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EFFECTS OF COMMERCIAL RAPID COOLING PROGRAMS ON 'ROSA' MANGO QUALITY

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KEYWORDS

postharvest, temperatures, forced-air cooling, conservation

ABSTRACT

Mango quality is affected by thermal storage conditions. Therefore, it is important to use cooling techniques and their monitoring to maintain desirable properties in the fruit. The objective of this study was to evaluate the effects of commercial rapid cooling programs on the quality of 'Rosa' mango. Mangoes were distributed on different horizontal positions of six pallets. All pallets were put through two rapid cooling times, three pallets for 120 minutes and three pallets for 240 minutes. Subsequently, the fruits were stored in a cold chamber for 7 and 14 days, followed by an evaluation of shelf life for 3 days at 20°C. Experimental design was in randomized blocks with three replicates, with one pallet per replicate. The weight, pH, and skin color of the fruit were assessed. According to the results, fruits closer to the air inlet in the packages showed the highest cooling rates. After storage and shelf life, quality parameters were not significantly affected by the rapid cooling programs. In conclusion, the 120-minute program can be satisfactorily adopted for the rapid cooling process of the 'Rosa' mango, considering the reduction of energy costs and the reduction of the dwell time of the fruit in the cold chamber.

INTRODUCTION

Mango (*Mangifera indica* L.) is one of the most cultivated fruits worldwide, and the second-largest agricultural crop in tropical territories, having as characteristics a varied constitution of carbohydrates and proteins (Canuto et al., 2009; Farina et al., 2017; Gentile et al., 2018). The largest amount, in tons, of production of the crop in Brazil is concentrated in the northeast region, with the states of Pernambuco (518,231 tons) and Bahia (442,233 tons) being the two largest producers (IBGE, 2019).

The extreme perishability, when associated with high postharvest temperatures, accelerates metabolic processes that result in loss of quality and consequent reduction of its shelf life. In this context, the implementation of cooling methods and chilled storage has been crucial to maintain physiological subsistence and preserve the integrity of commercial characteristics, highly valued by consumers (Redding et al., 2016; Zhang et al., 2017).

Rapid cooling by forced-air is widely used for agricultural products. This type of cooling can inhibit the pathogens growth, minimize water losses, increase fruit shelf life, and contribute to the design of cold rooms with lower energy costs (Elansari & Mostafa, 2018). At the commercial level, the inadequate adoption of rapid cooling programs can negatively affect the quality preservation process, and consequently, harm the entire mango production and marketing chain (O'sullivan, 2016; Berry et al., 2017).

There are many studies on fruit cooling, but most of them are being developed on laboratory scale. Investigations conducted in packing houses with commercial cooling systems are important to know the relationship between fruit quality and the dwell time in the chambers, which is established by hourly exposure programs (Elansari & Mostafa, 2018).

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Commercial research data may help to improve operational management practices of cooling programs, and to control the quality characteristics of the product. Thus, the objective of this work was to evaluate the effects of commercial rapid cooling programs on the quality of 'Rosa' mangoes.

MATERIAL AND METHODS

The study was conducted in a mango packing house in the São Francisco Valley region, Petrolina – PE (Brazil: 9° 23′ 39" S, 40° 30′ 35 "W). 'Rosa' mangoes (*Mangifera indica* L.) at the ripening stages between 4 and 5 (Santos et al., 2008) and caliber 9, were packed in double-walled cardboard packages lidless tray type with a capacity of 4 kg. Six pallets with dimensions of 1.14 x 1.08 x 1.20 m were assembled, consisting of 84 packages.

The pallets were subjected to two rapid cooling times, three pallets for 120 min, and three pallets for 240 min. The cooling chamber (3.35 m x 5.71 m x 3.00 m) has two non-synchronized industrial chillers with unidirectional forced-air flow of 2.7 $m.s^{-1}$, temperature range between 7 and 10°C, and average relative humidity of 70%. After the rapid cooling programs, the pallets were stored for 7 and 14 days in a cold chamber (4.48 m x 5.71 m x 3.00 m), containing a 5.5 hp compressor, temperature range between 5 and 9°C, with a set point at 6°C, and average relative humidity of 90%. After storage, the fruits were placed in shelf life conditions for 3 days at 20°C.

The internal temperature of the fruit was monitored by Hobo® U12 Temp/RH/2 sensors (Onset Computer Corporation, Massachusetts, USA), with an accuracy of ±0.35ºC. Twelve fruits individually connected to thermocouple probes at different horizontal positions of each pallet were used (Figure 1). All data were recorded with a sampling interval of one minute.

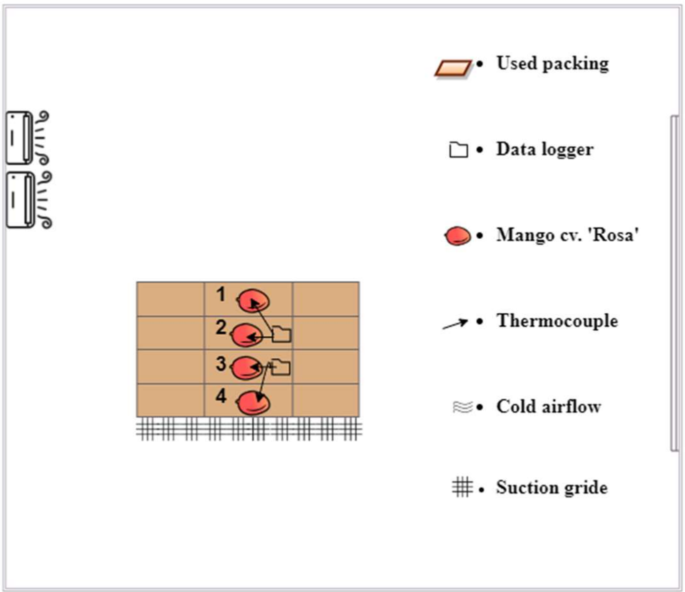

FIGURE 1. Top view of the rapid cooling chamber with the presence of industrial chillers, and the thermal recorders connected to the fruits of different horizontal positions of pallet. Legend: 1 - fruit 1; 2 - fruit 2; 3 - fruit 3; 4 - fruit 4.

