Physiological and Chemical Changes during Ripening of Costa Rican Bananas Harvested in Different Seasons

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Additional index words. *Musa* AAA, storage, postharvest physiology, respiration, ethylene, quality

Abstract. Mature green ‘Grande Naine’ bananas (*Musa* AAA) were harvested 13 weeks after flowering in June and Sept. 1993 and Feb. and Mar. 1994 and were sent air freight to Raleigh, N.C. Fruit were held under 1) storage (36 days at 14 °C and 80% to 90% relative humidity) or 2) ripening (8 days storage, followed by ethylene treatment on day 8 and subsequent storage at 17 °C and 80% to 90% relative humidity). Despite of similar grade and age, length of the preclimacteric phase (green life) was different between fruit harvested at different times of the year. Fruit harvested in February and March had a longer green life than those harvested in June and September. Rate of respiration best described changes that occurred during the postharvest life of bananas; however, variables such as pulp pH and soluble solids could be commercially useful measures. Once gassed with ethylene, ripening rates were similar between all four lots of fruit, indicating that seasonal variation probably doesn’t contribute much to variability seen during ripening. Hand position in the bunch did not have a large influence on variability during ripening or storage.

Bananas are one of the most popular fresh fruit in the world. The cultivation of banana and plantains in tropical America and the Caribbean countries is important, not only because they are part of the regional diet, but also because of their importance to the economics of the producing countries (Barrientos and Sanchez, 1992; Gonzalez, 1987; Jaramillo, 1987).

The preclimacteric or “green life” of the banana is essentially the same as its storage life. Once the climacteric begins, the fruit softens and becomes much more susceptible to mechanical damage. The length of the preclimacteric period is a function of fruit maturity, transit temperature, humidity, ventilation, mechanical damage, fungal infection, and many other factors (Marriot, 1980; Stover and Simmonds, 1987; Soto, 1992). Maturity at harvest is determined by the time required to transport the bananas to the market, although there are clonal and seasonal considerations. Harvest maturity of bananas is judged using a combination of banana age and grade. (Palmer, 1971; Soto, 1992; Stover and Simmonds, 1987).

The physiological maturity of banana fruit is not always the same, even in fruit of the same age. Physiological maturity may be influenced by different factors, such as time of the year, Sigatoka leaf spot diseases, or other environmental conditions (Liu, 1976; Marriot, 1980; Soto, 1992). Commercial banana ripeners sometimes encounter variability in ripening behavior. Neither fruit age nor size (diameter) have been totally reliable guides to predict the preclimacteric period. Therefore, a more precise method to mea-

sure the physiological stage of the fruit is needed to achieve maximum use of the fruit without risk of premature ripening.

Varieties and handling methods have changed since some of the early comprehensive banana studies were conducted. Many studies lack an integrated approach since they did not cover the changes from harvest to ripening. Commercial ripening practices assume that bananas are a consistent product that behave the same throughout the year. Our objectives were 1) to determine physiological and chemical changes during storage and ripening of ‘Grande Naine’ bananas and 2) to determine the variation in maturity of bananas in relation to their position in the bunch and the season in which they were harvested.

Materials and Methods

Plant material. Thirty bunches of mature green bananas (*Musa* AAA, ‘Grande Naine’, Cavendish subgroup) from San Pablo Farm, Limon, Costa Rica, were harvested 13 weeks after flowering. Eight-finger clusters from the centers of the second, fifth, and eighth hand were selected and treated with aluminum sulfate (200 mg·L⁻¹) and thiabendazole (300 mg·L⁻¹) (Metect 340F; Merck Agvet Div., Rathway, N.J.) before packing. Banana clusters were packed and sent via air freight to Raleigh, N.C., in June and Sept. 1993 and in Feb. and Mar. 1994. Sampling dates were selected based on the seasonal variation of the temperature in the area where the bananas were grown. After arrival in Raleigh, fruit were separated into two groups (15 “bunches” per group). One group was held in storage (to be described), and the other group was stored similarly for 8 d and then gassed with ethylene.

Storage conditions. Banana fruit were stored in cardboard boxes with polyethylene liners at 14 °C and 80% to 90% relative humidity for 30 to 36 d. Fruit were not treated with ethylene. An arbitrary sample from each of five clusters selected randomly from each hand position was taken every 2 d for destructive evaluation of fruit characteristics. Separating bananas from each cluster was performed by cutting the pedicel with a curved knife before evaluation.

