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Commercial fast-cooling programs for 'Rosa' mango: Impacts on fruit quality[1]

Programas comerciais de resfriamento rápido para manga 'Rosa': Impactos na qualidade da fruta

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HIGHLIGHTS:
Effects of commercial fast-cooling are important for post-harvest quality of 'Rosa' mango.
The relationship among cooling, cold storage, and fruit position influences the shelf-life of the product.
Choosing a time program for 'Rosa' mango contributes to its fast-cooling efficiency.

ABSTRACT: This study aimed to verify the impact of commercial fast-cooling programs on physicochemical quality of 'Rosa' mangoes. The study was carried out in a mango packing house in the São Francisco Valley region, Petrolina, PE, Brazil, between August and October 2018. The experiment followed a randomized block design, with three replicates and one pallet per replicate. The treatments were organized in a factorial scheme 2 × 2 × 3 (two fast-cooling times [120 and 240 min] × two storage times x three positions in the pallet). Sixty mangoes were proportionally distributed in three layers at different heights on each of the six pallets. Three pallets were subjected to fast cooling for 120 min and the other three for 240 min. All fruits were stored for 7 and 14 days at 6 °C plus three days of shelf-life at 20 °C. Regardless of cooling program and fruit position in the pallet, the seven-eighths cooling time (SECT) was not attained. The titratable acidity of fruits under 240-min fast cooling decreased significantly after 14 days of cold storage. Fruit weight loss, pulp firmness, dry matter, and soluble solids content were not affected by the fast-cooling programs, both after storage and during shelf-life period. Commercial fast-cooling program can be performed for 120 min.

Key words: cold storage, postharvest analysis of mango, physicochemical variables

RESUMO: Este estudo teve como objetivo verificar o impacto de programas comerciais de resfriamento rápido na qualidade físico-química de mangas 'Rosa'. O estudo foi realizado em um packing house de mangas na região do Vale do São Francisco, Petrolina, PE, Brasil, entre Agosto e Outubro de 2018. O experimento seguiu um delineamento em blocos casualizados com três repetições e um palete por repetição. Os tratamentos foram organizados em esquema fatorial 2 × 2 × 3 (dois tempos de resfriamento rápido [120 e 240 min] × dois tempos de armazenamento x três posições no palete). Sessenta mangas foram distribuídas proporcionalmente em três camadas de diferentes alturas em cada um dos seis paletes. Três paletes foram submetidos ao resfriamento rápido por 120 min e outros três por 240 min. Todas as frutas foram armazenadas por 7 e 14 dias a 6 °C mais três dias de vida de prateleira a 20 °C. Independentemente do programa de resfriamento e da posição da fruta no palete, o tempo de resfriamento de sete oitavos (SECT) não foi alcançado. A acidez titulável do fruto com 240 min de resfriamento rápido diminuiu significativamente após 14 dias de armazenamento refrigerado. A perda de peso das frutas, a firmeza da polpa, a matéria seca e o teor de sólidos solúveis não foram afetados pelos programas de resfriamento rápido, tanto após o armazenamento quanto durante a vida de prateleira. O programa comercial de resfriamento rápido pode ser executado por 120 min.

Palavras-chave: armazenamento à frio, análises pós-colheita de mangas, variáveis físico-químicas

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Introduction

Mango (*Mangifera indica* L.) is an important fruit crop in many tropical regions worldwide. Brazil is the seventh largest mango producer, with its production mostly concentrated in the São Francisco Valley, which is a region between the states of Bahia and Pernambuco, encompassing nearly 60% of the national mango production (FAOSTAT, 2017; CEPEA, 2019).

Mango is a highly perishable fruit and requires postharvest technologies to maintain its quality from harvest to the consumers' table. One of these techniques is fast cooling after harvest, which reduces fruit temperature and metabolic activity prior to cold storage (Zhang et al., 2012; Vasconcelos et al., 2019).

The prerequisites for the use of cooling programs are thermophysical heat transfer properties, product shape and size, packaging type, and storage place (Brosnan & Sun, 2001; Teruel, 2008). Environmental thermal variations, selection of specific cooling programs, and storage conditions have a great influence on fruit quality and thus affect their commercial value (Farina et al., 2017).

