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Ripening response of stored black Sigatoka-resistant banana fruits, to external application of ethylene

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Summary

Planting of banana hybrid FHIA-01 may be a good option for banana growers in the Mexican Pacific because it is resistant to black Sigatoka and is high-yielding. Normally, all banana varieties are treated with ethylene to achieve uniform ripening. To date, information on the response of this clone to external ethylene application (a postharvest activity carried out on empirically bases) is scanty. Therefore, the postharvest behavior of fruits of the FHIA-01 clone was evaluated after exposing them to three external ethylene concentrations: 10, 100 and, 1000 ppm for 12 h. Evaluations of physiological and quality parameters were carried out on the treated and nontreated fruits for 10 days during storage at 16 °C. On the 10th day of the ripening period, the physiological and quality characteristics were found to vary according to days of storage and, ethylene concentration. Eventually, at the final stage of ripening, the values of most parameters were similar among treated and, nontreated fruits. However, the ripening behavior of HIA-01 was better in fruits treated with 10 ppm ethylene. Respiration rate and ethylene production varied according to ethylene concentration. The climacteric behavior was observed in all fruits; treated and, nontreated. Ethylene production was initiated on the first day of ripening in ethylene-treated bananas. The content of malic acid increased
during ripening and, the total soluble solids (°Bx) of treated bananas at 10 ppm reached 19.0 %. Mass loss was significantly lower in treated fruits than in the nontreated ones, however, until the 8th day of ripening, firmness was higher in the nontreated fruits. As to color, the best characteristics were seen in bananas that had the 10 ppm treatment; their fruits had more intense yellow color. Before further recommendations are made, additional studies at the semi-commercial level should be done and, consumer acceptability should be determined. Given the response of the bananas to the 10 ppm ethylene concentration, the hybrid FHIA-has high potential to become a commercial variety at the international level.

Introduction

Banana fruits are one of the most important horticultural products in the west coast of the Mexican Pacific. The banana is consumed extensively and is valued for its flavor, nutritional value, and constant availability. The ripe fruit is high in carbohydrates (mainly sugar), fiber, potassium, phosphorus and, vitamins A, B6 and, C. It is low in protein and fat. However, production of this fruit has markedly declined due to the leaf spot disease, commonly named 'black Sigatoka' (*Mycosphaerella fijiensis* Morelet) (PLOETZ, 2001; MARÍN et al., 2003). The presence of black Sigatoka in Mexico was detected in the southeast part of the country in 1980. By 1994, this disease has appeared in the state of Nayarit, seriously affecting banana production by up to 50 % of total yield and drastically reducing the banana-growing area (CONTRERAS, 1983; OROZCO-SANTOS and OROZCO-ROMERO, 2004). Control of this disease involves frequent application of different fungicides and, intensive cultural methods. The first method includes the application of protectants and, systemic fungicides. Nevertheless, it is estimated that fungicidal application takes between 35 and, 45 % of the total cost of banana production (OROZCO-SANTOS and OROZCO-ROMERO, 2004). In addition, the strong fungicidal application has eventually resulted in increased strain resistance or tolerance. To resolve this situation, other alternatives have been proposed, such as the use of resistant varieties. The 'Fundación Hondureña de Investigación Agrícola' developed various banana hybrids tolerant of black Sigatoka. The hybrid FHIA-01, highly tolerant of this disease and, other fungi was introduced in the banana producing areas of Mexico with the objective to evaluate its performance under some soil conditions, assess disease incidence and, control the said disease (OROZCO-SANTOS, 1998). Results indicated FHIA-01's excellent adaptation to the west and central Pacific regions of Mexico, achieving up to 90 t ha^{-1} per year after the second bloom with an acceptable bunch weight (VAZQUEZ et al., 2004). Nevertheless, in spite of the adequate preharvest performance of FHIA-01 in the field, no information about its postharvest behavior has been generated in Mexico. This is an important subject if this clone is to be considered for export. Overall, conventional bananas are artificially ripened by applying ethylene gas in to accelerate the transition from green to yellow and to ensure uniformity of ripening (KADER, 2005). Bananas harvested from the western Pacific area of Mexico are ethylene-treated at the wholesale distribution sites with concentrations ranging from 100 to 300 ppm or higher (*personal communication*). Previous studies have demonstrated that the effect of external ethylene application on fruit quality and storage life varies, depending on ethylene concentration and, banana variety or hybrid (SEBERRY and HARRIS, 1998; PIÑA et al., 2006; DZOMEKU et al., 2007). Therefore, our investigation aimed to evaluate the physiological development and, quality of banana fruits obtained from the resistant clone FHIA-01 after been exposed to external ethylene concentrations during a given storage period at controlled temperature.

