Original Research Article

The role of ethylene on banana fruit ripening via sugar and starch metabolism

Abstract

Banana as a climacteric fruit has a relatively short shelf-life period and thus technologies that decrease the metabolism and the triggering of the maturation process are extremely necessary on its postharvest conservation. However, the consequences of these technologies on quality attributes are unknown. Therefore, we evaluate the effects of 1-MCP associated with low density polyethylene bags on physical and chemical attributes in the postharvest of banana fruits. Bananas were treated with different concentration of 1-MCP as 0, 50, 100, 150 and 200 $\eta L.L^{-1}$ under refrigeration and harvest in five different time of postharvest after low temperature storage. Further, fruits treated with 50 $\eta L.L^{-1}$ showed a more advanced stage of ripening after the 25 days of storage. Altogether, our results suggest 1-MCP is an effective treatment to control sugar and starch metabolism in banana and its efficiency is directly dependent of storage temperature. Additionally we identify interestingly correlation with skin color changes with sugars and starch content, which can indicate its potentiality of the fitted equations for prediction of central metabolism of bananas non-destructively using ‘hue angle and chrome’ value.

Keywords: Postharvest, banana quality, 1-MCP, sugar metabolism, starch

Introduction

Banana (*Musa* sp.) is an important commercial food crop exported to many countries. Banana are considered as a climacteric fruits which is characterized by two different of ethylene production are thought to operate, exhibiting a short shelf-life (Pech *et al.*, 2008). According to Golding *et al.*

(1998), during the maturation, there is a low basal rate of ethylene production termed System 1, followed by System 2 ethylene, which this second one is characterized by autocatalytic climacteric rise in ethylene production. Under normal condition, ethylene binds to receptor membrane proteins, triggering responses associated with maturation (Dubois *et al.*, 2018; McAtee *et al.*, 2013). This phytohormone is directly associated with several changes during the burst from autocatalytic stimulation (Yang and Hoffman, 1984). In this vein, banana ripening, according to Medina-Suárez *et al.* (1997) and Ghosh *et al.* (2016), is characterized by a significant up- and down-regulation of transcripts that encode enzymes involved in ethylene biosynthesis, respiration, starch metabolism as well as sugar metabolism and several other key metabolic events on the primary and secondary metabolism, such as chlorophyll breakdown and carotenoid accumulation (Katz *et al*., 2004). Hence, it is generally accepted that continued production and action of ethylene are required for integration of these biochemical events (Golding et al., 1998).

Notably, the quality of the fruit is related to the maintenance of the normal characteristics of the product, such as texture, color, flavor and aroma, the way the food is produced to the consumer for the longest possible time. However, these characteristics are directly depending on metabolic activity which is several factors-responsive. Thus, technologies that modulate the metabolism and inhibit the senescence process at the same moment are needed.

The use of ethylene inhibitors in banana can delay the maturation process by increasing the postharvest life of the fruit. In the same vein, the volatile ethylene nontoxic antagonists such as 1-methylcyclopropene (1-MCP) has provided a useful tool for elucidating the role of ethylene in ripening climacteric fruit (Dek *et al.*, 2018; Golding et al., 1998; Mazorra *et al.*, 2013; Nakatsuka *et al.*, 1997; Thongkum *et al.*, 2018). Recently, 1-MCP has been extensively used on climacteric and non-climacteric fruits for delaying fruit ripening and control fruit quality in tomato (Zou *et al.*, 2018), melon (Han *et al.*, 2015), plum (Martínez-Romero *et al.*, 2003), mango (Sakhale *et al.*, 2018; Trindade *et al.*, 2015), strawberry (Jiang *et al.*, 2001), papaya (Mazorra et al., 2013; Souza *et al.*, 2009), and bananas (Golding et al., 1998; Jiang *et al.*, 1999). Although various studies have focused on the 1-MCP effect on the storage of banana fruit ((Jiang *et al.* (2004); Zewter *et al.*, 2012), still in our knowledge, few works have been done associating the effect of 1-MCP combined with refrigeration and packaging on metabolic adjustment as well as changes in the color of the fruits. Furthermore, still remain unclear the correlation pattern of these parameters when the ethylene action is inhibited and how long they remain ethylene-dependent.

Hence, the objective of the present study was to evaluate the effect of 1-methylcyclopropene associated with low density polyethylene packaging in the preservation and maintenance of postharvest quality as well as its effects on the metabolism and correlation pattern of chemical, physical and metabolic attributes in banana 'Prata Gorutuba' (Musa spp. AAB 'Prata Anã' clone: Gorutuba) stored under refrigeration.

Material and Methods

Fruit material

Bananas bunches (containing 4 individual fruits) cv. Prata Gorutuba (*Musa* AAB 'Prata Anã') were provided by the Itapicuru Company, located in Minas Gerais State, Southeastern Brazil. Mature fruit showing totally green skin (maturity stage 2, see Supplementary fig.S1) were harvested, washed, carefully selected, and transported in a refrigerated truck at 15°C during 4h to the laboratory before performing analyzes.

Solution preparation and fruit treatment

The fruits were placed in hermetic plastic boxes (0.3 m³) and then submitted to 0, 50, 100, 150 e 200ηL.L^{-1} of 1-methylcyclopropene (1-MCP) (SmartFresh®) in the form of wettable-powder, containing 0,14% i.a. of 1-methylcyclopropene. After complete dissolution, the banana's fruits were exposed for 8 hours to the gas under room temperature (RT) 25±1ºC. After the treatment period, the fruits were packed in to Low Density Polyethylene (LDPE) plastic bags (25 µm), and then stored in cooling chamber at 14.5 ± 1 ºC and relative humidity air (RH) 95% ± 5 % during 25 days after treatment. Finally, after this storage time, the banana's bunches were removed from the packages and kept at RT for 5 days, and analyzes were taken daily until the last day.

Physical quality attributes

The firmness was performed using a penetrometer (Brookfield model CT3) with 4mm diameter. The evaluation made in two equidistant regions, on opposite sides, of the equatorial region of the fruits. The firmness was measured as the maximum penetration force expressed in Newton (N). The skin color of the fruit was performed using a Color Flex 45/0, stdzMode:45/0. To determine the chromaticity values (L^* – lightness, and h° – hue angle) were calculated using the chromaticity values a^* and b^* according to McGuire (1992).

Determination of chemical quality parameters

Around ten gram (10 g) of banana from each replicate were crushed and homogenized with 100 ml boiled distilled water (previously adjusted to pH 8.3). The pH was measured by using pH meter Crison MicropH 2001 (Crison Instruments SA, Barcelona, Spain). The mixture was titrated with 0.10 M NaOH to pH 8.3 and the result was expressed as mg malic acid per 100 g sample. The total soluble sugar content (SSC) were determined according to Madamba (1993) as previously described by (Bico *et al.*, 2009).