Inefficient cooling programs after harvest can lead to quantitative and qualitative losses, impacting the entire mango chain from growers to consumers. Although many studies have been conducted on fast-cooling systems for fruits, most of them were performed under laboratory conditions but not commercial conditions.

Studies under commercial conditions may generate subsidies to understand the relationship between mango quality characteristics and fast-cooling program efficiency. The information obtained can help optimize cooling programs and hence control fruit quality problems (Azene et al., 2011). Therefore, this study aimed to verify the impact of commercial fast-cooling programs on physicochemical quality of 'Rosa' mangoes.

Material and Methods

The study was carried out in a mango packing house located in the São Francisco Valley region, Petrolina, PE, Brazil (9° 23' 39" S, 40° 30' 35" W), between August and October 2018.

Mangoes (*Mangifera indica* L.) of the Rosa variety were harvested at maturity stages between 4 and 5 (Santos et al., 2008) with a caliber index nine, and then transported to the packing house. Sixty fruits were sorted and packed in twelve 4-kg double-walled cardboard cartons. These packages were used to assemble six pallets (1.14 × 1.08 × 1.20 m), which were made up of 84 boxes stacked in seven layers. On each pallet, the fruits were distributed proportionally into bottom, middle, and top layers. From the six pallets, three were subjected to fast cooling for 120 min and the other three for 240 min.

The cooling room measured 3.35 × 5.71 × 3.00 m and contained two asynchronous industrial coolers, with unidirectional forced airflow (2.7 m s^{-1}). The room operated within a temperature range of 7 to 10 °C and average relative air humidity of 70%.

After applying the fast-cooling programs, the pallets were stored in a cold room with dimension of 4.48 × 5.71 × 3.00 m for 7 and 14 days. This room contained a compressor of 5.5 hp and operated within a temperature range of 5 to 9 °C, with a set point at 6 °C and average relative air humidity of 90%. After the storage, the fruits were exposed to shelf-life conditions for three days at 20 °C.

Temperature was monitored by four Hobo U12 External Data Logger sensors (Onset Computer Corporation, Massachusetts, USA), with an accuracy of ± 0.35 °C. Thermocouple probes connected to the data logger sensors were individually inserted into the flesh of four mangoes in each pallet layer (Figure 1). All data were recorded within a one-minute sampling interval.

The experiment followed a randomized block design, with three replicates and one pallet per replicate. Treatments were organized in a factorial scheme 2 × 2 × 3 (two fast-cooling programs x two storage times x three positions in the pallet).

The performances of the cooling programs were evaluated using half cooling time (HCT) and seven-eighths cooling time (SECT), which are calculated using the fractional unaccomplished temperature change (Brosnan & Sun, 2001) (Eq. 1).

$$\check{T}\alpha\ (t) = \frac{T\alpha(t) - TA}{T\alpha,0(t) - TA} \quad (1)$$

wherein:

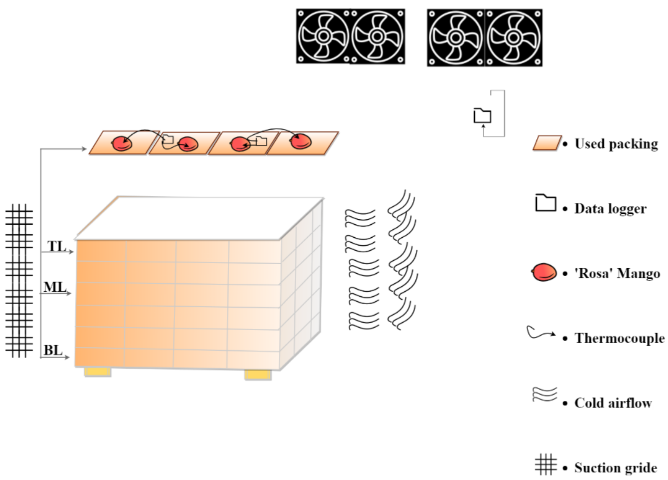
$\check{T}\alpha$ (t) - cooling rate (fractional unaccomplished temperature change), dimensionless;

$T\alpha$ (t) - fruit temperature over time, °C;

$T\alpha,0$ - initial temperature of the fruit, °C; and,

TA - refrigeration temperature, °C.