Ripening conditions. Fruit were held under storage conditions for 8 d to simulate the time from harvest to placement in ripening rooms. On day 8, fruit were placed in sealed drums and gassed with

Received for publication 10 Aug. 1995. Accepted for publication 8 July 1996. This research was supported in part by the National Banana Corp., the National Counsel for Scientific and Technological Research of Costa Rica, and the North Carolina Agricultural Research Service. Mention of a trademark or proprietary product does not constitute a guarantee or warranty of the product by the North Carolina Agricultural Research Service or the U.S. Dept. of Agriculture and does not imply its approval to the exclusion of other products that may also be suitable. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

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Table 1. Physiological and chemical variables (mean $\pm$ SE) during storage and ripening of Costa Rican bananas from 1993 to 1994 (analysis by hand).

Hand	Color (1 to 7) ^z	CO ₂ (L·g ⁻¹ ·h ⁻¹)	C ₂ H ₄ (L·kg ⁻¹ ·h ⁻¹)	Starch (1 to 10)	pH	Soluble solids (%)
<i>Storage</i>						
Second	2.34 $\pm$ 0.06	12.41 $\pm$ 0.36	0.78 $\pm$ 0.24	2.17 $\pm$ 0.09	5.39 $\pm$ 0.008	2.32 $\pm$ 0.09
Fifth	2.12 $\pm$ 0.04	12.74 $\pm$ 0.34	0.64 $\pm$ 0.20	1.96 $\pm$ 0.06	5.43 $\pm$ 0.007	1.87 $\pm$ 0.06
Eighth	2.07 $\pm$ 0.03	12.97 $\pm$ 0.30	0.57 $\pm$ 0.15	1.78 $\pm$ 0.04	5.46 $\pm$ 0.006	1.58 $\pm$ 0.04
<i>Ripening</i>						
Second	3.97 $\pm$ 0.12	45.75 $\pm$ 1.14	1.05 $\pm$ 0.05	4.87 $\pm$ 0.21	4.95 $\pm$ 0.01	6.08 $\pm$ 0.19
Fifth	3.87 $\pm$ 0.11	46.87 $\pm$ 1.24	1.20 $\pm$ 0.05	4.92 $\pm$ 0.21	4.94 $\pm$ 0.02	5.88 $\pm$ 0.20
Eighth	3.69 $\pm$ 0.11	49.37 $\pm$ 1.55	1.38 $\pm$ 0.06	4.66 $\pm$ 0.21	4.94 $\pm$ 0.02	5.48 $\pm$ 0.20

^zPeel color was recorded using the standard color scale of Von Loesecke (1950), which considers seven stages or grades: 1, green; 2, light green; 3, half yellow–half green; 4, three-quarters yellow with green; 5, yellow with green tips; 6, full yellow; and 7, yellow with brown spots.

ethylene (300 μ L·L⁻¹) at room temperature (21 °C). After 18 to 24 h of ethylene treatment, fruit were removed from the drums and placed at 17 °C and 80% to 90% relative humidity until they reached color 6 (Von Loesecke, 1950). A random sample of five bananas per hand position was taken from clusters every day for destructive analysis during ripening to determine fruit characteristics. Data analysis in the ripening study included only data taken from the time of ethylene treatment onward.

Gas measurements. Five bananas per hand position were weighed and placed in individual 3.8-L glass jars. Jars were fitted with lids containing a rubber septum. Jars were sealed for 2 h and a 1-mL gas sample was taken to determine the CO₂ concentration (in microliters per gram per hour) and ethylene (in microliters per gram per hour) accumulated. Carbon dioxide was measured with a gas partitioner (model 1200; Fisher, Pittsburgh) equipped with a thermal conductivity detector. Ethylene was measured with a gas chromatograph (series 1400, Varian Aerograph, Sugarland, Texas), equipped with an alumina column and a flame ionization detector. Measurements were taken on the same bananas every 2 d during the storage period and every day under ripening conditions.

Peel color. Peel color was recorded using the standard color scale of Von Loesecke (1950). This scale considers seven stages or grades: 1, green; 2, light green; 3, half yellow–half green; 4, three-quarters yellow with green; 5, yellow with green tips; 6, full yellow; and 7, yellow with brown spots.

Starch content. Starch content was determined using an iodine staining technique developed by Blankenship et al. (1993). Starch content patterns are based on unstained pulp area, ranging from <5% (stage 1) to >65% (stage 10).

pH and soluble solids. Ten grams of pulp from the central section of each fruit was placed in a 50-mL centrifuge tube with 12 mL of distilled water and blended with a homogenizer (Brinkmann Polytron, Westbury, N.Y.) until smooth. The pH was measured on grindate, and a sample was taken to measure soluble solids using an brix-meter digital refractometer (model PR-1; Atago, Tokyo).

