*Fruits*, 2015, vol. 70(3), p. 173-179

DOI: 10.1051/fruits/2015008

FRUITS

Available online at:
www.fruits-journal.org

ORIGINAL ARTICLE

# Postharvest evaluation of Goldfinger banana (FHIA-01) at different storage temperatures followed by an acclimation time

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Received 8 September 2014 – Accepted 29 January 2015

**Abstract – Introduction.** Banana fruit is one of the major staple crops grown in the humid tropical areas of Mexico. In spite of the adequate preharvest performance of Goldfinger banana (FHIA-01) in the field, little information about its postharvest behavior has been generated. We decided to study the ripening behavior and quality of fruit during controlled storage and acclimation time. **Materials and methods.** Banana fruit of the hybrid *Musa acuminata* X *balbisiana* 'FHIA-01 Goldfinger' were stored at 11, 13, 15 and 20 °C for 21 days and then transferred to 25 ± 2 °C for acclimation. Fruit sampling under controlled temperatures was performed after 1, 3 and 5 days and the samples were analyzed for $CO_2$ and ethylene production, weight loss, acidity, pH, firmness, and total soluble solids (TSS). **Results and discussion**. The physiological response and quality of cv. FHIA-01 were affected by the temperature and period of storage and acclimation. During the storage period at 20 °C banana fruit showed total loss of firmness, high TSS (23 °Brix) and full color development (yellow) after 15 days. Fruit at 11 °C and then transferred to 25 °C had delayed maturity with alteration of the ripening process. **Conclusion**. In general, the optimum storage temperatures for this banana cultivar were 13 °C and 15 °C for 7 to 14 days.

**Keywords:** Mexico / banana / *Musa* spp. / postharvest ripening / fruit maturity

**Résumé – Évaluation post-récolte de la banane Goldfinger (FHIA-01) stockée à différentes températures de conservation suivi d'un temps d'acclimatation. Introduction.** La banane est l'une des principales cultures vivrières cultivée dans les régions tropicales humides du Mexique. En dépit des bonnes performances avant-récolte de la banane Goldfinger (FHIA-01) au champ, peu d'informations sur son comportement post-récolte est disponible. Nous avons décidé d'étudier le comportement et la qualité des fruits en cours et en fin de stockage, en conditions contrôlées et sur un pas de temps d'acclimatation donné. **Matériel et méthodes.** Les fruits du bananier hybride *Musa acuminata* X *balbisiana* 'FHIA-01 Goldfinger' ont été stockés à 11, 13, 15 et 20 °C pendant 21 jours, puis transféré à 25 ± 2 °C pendant l'acclimatation. L'échantillonnage des fruits en température contrôlée a été réalisé après 1, 3 et 5 jours et les échantillons ont été analysés pour mesurer la production de $CO_2$ et d'éthylène, la perte de poids, l'acidité, le pH, la fermeté et la teneur en solides solubles totaux (TSS). **Résultats et discussion.** La réponse physiologique et la qualité des bananes cv. FHIA-01 ont été affectées par la température et par la durée de traitement appliquées au cours du stockage et de l'acclimatation. Pendant la période de conservation à 20 °C, les bananes ont montré une perte totale de fermeté, une hausse des TSS (23 °Brix) et une évolution de la couleur (jaune) après 15 jours. Au cours du traitement à 11 °C suivi d'un transfert à 25 °C, la maturité des bananes a été retardée en raison d'une altération du processus de mûrissage. **Conclusion.** Dans nos conditions expérimentales, les températures de stockage optimales pour ce cultivar de bananier sont de 13 °C à 15 °C pendant 7 à 14 jours.

**Mots clés :** Mexique / banane / *Musa* spp. / mûrissage / physiologie post-récolte / maturité du fruit

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## 1 Introduction

Statistics for the past few years show that Mexico has about 75,000 ha planted with bananas (*Musa* spp.). Total production is close to 2.2 million metric tons a year, giving an average yield of about 30 t $ha^{-1}$. More than 90% of bananas are consumed as a fresh fruit and per capita consumption is about 12 kg $year^{-1}$ [1, 2]. This fruit is one of the major staple crops grown in the humid tropical areas of Mexico, including among others the States of Chiapas, Tabasco, Veracruz and Colima. Some of the largest banana producers have been affected by the presence of black sigatoka fungus (*Mycosphaerella fijiensi*) in much of the production area [3, 4]. For controlling this fungus, alternatives have been proposed; among them, the use of resistant cultivars [5, 6].