The HCT ($\check{T}\alpha$ [t] = 0.5) is a dimensionless value within which a fruit reaches an average temperature between its initial temperature and environmental temperature. The SECT ($\check{T}\alpha$ [t] = 0.125) is a dimensionless value representing the 7/8 of the cooling time, which is the difference between fruit initial temperature and environmental temperature. When fruits reach the SECT, they are at an ideal temperature for cold storage (Mohsenin, 1980). A curve of fruit cooling temperature with time was modeled using VariCool v1.0 software (Olatunji et al., 2017).



BL - Bottom layer; ML - Middle layer; TL - Top layer

Figure 1. Diagram of the fast-cooling room with a pallet and thermal sensors connected to fruits in each layer

Mangoes were subjected to physicochemical analysis for weight loss, pulp firmness, dry matter, soluble solids content, and titratable acidity. Half of the fruits were evaluated at the end of storage (7 and 14 days) and the other half after the shelf-life time (three days).

Weight loss was determined by weighing fruits on a semi-analytical scale (Mars AS 1000 C, São Paulo, Brazil) with an accuracy of ± 0.01 g, before (initial weight) and after (final weight) each postharvest treatment (Eq. 2).

$$WL = \frac{IW - FW}{IW} 100 \tag{2}$$

wherein:

WL - percentage of weight loss, %;
IW - initial weight of fruit, g; and,
FW - final weight of fruit, g.

Pulp firmness was determined using a manual penetrometer (model FT 327, Wagner Instruments®), which consisted of a 6-mm-diameter stainless steel probe. Measurements were performed at two opposite points in the equatorial region of each fruit. The results were expressed as Newton (N).

Dry matter was measured as the difference between fresh (initial) and dry (final) weights of a fruit sample. To do so, samples were dried in an oven at 65 °C until constant weight (Eq. 3) (AOAC, 2016).

$$DM = \frac{FW}{IW} 100 \tag{3}$$

wherein:

DM - percentage of dry matter, %;
FW - final (dry) weight of sample, g; and,
IW - initial (fresh) weight of sample, g.

Contents of soluble solids were determined by a portable digital refractometer Pal-1 (Atago, São Paulo, Brazil), with an accuracy of ± 0.2%. Measurements were performed on 1-mL fruit juice samples. Results expressed as percentage of soluble solids per mL of mango juice.

Titratable acidity was determined by an automatic Titrino Plus titrator (Metrohm, São Paulo, Brazil). Measurements were made by titrating 1-g juice diluted with 50 mL distilled water and a 0.1-mol L^{-1} NaOH solution. Results were expressed as percentage of citric acid per g of juice.

At harvest time, twelve fruits were subjected to physicochemical analysis for initial characterization. The averages observed were flesh firmness of 21.6 N (± 2.1 N), dry matter of 20.2% (± 0.5%), soluble solids content of 14.2% (± 1.0%), and titratable acidity of 0.70%.

Data were subjected to analysis of variance (ANOVA) using the R 2.11.1 software (R Development Core Team, 2010). Means were compared by the Tukey's test at $p \leq 0.05$.

