mangos. There was an interaction between gas concentration and exposure time taken to initiate ripening. The 0.8 ml-liter⁻¹ acetylene treatment required 24 hours to initiate full ripening, while 8 hours were required with 1.6 ml-liter⁻¹ acetylene and 1.0 ml-liter⁻¹ ethylene. Mature and half-mature fruit showed a similar response to gas treatments; immature fruit failed to show full ripening initiation, although softening and peel color development were enhanced.

Mango is a climacteric fruit that undergoes a distinct ripening phase; which can be initiated by the exogenous application of ethylene gas (2, 5, 11). Acetylene, an ethylene analogue, can be used to initiate fruit ripening (16). Acetylene has a lower biological activity than ethylene, and higher concentrations for the same exposure period are generally required (4). In bananas, 0.01 ml-liter⁻¹ ethylene at 18C for 24 hr initiated ripening; while 1.0 ml-liter⁻¹ acetylene was required for a similar effect

(19). In several Florida mango cultivars, 0.005 and 0.01 ml-liter⁻¹ ethylene for 24 hr at 30C initiated ripening (1). Treatment of 'Tommy Atkins' mangos with a range of acetylene concentrations indicated that 1.0 ml-liter⁻¹ for 24 hr at 25C was required for ripening initiation (11).

Commercial ripening procedures employed in producer countries, such as Brazil and Senegal, generally use acetylene gas liberated from calcium carbide by the addition of water or by contact with moisture in the air (9). No specific quantities of calcium carbide are used; thus, treatments may involve exposure to various concentrations. The effects of acetylene liberated from calcium carbide has been investigated for Dashehari mangos (6). Color development at room temperatures was found to be better with 8 than with 4 g calcium carbide, but these were inferior in taste. Fruit ripened with 4 g were found to have good color and flavor and they were higher in soluble solids concentration (SSC),

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total sugars, and pigments, with lower amounts of acids than control fruits. Mangos exposed to acetylene gas and stored at low or ambient temperatures showed rapid color changes, but were insipid in flavor (18); no details were given on the cultivar. Acetylene added as calcium carbide at $2 \text{ g}\cdot\text{kg}^{-1}$ of fruit was found to halve, the ripening time of 'Alphonso' mangos, although treated fruits showed a reduced total carotenoid content and impaired odor development (13). Experiments with 'Tommy Atkins' mangos treated with 0.01, 0.1, 1.0, or 2.0 ml acetylene/liter for 24 hr at 25C indicated that 1.0 or 2.0 ml-liter⁻¹ was required to initiate ripening similar to that obtained with 1.0 ml ethylene/liter under the same conditions (11).

Treatment with exogenous ethylene or acetylene can synchronize ripening of fruits of varying maturities. Ten-day-old (highly immature) cantaloupe melons required 24-48 hr of ethylene at 0.1 ml-liter⁻¹ to induce a complete climacteric, but, in 30-day fruit, the period was 12-24 hr (8). This apparent increase in sensitivity to applied ethylene as the fruit approaches the onset of the natural climacteric has also been shown for bananas (3) and honeydew melons (14). If sufficient exogenous ethylene is made available to immature tissue, the system responsible for the natural tolerance should be overcome, and fruits of all physiological ages should commence to ripen at about the same time and rate; this phenomenon has been observed in several climacteric fruits (15).

Mangos harvested at various stages of physiological maturity showed a faster ripening rate with increasing harvest maturity (10). Storage suitability and the degree of ripening changes in mangos during low-temperature storage have also been found to be influenced by the stage of physiological maturity at harvest (12).

This study was undertaken to establish acetylene concentrations and exposure times required to initiate ripening in mangos harvested at varying stages of physiological maturity and to provide information for the commercial application of acetylene for ripening initiation of mangos.