Statistical analysis. The storage study was conducted as a 4 $\times$ 3 $\times$ 19 factorial [month of harvest $\times$ “hand” (position in the bunch) $\times$ day (time in storage)] in a completely random design with five replicates. The ripening study was conducted as a factorial (4 $\times$ 3 $\times$ 10, month, hand, day) in a completely random design with five replicates. Statistical procedures were performed using SAS 6.08 (SAS Institute, Cary, N.C.).

Results and Discussion

Differences due to hand position on the bunch as main effect were consistent for most of the variables studied (Table 1). The second hand was slightly more advanced than the eighth hand. The variation due to hand position during different months tended to be minimized toward September and February, and there were no differences in March (data not shown). Nevertheless, differences among hands were generally not large enough to consider separate sampling within a bunch. Additionally, fruit that arrive in the United States are not identified by hand, and the overall maturity of the fruit is what should be taken into consideration in typical commercial ripening facilities. In research studies on bananas, it appears that the presence of different hands in a box is not a major source of variation. Data shown in and all the figures are for second hands only.

Although the bananas in this study were all harvested 13 weeks from flowering, the bananas were not equivalent at different times of the year (Tables 2 and 3). Despite the same age and diameter of fruit (data not shown), the length of the preclimacteric phase was different among months, reflecting different physiological maturities of the fruit at harvest. When fruit characteristics during storage (Table 2) were analyzed by month, June fruit was more advanced in maturity than other months, particularly February and March. June fruit were slightly yellower and had higher respiration and higher soluble solids. The average production of CO₂ ($\approx$ 20 μ L·L⁻¹) was very similar to values reported previously (Ball et al.,

Table 2. Physiological and chemical variables (mean $\pm$ SE) during storage of Costa Rican bananas from 1993 to 1994 (analysis by month).

Month of harvest	Color (1 to 7) ^z	CO ₂ (μ L·g ⁻¹ ·h ⁻¹)	C ₂ H ₄ (μ L·kg ⁻¹ ·h ⁻¹)	Starch (1 to 10)	pH	Soluble solids (%)
February	2.03 $\pm$ 0.03	10.81 $\pm$ 0.20	1.46 $\pm$ 0.43	1.60 $\pm$ 0.03	5.46 $\pm$ 0.004	1.48 $\pm$ 0.03
March	2.02 $\pm$ 0.01	9.64 $\pm$ 0.23	0.10 $\pm$ 0.02	1.23 $\pm$ 0.02	5.51 $\pm$ 0.02	1.35 $\pm$ 0.02
June	2.60 $\pm$ 0.07	18.02 $\pm$ 0.46	0.72 $\pm$ 0.07	2.84 $\pm$ 0.08	5.38 $\pm$ 0.01	2.89 $\pm$ 0.11
September	2.11 $\pm$ 0.07	13.14 $\pm$ 0.41	0.35 $\pm$ 0.03	2.38 $\pm$ 0.10	5.35 $\pm$ 0.01	2.14 $\pm$ 0.09

^zPeel color was recorded using the standard color scale of Von Loesecke (1950), which considers seven stages or grades: 1, green; 2, light green; 3, half yellow–half green; 4, three-quarters yellow with green; 5, yellow with green tips; 6, full yellow; and 7, yellow with brown spots.

Table 3. Physiological and chemical variables (mean $\pm$ SE) during ripening of Costa Rican bananas from 1993 to 1994 (analysis by month).

Month of harvest	Color (1 to 7) ^z	CO ₂ ($\mu\text{L}\cdot\text{g}^{-1}\cdot\text{h}^{-1}$)	C ₂ H ₄ ($\mu\text{L}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$)	Starch (stage 1 to 10) ^y	pH	Soluble solids (%)
February	3.86 $\pm$ 0.12	39.99 $\pm$ 0.90	1.21 $\pm$ 0.07	4.24 $\pm$ 0.26	4.95 $\pm$ 0.02	5.42 $\pm$ 0.27
March	3.98 $\pm$ 0.13	48.51 $\pm$ 1.16	0.97 $\pm$ 0.03	4.32 $\pm$ 0.24	4.86 $\pm$ 0.02	6.64 $\pm$ 0.23
June	3.89 $\pm$ 0.13	56.56 $\pm$ 1.00	1.44 $\pm$ 0.08	6.01 $\pm$ 0.21	5.03 $\pm$ 0.02	5.98 $\pm$ 0.17
September	3.62 $\pm$ 0.14	46.36 $\pm$ 2.30	1.24 $\pm$ 0.07	4.97 $\pm$ 0.22	4.96 $\pm$ 0.01	5.30 $\pm$ 0.21

^zPeel color was recorded using the standard color scale of Von Loesecke (1950), which considers seven stages or grades: 1, green; 2, light green; 3, half yellow–half green; 4, three-quarters yellow with green; 5, yellow with green tips; 6, full yellow; and 7, yellow with brown spots.

