Ciência Rural, Santa Maria, v.53:1, e20210381, 2023 http://doi.org/10.1590/0103-8478cr20210381

Ciência Rural

ISSNe 1678-4596
CROP PRODUCTION

Ethylene concentrations and temperatures on degreening of bananas from a subtropical area

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ABSTRACT: *Brazil is one of the largest banana producers and despite overall adequate climatic conditions to produce good quality fruit, postharvest handling procedures still are inappropriate. Only a few growers have degreening facilities at their groves. Mostly, bananas are prepared for the market by distributors. Two banana cultivars: Grande Naine (group AAA) and Prata Anã (AAB) were harvested from commercial groves and immediately submitted to degreening procedures in which three temperatures and four ethylene concentrations were evaluated. Bananas were degreened at 24 hour intervals at 13, 17 and 21 °C with a commercial ethylene source (Banasil®) from which 12.5, 25, 50, and 100mL were placed in an ethylene generator. During the degreening process, ethylene concentrations in the degreening room were monitored for periods up to 6 hours. At the beginning of the degreening process and after three and five more days, epidermal color and pulp firmness were determined. Ethylene concentrations did not influence color changes and ripening processes of both cultivars. A maximum ethylene concentration (1,350 µL L^{-1}) was determined in the degreening room when 100 mL of Banasil® was used at 21°C. Even with the lowest Banasil® amount, a 90 µL L^{-1} ethylene peak was determined in the degreening room, enough to ripen adequately both cultivars. Degreening at 13 °C delayed for two days the ripening of 'Grande Naine' bananas. 'Grande Naine' reached the fully ripe stage in four days while 'Prata Anã' completed ripening after three days. 'Prata Anã' bananas are more responsive to ethylene degreening than 'Grande Naine' bananas.*
Key words: *banana ripening, Grande Naine, Prata Anã, climatization treatment.*

Efeitos de concentrações de etileno e temperaturas na climatização de bananas de regiões subtropicais

RESUMO: *O Brasil é um dos maiores produtores mundiais de bananas e mesmo com boas condições climáticas para produzir bananas de excelente qualidade, os procedimentos pós-colheita são ainda inapropriados. Somente alguns poucos produtores têm unidades de desverdecimento em suas propriedades. Predominantemente, as bananas são preparadas para o mercado por atacadistas. No presente trabalho duas cultivares de bananas, Grande Naine (grupo AAA) e Prata Anã (subgrupo AAB) da safra de inverno foram colhidas em bananais comerciais e logo após climatizadas em combinações de três temperaturas e quatro concentrações de etileno. As bananas foram desverdecidas em intervalos de 24 horas em temperaturas de 13, 17 ou 21 °C com uma fonte comercial de etileno (Banasil®) da qual 12,5, 25, 50 e 100mL foram colocados no gerador de etileno. Durante o processo de climatização, as concentrações de etileno na unidade de desverdecimento foram monitoradas por períodos de até seis horas. No início do processo de desverdecimento, no terceiro e no quinto dia a cor de cobertura da casca e firmeza de polpa foram determinadas. As concentrações de etileno não influenciam as modificações de cor de casca e o amadurecimento de ambas as cultivares. A máxima concentração de etileno (1.350ppm) foi determinada quando 100mL de Banasil® foram utilizados. Mesmo com o menor volume de Banasil® um pico de 90pmm de etileno foi determinado na unidade de climatização e esta concentração foi suficiente para amadurecer adequadamente as bananas das duas cultivares. Desverdecimento a 13 °C causou um atraso de dois dias no amadurecimento das bananas da cultivar Grande Naine. Bananas 'Grande Naine' atingiram o estádio de plenamente maduras em quatro dias enquanto que as bananas 'Prata Anã' completaram o amadurecimento em três dias. Bananas 'Prata Anã' respondem melhor ao processo de desverdecimento que bananas 'Grande Naine'.*
Palavras-chave: *desverdecimento, Grande Naine, Prata Anã, tratamento pós-colheita.*

INTRODUCTION

Bananas are amongst the leading fruit species cultivated all over the globe. According to FAO, (2019), bananas are produced in about 125 countries and are regularly consumed in almost every country. Banana production in less developed economies is of high social importance and the economy of those places is very much dependent on banana production. In many areas, the species is regarded as a staple food.