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Materials and methods

Banana fruits and storage conditions

The banana fruits of the hybrid FH1A-01 (approximately 400 kg) were harvested from the Experimental Station INIFAP at Santiago Ixcuintla, state of Nayarit, Mexico. These were harvested according to the degree of fullness of the fingers (3/4 fullness) and, the number of days after full bloom (90 days). Fruits were carefully transported in plastic boxes to the research laboratory at the Technological Institute of Tepic. The damaged or injured fruits were discarded. Later, the remaining fruits were washed, immersed in the fungicide Tecto 60 (0.5 g L^{-1}) and, dried under ambient condition. Four lots of fruits, approximately 100 kg each were randomly selected. The ethylene treatments given were 10, 100 and, 1000 ppm and, a control.

The external application of ethylene was carried out in hermetic chambers (approximately 0.83 m^3). The volume occupied by the fruits and, the volume of the chamber were considered in calculating the quantity of ethylene to be applied. A pressure regulator and a flow meter (35635-01 CGA, Infra) were used to know the exact flux for each treatment. After the treatment application (12 h), bananas were withdrawn from the chambers and, stored at 16 °C and, relative humidity of approximately 85-90 %.

Except for CO_2 and ethylene production and, mass loss, the following physicochemical parameters were evaluated every 2 days for a 10-day period at 16 °C.

Physiological characteristics

Respiration and, ethylene production

Carbon dioxide and, ethylene production was measured following the methodology of Alia-Tejacal (2000). Three replicates of three fruits each were held overnight at ambient temperature to stabilize their temperature. The gases were measured by placing fruits in separate air-tight glass jars of approximately 4-L capacity. Jars were sealed, incubated at 16 °C for 1 h; 1-mL gas samples were then taken from the headspace of each jar using an air-tight syringe. Carbon dioxide and, ethylene measurements were made from the same sample. An HP 6890 gas chromatograph, equipped with thermal conductivity and, flame ionization detectors, was used for CO_2 and ethylene production, respectively. Analytes were separated on a HP-Plot Q (estirene/divinylbenzene) packed column using He as a carrier gas. CO_2 and, ethylene production were calculated as $mg \cdot kg^{-1} \cdot h^{-1}$ and, $nmol \cdot kg^{-1} \cdot h^{-1}$, respectively. Evaluations were carried out daily during a 10-day period.

Mass loss

The weight of four banana hands of each treatment was determined every day during the 10-day ripening period. The rate of fruit water loss was calculated as the percentage of mass loss from the fruit with respect to the initial fruit mass.

Quality characteristics

Titratable acidity, pH and, °Brix

Titratable acidity, pH and, total soluble solid (°Brix) measurements were carried out following the methodologies of Bosquez (1992) and, Dadzie and Orchard (1997). For titratable acidity, 5 g of two banana pulps of two fruits per treatment was blended, adding 50 mL of distilled water. Twenty five milliliters of the filtrate was mixed again in water and, five drops of phenolphthalein were added. Samples were then titrated with 0.1 N sodium hydroxide until the indicator changed into pink/red color. Results were expressed as percentage of malic acid. The previous homogenized filtrated was used to measure pH values were recorded in a digital pH meter (Jenco Electronics L.T.D. Mod. 1671). Total soluble solids were measured from an aliquot obtained by homogenizing the banana flesh in water (1:5) and, filtering the homogenates through four layers of cheesecloth. A single drop of the filtrate was placed on the prism of a refractometer (Abbé °Brix range 0-60°). Readings were carried out at ambient temperature and, corrections were done following Table 20 of AOAC (1984). Results were reported as °Brix.