Results and Discussion

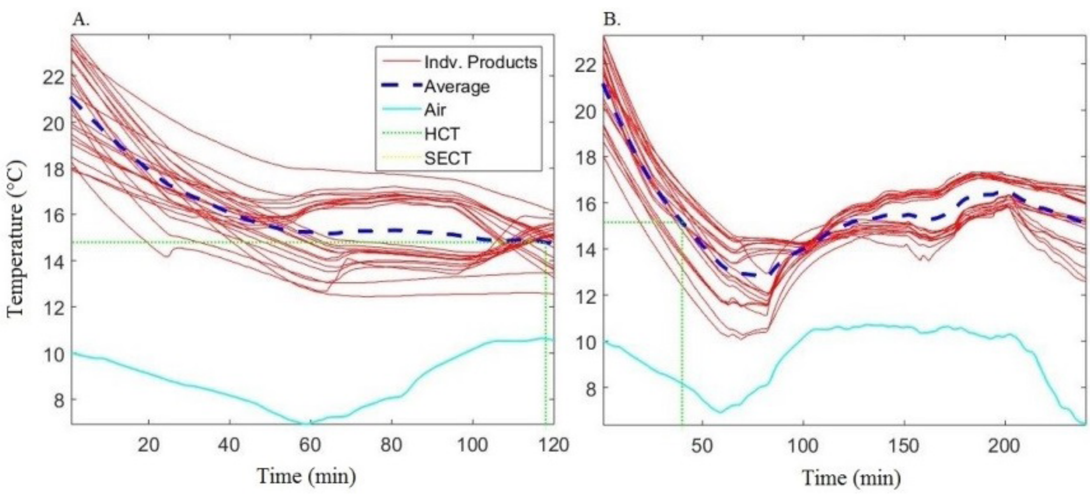
For both fast-cooling programs, 'Rosa' mangoes were introduced into the cooling room with an average temperature of 21 °C. It decreased significantly during the 5 min of cooling (Figure 2). The fruits subjected to 120-min fast cooling (Figure 2A) showed higher variability in flesh temperature than those subjected to 240-min fast cooling.

Average HCT for fruits subjected to 120-min fast cooling was 116 min, while for those under 240-min fast cooling it was 40 min. This result might be due to a higher speed and uniformity in cooling rates (Figure 2B).

After the HCT, external thermal interferences caused by movement of people in and out of the cold room increased air temperature, which noticeably reduced cooling rates and enhanced temperature variability.

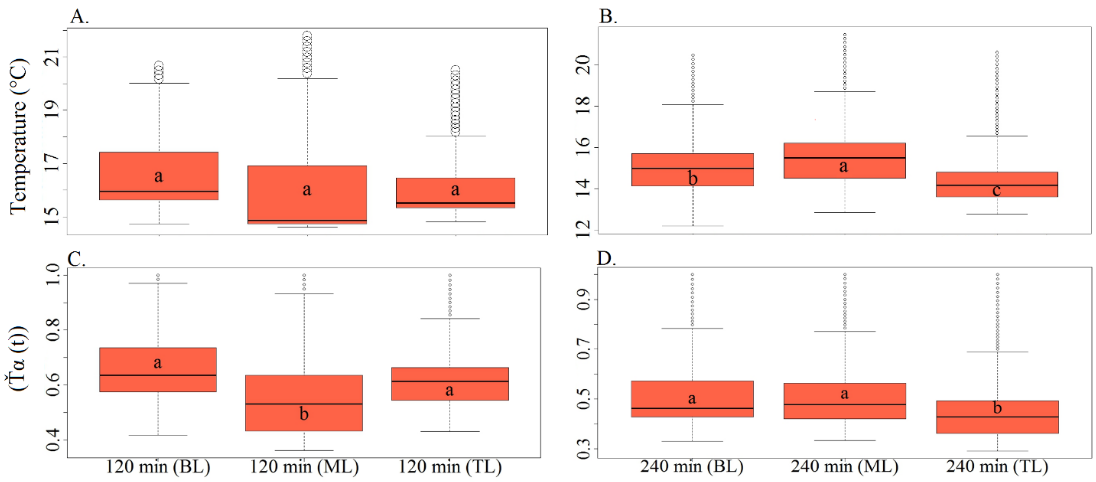
In a study on apple cooling, Han et al. (2017) showed that fruits tended to reach temperatures lower than the average between that of the beginning of the process and HCT, besides a trend to have higher temperatures than the average between HCT and SECT. According to the authors, the position of packages on pallets influences cooling rates and uniformity.

Figure 3 shows temperatures and cooling rates of fruit at different heights on the pallet. The lack of significant temperature differences ($p > 0.05$) demonstrates the homogeneity of 120-min cooling at different positions on the pallet. However, mangoes in the middle layer had greater



Air - Air temperature; HCT - Half cooling time; SECT - Seven-eighths cooling time; Indv. Products - Individual fruit temperatures; Average - Average temperature for the pallet

Figure 2. Experimental raw cooling curve for individual 'Rosa' mangoes under 120-min (A) and 240-min (B) fast cooling



BL - Bottom layer; ML - Middle layer; TL - Top layer; Boxplots followed by different letters are statistically different according to the Tukey's test at $p \leq 0.05$

Figure 3. Temperatures (A and B) and cooling rates (C and D) of 'Rosa' mangoes at different heights on the pallet under fast cooling for 120 and 240 min, respectively

temperature changes (Figure 3A). Conversely, cooling rates differed significantly, with fruits in the middle layer (ML) reaching the highest value (Figure 3C).