Received 05.13.21 Approved 02.11.22 Returned by the author 04.23.22
CR-2021-0381.R3
Editors: Leandro Souza da Silva Ivo Oliveira

The last data of FAO, (2019) indicate that the global volume of bananas produced in 2018 was of 127.3 million tones. According to the Brazilian Institute of Geography and Statistics (IBGE, 2021), in 2020 bananas were grown in an area of 466 thousand hectares yielding 6.7 million tons. These figures lead Brazil to be the fourth producer of bananas in the world: after India, China and Indonesia. In the state of Rio Grande do Sul, the southernmost state in Brazil, according to that same source in the year 2018, banana groves occupied 11,883 hectares from which 135.3 thousand tons of fruit were harvested.

Despite all the economic and social significance of bananas, there is limited information as for the reduction of losses and waste of fruit. Furthermore, after harvest handling such as ripening procedures have not changed in decades. Banana ripening might be completed under distinctive techniques and various techniques were developed to advance ripening processes of bananas without compromising quality traits of the fruit to avoid the offer lower quality bananas (ZHANG et al., 2018).

Commercial ripening is normally operated at temperatures and ethylene concentrations excessively high intending speeding up banana ripening (MEDINA & PEREIRA, 2004). MACNISH et al. (2000) indicated that ethylene concentrations affect the ripening processes even though there is little information in the literature on concentration effects on ripening.

LAROTONDA et al. (2008) applied various ethylene concentrations for cv. Nanica fruit. The authors did not observe significant differences on banana peel color after seven days. NOBRE et al. (2018) concluded that the number of ethylene treatments apparently did not affect the degreening of bananas of a specific cultivar.

There are, however, diverging opinions on ethylene concentrations to be applied in ripening rooms of bananas. There is also divergence on the temperature range at which banana ripening should be completed and, too, on the time intervals in between every ethylene treatment.

The recommended ethylene concentrations vary from 10 ppm (SANCHES, 2002) at a constant rate up to 1,000 ppm on a single dose (ALVES, 1999). LIVRAMENTO & NEGREIROS, (2017) recommend an ethylene concentration of 0.2 up to 2% of the air volume of the ripening room.

LOBO et al. (2005) in an experiment conducted in glass jars concluded that ethylene concentrations of 5, 50, 500 or 5,000 ppm did not influence the ripening of cv. Dwarf Cavendish bananas. According to the authors, there was only a difference in the contents of sucrose, fructose, and glucose in the 5 ppm ethylene treatment.

Therefore, because of all those disagreements and the lack of a precise treatment for bananas from a subtropical climate, the present work was conducted with two different cultivars cultivated in the main area of banana production at the southernmost state in Brazil, a typical subtropical climate. In the trials, also different degreening temperatures and ethylene concentrations were evaluated in order have more consistent data to recommend a procedure to properly ripen bananas.

MATERIALS AND METHODS

The bananas for the experiments were harvested from two commercial groves located in the northeastern coastal area of Rio Grande do Sul after the end of the winter season. Winter season bananas develop along May until November and are exposed predominantly to low temperatures. Bananas of the cultivar Prata Anã (AAB group) were harvested from a ten-year old banana field and cultivar Grande Naine (AAA group) were harvested from fields not older than 6 years. Both groves were managed under the customary production system of the southern Brazilian banana region.