Color and, firmness

Color was measured on two individual fruits according to the L*, a*, b* color system using a colorimeter (Minolta Mod. CR300). Measurements were taken at three points alongside the fruit peel and, the values averaged. Results were reported as lightness (L*), hue angle ((Hue = $\tan^{-1}$ b/a) and, chrome (chrome = $a^2 + b^2)^{1/2}$. Firmness was determined on the same fruits immediately after color was measured. After removal of the peel, two readings were taken in the flesh in opposite sides with a digital penetrometer (SHIMPO FGV-100). Results were averaged and, expressed as Newtons (N).

Statistical analysis

Treatments were arranged in a randomized block design. A Tukey test at a significance level of $P \leq 0.05$ was carried out to determine mean separation levels. Deviations standard were also calculated.

Results

Physiological characteristics

Respiration and ethylene production

As observed in Fig. 1a, the untreated fruits showed typical climacteric behavior with the climacteric peak occurring on the 10^{th} day of the ripening period with corresponding values of 56.8 $mg \cdot kg^{-1} \cdot h^{-1}$. The rate of respiration of the ethylene-treated fruits significantly increased ($P \leq 0.05$) and, the climacteric peak was reached on the 9^{th} day of ripening in fruits treated with 10 ppm (74.2 $mg \cdot kg^{-1} \cdot h^{-1}$). In fruits treated with 100 ppm was observed the climacteric peak at the 8th day of ripening with corresponding values of 67.0 $mg \cdot kg^{-1} \cdot h^{-1}$.

Ethylene production of the treated fruits was initiated on the 1^{st} day of ripening in fruits given 10 ppm ethylene concentration, while it began on the 2^{nd} day in fruits treated at 100 and 1000 ppm, respectively. In the untreated fruits, this was observed on the 7^{th} day of ripening (Fig. 1b). The highest ethylene production (4.7 $nmol \cdot kg^{-1} \cdot h^{-1}$) was in

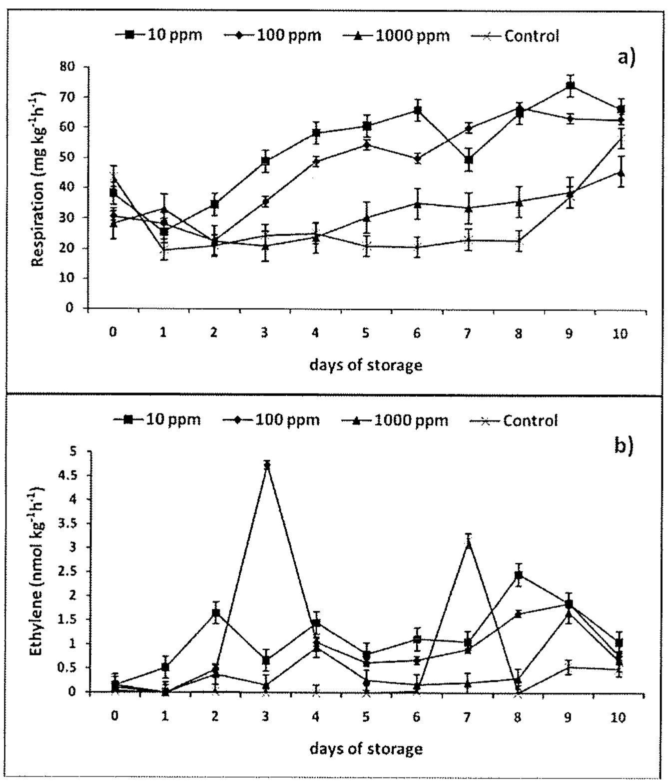

Fig. 1: Rate of respiration a) and, ethylene production b) during ripening of ethylene-treated banana fruits from the clone FIHA-01, at controlled temperature.

fruits treated with 100 ppm ethylene. The climacteric ethylene peak of the treated fruits varied according to concentration. Thus, fruits treated with 10 and, 1000 ppm showed the respective highest ethylene peaks on the 8th (2.4 $nmol \cdot kg^{-1} \cdot h^{-1}$) and, 9th (1.6 $nmol \cdot kg^{-1} \cdot h^{-1}$) days of the ripening period, while in the control fruits, it was observed on the 7th day of ripening (3.1 $nmol \cdot kg^{-1} \cdot h^{-1}$).

Mass loss

Fig. 2 shows the mass loss in the treated and, untreated fruits. In general, bananas treated with ethylene had a significantly lower percentage mass loss ($P \leq 0.05$) than the untreated bananas. In this case, a markedly higher mass loss in control fruits was observed during the entire evaluation period. At the end of the 10th day, untreated fruits lost 9.8 % of their total mass compared with 5.4 % of the treated ones.