The mangoes subjected to 240-min fast cooling showed significant differences ($p \leq 0.05$) in temperature among the different fruit positions. The fruits placed on the top layer showed the lowest temperatures (Figure 3B). This must have occurred because the fruits were in the direction of the refrigerated air flow, promoting cooling rates below HCT (Figure 3D). Other studies on fast cooling of fruits already showed the influence of product height/position regarding air flow outlet on fruit temperature (Alvarez & Trystram, 1995; Ferrua & Singh, 2009; Wu et al., 2019).

In this study, fast-cooling programs (Figure 2) and their combination with fruit position on the pallet (Figure 3) were not efficient to make mangoes achieve the SECT. Reaching SECT is one of the hardest obstacles for commercial fast cooling, mainly because it could require longer times than those commonly adopted (Mercier et al., 2018). These results also show significant differences ($p \leq 0.05$) between the fast-cooling programs for fruit titratable acidity after cold storage for 7 and 14 days (Table 1).

The titratable acidity of fruits subjected to 240-min fast cooling decreased after 14 days of cold storage and reached stability after three days of shelf-life. Acidity decreased due to the oxidative degradation of citric acid, which is an organic substance essential for energy production during respiration of fruits in storage (Chitarra & Chitarra, 2005; Emongor, 2015; Nordey et al., 2016; Lawson et al., 2019).

After three days of shelf-life, mangoes of all treatments showed weight loss around 4.20 and 4.62%. Chitarra & Chitarra (2005) considered that weight losses between 3 and 6% cause a significant reduction in fruit quality; however, some fruits can be marketed with up to 10% weight loss without strongly affecting fruit appearance and quality (França et al., 2018).

Previous studies on mangoes of other varieties and other fruits have shown that weight loss from water loss is always continuous and independent of refrigeration during storage. In these studies, temperature and relative air humidity, when properly adjusted, influence metabolic process reduction, inhibiting fruit respiratory activity and carbon loss, as well as water loss from fruits to the environment (Azene et al., 2011; Chiumarelli et al., 2011; Wijewardane & Guleria, 2013).

However, the absence of significant differences between treatments may emphasize that the conditions imposed by the refrigerated environments kept weight loss at balanced levels.

Table 1. Physicochemical quality of 'Rosa' mangoes exposed to two fast-cooling programs and stored for 7 and 14 days at low temperatures plus three days of shelf-life at 20 °C

Fast cooling programs (min)	Cold storage programs (days)	Shelf days	
		0	3
		WL (%)	
120	7	1.75 ± 0.25 a	4.62 ± 0.39 a
	14	2.01 ± 0.09 a	4.45 ± 0.16 a
240	7	1.71 ± 0.34 a	4.20 ± 0.29 a
	14	2.62 ± 0.73 a	4.51 ± 0.31 a
CV (%)		28.58	12.97
		PF (N)	
120	7	14.77 ± 2.75 a	17.31 ± 3.47 a
	14	12.00 ± 2.52 a	15.71 ± 0.56 a
240	7	16.05 ± 1.77 a	20.24 ± 3.36 a
	14	14.85 ± 1.22 a	16.53 ± 1.56 a
CV (%)		18.29	17.95
		DM (%)	
120	7	19.25 ± 0.92 a	19.78 ± 0.58 a
	14	18.79 ± 0.77 a	19.40 ± 0.56 a
240	7	19.30 ± 0.26 a	19.81 ± 0.16 a
	14	18.43 ± 0.30 a	19.29 ± 1.18 a
CV (%)		3.90	4.25
		TSS (%)	
120	7	14.07 ± 1.06 a	14.57 ± 0.49 a
	14	14.30 ± 1.40 a	14.22 ± 0.87 a
240	7	13.51 ± 1.80 a	14.43 ± 0.21 a
	14	14.82 ± 1.34 a	14.67 ± 1.45 a
CV (%)		11.74	7.81
		TA (%)	
120	7	$0.79 \pm 3.53 \times 10^{-3}$ a	$0.80 \pm 1.70 \times 10^{-3}$ a
	14	$0.76 \pm 1.1 \times 10^{-16}$ ab	$0.77 \pm 9.43 \times 10^{-5}$ a
240	7	0.76 ± 0.06 ab	$0.80 \pm 4.71 \times 10^{-3}$ a
	14	0.56 ± 0.01 c	$0.79 \pm 6.27 \times 10^{-3}$ a
CV (%)		5.32	2.10