The banana bunches were harvested at the commercial ripeness stage: bananas from the second hand of the bunch with 36 mm diameter, which is also called: ¾ full size (ALVES et al., 2004). The banana hands were trimmed from the bunches at the packing facility located in the groves and immersed in water tanks containing 0.5 mL L^{-1} (v/v) of a household detergent and 0.2 g L^{-1} (w/v) aluminum sulfate. Immediately after, the banana hands were arranged in plastic boxes and transferred to storage units set at 13 °C. After reaching the storage temperature five hands of about 8 to 10 bananas from both cultivars were retrieved and transported to the postharvest laboratory to run the degreening trials.

The degreening of the bananas was achieved by pouring an ethyl liquid concentrate (Banasil®) into a specific ethylene generator, from that same company, placed in the degreening room of 15 m^3 internal volume. Three degreening temperatures were tested: 12-14 ºC; 16-18 ºC or 20-22 ºC combined with four different volumes of the Banasil® ethyl concentrate: 12.5, 25, 50 or 100 mL.

To complete the ripening of the bananas in every trial, the process of ethylene generation was repeated three times at 24-hour intervals. The degreening unit was aerated for about 2 hours after every 24 hours of ethylene application. Ethylene concentrations in the degreening room were determined via a gas chromatograph (GC) equipped with a flame ionization detector and a niquel 60/80 mesh activated alumina column (1.8 m x 1/8 inch). Air samples from inside the degreening room were pumped through a silicon tube from which a one-mL sample was retrieved with a syringe and injected immediately into to the GC calibrated to an ethylene standard of 1 µL L^{-1}. Integration of the ethylene peaks was performed via software (Clarity™, DataApex). The same software also runs the GC.

Pulp firmness, expressed in Newton (N), was determined with digital penetrometer on transversal sections of the median portions of five bananas and two measurements on each banana.

Peel color of the bananas was determined before the start of the degreening processes and after five days after harvest: three days of ethylene treatments plus two more days at room temperature as for ripening processes of the bananas to be completed. The color difference (ΔE) was determined via the equation of GOYENECHE et al. (2014).

$$\Delta E = (\Delta L^{*}2 + \Delta a^{*}2 + \Delta b^{*}2)1/2$$

where the variables L^*, a^* and b^* are obtained from the measurements of the Konica/Minolta color meter, model CR 400 calibrated to a white standard plate (CR043).

The experiments were conducted in completely randomized designs. Statistical analysis of the data was performed applying a factorial design analyzing the main components: ethylene concentration, cultivars and degreening temperature using SAS for PC (SAS Institute Inc., Cary, NC). When the interactions within factors were significant, then regression analyses were performed for every set of degreening temperature through SAS for PC (Anova table at the end of the reference list table 1).

RESULTS AND DISCUSSION

The ripening procedures of the bananas by using the liquid ethyl concentrate Banasil® indicate that any of the tested volumes in the ethylene generator result in elevated enough ethylene concentrations in the degreening room to speed up the ripening of bananas (Figure 1). The different volumes of the concentrate produced ethylene concentrations beyond of the recommended concentration to ripen both banana cultivars. With the lowest Banasil® volume dispensed into the ethylene generator a maximum peak of 72.76 µL L^{-1} ambient ethylene was determined after 60 minutes. After more than 5 hours of the climatization treatment, the ethylene concentrations (7.13 µL L^{-1}) were still in the range of concentrations necessary to ripen bananas as indicated by SANCHES, (2002).

All of the tested Banasil® volumes generated similar ethylene concentration curves, though, the greater the volume of the ethyl concentrate the longer the ethylene generator takes to produce the maximum ambient concentration. Dispensing

Table 1 - Statistical analysis of the data was performed applying a factorial design analyzing the main components: ethylene concentration (=dose), cultivars and degreening temperature using SAS for PC.