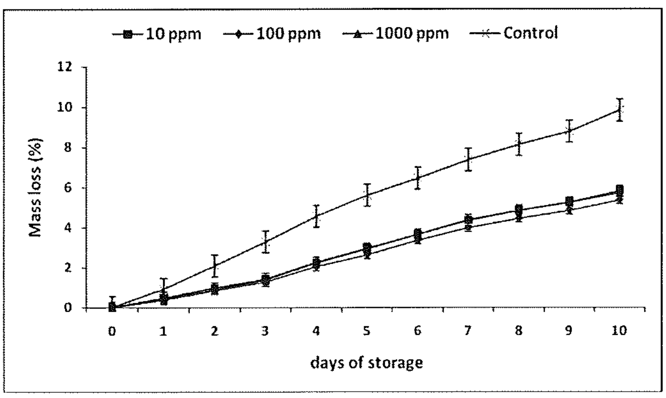

Fig. 2: Percentage mass loss of ethylene-treated banana fruits from the clone FIHA-01 during ripening at controlled temperature.

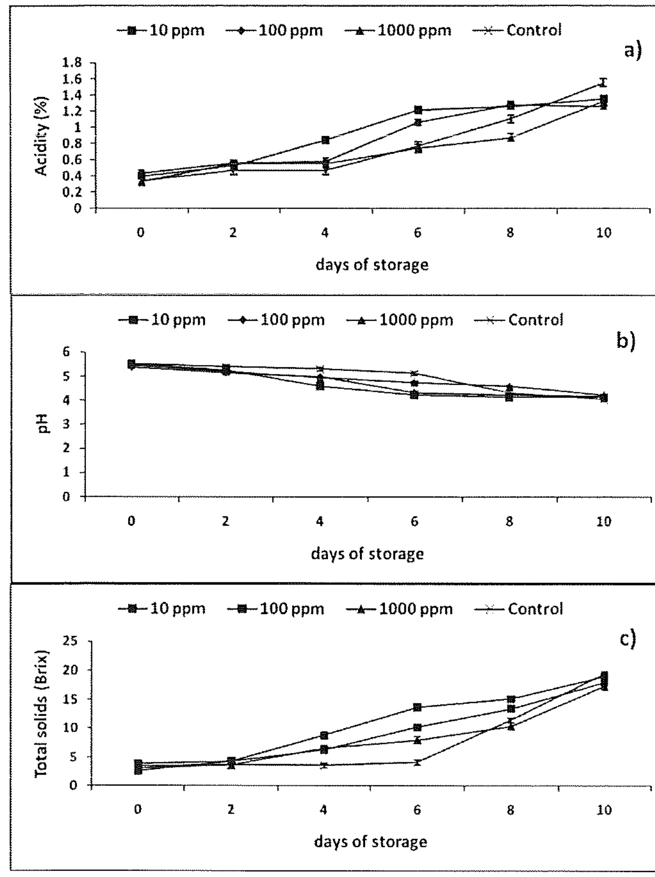

Fig. 3: Development of quality parameters of ethylene-treated bananas from the clone FHIA-01 during ripening at controlled temperature. a) acidity, b) pH and, c) °Brix levels.

Quality characteristics

Titratable acidity, pH, and, °Brix

With respect to titratable acidity, no statistical differences were observed among treatments. Overall, the content of malic acid gradually increased during the 10-day ripening period (Fig. 3a). During storage, the acidity levels of the fruits externally treated with external ethylene were similar (average value of 0.52 %) to those of the untreated fruits during the first 2 days of ripening. Three days after, acidity of the fruits treated with 10 ppm ethylene was higher (1.32 %) than the other treatments; however, at the end of the ripening period, the acidity of the ethylene-treated fruits was similar. The pH decreased during storage of the fruits (Fig. 3b). No significant differences were observed among treatments. At the beginning of the ripening period, the average pH value was 5.4, at the end, it was of 4.1. °Brix levels systematically increased during storage of fruits in all treatments (Fig. 3c). As observed in the two above mentioned parameters, no changes were shown between treated and untreated bananas, until the 2nd day. °Brix levels were higher in the untreated fruits (19.4 %). Of the ethylene-treated fruits, the 10 ppm treatment gave the highest °Brix levels at the end of the ripening period (19.0 %).