^yStarch content patterns are based on unstained pulp area, ranging from <5% (stage 1) to >65% (stage 10).

1991; Palmer, 1971; Wills et al., 1984). However, ethylene production in June was not as high as in February. Fruit in February produced a high concentration of ethylene for a short time at the beginning of storage, but it did not stimulate ripening or shorten green life. Stored fruit in September produced less ethylene than February fruit and only slightly more than March fruit, yet it had a shorter green life (data not shown). All fruit in storage averaged more than the 0.01 $\mu\text{L}\cdot\text{L}^{-1}$, which is sufficient to stimulate ripening in banana (Marriot, 1980). Although it cannot be concluded from only 4 months of data, it appears from a simple plot of the means (plot not shown) that fruit green life may oscillate during the year with summer fruit being more advanced than winter fruit.

The results obtained in the storage study were probably affected by the environment and the presence of diseases (incidence and severity) during the vegetative and reproductive phases of the banana plants. However, the air and ground transportation conditions (ethylene exposure and temperature fluctuations) from Costa Rica to Raleigh might account for the differences seen in this work. It seems that the likelihood of the climacteric occurring during transit is relatively low if bananas are harvested with the same criteria used in this study. Liu (1976) and Peacock, cited by Marriot (1980), independently stated that for a limited period after harvest, bananas are relatively insensitive to exposure to ethylene. It is possible that warmer temperatures during transit in June and September compared to February and March are responsible for the shorter green life; however, June and September fruit also had warmer temperatures and more rainfall during fruit development.

Biotic and abiotic factors that affect banana maturity need to be considered when studying postharvest life of this fruit. Diseases such as black sigatoka (*Mycosphaerella fijiensis* Morelet) and black-head-toppling disease (burrowing nematode, *Radopholus similis*) are more severe in Costa Rica from May to September due to the presence of more conducive conditions for pathogens and less favorable conditions for the growth of the banana plant (R. Romero, personal communication). The incidence of black sigatoka on leaves of the banana plants used in this study increased with warm weather (Marin, 1994). Temperature and rainfall data for the growing area are available (Marin, 1994). A considerable number of hours at <21 °C occurred during the cooler months, particularly January to March.

While the green life of fruit from different times of year varied, there was much less variation in ripening characteristics of the fruit (Table 3). Regardless of time of year, once gassed, bananas appeared to behave in a similar fashion. There was more starch loss in June, but higher soluble solids levels in March. Color changes were equivalent at all times of year, which would indicate that the variability that commercial banana ripeners see in lots of fruit is not due to seasonal variation but other undetermined factors, such as country of origin or different transit conditions.

After ethylene exposure, respiration was four- to 14-fold higher

Fig. 1. Changes in peel color (second hand) during storage and ripening of Costa Rican bananas in June 1993 and Mar. 1994. Bar indicates ethylene exposure for bananas held under ripening conditions. Each point in the graph is a mean of five values.

than rates under storage conditions. In this study, CO₂ production remained high after the climacteric, as was described by Beaudry et al. (1983). These results also agreed with those reported previously (Ball et al., 1991; Inaba and Nakamura, 1986; Kanellis et al., 1989; Lizada et al., 1990; Palmer, 1971; Wills et al., 1984). It was clear that climacteric in this study occurred at any point during ripening (data not shown), ranging from colors 2 to 5, except at very early stages. These results confirm those of Lizada et al. (1990) who reported climacteric peaks at different color stages. In contrast, Wills et al. (1984) reported a characteristic respiratory burst at color 3 only. Ethylene increases in all months were short in duration and occurred earlier than respiratory peak (data not shown). Comparable responses have been observed in other studies (Beaudry et al., 1989; Burg and Burg, 1965; Satyan et al., 1992).

When rates of change in color change during storage and ripening were compared for June and March, the two most different times of year, ripening proceeded at a similar rate, whereas there was an obvious difference in rate of color change in storage (Fig. 1). Comparable results were obtained for CO₂ production (Fig. 2) and soluble solids (Fig. 3). The regression analyses in

Fig. 2. Carbon dioxide evolution (second hand) during storage and ripening of Costa Rican bananas in June 1993 and Mar. 1994. Bar indicates ethylene exposure for bananas held under ripening conditions. Each point in the graph is a mean of five values.