Physiological parameters

The soluble sugars were determined by the anthrone method Dubois *et al.* (1956). The quantification of starch was carried out according to the method described by Yemm and Willis (1954) and dosages were made by the anthrone method Dubois et al. (1956). The starch was obtained by spectrophotometry, with reading at 510 nm, according to the method described by Nelson (1944).

Experimental design and statistical analyzes

The experiment was performed in a completely randomized design (CRD), with five replicates. Statistical analyzes were performed using the GENES software (Cruz, 2006). The averages of the treatments were compared by the Tukey's test ($P \leq 0.05$). Pearson's correlations were also calculated. Analyzes were performed using Sigma Stat software v.2.0 (SPSS Inc., Chicago, IL, USA) and GraphPad prism 6 (GraphPad Prism version 6 for Windows, GraphPad Software, La Jolla, California, USA).

Results

Effect of 1-MCP in physical quality parameters during banana ripening

As shown in Fig.S1, the 1-MCP could delay the ripening of banana fruit and in complement, the physical quality parameters follows the same visual response (Fig.1). Among the treatment, $50\eta L.L^{-1}$ 1-MCP treatment had the similar effect with a normal ripening, which after 3 days there was not more significantly difference in comparison with $0\eta L.L^{-1}$ 1-MCP (See in Fig.1 and Supplemental table S.1). However, in higher concentrations the firmness in the control fruit dropped sharply from of 30.59N on the 1st day to 4.03N on the 5th day after remove from the refrigeration (Fig. 1A). Interestingly, the L value the 1-MCP treatment has not shown drastically changes during fruit ripening, except in 3th day where, the L value was reduced in 100, 150 and $200\eta L.L^{-1}$ 1-MCP (60.97, 58.96 and 63.04 respectively, see in Fig.1B and supplemental table S1). The change of the peel color was expressed in hue angle (*h*º) values. As is shown in Fig. 1C, the peel color of banana fruit in all treatments turned more yellow through the period of storage (Supplemental Fig.S1 and S2). Banana treated with 1-MCP showed a significantly higher level of hue angle values compared to that of other treatments. This effect was considered dose response, the higher the concentration of 1-MCP, the greater the delay in the peel color changes (Fig.1C and Supplemental Fig. S1). At the same time, the Chroma (Fig.1D), a similar results from the previous observed with hue angle, showing a higher color intensity (Chroma), mainly after 5th day of storage at 25ºC with reduced values to 1-MCP treatments (Supplemental table S1).

Effect of 1-MCP in chemical quality parameters during banana ripening

As shown in Fig. 2A, the pH values had significant reduced during fruit ripening and these effects were retard by with increased concentrations of 1-MCP. The lowest values on the 4^{th} day after treatment and storage (4.42, 4.43, 4.46 and 4.57) were detected in the control and fruits submitted to the lowest concentrations of 1-MCP (0, 50, 100 and 150ηL. L-1, respectively). These effects are in a close relationship with malic acids content in the (Fig.2B). During fruit ripening fruit, the 1-MCP significantly has affected the malic acid, which has kept enhanced the values in fruits treated with 100, 150 and 200ηL. L-1 (Fig.2B and Supplemental table S2). As shown in Fig.2C, the SSC (ºbrix) increased during fruit ripening in all treatments. A significant extension in ripening time was obtained for all concentrations of 1-MCP with the increase in time to ripen over untreated fruit. The 1-MCP treatment has suppressed significantly the SSC content over fruit ripening as compared with control (Fig.2C). The rate of sugar content evolution is drastically affected in 5th day after treatment and storage, which 200ηL.L^{-1} 1-MCP has suppressed ~50% of SSC in the fruit juice. The malic content changes has influenced the brix/acid ratio (Fig.2D), showing to be due mainly to a higher TA in 1-MCP treated fruit rather than a lower level of SSC, which malic acid degradation over ripening is reduced in 1-MCP treatment.

Effect of 1-MCP in physiological quality parameters during banana ripening

The ripening are a complex process genetically programmed, culminating in a dramatic changes, mainly in color, texture, flavor and soluble solids and volatile aroma (Osorio *et al.*, 2013). In order to characterize better the 1-MCP after refrigerating storage on physiological traits, we measured the sugars, starch contents as well as the ratio sugar/starch (Fig.3). As shown in Fig.3 the non-reducing sugar has been found in larger quantities and lower concentration to reducing-sugars (Fig.3A and B). However, both have increased in quantity during fruit ripening, reaching the higher levels at 5^{th} in control fruits. Additionally, the sugar content has increased during ripening fruit, concomitantly with the evolution of SSC. The 1-MCP treatment has delayed the accumulation of sugars and starch degradation (Fig.3). As shown on Fig.3C, fruits treated with 200 ŋ.L.L^{-1} 1-MCP have had reductions in the total sugar content of 25% in the 5th day after treatment and lower temperature storage in comparison with untreated fruits at the same time. Therefore, the 1-MCP combined with lower temperature storage can significant influence on the ripening process of bananas mainly controlling the sugar content in banana fruits. As shown in Fig.3D, the starch content is decreased during fruit ripening, as expected, however the 1-MCP has a directly influence in starch catabolism during ripening process, suggesting the connection directly with enzymes involved with degradation of this compound. The treatment with 200 ŋ.L.L-¹ has reduced 2-fold when compared with control (untreated fruits). Additionally, the variation in the sugars and starch content correlated strongly with some physical properties of the fruit, such as SSC, skin color parameter and the malic acids (Fig.5). Interestingly, starch has negatively correlated with SSC (-0.92), the ratio SSC/TA (-0.89), *L** (-0.81) and Chrome (-0.90) (Fig.5). This expected negative correlation shows the importance of the degradation of the reserves (starch) for increasing the sugars content of sugars and increase in the content of soluble solids of the fruits.

Multivariate analysis

All measured variables were used to perform the analysis of the principal components (PCA). Furthermore, the PCA was performed to explore more deeply the contribution of changes 1-MCP treatment followed by lower temperature storage in the metabolite composition as well as physical parameters across fruit developmental stages by score plot and loading plot (Fig.4). Through the PCA, this fingerprint analyzes showed that indeed the dominant source of variation in the combined dataset is the differential contribution of the metabolite composition across fruits ripening in 1-MCP treatment. The first component (PC1) explained 89.6% of the variation and the second component (PC2) only 9.7%, which showed no distinguish between the 1-MCP treatment and time after storage. Therefore, our attention was turned to the PC1 (Fig.4A). Our results were separated in three groups whose were also confirmed by Euclidean distances. In the group I, include the time over fruit ripening, which low concentrations of 1-MCP such as 0 and 50 in ripe fruit (T4 and T5) characterized by low influences of 1-MCP and fruit complete ripe (See Fig. 4A – orange circle) while the group II, include the blue circle group and it is composed by intermediate fruit ripe and mixed with higher 1-MCP such as 100 and 150nL.L^{-1}, showing a mix of effect by 1-MCP treatment and time of storage. Finally, the group III composed by unripe fruit under storage independently of 1-MCP treatment and 1-MCP, mainly by higher 1-MCP concentrations influences (Fig.4A). In a complementary manner, we also performed the loading plot, intending to analyze the variables that contributed to the separation of the groups. Ripe fruits (Group I) was separated mainly by non-reducing sugars (Fructose and Glucose), total sugars content as well as the ratio SSC/TA, which are associated with fruit quality (Fig.4B). This results shows that 50nL.L^{-1} in T5 (5 days after storage) does not have any influences in avoid starch catabolism and control of fruit ripening, showing results similar with control. The group II was mainly separated by color and soluble solids contents and by reducing-sugars. In the last case, the group III interestingly was separated by starch, firmness and Angle hue. Both of these variables are directly controlled by 1-MCP concentrations and stage of fruit ripening process (See in Fig.4B).