Color and firmness

In Fig. 4a is shown the color variation of the ethylene-treated fruits with respect to the hue, chrome and lightness parameters. There were significant differences among treatments ($P \leq 0.05$). Overall, the hue angle decreased for all treated fruits, although markedly lower values were recorded in bananas treated with 10 ppm ethylene (°h = 92.3). The untreated fruits showed the highest values with respect to the remaining treatments (°h = 116.8). Chrome values remained similar until the 2nd day of ripening in fruits from all treatments, increasing on the 4th day of storage; however, on the 6th day, there was a dramatic decrease remaining the same until the end of the fruit ripening (C = 32-33) (Fig. 4b). Except for the 10 ppm treatment (L = 55-56), the lightness values of fruits from the treatments of 100 and, 1000 ppm were similar (L = 62) but higher with respect to the nontreated fruits (L = 51) (Fig. 4c).

In general, firmness loss in the treated and untreated bananas began on the 4th day of ripening, following, in most cases, a continuous decrease (Fig. 5). Bananas treated with 10 ppm ethylene had significantly ($P \leq 0.05$) higher loss of firmness on the 4th (31.5 N) and 6th day (19.3) of ripening. At the end of the maturation evaluation, approximately similar firmness loss values were recorded in the ethylene-treated fruit (14-15.9 N); these were higher in the nontreated ones (17.8 N).

Discussion

Overall, the bananas of clone FHIA-01 showed ripening characteristics similar to those previously reported in other varieties. However, the application of ethylene influenced the ripening behavior of the treated bananas. The two concentrations of ethylene that had major effects on maturation were 10 and, 100 ppm. Applications at these two concentrations accelerated the rate of respiration and ethylene production and, compared with other banana varieties such as 'Cavendish,' the onset of the climacteric peak took place

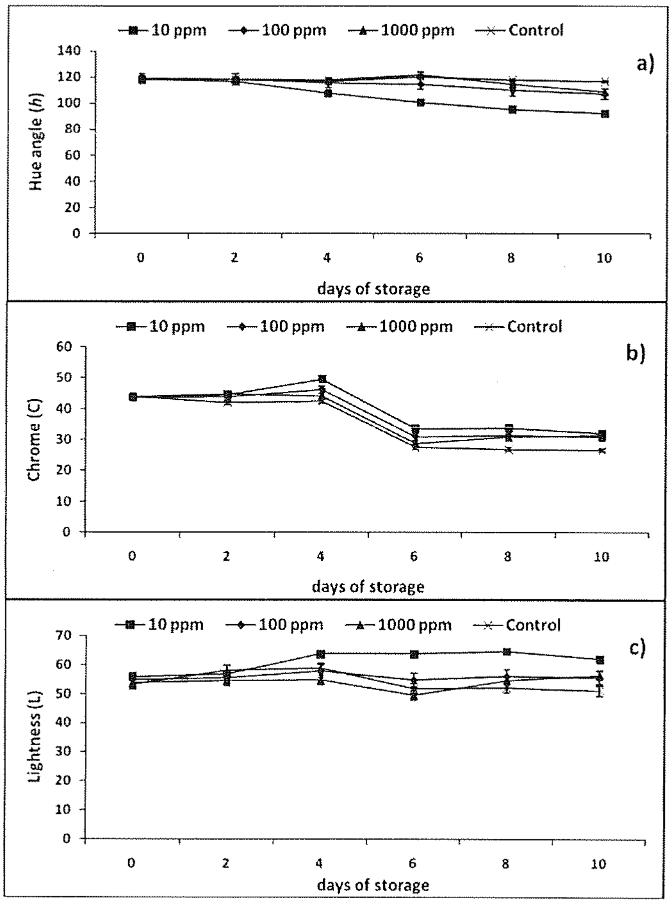

Fig. 4: Color development of ethylene-treated bananas from the clone FHIA-01 during ripening at controlled temperature. a) hue, b) chrome and, c) lightness.