		--------------------3 days---------------------		--------------------5 days--------------------	
Main effects	Number of DF	F value Pr > F	F value	Pr > F	F value
Dose (D)	3	74.19	<.0001	18.81	< .0001
Cultivar (C)	1	324.9	<.0001	321.81	< .0001
Temperature (T)	2	715.38	<.0001	718.96	< .0001
D x C	3	22.02	<.0001	8.02	< .0001
D x T	6	29.97	<.0001	46.9	< .0001
C x T	2	96.09	<.0001	63.29	< .0001
D x C x T	6	33.35	<.0001	37.12	< .0001

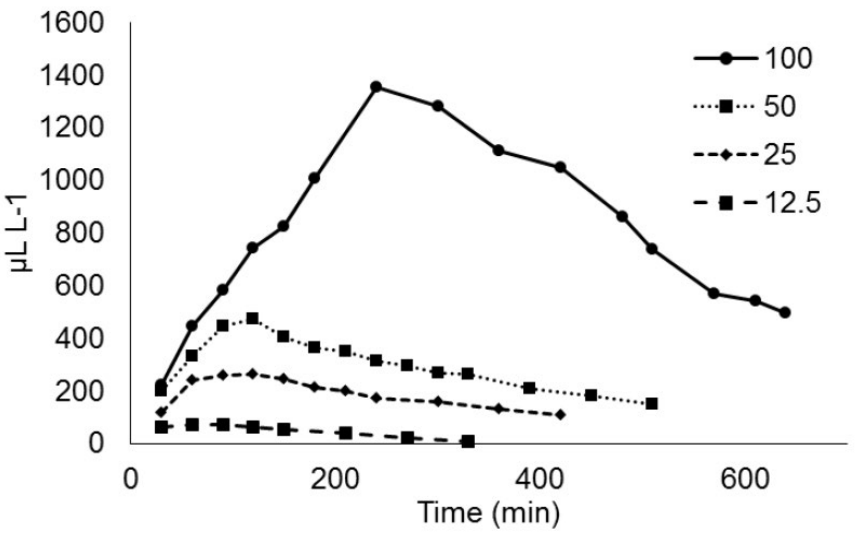

Figure 1 - Ethylene concentrations inside the degreening room of 15 m3 along a maximum period of 640 minutes. Different volumes of the Banasil® ethyl concentrate were dispensed in the ethylene generator.

100 mL of the ethyl concentrate the highest ethylene concentration (1,353.59 µL L^{-1}) was determined after 4 hours of climatization. Even after ten hours, the ethylene concentration in the ripening room was 495.41 µL L^{-1}, a concentration way beyond the need to properly ripen bananas.

Amongst the many changes in banana fruit quality after the ethylene treatments pulp firmness is a very evident change together with peel color. The ripening of the bananas of both cultivars after the degreening procedures do indicate that the temperatures at which the degreening was performed influence the firmness of the fruit (Table 2). Even as more usual techniques for firmness determination, such as the penetrometer test, are considered not as precise to assess tissue softening according to the conclusions of NUSSINOVITCH et al. (1990), the variations in pulp firmness determined after three or five days after the beginning of degreening indicate that banana ripening proceeded as expected after the ethylene treatment.

Banana pulp firmness data indicated interactions of the factors cultivar, dispensed Banasil® volume and degreening temperature after three and five days of degreening procedures start. In figure 2, the interactions in between factors are dissected for every cultivar and for every degreening temperature under the distinct Banasil® volumes. Independently of the dispensed Banasil® volume, cv. Grande Naine bananas require higher temperatures to reach the equivalent firmness of cv. Prata bananas. After three days of degreening, the lowest points of the regression analyses for banana pulp firmness were determined when the lowest Banasil® volumes were dispensed at the lowest temperatures. After five days for cv. Grande Naine, calculations of the minimal points indicate that higher volumes of Banasil® enable degreening of that cultivar at lower temperatures.