Discussion

The 1-MCP as an inhibitor of ethylene perception has been investigated in a large number of researches as an agent maintaining the quality as well as to investigate the role of ethylene in ripening and senescence of many fruits and vegetables (Dek et al., 2018), including bananas (Harris *et al.*, 2000; Zhu *et al.*, 2015). These responses are also investigated alone, or in association with different agents such as chitosan (Qiuping and Wenshui, 2007), and hormones (Zhu et al., 2015) as well as atmospheric modification (Vilas-Boas and Kader, 2006). However, according with Blankenship and Dole (2003) the 1-MCP treatment depend on numerous factors and are dependent on plant material. In banana, with at least 5 and 50 nL.L^{-1} had no effect on unripe bananas, 500 nL.L^{-1} delayed ripening (Harris et al., 2000). However, few works has associated the 1-MCP treatment associated with low density polyethylene packaging in the preservation and maintenance of postharvest quality as well as its effects on the metabolism of sugars and banana, once 1-MCP has a strong completive ability with ethylene receptors and suppress the respiration and climacteric peck in fruit (Blankenship and Dole, 2003; Harris et al., 2000; Lima *et al.*, 2010).

This search becomes pertinent, since it is known that one of the factors that most affects the responses to 1-MCP is the active concentration and treatment duration and the relation between concentrations exposing time are directly interdependent (Bagnato *et al.*, 2003). In our study, the 1-MCP treatment associated low density polyethylene packaging in the preservation can effectively delay ripening via significantly changes in physical (See in Fig.1 and Supplemental table S1), chemical (See in Fig.2 and Supplemental table S2) and physiological traits (See in Fig.3 and Supplemental table S3), delaying fruit firmness, skin color and controlling the cellular pH by increasing of malic acid which are directly associated with reparation rate. Consequently, the ratio SSC/TA is altered which is separated by PCA analysis in three independent group according fruit age and 1-MCP treatment (Fig.4). Additionally, the sugar content both, non-reducing and reducing-sugar are suppressed by 1-MCP treatment, which can be explained partially by starch degradation (Fig. 3D). Starch degradation is delayed over fruit ripening by 1-MCP treatment driving a few alterations in sugars and soluble solids contents. Therefore, reducing in sugar/starch ration in treated fruit was reduced in comparison with untreated fruits (Fig.3E). Overall, our data indicate that the conversion of starch to sugars is in good agreement with fruit softening and ethylene production during banana ripening.

The influence of 1-MCP treatment in respiration and ethylene production is already well documented by Jiang et al. (1999) and (Harris et al., 2000). Therefore, the reduction in respiration rate is possibly the result of reduction in several essential respiratory steps such as, glycolysis and TCA, as well as phosphorylating chain (OXPHOS), decreasing the ATP production and starting the anaerobic pathway, resulting in lower SSC due to the slower hydrolysis of carbohydrates (Starch to sugars) (Araujo *et al.*, 2012; Krebs, 1937). Our results show that 1-MCP and low density polyethylene packaging might be a viable alternative to extend the post-harvest life of banana and function as a controlling agent of the nutritional levels. In agreement with those found by (Purgatto *et al.*, 2002)which banana fruit ripening is characterized by textural softening, sugar content, acidity and color changes. In addition, Ziliotto *et al.* (2008) have shown in transcriptome profiling of ripening nectarine treated with 1-MCP has in comparison with untreated fruit after 24h, 106 targets differentially genes were expressed and 30% of their targets correspond to gene involved in primary metabolism related with ethylene and other phytohormones as well as some gene involved in softening, skin color development and sugar metabolism. Interestingly, in our results, angle hue (º*h*) is an important skin-color parameters to identify the sugar content in banana fruit, hence they shows a higher and positive correlation with starch content and been an important variable that has contributed to separate groups in PCA analysis (See in Fig.4A and Fig.5).

Faced to physical variables changes, such as Firmness, *L*, hº* and chrome, the firmness reduced during maturation for all treatments, however the fruit softening was reduced following the increase in the 1-MCP concentrations, resulting in a smaller loss of firmness after removal of the refrigerated chamber. According with Ali *et al.* (2004), the fruit softening occurs due to deterioration of structural and non-structural carbohydrates such as, cell wall and-or starch oxidation, resulting in an increase in the sugars content. In banana fruit softening were reported by a coordinated degradation of pectic, hemicellulosic polysaccharides in the cell wall and starch (Shiga *et al.*, 2011). In banana, several gene is are involved in starch-to-sugars conversions during ripening process has been reported, including the amylases such as *MAmy*, *Ma-bms*, *Maisa* and *MaDEBs* (Bierhals *et al.*, 2004; do Nascimento *et al.*, 2006; Jourda *et al.*, 2016; Junior *et al.*, 2006). Recently, Xiao *et al.* (2018) has shown a complex actions of numerous enzymes related to starch breakdown at transcriptional and translational levels and proved that MabHLH6 may act as a positive regulator of this process via activation of a series of starch degradation-related genes. Taken together, our study suggests that 1-MCP treatment can be involved regulating somehow the starch-degradation gene and acting mediating partially transcription factors responsive to ethylene. In the same way, according with Zewter et al. (2012), bananas treated with 1-MCP kept in a package of non-perforated polyethylene, showed an increase in total sugars, provided by conversion of starch to sugar, as with the advancement of ripening a decline occurs after reaching a certain peak when the fruits enter the senescence phase. In summary, the treatment 100, 150 and 200 ηL.L-¹ de 1-MCP in bananas 'Prata Gorutuba' for 8 hours delay the ripening in approximately 25 days, when packed in PEDB and stored under refrigeration (14.5°C), without changes in their physical and chemical characteristics. In complement, our results suggest 1-MCP treatment effectively prolongs the quality attributes not compromising the normal ripening after removal of package and kept in room temperature (25ºC), accumulating sugars by starch degradation. Furthermore, the correlation pattern of physical and chemical attributes demonstrates thus the dependence of ethylene action and of the interplay between these events despite mechanism to be distinct and act in different area in the fruit.