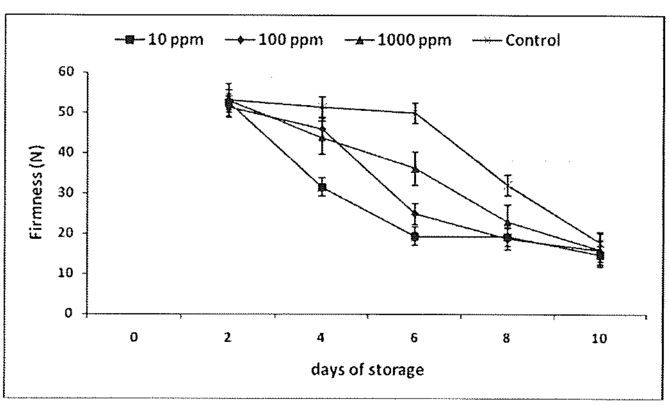

Fig. 5: Firmness loss of ethylene-treated banana fruits from the clone FIHA-01, during ripening at controlled temperature.

3-4 days later at temperatures 20 °C and 25 °C (INABA and NAKAMURA, 1986; INABA et al., 1984). The explanation for this effect might be the variety tested and, the storage temperature used. In our study the storage temperature was 16 °C. In further studies, untreated bananas of this clone (FHIA-01) showed the climacteric CO_2 peak after 10 and 12 days of harvest at 20 °C (SEBERRY and HARRIS, 1998). In our study, we also observed that the exogenous ethylene activated the internal ethylene synthesis of the treated fruits an observation, previously reported by INABA and NAKAMURA (1986). The highest effect was observed in fruits treated with 1000 ppm. Nevertheless, we did not observe a synergistic effect between the applications of exogenous ethylene with CO_2 evolution during the ripening of the fruits. The changes in acidity values, brix levels and, pH of the treated and untreated fruits followed the normal ripening evolution. After the 4th and 6th days of ripening, acidity and, total solids were lower than those of untreated fruits. DADZIE (1998), reported in nontreated bananas of this clone, values of acidity of 5.5 meq 100 g^{-1}, lower total solids (approximately 12.0 %) and, similar pH values (4.3) at the color stage 8 corresponding to the highest ripening level. In our study, weight loss and, firmness of bananas declined as ripening progressed. During the ripening period, the ethylene-treated fruits, at whatever concentration tested, had lower mass loss and, firmness than the untreated fruits. In this respect, other authors (SEBERRY and HARRIS, 1998) mentioned similar responses in terms of firmness. In that study, of the three varieties studied, FHIA-01 softened faster than varieties 'Lady Finger' and, 'Williams' after application of ethylene, however, they reported that the banana shelf life was longer in the clone FHIA-01. In another study, it was reported that nontreated fruits of this clone showed a final firmness of 19.4 and 18.8 N, depending on the cropping system (sole and alley cropping, respectively) (BAIYERI et al., 1999). In our study, the final firmness of the ethylene-treated fruits was slightly lower than that of the untreated ones; however, the values reached at the end of the ripening period (17.6 N) fit the average values for consumer acceptance. Color development during the ripening period depended on ethylene treatments. Fruits treated with 10 ppm ethylene were less dark than the untreated fruits. Overall, the intensity and yellow color was higher in fruits treated with this concentration. Similar findings were reported by KAJUNA et al. (1995).

In spite of the importance of this black Sigatoka-resistant clone, and its worldwide distribution, not enough information has so far been generated about the effects of ethylene application on its ripening behavior. Our results show, that in general fruits of FHIA-01 present adequate postharvest behavior during storage. For the local and, export markets, ethylene application is a normal practice carried out at wholesale locations in the west-central Pacific area. Nevertheless, the commercial ethylene concentrations applied in this region, ranged from100 to 300 ppm, doses dramatically higher than the 10 ppm applied in our study. Our findings reveal that this ethylene concentration maintains and sometimes improves banana quality during ripening and storage. However, before any public recommendation can be made, further studies should be carried out on a semi-commercial level.

We do believe that the quality differences we observed in comparison with other investigations are associated mostly with aspects such as cropping system, cultural practices and, ambient temperature. In addition, to have a complete evaluation of the clone FHIA-01, we agree with DZOMEKI et al. (2007), who stressed that 'to succeed in the introduction of any Musa variety, further studies concerning consumer acceptability which include texture, taste, sweetness, internal color and, acceptability should be carried out'.

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