Banana firmness losses at the highest temperatures (16-18 °C or 20-22 °C) were similar in both cultivars. The values observed in the present trials were not as low as the firmness values determined by BUGAUD et al. (2007). The authors observed firmness values in the range of 2.8 N/s up to 4.2 N/s after six days at 20 °C following a single 1,000-ppm ethylene treatment at 16 °C. One reason could be related to the harvest point. BUGAUD et al. (2007) harvested bananas of the AAA group (Cavendish), one of the cultivars tested in the present trial, at different sites with diverse edafoclimatic conditions

Table 2 - Banana pulp firmness (N) changes after harvest or after degreening: three or five more days of winter season cultivar Prata Anã (AAB) and Grande Naine (AAA) and harvested in November. Banana hands were degreened for three days at temperatures of 12 - 14 ºC, 16 – 18 ºC or 20 - 22 ºC with different volumes (12.5, 25, 50 or 100 mL) of an ethyl concentrate (Banasil®) and were transferred thereafter to room temperature.

	------------------12-14 °C---------------			---------------16-18 °C-------------			------------22-22 °C----------		
Ethyl concentrate	At harvest	+ 3d	+ 5d	At harvest	+ 3d	+ 5d	At harvest	+ 3d	+ 5d
	---Cv. Prata Anã---								
12.5 mL	44.8	46.6	22.9	34.1	16.7	8.8	40.3	19.1	7.3
25 mL	26.2	25.6	11.0	33.8	18.0	11.3	48.2	8.7	7.3
50 mL	35.4	37.3	19.9	44.2	33.6	12.9	44.7	16.4	7.3
100 mL	40.1	38.9	19.7	43.6	33.7	12.8	45.4	16	7.1
	---Cv. Grand Naine---								
12.5 mL	38.9	37.7	21.9	42.2	43.8	18.3	41.0	21.3	9.0
25 mL	34.6	27.4	21.4	45.6	42.4	24.4	40.4	23.9	5.9
50 mL	43.8	43.4	36.5	43.3	39.9	13.4	45.5	19.5	8.5
100 mL	43.7	45.2	36.5	41.6	41.0	14.6	43.2	20.3	10.7

and at a much lower firmness: in the range of 17.0 N/s up to 19.1 N/s. In the present trials, average firmness of the bananas at harvest was 36.6 N and 40.2 N for Prata Anã and Grande Naine, respectively.

Afar from edafoclimatic conditions, temperature regimes operated after harvest might also result in different values in firmness determined after ripening procedures. NASCIMENTO JUNIOR et al. (2008) evaluated firmness of bananas from the same subgroups harvested at a more tropical area of the southeastern part of Brazil and ripened with 1,000 µL L^{-1} at 15 °C for one single period of 24 hours. The authors indicated that bananas of the cultivars Nanicão (also group AAA) and Prata Anã had fruit firmness values of 13.34 N and 15.12 N, respectively, after two days at 24 ^{0}C, a period comparable to the three days after starting degreening of the present trial.

At the lower degreening temperature (13 °C), in general, the fruit firmness remained higher after the complete ripening. The exceptions are the values of cv. Prata Anã bananas degreened at 12-14 °C with 25 mL of the ethyl concentrate. The reason for that result should be attributed to an already lower firmness value at harvest (26.2 N). Banana fruit firmness losses are, according to KOJIMA et al. (1992), a result of biochemical and compositional changes and amongst those, modifications in starch grain organization in the pulp. Moreover, SALVADOR et al. (2007) concluded that at least two distinct processes are involved in firmness reductions in bananas: starch breakdown and cell wall degradation. Nonetheless, SHIGA et al. (2011) concluded that in some banana cultivars fruit softening could be more related to starch contents than to cell wall changes. Solubilization of pectins in the middle lamella affecting its cohesion does also result in lower firmness (SMITH et al., 1990).

At higher degreening temperatures, YAN et al. (2011) observed that banana firmness decreased significantly. In the present trials, the higher the temperature during degreening the lower the pulp firmness after 5 days (Figure 2). Higher firmness values, though, determined in both cultivars under 12-14 °C degreening might not be a chilling effect. WANG et al. (2006) observed that chilling injuries occurred only after seven days of storage at 7 °C and that applying an ethylene analog alleviated chilling injury symptoms. JIANG et al. (2004) concluded that 11 °C for bananas is the critical temperature below which physiological disorders escalate.