Materials and Methods

Studies were carried out over two successive mango seasons in Brazil (Nov.-Feb. 1985-86 and 1986-87) and Senegal (June-July 1986; June-Aug. 1987). 'Tommy Atkins' and 'Ruby' mangos (harvested from Taquaritinga, São Paulo) and 'Amelie' (harvested from Sangalkam, Dakar) were used in the Brazil and Senegal experiments, respectively. After harvest, undamaged fruit free from apparent pathogen infection were selected and taken to the laboratory, where they were placed under experimental conditions within 24 hr.

Fruit maturity at harvest was based on the morphological characteristics as described by Medlicott et al.; 1988 (10). A mature fruit was defined as having full raised shoulders at the stem end, but remaining firm and green. Half-mature fruit had shoulders in line with the stem, while immature fruit had shoulders that were below the pedicel insertion.

Experiments in Brazil were conducted in 80-m³ ripening rooms at $25 \pm 1\text{C}$, 85% to 95% RH and, in Senegal, under ambient conditions of 27.5 to 30.5C and 65% to 83% RH. Gas treatment was given to the unripe mangos placed in airtight containers fitted with an inlet and outlet. Ethylene was available as commercially prepared mixtures in air at concentrations of 95% in Brazil (Etil-5) and 5.5% in Senegal (Azetyl); acetylene was available in the commercially pure form in both countries. The required gas concentrations were achieved by injecting a known volume of gas into the container through rubber septa that sealed

the inlet and outlet, or by mixture with air using flow meters, control valves, and a gas mixing manifold. The gas was then pumped into the containers until a complete air change was achieved. The containers were sealed for specific periods of time, removed from the ripening room, opened, the fruit placed into ventilated fiberboard cartons and returned to the ripening rooms.

Physico-chemical analyses to determine the stage of ripeness were carried out at harvest and at intervals during ripening. Each sample consisted of eight fruit that were analyzed for pulp rupture force, SSC, pH, and visual assessment of the peel and pulp color. Pulp rupture force was determined on each mango on opposite sides of the fruit. A portion of the peel was removed and a compression force was applied to the pulp using a 6-mm-diameter cylindrical probe, fitted to a bench top pressure tester with a 0- to 10-kg Salter electronic force gauge (Mecmesin, Surrey, England). The value recorded for the pulp rupture force was the maximum force required for the pulp to yield to the tip of the probe. SSC of the expressed juice was measured with a Bellingham-Stanley hand-held refractometer (Tunbridge Wells, England) and pH with a Gallenkamp digital pH meter (Loughborough, England). Peel and pulp color were scored on the following scales: peel: 1 = green, 2 = more green than yellow, 3 = equal amounts of green and yellow, 4 = more yellow than green, 5 = yellow; pulp: 1 = white, 2 = yellow-white, 3 = yellow, 4 = yellow-orange, 5 = orange.

Eight fruit were used in each treatment, experiments were repeated three to five times and carried out as randomized complete-block designs.

Results

Effects of acetylene concentration on ripening initiation. 'Tommy Atkins' mangos treated for 24 hr at 25C with 0.4, 0.8, or 1.6 ml acetylene/liter showed a rapid advancement of ripening after 3 additional days of storage in normal air (Table 1). There were no significant differences between any acetylene and ethylene treatments for the ripening characteristics measured. Control fruit sampled after 3 days showed no major ripening changes compared to the initial values at harvest although peel color development had begun. Comparisons of control fruit and that treated with acetylene at 0.1 ml-liter⁻¹ showed no change in the pH and peel and pulp color development. Textural changes and those in SSC in these particular treatments, however, were significantly advanced compared to controls, but not to the extent shown by ethylene and the higher concentrations of acetylene. On day 8, control fruit were not fully ripe, requiring further time for full ripeness; ethylene-treated fruit, by contrast, appeared to be in the post-climacteric stage, as indicated by lower SSC (data not shown).

Similar responses were obtained with 'Ruby' and 'Keitt' mangos, although 0.8 ml acetylene/liter at 25C for 24 hr was required for full ripening initiation (data not shown).