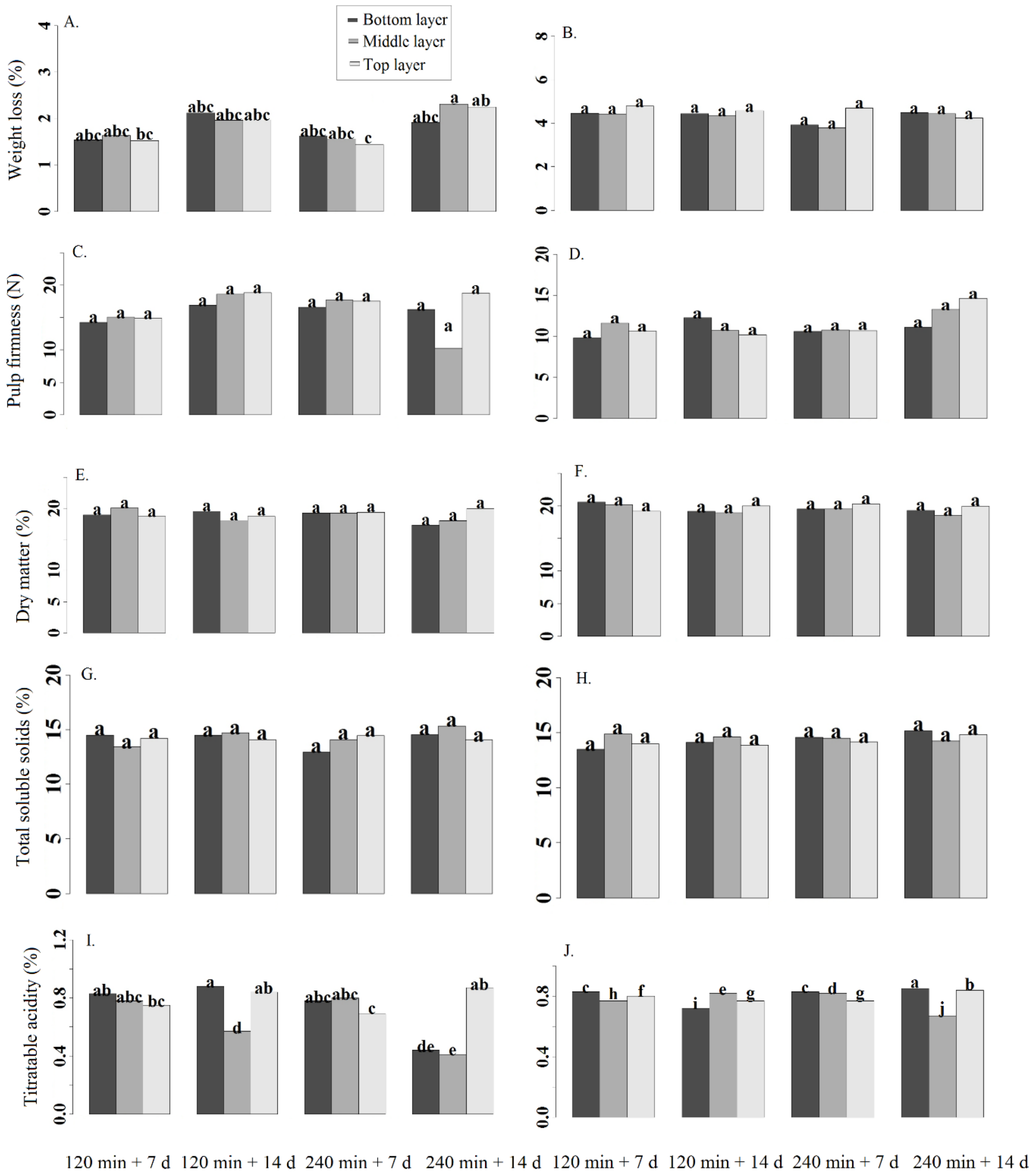
Mean values followed by the same letter within column do not differ statistically by the Tukey's test ($p \leq 0.05$). Means followed by ± standard deviation. WL - Weight loss; PF - Pulp firmness; DM - Dry matter; TSS - Total soluble solids; TA - Titratable acidity; CV - Coefficient of variation of variables evaluated