The Fundación Hondureña de Investigación Agrícola (FHIA) developed various banana hybrids tolerant to black sigatoka (*Mycosphaerella fijiensi*). The cultivar FHIA-01 Goldfinger is also highly tolerant to various strains of the Panama disease (*Fusarium oxysporum* f. sp. *cubense*) that affects the Musaceae family [7, 8]. The cultivar FHIA-01, highly tolerant of this disease and other fungi, was introduced into the banana-producing areas of Mexico with the objective of evaluating its performance under some soil conditions, assessing disease incidence and control [9]. The results indicated FHIA-01's excellent adaptation, achieving up to 90 t $ha^{-1}$ per year in the west and central Pacific regions of Mexico [10] including the state of Nayarit, where banana cultivation has become one of the most important fruit, covering an area of 7,500 ha. It comprises the second crop in importance, only overtaken by mango production. Nevertheless, in spite of the adequate preharvest performance of FHIA-01 in the field, overall little information about its postharvest behavior during storage has been generated in Mexico [11, 12].

Storage temperature is one of the main factors that can influence the normal ripening of banana fruit. Several physiological disadvantages may occur when the storage temperature is not adequate, including uneven ripening, vascular browning, black spots and in extreme cases chilling injury, making fruit unmarketable. Overall, the storage temperature of mature-green banana is reported to range between 13 and 14 °C, while the most adequate ripening temperatures may vary from 15 to 20 °C [13]. However, the recommended storage temperatures for fruit quality maintenance and normal ripening may vary according to the banana cultivar. For cv. Prata subgroup and cv. Milk bananas, the recommended storage temperatures were 10–12 °C [14, 15]. For this last cultivar, storage temperatures of 11 and 12 °C extended the shelf life and enhanced vitamin C content. On this matter, Inaba *et al.* [16] reported alterations in the ripening behavior of cv. Cavendish fruit held at other temperatures than the recommended ones. In that study, it was demonstrated that 20 and 25 °C were the best temperatures to achieve normal ripening, as compared with 15, 30 and 35 °C, under which temperature alterations such as failure to ripen were observed. In another report [17], the ripening behavior of banana of the same cv. was dependent on the storage temperature and ethylene application. Color, total soluble solids and firmness evolution were affected at temperatures up to 14 °C. In addition, a low respiration rate and ethylene production were recorded during the one-month storage. In further studies, it was demonstrated that color development (green to yellow) in banana fruit of the above-mentioned cultivar did not take place at temperatures up to 24 °C [18]. In additional investigations carried out by these authors it was also demonstrated that regardless of external ethylene application at a concentration of 10 μL $L^{-1}$, the fruit did not change color when stored at 30 °C for a period of seven days [19]. In other studies, greater and faster loss of firmness was observed in fruit of the banana cv. Santa Catarina, as the storage period and ripening temperature increased (from 7.5 to 15.0 °C) [20]; however, weight loss values were very consistent regardless of the temperature. In this study, a double peak of ethylene production was detected at a temperature of 22.5 °C, while the highest $CO_2$ production (ca. 110 mg $kg^{-1}$ $h^{-1}$) appeared after 4 days of storage.

The aim of our work is to improve the storage and acclimation of bananas produced in Mexico for a sound export program. A first step is to define the reference temperatures of storage and acclimation of the most resistant banana cultivar grown in Mexico. The objective of this study was therefore to evaluate the physiological response and the quality characteristics of banana fruit of the black sigatoka-resistant cv. FHIA-01 during a storage period of 21 days at temperatures of 11, 13, 15 and 20 °C and during given acclimation periods at ambient temperature.

## 2 Materials and methods

### 2.1 Banana fruit and storage conditions

The Goldfinger FHIA-01 banana is a tetraploid (AAAB) hybrid *Musa acuminata* X *balbisiana*. The banana fruit of cv. FH1A-01 was harvested from the Experimental Station INIFAP in Santiago Ixcuintla, State of Nayarit, Mexico. Approximately 300 kg were harvested according to the degree of fullness of the fingers (3/4 fullness) and the number of days after full bloom (90 days). Fruit was 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 in ambient conditions. Four lots of fruit, approximately 75 kg each, were randomly selected. To evaluate the physiological response and quality attributes during controlled storage, fruits were then held at 11, 13, 15 and 20 °C. The storage time at these temperatures was a maximum of 21 days. To evaluate fruit response during this storage period, fruit from 11, 13 and 15 °C were sampled after 7, 14 and 21 days and transferred to an ambient temperature of 25 ± 2 °C for 5 to 7 days approximately (acclimation period). For all temperatures, relative humidity was kept at 90–95%. During storage at controlled temperatures and the acclimation period, fruit was packed in carton boxes with perforated film lining.