Effects of exposure period and gas treatment on ripening initiation. For 'Ruby' mangos, minimum exposure time required for advancement of ripening depended on gas concentration (Table 2). Measurement of the characteristics associated with ripening after 4 days following acetylene at 0.8 ml-liter⁻¹ indicated that a 24-hr treatment was required for advancement of each of the ripening processes analyzed. Treatment with either 1.6 ml acetylene/liter or 1.0 ml ethylene/liter required 8 hr to initiate ripening. Only the 4-hr exposure period at these concentrations showed no differences from the controls. Differences, however, were found between the control and the 8-,

Table 1. Ripeness characteristics of mature 'Tommy Atkins' mango after 4 days at 25C, 85% to 95% RH, in response to the application of ethylene and varying acetylene concentration for the first 24 hr.

Treatment	Pulp rupture force (kgf)	Soluble solids concn (%)	pH	Peel color ^z	Pulp color ^y
At harvest	8.28	7.6	3.35	1.0	2.7
Control (untreated)	7.04	7.2	3.27	1.6	2.8
Ethylene (1.0 ml·liter ⁻¹)	0.75	11.6	3.61	4.1	4.4
Acetylene (ml·liter ⁻¹)					
0.1	4.18	9.0	3.21	1.8	2.8
0.2	4.67	9.9	3.28	1.6	3.3
0.4	0.99	12.8	3.63	2.8	4.0
0.8	0.91	11.9	3.59	3.4	4.3
1.6	0.78	12.1	3.80	4.5	4.4
Source	df	MS	MS	MS	MS
Treatment (A)	7	74.44**	39.41**	0.37**	13.75**
Error (A)	56	1.91	1.32	0.06	0.13

^z1 = green, 5 = yellow.

^y1 = white, 5 = orange.

**Significant at $P = 0.01$.

Table 2. Effect of exposure time to ethylene and acetylene on the ripeness characteristics of mature 'Ruby' mangos sampled after 4 days at 25C.

Gas and concn (ml·liter ⁻¹)	Exposure time (hrs)	Pulp rupture force (kgf)	Soluble solids concn (%)	pH	Peel color ^z	Pulp color ^y
Acetylene	0	8.91	8.3	3.86	1.8	2.1
0.8	4	9.46	7.7	3.98	2.4	1.9
	8	6.99	9.9	4.06	2.4	2.6
	12	10.10	8.4	4.01	2.4	2.2
	24	1.23	15.0	4.47	3.9	4.1
1.6	4	8.43	8.4	3.91	1.9	2.1
	8	1.32	13.1	4.19	2.9	3.8
	12	3.02	12.4	4.15	2.6	3.5
	24	1.06	13.5	4.43	4.1	4.1
Ethylene						
1.0	4	8.38	9.6	3.92	2.3	2.4
	8	0.90	15.0	4.68	4.0	4.5
	12	2.09	11.9	4.12	3.4	3.1
	24	0.83	14.6	4.28	4.9	4.3
Source	df	MS	MS	MS	MS	MS
Replicates	7	3.57	1.37	0.02	0.27	0.74
Gas treatment (A)	2	117.43**	40.85**	0.09	3.23**	5.05**
Error (A)	14	3.56	1.89	0.05	0.56	0.55
Exposure (A)	4	288.97**	164.22**	1.24*	17.09**	19.22**
Interaction AB	8	33.01**	15.54**	0.22*	1.19**	1.64**
Error	84	3.51	1.29	0.06	0.37	0.54

^z1 = green, 5 = yellow.

^y1 = white, 5 = orange.

***Significant at $P = 0.05$ or 0.01 , respectively.

12-, and 24-hr acetylene treatments at 1.6 ml·liter⁻¹, with the 24-hr exposure appearing most effective, particularly in effects on peel and pulp color development. On day 9, fruit exposed to ethylene or acetylene appeared similar, but the untreated fruit required additional storage time to reach full ripeness (data not shown).