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Highlights

- 1-MCP is an effective treatment to control sugar and starch metabolism in banana.
- Skin color changes is an important predictive variable to identify changes in the central metabolism in banana fruits.
- Ethylene action is an interplay of physical and chemical changes in banana fruit.

Figures

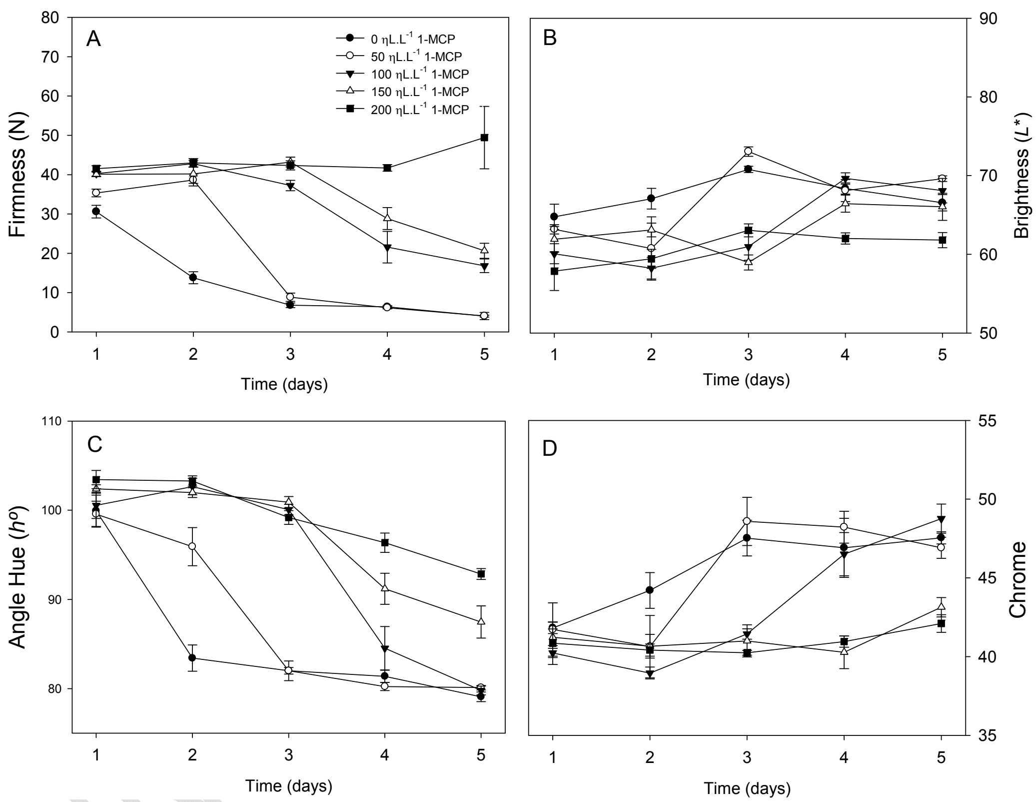


Fig. 1 – Physical quality attributes in banana cv. Prata Gorutuba (*Musa* AAB 'Prata Anã') under different concentrations of 1-MCP during 5 times of storage in room temperature. **A**: Firmness, **B**: Brightness, **C**: Angle hue and **D**: Chrome. Each value is the mean for four replicates, and vertical bars indicate the standard errors (n = 5).

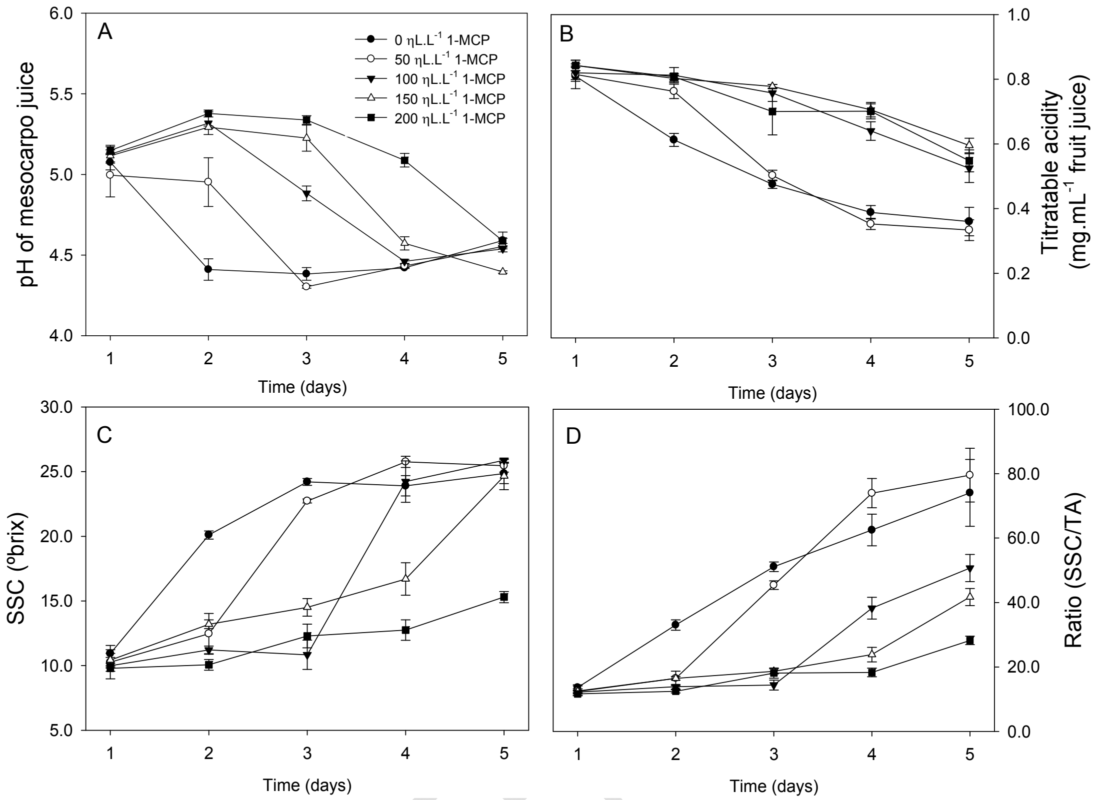


Fig. 2 – Chemical traits of quality in banana cv. Prata Gorutuba (*Musa* AAB 'Prata Anã') under different concentrations of 1-MCP during 5 times of storage in room temperature. **A**: pH of mesocarp juice, **B**: Titratable acidity, **C**: SSC and D: SSC/TA. Each value is the mean for four replicates, and vertical bars indicate the standard errors (n = 5).