### 2.2 Physiological evaluations

#### 2.2.1 Respiration and ethylene production

Carbon dioxide and ethylene production were measured following the methodology of Ramos *et al.* [21]. Three replicates of three fruits per treatment 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 and incubated at 16 °C for 1 h. One-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. A HP 6890 gas chromatograph, equipped with thermal conductivity and flame ionization detectors, was used for $CO_2$ and ethylene production, respectively. Analyses were separated on a HP-Plot Q (styrene/divinylbenzene) packed column using He as a carrier gas. $CO_2$ and ethylene production were calculated as mg $kg^{-1}$ $h^{-1}$ and nmol $kg^{-1}$ $h^{-1}$, respectively. Evaluations were carried out throughout the whole storage period for a 21-day period and during the ripening time for approximately 7 days.

#### 2.2.2 Weight loss

The weight of four banana hands of each treatment was determined every day during a 21-day period of storage, and after fruit transfer to ambient temperature, evaluations were made for five to seven days. The rate of fruit water loss was calculated as the percentage of weight loss from the fruit with respect to the initial fruit weight.

### 2.3 Quality characteristics

#### 2.3.1 Total soluble solids (TSS), titratable acidity and pH

Total soluble solids (TSS in °Brix), titratable acidity and pH measurements were carried out following the methodologies of Bosquez [22], and Dadzie and Orchard [23]. Total soluble solids (TSS) were measured from two replicates of 5 fruits per treatment, from an aliquot obtained by homogenizing 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 made following Table 20 of AOAC [24]. Results were reported as °Brix. For titratable acidity, 5 g banana pulp of five fruits per treatment were blended, adding 50 mL of distilled water. Twenty-five mL of the filtrate were 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 a pink/red color. Results were expressed as meq malic acid 100 $g^{-1}$ fresh weight (fw). The previously homogenized filtrate was used to measure pH values, which were recorded in a digital pH meter (Jenco Electronics, Ltd., Mod. 1671). Firmness was determined after removal of the peel of five individual fruits per treatment. Two readings were taken in the flesh in opposite sides with a digital penetrometer (SHIMPO FGV-100). Results were averaged and expressed in Newtons (N). Evaluations were carried out every two days during the storage and acclimation periods.

#### 2.3.2 Firmness and color

Color was measured on two replicates of 5 individual fruits per treatment 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 = $a^2 + b^2)^{1/2}$. Evaluations were carried out only during the storage period every two days.

### 2.4 Statistical analysis

Data were subjected to Analysis of Variance by using JMP statistical software, version 5.0.1. Mean separation was carried out by Tukey's multiple range test ($P \leqslant 0.05$). For data of the storage period, standard deviations of the mean were also calculated.

## 3 Results and discussion

There were significant differences ($P \leqslant 0.05$) in fruits held at different temperatures, holding periods (*figures 1* and *2*) and acclimation days (*tables I and II*). During storage, only banana fruit held at 20 °C exhibited the typical climacteric behavior after 15 days of storage at this temperature, while fruit stored at the remaining temperatures reached their climacteric peaks during the acclimation period at an ambient temperature of 25 ± 2 °C. The temperature of 20 °C accelerated fruit metabolism, expressed by the highest peak of $CO_2$ (46.6 mg $kg^{-1}$ $h^{-1}$) and ethylene (2.2 nmol $kg^{-1}$ $h^{-1}$) values, after 15 and 12 days of storage, respectively. Additional effects on quality were: high loss of firmness after 15 days (0.5 N), high levels of TSS (23.0 °Brix) and rapid color development. In consequence, the shelf life of cv. FHIA-01 was dramatically shortened to only 16 days; therefore, the fruit became unsalable. In this regard, Inaba *et al.* [25] reported that generally increasing temperatures during ripening decreased the storage life of this fruit; however; contrary to our results, in that study, the temperature of 20 °C did not affect the ripening behavior; an explanation for this might rely on the cultivar tested, since the cv. they evaluated was Cavendish. Another study [26] on Cavendish concluded that storage temperature at 18 °C also affected color development of the fruit peel.

