Relationship Between the Stage of Development of the Fruit Harvested and the Color of Frozen Green Bananas[1]

F. Sánchez Nieva and M. Mercado[2]

ABSTRACT

The color of hot water-peeled green bananas was found to range from a light gray to a deep yellow. Visual color examinations and color measurements with the Hunterlab meter showed that yellowness of green bananas increased with maturity. Hunter *L* and *b* values showed a significant correlation with pulp to peel ratios in hot water-peeled fruit, frozen thawed fruit and cooked fruit. The *L* values decreased and the *b* values increased as the pulp to peel ratios increased. In order to obtain color uniformity in the frozen product, the green bananas should be harvested at a pulp to peel ratio of about 1.5. The carotenes content of the green bananas increased as pulp to peel ratio increased. The increase in the carotenes was significantly correlated with the Hunter *b* values. When green bananas harvested at different pulp to peel ratios are hand-peeled, only a slight if any difference in color can be detected among the different grades. However, when the fruit is heated to inactivate the enzyme system before peeling, the yellow color appears.

INTRODUCTION

Sánchez Nieva and Mercado (10) showed that for a frozen product of good quality, the enzyme system in green bananas must be inactivated before peeling by treating the fruit in water at 200 F (93 C) for 30 min. In the course of these studies it was observed that the color of the hot water-peeled fruit ranged from a light gray to a deep yellow. In some lots the gray or yellow color predominated, while in others the peeled fruit was a mixture varying in color from light gray to different shades of yellow. This variation in the color of the fruit had an adverse effect on the quality of the frozen product.

In the early part of these investigations the fruit to be processed was purchased in the market. Therefore, its age at harvest and post-harvest handling and storage treatments was not known. Nevertheless, from the correlation of pulp to peel ratio (which changes linearly with age (9, 11) with the color of the processed fruit, it was inferred that the changes in color observed were related to the stage of development at harvest. To investigate further the relationship of stage of development at harvest to

[1] Manuscript submitted to Editorial Board [1] July 9, 1979.

[2] Consultant Chemical Engineer and Research Assistant, respectively, Food Technology Laboratory, Agricultural Experiment Station, Mayagüez Campus, Río Piedras, P.R. The authors wish to express their appreciation to the staff of the Corozal Substation and to Mr. R. Guadalupe, Assistant Horticulturist, Food Technology Laboratory who were in charge of the experimental plot and harvesting of the fruit used in these studies, and to Mrs. I. Caloni, Assistant Food Technolosist, Food Technology Laboratory, for conducting the organoleptic tests.

the color of the processed fruit, further studies were conducted in which fruit for processing was harvested at known stages of development from an experimental plot of Montecristo bananas.

MATERIALS AND METHODS

A plot of 200 plants of Montecristo bananas was established at the Corozal Substation. The corms for planting were obtained from the Adjuntas Substation and were selected to be as uniform as possible. Land preparation, planting, cultivation, and insect and pest control followed the practices recommended for commercial plantations by the Puerto Rico Agricultural Experiment Station (1). During dry weather, irrigation was applied as needed.

The date of flowering for each tree was recorded. Harvesting started about 70 days after flowering. Selected bunches were harvested weekly ranging from 70 to 130 days from the date of flowering. The bunches were harvested early in the morning and transported immediately to the Laboratory in banana crates to avoid bruising. The fruit was stored at 45° F (7.2° C) until processed. With few exceptions, the fruit was processed the next day after harvest to avoid chilling injury.

The hands were separated from the stems and weighed. Pulp to peel ratio was determined in fruit from the second hand by weighing the pulp and the peel from hand-peeled fruit. The fruit for processing was grouped into lots according to their pulp to peel ratio.

The fruit was peeled and frozen as described by Sánchez and Mercado (10) with the following modifications: The fruit was sliced after peeling without immersing it in water, packed immediately and quick frozen at −40° F (−40° C). Forty-five lots ranging in pulp to peel ratio from .99 to 1.87 were frozen and stored at −23.3° C (−10° F).