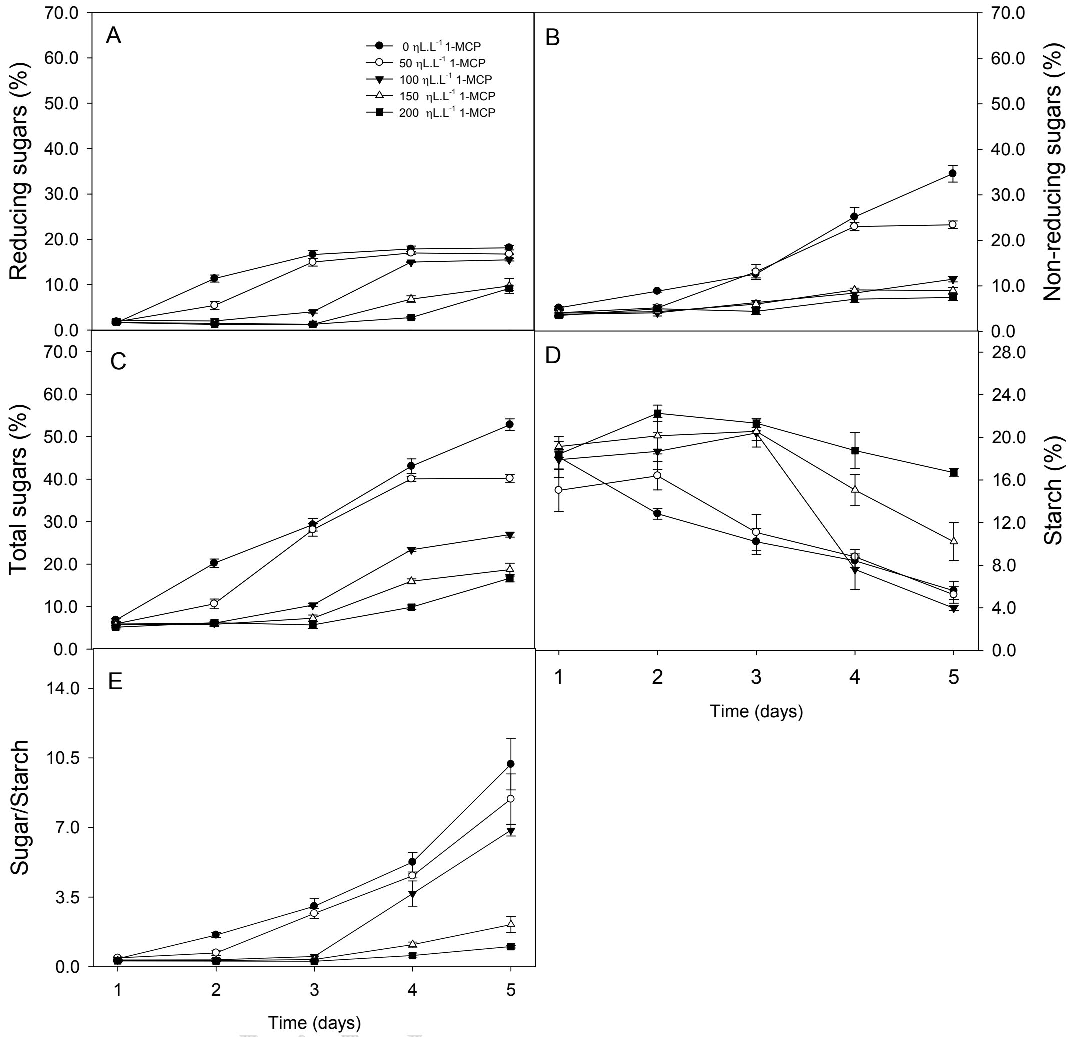


Fig.3 - Physiological traits of quality in banana cv. Prata Gorutuba (*Musa* AAB 'Prata Anã') under different concentrations of 1-MCP during 5 times of storage in room temperature. **A**: Reducing sugars content, **B**: Non-reducing sugars content, **C**: Total sugar content **D**: Starch content and **E**: Sugar/Starch ratio. Each value is the mean for four replicates, and vertical bars indicate the standard errors (n = 5).