Fig. 3. Changes in soluble solids content (second hand) during storage and ripening of Costa Rican bananas in June 1993 and Mar. 1994. Bar indicates ethylene exposure for bananas held under ripening conditions. Each point in the graph is a mean of five values.

Table 4 further support the differences in rates between the two lots of fruit. Slopes obtained during the storage phase were significantly different for color, CO_2 , and soluble solids. A t test also was performed to statistically determine these differences. During ripening, slopes obtained were numerically very similar, and the t test supports that observation for color change. No comparison of slopes for CO_2 was performed due to the quadratic behavior of the data; however, values for both coefficients (linear and quadratic) are numerically very similar. Slopes for soluble solids were different according to the t test. This unexpected result was caused by the higher final soluble solids content during March, which made the rate slightly higher.

In these studies, we used bananas harvested from the same location under the same criteria. Despite the commonality, the variability shown in color changes, respiratory behavior, ethylene concentrations, and other internal characteristics under storage conditions emphasizes that, although bananas are available throughout the year, they may show considerable differences from one lot to the next.

Variation in maturity was of more practical significance under storage conditions than under ripening conditions. This variation should be analyzed carefully by producers of bananas for export to improve the management strategies of bananas during transit time in relation to specific harvest seasons. Banana ripeners should not be experiencing variability due to different hands in the box or seasonal effects. Other factors may predominate in variability in banana ripening rooms.

Differences between sampling months were consistent across all the variables measured. Consequently, better information on the variation in the physiological stage of the fruit would provide information to reduce losses during transit and storage. Respiration rate best reflected the changes that occurred in this study. However, other variables, such as pH and SS, could be useful measures at a practical level, not only in the field but also in ripening facilities. Studies to determine seasonal variation of bananas are lacking in most of the banana-growing areas of the world. Temperatures in the field may be one of the major factors in determining the green life of the fruit.

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Table 4. Regression analyses for color change, CO₂ evolution, and soluble solids during storage^z and ripening^y of Costa Rican bananas (second hand) in June 1993 and Mar. 1994.

Month of harvest	Color (1 to 7) ^x	CO ₂ (μL·g ⁻¹ ·h ⁻¹)	Soluble solids (%)
<i>Storage</i>			
March			
Mean ± SE	2.030 ± 0.008	8.94 ± 0.25	1.44 ± 0.02
Coefficient of determination (<i>r</i> ²)	0.03	0.14	0.60
Intercept	2.01	10.49	1.12
Slope ± SE	0.001 ± 0.001 a ^w	-0.09 ± 0.05 a	0.02 ± 0.003 a
June			
Mean ± SE	3.04 ± 0.005	20.17 ± 0.65	3.76 ± 0.15
Coefficient of determination (<i>r</i> ²)	0.84	0.78	0.85
Intercept	1.39	9.03	1.62
Slope ± SE	0.11 ± 0.013 b	0.62 ± 0.13 b	0.14 ± 0.02 b
<i>Ripening</i>			
March			
Mean ± SE	3.88 ± 0.51	43.00 ± 7.67	6.19 ± 0.77
Coefficient of determination (<i>r</i> ²)	0.92	0.84	0.95
Intercept	0.99	-9.92	0.32
Slope (x) ± SE	0.53 ± 0.06 a	21.13 ± 3.77	1.07 ± 0.09 a
(x ²) ± SE	-1.64 ± 0.33		
June			
Mean ± SE	4.07 ± 0.11	48.63 ± 1.96	5.77 ± 0.05
Coefficient of determination (<i>r</i> ²)	0.83	0.57	0.98
Intercept	1.00	0.80	1.92
Slope (x) ± SE	0.61 ± 0.10 a	19.46 ± 8.12	0.77 ± 0.04 b
(x ²) ± SE	-1.59 ± 0.79		

^zRegression analyses were done with observations from day 0 to 36.

^yRegression analyses were done with observations from day 8 to 18.

^xPeel color was recorded using the standard color scale of Von Loesecke (1950), which considers seven stages or grades: 1, green; 2, light green; 3, half yellow-half green; 4, three-quarters yellow with green; 5, yellow with green tips; 6, full yellow; and 7, yellow with brown spots.

^wSlopes in the same column and treatment followed by the same letter are not statistically different according to *t* test (*P* < 0.05).

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