Color was measured on the exterior and interior surface of peeled, thawed and cooked fruit with a Hunterlab Model D color difference meter[3] calibrated with Hunterlab yellow standard No. 3127 ($L = 78.2$, $a = 4.1$, $b = 30.8$). For measuring the color of the exterior surface the sliced fruit was placed on its side in the cell with the cell as full as possible to avoid excessive open areas. For measuring the interior color, the slices were cut lengthwise in halves, and the halves were placed with cut surface down in the cell. The cell was covered with a Kodak Neutral test card with the white side of 90% reflectance down. The color of the peeled fruit was measured immediately after peeling, when the slices cooled to room temperature. The frozen product was thawed at room temperature for

[3] Trade names in this publication are used only to provide specific information. Mention of a trade name does not constitute a warranty of equipment or materials by the Agricultural Experiment Station of the University of Puerto Rico, nor is this mention a statement of preference over other equipment or materials.

about 2 hours until the temperature reached about 70 F before color measurement. For the cooked product, about 12 oz (320 g) of frozen slices were placed in one liter of boiling water and cooked for 5 minutes after the water boiled again.

Carotenes were determined in the stored frozen samples and in the fresh hand peeled fruit by the AOAC official method (7). Tannins were determined as described by Leonard et al. (6).

For sensory evaluation the content of one box (12 oz approx. −320 g) were added to ½ liter of boiling water to which 2 teaspoon of salt were added. The bananas were boiled for 5 minutes after the water started to boil again. To avoid changes in color due to contact with metals, the fruit was placed in distilled water and boiled in glass saucepans.

Ranking for intensity of the yellow color was carried out under normal fluorescent room lighting. The panelists were required to rank the samples according to the intensity of the yellow. Rating tests with a 6-point

TABLE 1.—*Relationship of visual color of hot water peeled green bananas to age at harvest and pulp to peel ratio*

Visual color of exterior surface	Age at harvest		Pulp/peel ratio	
	Range	Mean	Range	Mean
	Days			
Gray	77–90	79.5	0.99–1.30	1.15
Pale yellow	84–92	89.15	1.23–1.33	1.28
Yellow	99–134	113.0	1.25–1.69	1.53
Deep Yellow	93–121	114.8	1.41–1.87	1.68

scale (0-poor, 6-very attractive) were used for evaluation of the color and appearance of the product. In these tests single samples were judged.

RESULTS AND DISCUSSIONS

Table 1 shows the relationship of the visual color of the exterior surface of hot water-peeled bananas with age at harvest and pulp to peel ratios in over 150 bunches processed. The data show that in the early stages of development the fruit looks grayish, becoming yellow as it matures. In the later stages of development the color of the hot water-peeled fruit turned to a deeper yellow. No significant difference in color was observed among the hands of the bunches examined. When the fruit was sliced lengthwise it was observed that the core was a deeper yellow than the exterior surface, becoming even a deeper yellow as pulp to peel ratio increased.

In studying color changes in food products, it is highly desirable to use objective methods of color measurements for correlating color changes with other parameters. Tristimulus colorimetry is extensively used for

this purpose. Clysdale (2) recently reviewed the application of colorimetry in the measurement of food products. Ezell et al. (3) and Lauber et al. (5) investigated the use of tristimulus colorimetry to determine the levels of carotenoid pigments in sweet potatoes. To correlate the changes in color observed in the green bananas with the stage of development tristimulus colorimeter readings were taken on samples ranging in pulp to peel ratios from 0.95 to 1.8.