The lack of significant differences between fast-cooling programs for physicochemical quality variables such as pulp firmness, dry matter, and total soluble solids contents may be related to the fact that fruit were harvested at very advanced maturity stages when most of the ripening processes have already started.

Therefore, at such advanced maturity stages, most of the biochemical and structural transformations were already accomplished in the fruit (Goulao & Oliveira, 2008; Baloch & Bibi, 2012), decreasing the reducing effect of temperature on metabolic activities to maintain fruit quality (Sirisomboon et al., 2008).

Weight loss (Figure 4A) and titratable acidity (Figure 4I) were significantly affected by pallet heights after storage at low temperature and after three days of shelf-life (Figure 4J).

Fruits at the middle layer exposed to fast cooling for 240 min and stored at low temperature for 14 days showed the



min - Minutes; d - Days; Bars followed by different letters differ statistically according to the Tukey's test at $p \leq 0.05$

Figure 4. Effects of fast-cooling programs (120 and 240 min), storage time (7 and 14 days), and pallet heights (bottom, middle, and top layers) on mango weight loss (A and B), pulp firmness (C and D), dry matter content (E and F), total soluble solids (G and H), and titratable acidity (I and J) after cold storage (A, C, E, G, and I) and after cold storage plus three days of shelf-life (B, D, F, H, and J)

highest percentage of weight loss (2.31%), while the lowest (1.44%) was observed for fruits at the top layer exposed to fast cooling for 240 min and stored at low temperature for 7 days (Figure 4A).

Fruits at the middle layer exposed to fast cooling for 240 min and stored at low temperature for 14 days showed the lowest titratable acidity (0.41%) (Figure 4I). After three days of shelf-life, fruit at the bottom layer exposed to fast cooling for 240 min and stored at low temperature for 14 days showed the highest titratable acidity (0.85%), whereas those at the middle layer exposed to fast cooling for 240 min and stored at low temperature for 14 days had the lowest (0.67%) (Figure 4J).

The heterogeneity of cooling rates along the pallet heights may have exposed the middle layer to lower cold air volumes, maintaining higher temperatures; therefore, fruits in this layer had significant weight and titratable acidity reductions (Mukama et al., 2018).

After three days of shelf-life, treatments showed no statistical difference for fruit weight loss (Figure 4B). Moreover, treatments showed no significant differences for pulp firmness (Figures 4C, D), dry matter (Figures 4E, F), and total soluble solids content (Figures 4G, H) among pallet layers under all conditions studied.

In short, these findings indicated that air conditions and fruit location on pallets cause slight changes in physicochemical variables whether using a 120-min or 240-min fast-cooling program (Akdemir & Bal, 2019).

Conclusions

1. Fast cooling programs for 120 and 240 min followed by storage for 7 and 14 days affected titratable acidity of 'Rosa' mangoes, while the other physicochemical variables were not affected. However, weight loss increased up to 5% due to fruit exposure to the cooling conditions.

2. Weight loss and titratable acidity were significantly affected by pallet height for mangoes fast cooled for 240 min. Thermal conditions of the cooling room increased weight loss and acidity heterogeneity; therefore, relative air humidity should be managed to adjust humidity at the different pallet heights.

3. The absence of differences for most of the physicochemical quality variables in response to the fast-cooling programs suggests that the packing house should use the shortest fast-cooling program (120 min) to save time and energy for mango cooling.

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