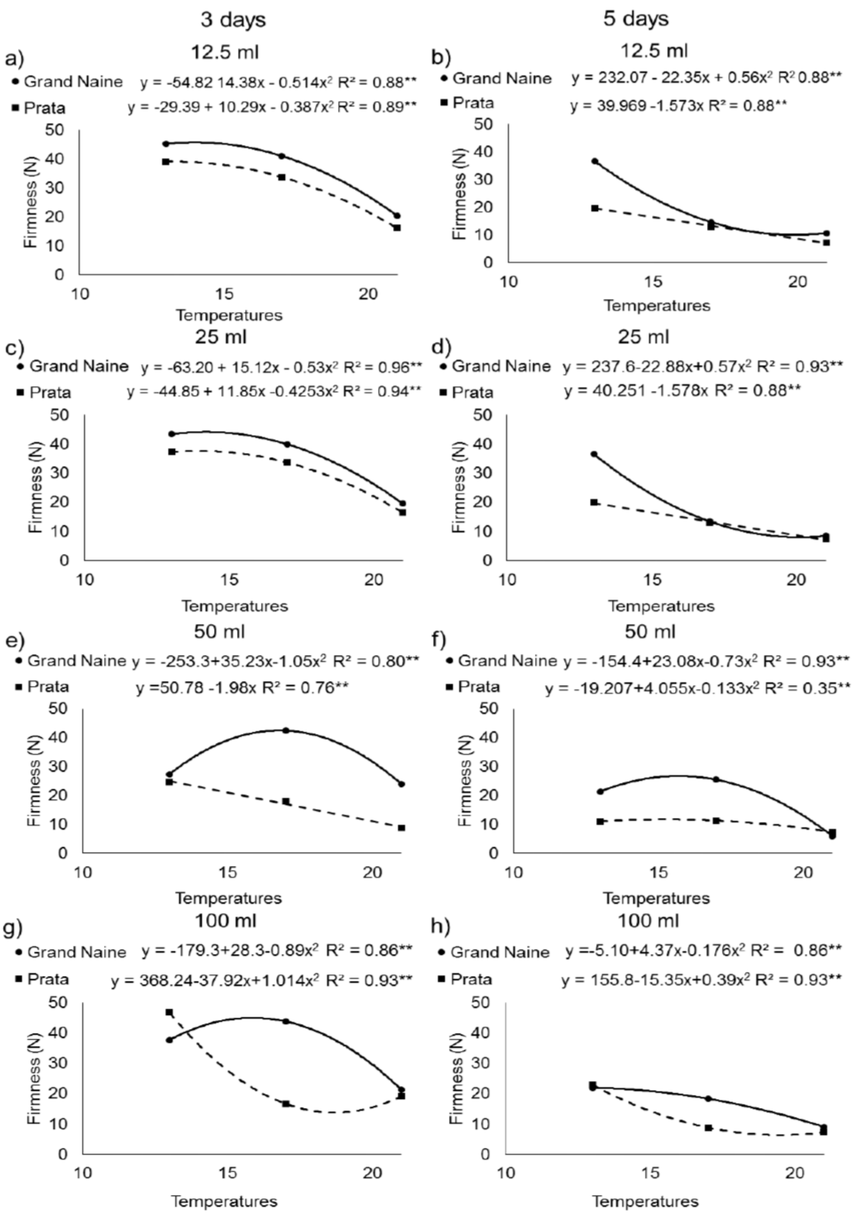

Figure 2 - Pulp firmness (N) of winter season bananas of the cultivars Grande Naine and Prata-Anã (harvested in November) after three or five days after degreening at three different temperatures (12 - 14 ºC, 16 – 18 ºC or 20 - 22 ºC) with different volumes (12.5, 25, 50 or 100 mL) of an ethyl concentrate (Banasil®).