Table 2 shows the mean values for Hunter *L*, *a* and *b* measured on the inner and outer surfaces of hot water-peeled fruit at different stages of development. Results of the statistical analysis of the data for 53 samples are given in table 3. Highly significant correlations of pulp to peel ratios with *L*, *a* and *b* were found when the color was measured on the outer surface, and a highly significant correlation with *L* and *b* when the color

TABLE 2.—*Hunter* L, a *and* b *color values for hot water peeled fruit harvested at different pulp to peel ratios*

Pulp/peel ratio interval	Hunter color values measured on:[1]					
	Outer surface			Inner surface		
	L	*a*	*b*	*L*	*a*	*b*
.95–1.0	61.46	−2.19	15.43	63.51	−2.6	16.58
1.01–1.10	59.53	−2.28	16.18	61.61	−2.58	17.15
1.11–1.20	59.23	−2.14	15.78	62.50	−2.73	17.65
1.21–1.30	59.45	−2.19	15.50	63.31	−2.83	17.64
1.31–1.40	58.72	−2.17	16.87	62.35	−2.9	19.34
1.41–1.50	56.47	−2.34	17.66	60.53	−2.88	21.14
1.51–1.60	55.90	−2.14	18.80	60.46	−2.83	22.96
1.61–1.70	56.70	−1.97	18.32	60.30	−2.70	22.24
1.71–1.80	58.25	−1.8	16.35	61.35	−2.70	19.0
+1.8	57.15	−1.5	18.00	61.30	−2.55	22.3

[1] Values are mean values for all bunches falling in a pulp/peel ratio interval.

was measured on the inner surface, but no significant correlation with *a*. *L* values for both outer and inner surfaces decreased as the pulp to peel ratios increased and *a* values for the outer surface decreased in negativity. The *b* values for both surfaces increased with pulp to peel ratios indicating an increase in yellowness. The change in tristimulus values correlate with visual color observations which showed that as the bananas mature the color changes from a light gray to yellow.

In a series of experiments conducted with fruit purchased from a ripening plant in which the color was measured on the outer surface and on the cut ends of frozen slices thawed under water, similar correlations of pulp to peel ratios were obtained with Hunter tristimulus values. When the color was measured on the outer surface, a significant correlation of pulp to peel ratio at 1% P was obtained with *L* and *b* and at 5% P with *a*.

When the color was measured on the cut ends, a highly significant correlation was obtained between pulp to peel ratio and *L* and *b* values, but no significant correlation with *a*.

The results of statistical analysis of the color data also showed a significant difference between the corresponding *L*, *a* and *b* values of the outer and inner surfaces. There was a striking difference in the colors of the surfaces, the core being always yellower than the outer surface irrespective of the stage of development at harvest.

For serving, the frozen green bananas were cooked in boiling water; a change in color was observed, the fruit looking more grayish when cooked than when frozen or thawed. Therefore, it was felt necessary to determine whether the color of the processed fruit affected in any way the quality of the cooked bananas.

TABLE 3.—*Results of the statistical analysis of the data on the relationship of pulp to peel ratios with Hunter* L, a *and* b *values*

Correlation tested	Correlation coefficient	Mean values for—	
		Hunter value	Pulp/peel ratio
Pulp/peel ratio with Hunter values of outer surface			
L	−.6252**	57.62	1.39
a	.2723*	−2.15	1.39
b	.61201**	+17.26	1.39
Pulp/peel ratio with Hunter values of inner surface			
L	−.528**	61.35	1.39
a	.0308 (N.S.)	−2.76	1.39
b	.745**	20.27	1.39

In fruit ranging in pulp to peel ratios from 1.01 to 1.69, boiled for 5 min, Hunter *b* values showed a highly significant correlation with the pulp to peel ratio, increasing as the pulp to peel ratios increased. This indicates that the increase in yellowness with maturity was not appreciably affected by cooking.

Sensory tests in which the tasters were required to rank the cooked bananas according to the intensity of the yellow color showed that tasters were able to detect the increase in yellowness with maturity indicated by the increase in Hunter *b* values. When these samples were judged for appearance using a 6-point scale (0-poor to 6-very attractive) the results shown in the following tabulation were obtained.