Effects of harvest maturity and acetylene at 0.5 or 1.0 ml·liter⁻¹ on ripening. During storage of 'Amelie' mangos under ambient conditions, untreated fruit showed a trend to increased rates of ripening from the immature to the mature stages of harvest (Table 3). These increases, shown in all the ripeness characteristics

assessed, were most apparent for textural changes, and least for peel color development. Application of either 0.5 or 1.0 ml acetylene/liter for 24 hr under ambient temperatures advanced ripening in each harvest maturity, although to differing degrees. Advanced ripening was apparent in both mature and half-mature acetylene-treated fruit as indicated by the ripeness characteristics when analyzed on day 5 after harvest. The extent of change was greater in fruit harvested at the mature than at the half-mature stage, although this depended on the ripeness characteristic. No differences were noted between the effects of 0.5 and 1.0 ml·liter⁻¹ treatments on either mature or half-mature fruit.

Table 3. Ripeness after 5 days under ambient conditions (25 to 30C, 75% to 85% RH) of 'Amelie' mangos harvested at three stages of maturity followinn a 24-hr application of acetylene.

Fruit maturity	Acetylene concn (ml·liter ⁻¹)	Pulp rupture force (kgf)	Soluble solids concn (%)	pH	Peel color*	Pulp color ^y
Mature	0	2.59	8.3	3.37	1.5	4.1
	0.5	0.34	10.9	4.16	2.0	4.5
	1.0	0.45	9.9	3.98	2.0	4.5
Half-mature	0	4.64	7.3	3.22	1.6	3.8
	0.5	0.56	9.4	3.87	1.8	4.5
	1.0	0.58	9.3	3.69	2.2	4.3
Immature	0	5.65	7.1	3.21	1.6	2.8
	0.5	2.05	7.9	3.25	1.5	3.5
	1.0	1.29	7.9	3.28	1.7	3.4
Source	df	MS	MS	MS	MS	MS
Replicates	5	0.68	0.58	0.08	0.04	0.09
Maturity (A)	2	70.17**	18.40**	1.20**	0.59**	2.68**
Error (A)	10	1.00	0.53	0.12	0.07	0.18
Concentration (B)	2	15.86**	19.01**	1.58**	0.46**	6.22**
Interaction AB	4	2.57**	1.61**	0.26*	0.16	0.17
Error	30	0.89	0.53	0.11	0.09	0.12

*1 = green, 5 = yellow.

^y1 = white, 5 = orange.

***Significant at $P = 0.05$ or 0.01 , respectively.

Ripening initiation, occurred in immature treated fruit when compared to untreated, but the ripeness stage was less-advanced than in mature and half-mature fruit. Treatment of immature fruit with acetylene at either 0.5 or 1.0 ml·liter⁻¹ had no significant effect on SSC or pH. Acetylene treatment of 'Amelie' mangos at all maturities had only limited effects on peel color development.

Discussion

Previous investigations on the effects of 0.01, 0.1, or 1.0 ml acetylene/liter for 24 hr at 25C on ripening initiation of 'Tommy Atkins' mango indicated that softening and peel color development could be advanced with 0.1 ml·liter⁻¹, while acidity loss, soluble solids accumulation, and peel color development required 1.0 ml·liter⁻¹ (11). Similar observations have been made in bananas, where 0.1 ml acetylene/liter induced the respiratory climacteric, while degreening and SSC development were delayed (19). This differential effect on the initiation of individual ripening processes with acetylene has also been found with ethylene, although at substantially lower concentrations. Pears have been shown to require 0.08 µl ethylene/liter to initiate softening, while initiation of the respiratory climacteric required 0.46 µl·liter⁻¹ (20).

Experiments involving varying exposure times, to exogenously applied ethylene and acetylene have shown that a minimum period of exposure was required, which varied with gas treatments. In ripening initiation of bananas, a relationship was found between acetylene concentration, time of exposure, and pulp temperature; fruits stored at higher temperatures required shorter exposure times or lower concentrations for initiation (17).

We found the initiation of ripening of mangos to be dependent on physiological maturity at harvest. In immature climacteric fruit, the system responsible for the 'natural tolerance to initiating gases can be overcome if sufficient gas is made available

to the fruit (14). However, under the conditions used in this study, full initiation of ripening did not occur in immature fruits, although some of the ripening processes were advanced.