ZHU et al. (2018) indicate that 13 °C is a non-chilling temperature for bananas.

Even though, peel color progress at the lowest degreening temperature indicates that a temperature effect occurred. The color differences (ΔE) changes of the bananas degreened at 12-14 °C were not as highly evident two days after the third ethylene treatment as at the higher degreening temperatures. The color of the bananas of both cultivars harvested either at the end of the winter period did change independently from the ethyl concentrate dispensed in the ethylene generator. It is evident that peel color changes in the bananas are extremely dependent on the temperature regime during the degreening processes of both cultivars. Also is manifest that exposure to low ethylene concentrations in the degreening room resulting from the lowest volume of the ethyl concentrate (12.5 mL) dispensed into the ethylene generator were sufficient to ripen properly the bananas at higher temperatures and that acclimatization below 14 °C did not result in a satisfying peel color change.

Bananas acquire an adequate yellow peel color after ripened at temperatures in the range of 18 ºC and 24 ºC (DU et al., 2014). The authors concluded that ripening at temperatures above that range results in unattractive color. BLACKBOURN et al. (1990) indicated that ripening beyond 24 ºC the bananas do not develop a usual yellow peel and stay greener. That same phenomenon might be the cause of the less attractive peel color of the bananas degreened at 12 - 14 ºC after five days of ripening at room temperatures. Lower Delta E values are indicative of reduced color changes, *i.e.*, peel color similar to the initial value determined at harvest.

Greener bananas are also a result of low storage temperatures. OLIVEIRA et al. (2016) observed that maintaining the bananas at lower storage temperatures (10.53 ± 0.37 ºC) a longer period of time at f 22 °C was necessary for bananas of different cultivars reach a peel color index of 6. An index indicative of complete ripening according to the authors.

The bananas harvested in the winter season had been exposed during the development phase to low temperatures, which probably might have inflicted chilling injuries with damages to color development. Winter bananas present a more opaque peel color in comparison to summer bananas. Even though, those winter temperatures effects did not alter the responses to the different volumes of the ethyl concentrate, which delivered ethylene concentrations in the degreening room beyond the physiological requirement for bananas to carry on ripening according to conclusions of SANCHES, (2002).

Bananas of the cultivar Prata Anã present a more accelerated peel color development. Chlorophyll breakdown in that group (AAB) is faster as compared to bananas of the Cavendish subgroup (AAA) in accordance to NOBRE et al. (2018). That statement corroborates the results observed with Prata Anã as a cultivar more easily degreened and with lower ethylene concentrations requirement to properly advance ripening (Figure 3).

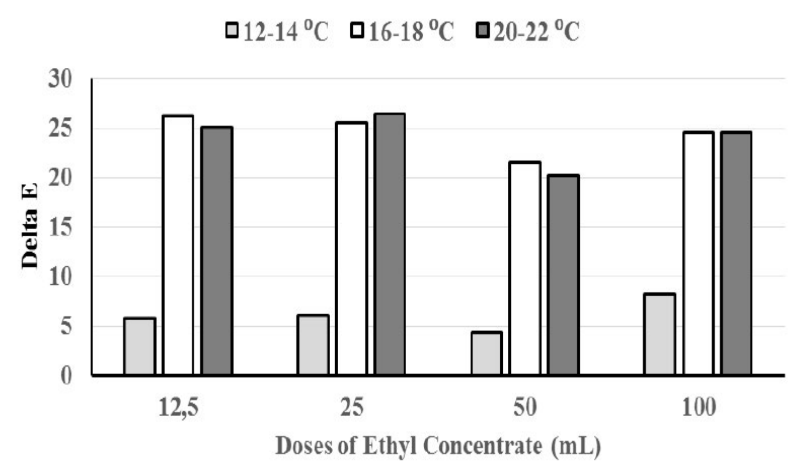

Figure 3 - Delta E values determined two days after finalizing degreening of winter season cv. Prata Anã bananas (harvested in November) and submitted to different doses of an ethyl concentrate at three degreening temperatures (12 - 14 ºC, 16 – 18 ºC or 20 - 22 ºC).