Pulp: peel ratio	1.01	1.21	1.30	1.50	1.60	1.69
Appearance score	1.1	2.6	2.7	3.2	4.4	4.6

Since the tasters gave a higher rating to the samples in direct relationship to the increase in yellowness, from the quality standpoint the fruit for freezing must be harvested at a stage of development which will result in a yellowish color when processed and cooked.

Table 4 summarizes the data on the relationship of visual color and Hunter *b* with age at harvest and pulp to peel ratio. It is evident that although there is a definite increase in yellowness and pulp to peel ratios with age, a fairly wide variation in the color of the processed fruit can be expected at any given age.

Although the smallness of the taste panel used to rate the experimental samples may not be truly representative of the consumer reaction to this product, the consensus of the tasters was that uniformity of color was more important from the quality standpoint than the color itself.

TABLE 4.—*Relationship of visual color with age at harvest, pulp to peel ratio and Hunter* b *value—Hot water peeled*

Visual color	Age at harvest		Pulp peel ratio		Hunter b	
	Range	Mean	Range	Mean	Range	Mean
	Days					
			Outer surface			
Gray	71–85	76.4	0.97–1.4	1.01	15.0–16.2	15.8
Yellowish gray	85–103	80.85	1.18–1.43	1.34	16.5–17.35	16.87
Light yellow	103–119	113.5	1.48–1.56	1.53	17.5–20.45	18.56
Yellow	116–134	121.66	1.48–1.62	1.55	18.6–20.95	20.03
			Inner surface			
Gray	21–78	74.25	0.97–1.1	1.01	16.6–17.5	17.03
Yellowish gray	85–111	81.34	1.18–1.43	1.35	17.85–21.05	19.26
Yellow	103–119	113.5	1.48–1.59	1.53	20.9–23.55	23.0
Intense yellow	116–134	121.66	1.48–1.62	1.55	23.4–26.3	24.34

Since harvesting the fruit by age as measured from the date of inflorescence, apparently would not assure uniformity of color of the processed product, it would be necessary to determine the stage for harvesting at which the least difference in color would result.

To determine the difference in color among the fruit harvested at different stages of development, the tristimulus values for the color of the fruit with the lowest pulp to peel ratio was used as a reference point to calculate the color difference $\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$ between these sample and each of the other samples harvested at progressively higher pulp to peel ratios. Figure 1 shows the values for ΔE calculated as indicated, plotted against pulp to peel ratio. The visual color observed for the ranges of pulp to peel ratios are also indicated on figure 1.

Figure 1 also shows that the difference in color ΔE among samples

harvested at pulp to peel ratio below 1.4 is small, ranging from 1 to 3 ΔE units. From a pulp to peel ratio of 1.35 to 1.53, color differences become greater. From a pulp to peel ratio of 1.45 to 1.85 ΔE values again show a smaller difference in color of about 3 ΔE units. Therefore, in order to obtain a product of fairly uniform appearance, fruits would have to be harvested at a stage at which the pulp to peel ratio would be about 1.5. Harvesting at this stage of development will assure that the color of the frozen product will be more yellow than gray, although probably varying in intensity from a light to deep yellow.