Commercial ripening of some fruit, such as bananas, using ethylene gas is highly successful (7). This study has shown that ethylene can be used to control the onset of ripening in mangos, if immature fruit are avoided. Commercial use of acetylene, as liberated from calcium carbide, often results in fruits that are soft and have good peel color development, but are poor in flavor (9, 18). This study has shown that acetylene concentrations <0.4 ml·liter⁻¹ for 24 hr at 25C may advance softening and peel color development in some cultivars, while other major ripening changes continue at a natural rate. Thus, where calcium carbide is to be used in commercial practice, it should be ensured that the fruit arc in contact with sufficient acetylene for an adequate period of time to initiate full ripening.

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Ripening of Mangos Following Low-temperature Storage

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Abstract. The effects of harvest maturity of mangos (*Mangifera indica* L.) on storage under various low-temperature regimes and the influence of storage on quality development during subsequent ripening at higher temperatures were investigated. The capacity for storage of mango fruit depended on harvest maturity, storage temperature, and the time of harvest within the season. Development of peel and pulp color, soluble solids concentration, pH, and softening in 'Amelie', 'Tommy Atkins', and 'Keitt' mangos occurred progressively during storage for up to 21 days at 12C. Based on the level of ripening change that occurred during 12C storage, immature fruit showed superior storage capacity than fruit harvested at more-advanced stages of physiological maturity. On transfer to ripening temperatures (25C); however, immature fruit failed to develop full ripeness characteristics. Mature and half-mature fruit underwent limited ripening during storage at 12C, the extent of which increased with progressive harvests during the season. Ripening changes during storage for 21 days were less at 8 and 10C than at 12C. Chilling injury, as indicated by inhibition of ripening, was found at all harvest stored at 8C, and in early season harvests stored at 10C. Fruit from mid- and late-season harvests stored better at 10 than at 12C, with no apparent signs of chilling injury. Flavor of mangos ripened after low-temperature storage was less acceptable than of those ripened immediately after harvest. Suggestions are made for maximizing storage potential by controlling harvest maturity and storage temperature for progressive harvests throughout the season.

Mangos are judged as luxury items on the markets of most industrialized countries, although a reduction in price, together with improved and consistent quality, likely could result in increased consumption. The high cost of mangos in importing countries is due primarily to airfreight charges, but air transport does have the advantage of speed over sea transport. Sea transport is less expensive and enables transport of larger volumes, and thus would aid in the expansion of mango export industries. At the present stage of technical development, however, sea shipment does not guarantee good-quality fruit on arrival nor sufficiently long shelf life for successful marketing.

Sea transport generally involves the use of low-temperature storage in an attempt to prolong storage life. In practice, the minimum temperature for storage of most tropical fruits is determined by their susceptibility to chilling injury (CI). Between 12 and 13C generally is considered as optimum for mango storage (4, 10, 13), although suitable temperatures have been given as 10C (12) and 5C (1, 14). The variation in reported optimum

temperatures may be a cultivar effect, and may also be related to, the stage of harvest maturity and ripeness of the mangos when placed in storage.

Harvest in the fully mature, firm, green, pre-climacteric stage and transport in this condition has been recommended (2, 16). However, in commercial situations where transport over long distances is involved, mangos are generally harvested before full maturity, which may result in fruit of reduced quality (8). In commercial conditions, fruit are harvested at several stages of maturity and are shipped together, which results in a lack of uniformity of ripening among fruits. In addition, quality of ripened mango fruit has been found to be temperature-dependent, with the range of 21 to 24C being optimum for the Florida cultivars (3). Varying ripening rates have been reported on mangos harvested at different times after fruit set (4), while immature mangos undergo only limited ripening changes (8).

This paper reports a study aimed at determining the effects of harvest maturity, storage period, and temperature, and the time of harvest within the season, on storage potential and quality development during subsequent ripening on transfer to higher temperatures.

Materials and Methods

Studies were carried out over two successive mango seasons in Brazil (Nov.-Feb. 1985-86 and 1986-87) and Senegal (June-

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