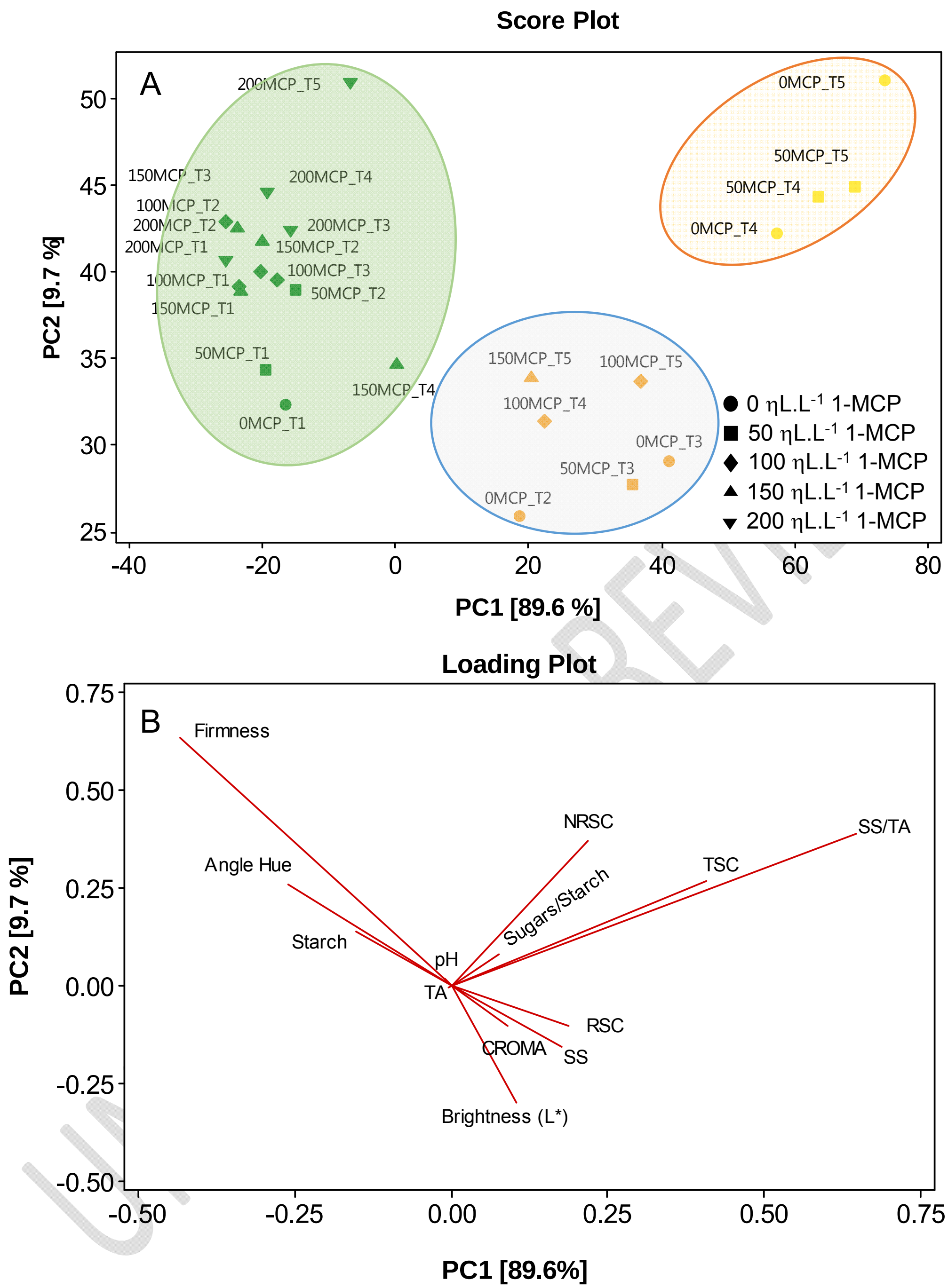


Fig.4 - Principal component analysis. (A) Score plot derived data of 1-MCP treatment under different days after treatment [0 days (T1), 1 day (T1), 2 days (T2), 3 days (T3), 4 days (T4) and 5 days (T5). The large circles represent the three clusters formed by the Euclidean distance method. (B) In loading plot the direction and length of the lines are directly proportional to variables importance in separating groups. PC1, principal component 1; PC2, principal component 2. Abbreviations: Hidrogenionic potential (pH), NRSC (Non-reducing sugar content), Total sugar content (TSC), Reducing sugar content (RSC), Soluble solids content/Titratable acidity ratio (SS/TA), Soluble solids content (SS), Titratable acidity (TA).

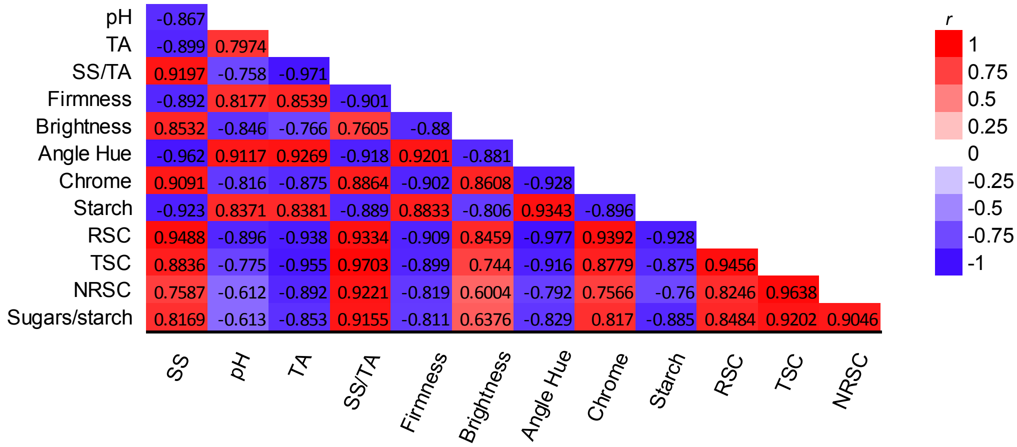
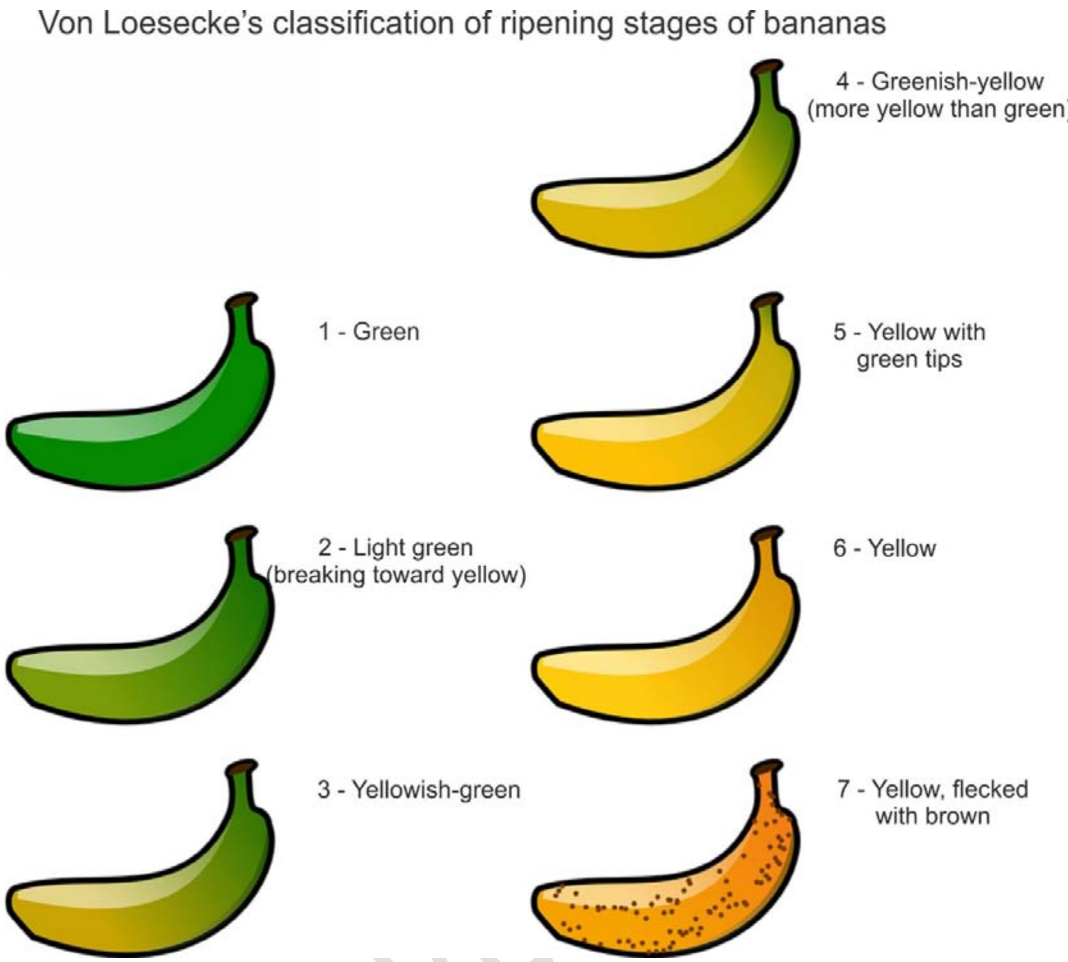


Fig. 5. Correlation matrix based on Pearson coefficients derived from physical, chemical and physiological trails data from banana cv. Prata Gorutuba (*Musa* AAB 'Prata Anã') under different concentrations of 1-MCP during 5 times of storage in room temperature. Correlation coefficients are presented in colors, and the significant ones are indicated in bold (P) based on p-value corrected by FDR correction (Bonferroni-Hochberg). Abbreviations: Hidrogenionic potential (pH), NRSC (Non-reducing sugar content), Total sugar content (TSC), Reducing sugar content (RSC), Soluble solids content/Titratable acidity ratio (SS/TA), Soluble solids content (SS), Titratable acidity (TA).