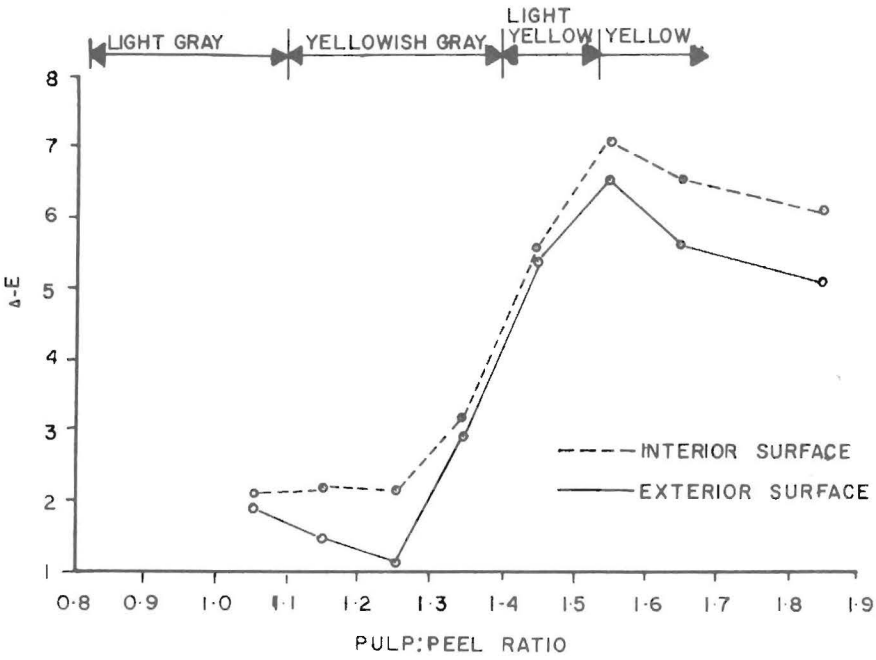

FIG. 1.—Difference in color ΔE between the sample with the lowest pupl:peel ratio and each other sample of higher pulp:peel ratio.

When bananas harvested at different stages of development are hand-peeled, before browning develops, only a slight difference in color is observed; fruit harvested at a higher pulp to peel ratio look slightly more yellowish than the less mature fruit. However, when the fruit is heated for peeling, the difference in color among the different stages of development becomes quite striking.

The pulp of mature banana fruit was found to contain from 6-1.0 μg carotenoids per g fresh weight, consisting principally of α carotene, β carotene and lutein (4). Therefore, it was theorized that the change in

color with maturity in the green bananas would probably involve an increase in carotenoid pigments, which on heating, changed in color. Table 5 shows the carotene content of the fruit at different stages of development indicated by pulp to peel ratios and the corresponding Hunter *b* values. The carotene content increased in direct relationship to the pulp to peel ratio (r = .708**). A highly significant correlation was found also between carotenes and Hunter *b* values (r = .909**).

As previously indicated, a significant difference in Hunter *b* values was found between the outer and inner surfaces of the hot water peeled bananas. When the hot water peeled bananas were sliced lengthwise a strong yellow pigmentation was observed in the core. In fruit with a pulp to peel ratio of 1.55 the cores were found to have a carotene content of 2.68 mg/100 g fresh weight, while the remaining tissue had only 0.55 mg/100 g fresh weight.

TABLE 5.—*Carotene content of hot water peeled bananas harvested at different pulp to peel ratios*

Pulp:peel ratio	Carotene	Hunter *b*
	mg/100g	
0.99	0.134	14.8
1.04	0.309	16.45
1.19	0.212	18.80
1.24	0.164	16.65
1.40	0.296	18.15
1.41	0.529	18.4
1.52	0.310	19.55
1.53	0.716	20.9
1.55	1.130	28.85
1.62	0.748	23.9
1.83	0.954	22.3

Absorption spectra of the carotenes extracted from unheated hand-peeled fruit and from hot water treated fruit were similar (fig. 2), as well as their total carotene content. These results suggest that the increase in the yellow color of heat-treated bananas with pulp to peel ratios is due to an increase in carotene pigments. The change in color observed during heating is probably due to a physical change in the carotene pigments. Purcell et al. (8) observed a similar shift in the color of some high carotenoid vegetables which they attributed to the degradation of chromoplasts and solution of the carotenoids in other cellular lipids.