With respect to the fruit stored at the remaining temperatures of 11, 13 and 15 °C, fruit ripening was delayed and hence, they could be transferred to ambient temperature. Overall $CO_2$ production rates during these controlled

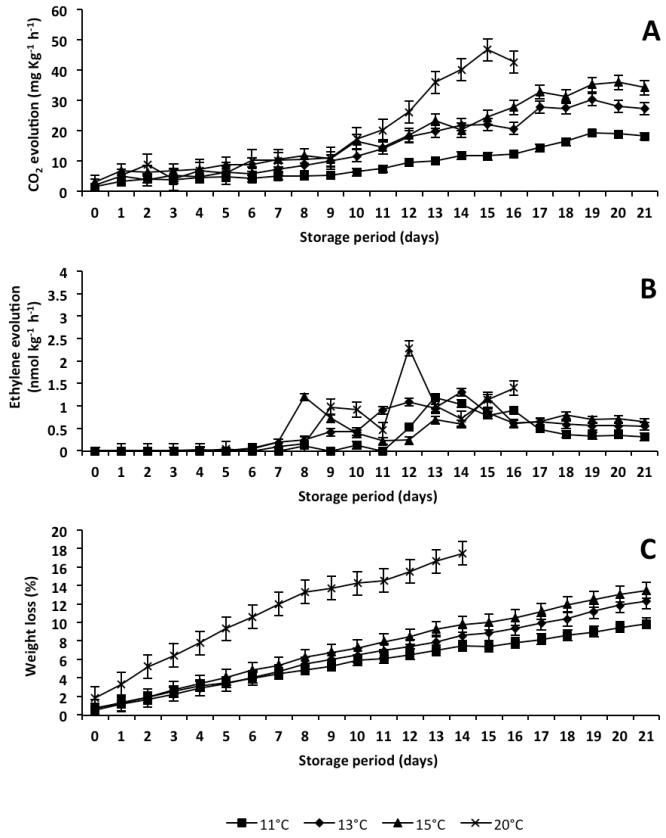


**Figure 1.** $CO_2$ (A) and ethylene production (B), and weight loss (C) of bananas cv. FHIA-01 stored at 11, 13, 15 and 20 °C, during 21 days. Bars indicate standard deviations of the mean.

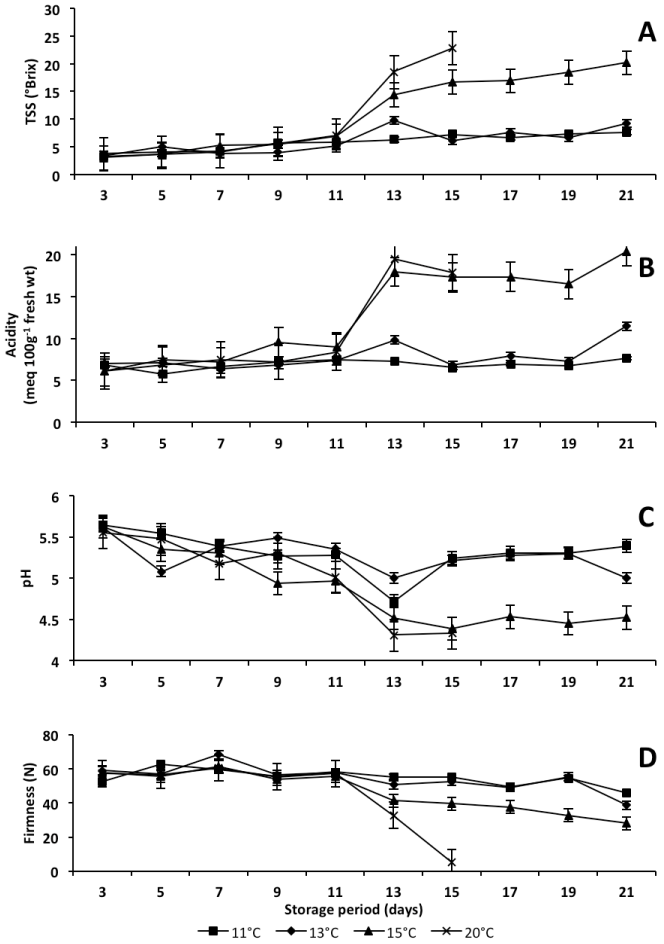


**Figure 2.** Total solid solubles (A), acidity (B), pH (C) and firmness of bananas cv. FHIA-01 stored at 11, 13, 15 and 20 °C, during 21 days. Bars indicate standard deviations of the mean.