Supplemental Figure

Supplemental Fig.S 1 – Representative figure of banana ripening under different 1-MCP concentration in 4 replicates after 25 days stored at 14 ºC.



Supplemental Fig. S2. Color index scheme number of banana ripening. Banana's ripening pattern during the final development of fruits. Scale marking of color changes of the skin color 1 (green), 2 (light green), 3 (yellowish-green), 4 (greenish-yellow), 5 (yellow with green tips), 6 (yellow) and finally 7 (yellow, flecked with brown). Adapted from CQH/CEAGESP. 2003. São Paulo (CEAGESP, 2009. Doc.33).

Supplemental table S1. Effect of 1-MCP on banana fruits stored at 14.5 ºC on physical quality parameters during 5 days at shelf life. Each value is the mean for four replicates ± standard error (n = 5).

Treatment	**Time after treatment**				
ηL.L^{-1} of 1-MCP	**1**	**2**	**3**	**4**	**5**
***Firmness* (N)**					
0	30.59 ± 1.61 bA	13.78 ± 1.52 bB	6.78 ± 0.57 bC	6.41 ± 0.30 cC	4.03 ± 0.23 cD
50	35.33 ± 0.99 abA	38.65 ± 1.54 aA	8.84 ± 1.06 bB	6.16 ± 0.31 cB	4.06 ± 0.90 cC
100	40.26 ± 0.62 abA	42.81 ± 0.84 aA	37.23 ± 0.32 aA	21.58 ± 4.01 bB	16.83 ± 1.72 bB
150	40.10 ± 0.60 abA	40.19 ± 2.43 aA	43.22 ± 1.23 aA	28.84 ± 1.79 bB	20.63 ± 1.91 bB
200	41.54 ± 0.71 aA	43.00 ± 1.09 aA	42.37 ± 1.19 aA	41.71 ± 0.82 aA	49.42 ± 7.94 aA
Brightness (L*)					
0	64.75 ± 1.61 aA	67.07 ± 1.31 aA	70.80 ± 0.40 aA	68.36 ± 0.72 abA	66.56 ± 1.04 abA
50	63.18 ± 0.59 abBC	60.74 ± 4.02 abC	73.05 ± 0.60 aA	68.10 ± 1.41 abAB	69.61 ± 0.36 aAB
100	60.07 ± 1.27 abB	58.24 ± 1.37 bB	60.97 ± 1.72 bB	69.64 ± 0.73 aA	68.09 ± 1.55 abA
150	61.91 ± 1.62 abAB	63.09 ± 0.88 abAB	58.96 ± 0.96 bB	66.43 ± 1.09 abA	66.04 ± 1.72 abA
200	57.86 ± 2.46 bA	59.42 ± 1.22 bA	63.04 ± 0.83 bA	62.01 ± 0.72 bA	61.81 ± 0.96 bA
Angle hue (*h*)					
0	94.56 ± 1.67 aA	83.42 ± 1.47 cB	81.99 ± 1.10 bB	81.38 ± 0.67 bB	79.08 ± 0.54 cC
50	99.57 ± 1.46 aA	95.92 ± 2.13 bA	82.00 ± 0.37 bB	80.23 ± 0.45 bC	80.11 ± 0.24 cC
100	100.55 ± 1.47 aA	102.65 ± 0.92 aA	100.07 ± 0.58 aA	84.53 ± 2.43 bB	79.79 ± 0.49 cC
150	102.39 ± 0.47 aA	101.98 ± 0.53 aA	100.90 ± 0.63 aA	91.20 ± 1.74 aB	87.46 ± 1.81 bB
200	103.43 ± 1.02 aA	103.28 ± 0.57 aA	99.19 ± 0.77 aAB	96.36 ± 1.09 aBC	92.86 ± 0.61 aC
Chrome (*C*)					
0	41.83 ± 0.36 aB	44.20 ± 1.13 aAB	47.52 ± 1.13 aA	46.91 ± 1.88 aA	47.54 ± 0.38 abA
50	41.72 ± 1.69 aB	40.63 ± 1.97 abB	48.59 ± 1.53 aA	48.22 ± 1.01 aA	46.91 ± 0.67 abA
100	40.23 ± 0.29 aB	38.96 ± 0.37 bB	41.44 ± 0.33 bB	46.51 ± 1.37 aA	48.76 ± 0.92 aA
150	39.23 ± 0.53 aA	40.66 ± 0.75 abA	41.00 ± 1.02 bA	40.27 ± 1.04 bA	43.14 ± 0.61 bcA
200	40.85 ± 1.35 aA	40.41 ± 0.38 abA	40.24 ± 0.15 bA	40.95 ± 0.35 bA	42.10 ± 0.56 cA

*Means followed by the same lower case letters in a column and capital letters on the lines do not differ significantly by the Tukey test ($P < 0.05$).

Supplemental table S2. Effect of 1-MCP on banana fruits stored at 14.5 ºC on chemical quality parameters during 5 days at shelf life. Each value is the mean for four replicates ± standard error (n = 5).

Treatment	**Time after treatment**				
ηL.L-1 of 1-MCP	**1**	**2**	**3**	**4**	**5**
pH					
0	5.08 ± 0.04 aA	4.47 ± 0.02 cB	4.38 ± 0.04 cB	4.42 ± 0.01 bB	4.59 ± 0.05 aB
50	4.99 ± 0.13 aA	4.95 ± 0.15 bA	4.30 ± 0.01 cB	4.43 ± 0.01 bB	4.55 ± 0.00 aB
100	5.13 ± 0.05 aAB	5.32 ± 0.07 aA	4.88 ± 0.05 bB	4.46 ± 0.01 bC	4.54 ± 0.02 aC
150	5.11 ± 0.03 aA	5.29 ± 0.01 aA	5.23 ± 0.08 bB	4.57 ± 0.04 bB	4.40 ± 0.01 aB
200	5.14 ± 0.02 aAB	5.38 ± 0.02 aA	5.34 ± 0.02 aAB	5.09 ± 0.04 aB	4.59 ± 0.02 aC
AT					
0	0.81 ± 0.04 aA	0.61 ± 0.02 bB	0.48 ± 0.01 bC	0.39 ± 0.02 bC	0.36 ± 0.05 bC
50	0.82 ± 0.02 aA	0.76 ± 0.02 bA	0.50 ± 0.02 bB	0.35 ± 0.02 bC	0.33 ± 0.03 bC
100	0.82 ± 0.02 aA	0.81 ± 0.02 a A	0.76 ± 0.03 aAB	0.64 ± 0.03 aBC	0.53 ± 0.04 aC
150	0.84 ± 0.02 aA	0.80 ± 0.01 aAB	0.78 ± 0.01 aAB	0.71 ± 0.02 aBC	0.60 ± 0.02 aC
200	0.84 ± 0.02 aA	0.81 ± 0.01 aAB	0.70 ± 0.07 aB	0.70 ± 0.02 aB	0.55 ± 0.03 aC
SSC					
0	10.93 ± 0.30 aC	20.10 ± 0.32 aB	24.20 ± 0.26 aA	23.90 ± 0.79 aA	24.85 ± 0.79 aA
50	10.27 ± 1.29 aB	12.46 ± 1.58 bB	22.73 ± 0.15 aA	25.75 ± 0.43 aA	25.45 ± 0.48 aA
100	10.00 ± 0.19 aB	11.22 ± 0.29 bB	10.84 ± 1.13 cB	24.23 ± 1.59 aA	25.88 ± 0.15 aA
150	10.43 ± 0.51 aC	13.20 ± 0.34 bBC	14.51 ± 0.68 bB	16.70 ± 1.26 bB	24.65 ± 1.04 aA
200	9.79 ± 0.23 aC	10.06 ± 0.41 bBC	12.29 ± 0.91 bcB	12.75 ± 0.79 cB	15.30 ± 0.43 bA
SSC/AT					
0	13.66 ± 0.85 aD	33.03 ± 1.63 aC	51.10 ± 1.49 aB	62.50 ± 4.92 aAB	74.02 ± 10.36 aA
50	12.58 ± 1.53 aC	16.46 ± 2.25 bC	45.39 ± 1.32 aB	73.94 ± 4.53 aA	79.51 ± 8.32 aA
100	12.22 ± 0.37 aB	13.89 ± 0.72 bB	14.40 ± 1.55 bB	38.26 ± 3.39 bA	50.70 ± 4.23 bA
150	12.42 ± 0.79 aB	16.47 ± 0.57 bB	18.64 ± 0.79 bB	23.83 ± 2.25 bcB	41.72 ± 2.66 bcA
200	11.66 ± 0.49 aB	12.46 ± 0.48 bB	18.11 ± 1.61 bAB	18.29 ± 1.36 cAB	28.24 ± 1.32 cA