RESUMEN

En el transcurso de estudios llevados a cabo para desarrollar procedimientos para la congelación de guineos verdes se observó que el color

de la fruta tratada antes de pelar con agua caliente para inactivar los sistemas enzimáticos variaba entre un blanco grisáceo a un amarillo intenso. El tejido interior de la fruta tenía un color amarillo más subido que el de la superficie.

Utilizando la razón de pulpa a cáscara como índice del estado de

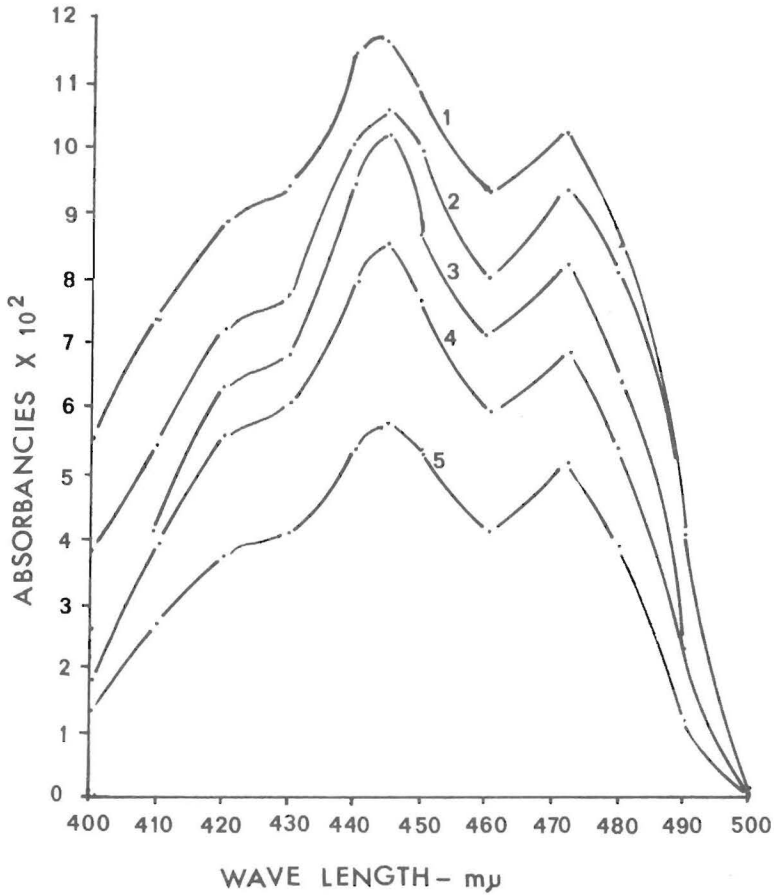

FIG. 2.—Comparison of light absorption curves: Hot water peeled green bananas. 1, Whole fruit with pulp:peel ratio of 1.5;2, Exterior surface; 3, Interior yellow core; 4, Hand-peeled green whole fruit; 5, Hot-water-peeled green fruit from same bunch as 4.

desarrollo de la fruta, se trató una serie de lotes en distintos estados de desarrollo. Por observación visual se comprobó que la intensidad del color amarillo progresaba al aumentar la razón de pulpa a cáscara. El color de guineos tratados en agua caliente, tanto descongelados por dos horas a temperatura ambiente como hervidos por 5 minutos después de

congelados, se midió con un metro HunterLab 25, registrándose los valores de *L*, *a* y *b* del color de la superficie lateral y del tejido interno. El análisis estadístico de estos datos reveló una correlación significativa entre los valores *L*, *a* y *b* de la superficie con la razón de pulpa a cáscara. En el tejido interior se encontró una correlación significativa entre los valores *L* y *b* con la razón pulpa a cáscara, pero no con los valores *a*. Los valores *L* disminuyeron al aumentar la razón de pulpa a cáscara y los *b* aumentaron indicando intensidad en la amarillez de la fruta, lo cual concuerda con el resultado de las evaluaciones visuales. Cuando la fruta congelada se hirvió el color se tornó algo grisáceo, pero el aumento en los valores *b* con la razón de pulpa a cáscara siguió el mismo patrón que en las muestras frescas tratadas con agua caliente.