temperatures were 18.1 mg kg$^{-1}$ h$^{-1}$, 27.2 mg kg$^{-1}$ h$^{-1}$ and 34.2 mg kg$^{-1}$ h$^{-1}$, respectively, with an average ethylene value of 0.7 nmol kg$^{-1}$ h$^{-1}$. Values associated with quality, including firmness (27–45N), TSS (10–20 °Brix), acidity (7–20 meq malic acid 100 g$^{-1}$ fw), pH (4–5) and color, were within the ranges reported by Dazdie [27] for this banana cultivar.

During acclimation, the process of ripening of fruits cv FHIA-01 previously stored at 13 °C and 15 °C and sampled after 7 and 14 days did not follow a specific pattern and it changed according to the three sampling periods and controlled temperatures. In fact, in fruit held at 11 °C, the ripening process was not properly attained. In these fruit, values of ethylene production were not detected and in some cases TSS levels and acidity values were the lowest (4.7 °Brix and 5.8 meq malic acid 100 g$^{-1}$, respectively) compared with the remaining treatments. At this temperature, values of weight loss were among the highest (33.5%) after 21 days of storage, indicating effects on the metabolic activity and probably fruit cold damage. On this matter, Litchember *et al.* [28] reported that banana peel color became darker as storage time at 10 °C increased. In our study, the low storage temperature of 11 °C is supposed to reduce the fruit metabolism, especially the respiration process, to detain as far as possible the climacteric onset, and hence, delaying the ripening process.

At the remaining temperatures, during the 5-day period of fruit sampling, parameters such as weight loss, TSS, color and firmness of fruit followed a similar pattern to that reported by Win *et al.* [29] with bananas of the cv. Kluai Hom Thong, when treated with various natural compounds and stored at 13 °C for 1 month. In this regard, in another study [30] rather similar TSS values (21.3 °Brix) to ours in banana fruit ripened at 26 °C were also obtained. Nevertheless, in other studies, the final values of acidity and pH (3.2) of fruit of the cv. Sigatoka were slightly lower than other values reported for other FHIA cultivars [27].

As mentioned by several authors, temperature is the key factor affecting quality of banana fruit [16,18,20,31]; nevertheless, it is important to bear in mind that other factors may have influenced the physiological behavior of this cultivar, such as maturity at harvest [32], external ethylene production [25] and preharvest disease incidence [33–35], among others. On this matter, Mitra [36] mentioned that overall optimum minimal storage temperatures for tropical fruit including banana may be from 11–14 °C with a concomitant shorter storage life as temperature increases.

**Table I.** Physiological response of previously stored banana fruit cv. FHIA-01 at three different temperatures for a given time, and transferred to an ambient temperature of 25 ± 2 °C for 1–5 days.

| Storage temperature (°C) | Sampling period (days) | Acclimation period at ambient temperature (days) | $CO_2$ production (mg $kg^{-1}$ $h^{-1}$) | Ethylene production (nmol $kg^{-1}$ $h^{-1}$) | Weight loss (%) |
|---|---|---|---|---|---|
| 11 | 7 | 1 | 25.7b | 0.5a | 4.8a |
| | | 3 | 28.6c | 0.5a | 8.5b |
| | | 5 | 23.0a | 0.5a | 11.9c |
| | 14 | 1 | 27.4c | 0.0a | 10.4c |
| | | 3 | 87.7f | 0.0a | 14.1c |
| | | 5 | 76.8e | 3.4c | 18.0d |
| | 21 | 1 | 90.6g | 2.2b | 28.8e |
| | | 3 | 72.4d | 3.6c | 31.3f |
| | | 5 | 70.6d | 6.4d | 33.5f |
| 13 | 7 | 1 | 25.7a | 0.0a | 6.3a |
| | | 3 | 28.6b | 0.2a | 9.3b |
| | | 5 | 96.5d | 2.7b | 11.4c |
| | 14 | 1 | 27.4b | 0.0a | 10.6c |
| | | 3 | 26.8a | 4.7d | 14.2d |
| | | 5 | 101.7e | 3.6c | 18.2f |
| | 21 | 1 | 99.8e | 2.1b | 13.1d |
| | | 3 | 97.8d | 3.9c | 15.9e |
| | | 5 | 82.8c | 7.6e | 18.1f |
| 15 | 7 | 1 | 87.2c | 5.2c | 5.5a |
| | | 3 | 72.0b | 7.0d | 7.9b |
| | | 5 | 85.7c | 9.5e | 10.5d |
| | 14 | 1 | 101.5e | 2.2a | 9.3c |
| | | 3 | 87.7c | 3.6b | 12.9e |
| | | 5 | 89.0e | 9.7e | 16.8g |
| | 21 | 1 | 90.6e | 2.2a | 11.9e |
| | | 3 | 72.4b | 3.7b | 14.3f |
| | | 5 | 70.6a | 6.8d | 17.0h |