*Means followed by the same lower case letters in a column and capital letters on the lines do not differ significantly by the Tukey test (*P*< 0.05).

Supplemental table S3. Effect of 1-MCP on banana fruits stored at 14.5 ºC on physiological quality parameters during 5 days at shelf life. Each value is the mean for four replicates ± standard error (n = 5).

Treatment ηL.L-1 of 1-MCP	Time after treatment 1	2	3	4	5
RSC					
0	1.64 ± 0.203 aC	11.36 ± 0.779 aB	16.66 ± 0.904 aA	17.89 ± 0.617 aA	18.15 ± 0.473 aA
50	1.84 ± 0.325 aC	5.42 ± 0.921 bB	14.97 ± 0.871 aA	17.00 ± 0.271 abA	16.74 ± 0.054 abA
100	2.12 ± 0.266 aB	2.01 ± 0.203 cB	4.01 ± 0.284 bB	14.98 ± 0.093 bA	15.49 ± 0.262 bA
150	1.67 ± 0.053 aC	1.51 ± 0.090 cC	1.26 ± 0.013 cC	6.83 ± 0.704 cB	9.73 ± 1.633 cB
200	1.66 ± 0.186 aB	1.24 ± 0.104 cB	1.27 ± 0.197 cB	2.75 ± 0.269 dB	9.20 ± 0.531 cA
NRSC					
0	5.18 ± 0.368 aD	8.85 ± 0.230 aCD	12.62 ± 0.869 aC	25.15 ± 2.087 aB	34.65 ± 1.857 aA
50	4.10 ± 0.863 aC	5.20 ± 0.649 abC	13.10 ± 1.642 aB	23.04 ± 0.866 aA	23.42 ± 0.858 bA
100	3.77 ± 0.301 aC	4.09 ± 0.680 bC	6.35 ± 0.359 bBC	8.42 ± 0.461 bAB	11.47 ± 0.569 cA
150	4.05 ± 0.556 aB	4.34 ± 0.334 bB	6.01 ± 0.753 bAB	9.11 ± 0.391 bA	8.97 ± 0.680 cdA
200	3.50 ± 0.327 aB	4.99 ± 0.279 abAB	4.41 ± 0.737 bAB	7.09 ± 0.750 bAB	7.50 ± 0.693 dA
TS					
0	6.82 ± 0.408 aE	20.21 ± 0.996 aD	29.28 ± 1.492 aC	43.04 ± 1.749 aB	52.80 ± 1.389 aA
50	5.94 ± 0.556 aD	10.62 ± 1.147 bC	28.07 ± 1.468 aB	40.04 ± 0.596 aA	40.16 ± 0.884 bA
100	5.89 ± 0.191 aC	6.10 ± 0.777 cC	10.36 ± 0.360 bB	23.40 ± 0.434 bA	26.96 ± 0.583 cA
150	5.72 ± 0.575 aB	5.84 ± 0.382 cB	7.27 ± 0.751 bcB	15.94 ± 0.597 cA	18.69 ± 1.516 dA
200	5.16 ± 0.399 aC	6.23 ± 0.247 cBC	5.68 ± 0.884 cC	9.84 ± 0.551 dB	16.70 ± 0.912 dA
Starch					
0	18.15 ± 1.919 aA	12.83 ± 0.516 cAB	10.21 ± 1.231 bBC	8.42 ± 0.638 bBC	5.60 ± 0.838 bcC
50	15.03 ± 2.000 aA	16.39 ± 1.326 bcA	11.08 ± 1.677 bAB	8.78 ± 0.081 bBC	5.23 ± 0.799 bcC
100	17.92 ± 0.949 aA	18.69 ± 1.734 abA	20.41 ± 1.321 aA	7.60 ± 1.867 bB	3.97 ± 0.229 cB
150	19.14 ± 0.496 aA	20.15 ± 1.700 abA	20.57 ± 0.831 aA	15.05 ± 1.469 aAB	10.21 ± 1.782 bB
200	18.42 ± 0.310 aA	22.26 ± 0.777 aA	21.33 ± 0.414 aA	18.76 ± 1.687 aA	16.70 ± 0.401 aA
Sugar/Starch					
0	0.40 ± 0.053 aD	1.59 ± 0.125 aCD	3.04 ± 0.37 aC	5.25 ± 0.49 aB	10.18 ± 1.29 aA
50	0.43 ± 0.088 aC	0.69 ± 0.137 aC	2.67 ± 0.24 aB	4.56 ± 0.10 aB	8.43 ± 1.26 abA
100	0.33 ± 0.011 aC	0.34 ± 0.058 bC	0.51 ± 0.02 bC	3.67 ± 0.64 aB	6.86 ± 0.28 bA
150	0.30 ± 0.032 aA	0.30 ± 0.031 bA	0.35 ± 0.02 bcA	1.11 ± 0.12 bA	2.11 ± 0.40 cA
200	0.28 ± 0.025 aA	0.28 ± 0.011 bA	0.27 ± 0.04 cA	0.55 ± 0.08 bA	1.01 ± 0.07 cA

*Means followed by the same lower case letters in a column and capital letters on the lines do not differ significantly by the Tukey test (*P*< 0.05).