Cuando muestras que variaban en la razón de pulpa a cáscara entre 1.01 a 1.69 se cataron, los catadores pudieron ordenar las muestras según el aumento en la intensidad del color amarillo siguiendo el mismo patrón indicado por los valores *b* del metro Hunter. Al evaluarse las muestras para apariencia en una escala de 6 puntos los catadores asignaron los valores más altos a las muestras más amarillas. Sin embargo aun cuando los catadores indicaron que las muestras amarillas eran de calidad superior a las grisáceas, indicaron que la uniformidad de color del producto congelado tenía mayor importancia en la evaluación de la calidad del producto que el color en sí.

Ultilizando la diferencia en el color indicada por la relación $\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$ entre la muestra de la razón de pulpa a cáscara más baja y cada una de las otras muestras se encontró (figura 1) que, cosechando los guineos verdes a una razón de pulpa a cáscara de alrededor de 1.5 sería posible elaborar un producto de color amarillo relativamente uniforme.

El análisis de las muestras para carotenos reveló que el contenido de éstos aumentaba en relación directa con el aumento en la razón de pulpa a cáscara. El tejido interno era más rico en carotenos que el de la superficie. Cuando el guineo verdo se pela a mano, no se observa gran diferencia en el color de la fruta intre las más tiernas y las más desarrolladas. Como el color amarillo se intensifica al calentar, se presume que el cambio se debe a alteraciones que sufren los carotenos al calentarse.

LITERATURE CITED

1. Annon., 1975. Conjunto tecnológico para la producción de plátanos y guineos. Esta. Exp. Agri. Univ. P.R., Pub. 97.
2. Clydesdale, F. M., 1978. Colorimetry, methods and applications, Critical Reviews in Food Sci. and Nutr. 10 (3): 243-321.

3. Ezzel, B. D., Wilcox, M. S., and Demaree, K. D., 1959. Relationship of tristimulus colorimeter readings to carotenoid pigments in sweet potatoes, J. Agri. Food Chem. 7 (1): 44–7.
4. Gross, J., Carmon, M., Lifshitz, A., and Costes, C., 1976. Carotenoids of banana pulp, peel and leaves, Lebensm. Wiss. + Technol. 9 (4): 211–4, (FSTA 9 (1) 1J11, 1977).
5. Lauber, J. I., Taylor, G. A., and Drinkwater, W. O., 1967. The use of tristimulus colorimetry for the estimation of carotenoid content of raw sweet potatoes roots, Proc. Am. So. Hort. Sci. 91: 472–7.
6. Leonard, S., Luh, B. S., and Heireiner, E. (1953). Flavor evaluation of canned Cling peaches, Food Technol. 7: 480–5.
7. Official Methods of Analysis of the Association of Official Agriculture Chemists, 12 ed, Washington, D.C. 1975.
8. Purcell, A. E., Walter, Jr. W. W., and Thompkins, W. T., 1969. Relationship of vegetable color to physical state of carotenes, J. Agri. Food Chem. 17 (1): 41–2.
9. Sánchez Nieva F., Colom Covas, G., Hernández, I., Bueso, C., and Guadalupe, R. 1969. Studies on the production of Montecristo bananas grown on the south coast of Puerto Rico, J. Agri. Univ. P.R. 53 (4): 284–306.
10. ——and Mercado, M., 1978. Effect of peeling method and sulfitation on the shelf life of frozen green bananas, J. Agri. Univ. P.R. 67 (3): 241–8.
11. Wardlaw, C. W., Leonard, E. R., and Barnell, H. R., 1939. Metabolic and storage investigations on the banana, Low Temp. Res. Stn., Imp. Coll. Trop. Agri. Trinidad, Memoir 11: 3–8.