Means followed by the same letter are not significantly different ($P \leqslant 0.05$), determined by Tukey's multiple test.

## 4 Conclusion

In this study, it is clear that ripening behavior and quality of banana fruit may be associated with the temperature and holding period. Although little published literature about the direct effect of temperature alone on this specific cultivar has been generated, we may conclude that for the cv. FH1A-01 the most adequate temperatures will depend on the expected shelf life of the fruit and market destiny, and they fall within a range of 13–15 °C for a period of up to 21 days. However, since most banana commercial cultivars require exposure to ethylene to enhance ripening, the combination of this natural compound with the best storage temperatures needs to be further investigated.

**Table II.** Quality of previously stored banana fruit cv. FHIA-01 at three different temperatures for a given time, and transferred to an ambient temperature of 25 ± 2 °C for 1–5 days.

| Storage temperature (°C) | Sampling period (days) | Acclimation period at ambient temperature (days) | TSS (°Brix) | Acidity (meq malic acid 100 $g^{-1}$ fresh weight) | pH | Firmness (N) |
|---|---|---|---|---|---|---|
| 11 | 7 | 1 | 4.7a | 5.8a | 5.6c | 47.9f |
| | | 3 | 12.0b | 10.2c | 5.0b | 48.0f |
| | | 5 | 13.9c | 12.4e | 4.9a | 39.0e |
| | 14 | 1 | 6.6a | 6.9b | 5.3b | 60.3g |
| | | 3 | 14.4c | 11.9d | 5.0b | 34.5d |
| | | 5 | 19.7d | 15.6f | 4.6a | 26.1c |
| | 21 | 1 | 12.4b | 10.4c | 5.0b | 27.4c |
| | | 3 | 22.0e | 14.3f | 4.6a | 15.6b |
| | | 5 | 22.6e | 11.3d | 5.0b | 12.4a |
| 13 | 7 | 1 | 5.1a | 6.0a | 5.5e | 54.4f |
| | | 3 | 6.9b | 9.1b | 5.0d | 56.7f |
| | | 5 | 19.3e | 19.5g | 4.3a | 23.0c |
| | 14 | 1 | 9.9c | 10.7c | 4.8c | 47.9e |
| | | 3 | 16.2d | 13.7d | 4.6b | 25.0d |
| | | 5 | 21.7f | 15.0e | 4.6b | 15.9b |
| | 21 | 1 | 16.2d | 15.8e | 4.7c | 12.3a |
| | | 3 | 21.3f | 16.5f | 4.5a | 14.3b |
| | | 5 | 22.3f | 10.5c | 4.8c | 12.8a |
| 15 | 7 | 1 | 11.4a | 13.8d | 4.6b | 36.3f |
| | | 3 | 20.6b | 16.5f | 4.3a | 16.8e |
| | | 5 | 22.4d | 14.9e | 4.5a | 15.7d |
| | 14 | 1 | 20.3b | 16.5f | 4.4a | 19.1f |
| | | 3 | 21.8c | 11.4b | 4.7b | 9.2b |
| | | 5 | 21.8c | 8.9a | 5.1d | 10.1c |
| | 21 | 1 | 21.3c | 12.9c | 4.9c | 8.1a |
| | | 3 | 20.8b | 11.8b | 4.8c | 12.2c |
| | | 5 | – | – | – | – |

Means followed by the same letter are not significantly different ($P \leqslant 0.05$), determined by Tukey's multiple test (– : data not recorded).

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**Cite this article as:** Porfirio Gutiérrez-Martínez, Rosa Cristina Avila-Peña, Dharini Sivakumar, Silvia Bautista-Baños. Postharvest evaluation of Goldfinger banana (FHIA-01) at different storage temperatures followed by an acclimation time. *Fruits* 70 (2015) 173–179.