The peel color difference of the cv. Prata Anã is similar at both higher temperatures (16 - 18 ºC and 20 - 22 ºC). Only at the lowest temperature (12 - 14 ºC), epidermal color changes were not significant. In essence, that same result was observed in all combinations of degreening temperatures, ethyl concentrate volumes and cultivars. Preliminary data indicated that degreening of bananas when fruit temperature is low, the ripening process, *i. e.*, color development is imperiled. Chlorophyll breakdown, mainly in fruits of the cultivar Grand Naine is limited and even with a subsequent rise in temperatures, the bananas do not respond to ethylene applications as expected (Figure 4). Grande Naine bananas harvested in the summer season and submitted to the same experimental settings presented similar results of color differences. The same is true for winter season cv. Prata Anã bananas (data not shown).

CONCLUSION

The use of the lowest volume of the ethyl concentrate Banasil® in the ethylene generator delivers enough ethylene to ripen properly bananas of both banana cultivars: Prata Anã and Grande Naine.

Moreover, the factors cultivar and degreening temperature, on the contrary of volume of the dispensed ethyl concentrate, are the most influential in the degreening results.

In subtropical areas, winter season bananas are more prone to present unappealing peel color after the degreening process, which might be a result of longer development periods needed to the bananas reach the harvesting point.

Degreening bananas at 12 - 14 ºC delays ripening of cultivar Grande Naine bananas. At 20 - 22 ºC, ripening processes are boosted affecting pulp firmness.

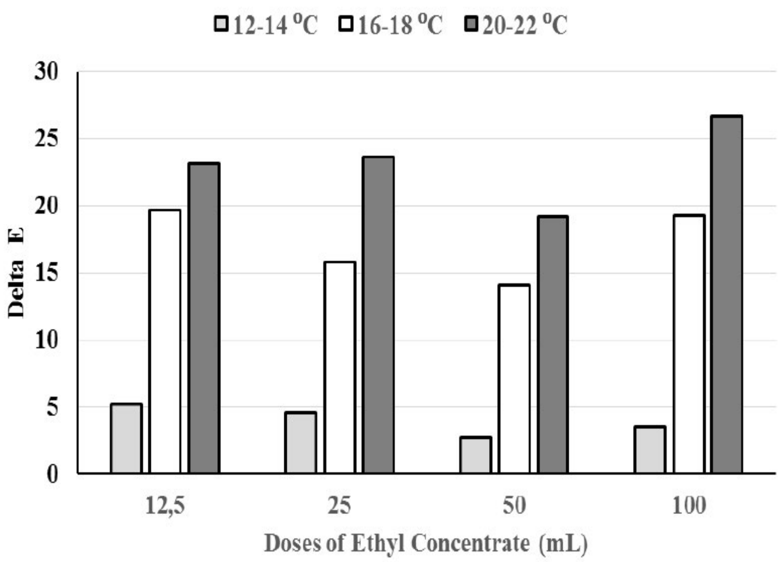

Figure 4 - Delta E values determined two days after finalizing degreening of winter season cv. Grande Naine (harvested in November) and submitted to different doses of an ethyl concentrate at three degreening temperatures (12 - 14 ºC, 16 – 18 ºC or 20 - 22 ºC).

ACKNOWLEDGEMENTS

The present work was financed in part (scholarship for the first author for a short period) by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), Brazil.

DECLARATION OF CONFLICT OF INTERESTS

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

Conceptualization: BKP and RJB. Data acquisition: BKP and RJB. Design of methodology and data analysis: BKP, GKA and RJB. BKP prepared the draft of the manuscript. All authors critically revised the manuscript and approved the final version.

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