The experiment followed a randomized block design with three replicates, with one pallet per replicate. The performance of the cooling programs was evaluated using the parameters half cooling time (HCT), seven-eighths cooling time (SECT), and rate of temperature change (°C). The HCT and SECT were calculated using the fractional unaccomplished temperature change (Equation 1).

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

where:

Y - fractional unaccomplished temperature change;

Tα (t) - fruit temperature over time;

Tα,0 - initial fruit temperature,

TA - refrigeration temperature.

The HCT (Y = 0.5) is a dimensionless value at which the fruit reaches an average temperature between the initial temperature and the room temperature. The SECT (Y = 0.125) is a dimensionless value representing 7/8 of the cooling time, given by the difference between the initial temperature and the room temperature. The rate of temperature change given by the experimental and theoretical cooling coefficients was calculated by [eq. (2)].

$$C = \frac{lnY}{\theta} \tag{2}$$

where:

C - cooling coefficient;

θ - cooling time,

Y - fractional unaccomplished temperature change.

Through mathematical models developed by Microfit software (Siqueira et al., 2014), the theoretical coefficients were fitted according to the experimental coefficients. The Skew-normal distribution of temperatures were plotted according to mean fixed intervals of Y using the VariCool v1.0 algorithm (Olatunji et al., 2017), from parameters of the mean (ε), standard deviation (ω), and shape (α) ($\alpha > 0$ means higher proportion of warmer temperatures, and $\alpha < 0$ means higher proportion of cooler temperatures).

After cold chamber storage (7 and 14 days) and 3 days of shelf life at 20ºC, a total of 48 mangoes per pallet were submitted to weight, potential of hydrogen (pH), and epidermis color analysis. Weight was determined by weighing the fruit on a semi-analytical balance (Marte AS 1000 C, São Paulo, Brazil), with an accuracy of ±0.01 g. The pH was measured with the fruit juice in a glass membrane potentiometer coupled to a digital burette (Metrohm, São Paulo, Brazil), being calibrated with pH 4, 7, and 9 buffers. The color of the epidermis was measured on the two opposite sides of the fruit by a portable CR-400 colorimeter (Konika Minolta Inc, Tokyo, Japan), and the results were expressed in terms of luminosity (L), chroma (C), and hue angle (ºh).

At harvest, a sample of 12 mangoes taken at random were evaluated and had an average weight of 561 ± 46 g, pH of 4.08 ± 0.28, in addition to L, C, and h° of 64 ± 4, 44 ± 5, and 96 ± 12, respectively. An analysis of variance (ANOVA) was performed with the free software R 2.11.1 (R Development Core Team, Berlin, Germany). Tukey's significance test was used to compare the results considering a critical p-value of 0.05 ($p \leq 0.05$).

RESULTS AND DISCUSSION

'Rosa' mangoes submitted to the rapid cooling programs showed final temperatures significantly different ($p \leq 0.05$) from the initial temperatures recorded. However, between the final temperatures, there were no significant differences ($p > 0.05$) (Figure 2). The low air chamber temperature induced the decrease in fruit temperature, which ranged from 21 to 15°C for fruits with 120 min of cooling and from 21 to 14°C for fruits with 240 min of cooling. However, it was not able to provide an average final temperature of 10°C, which would be ideal for subsequent cold storage (Filgueiras, 2000).

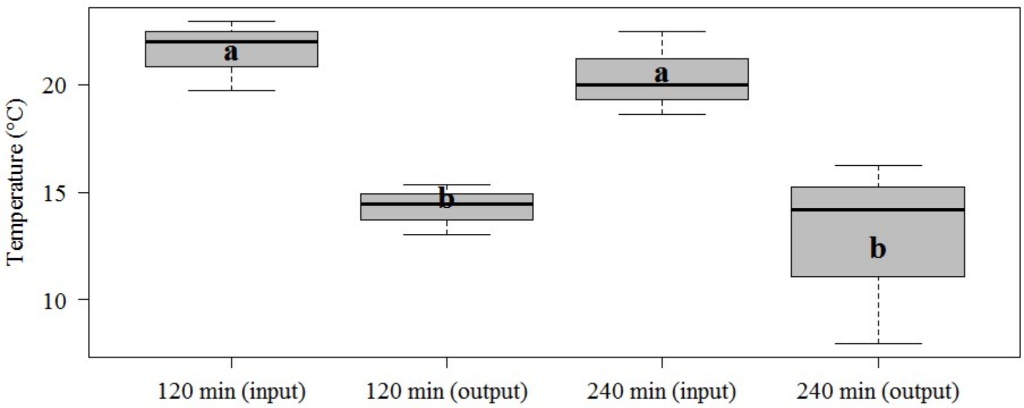

FIGURE 2. Pulp temperature for 'Rosa' mangoes submitted to 120 or 240 min of rapid cooling. Boxplots followed by different letters differ according to Tukey's test at 5% significance ($p \leq 0.05$).

Figure 3 shows the temperatures and cooling rates of the fruit under different positions on the pallet. In the first 60 minutes, the temperature decreased expressively due to the intense convective exchanges between the chamber and the pallets. After 120 minutes, when the first pallets were removed from the chamber, the temperature of the fruit on the pallet under the 240 minutes program increased, because of a thermal increment resulting from the door opening (Figure 3B). The influence of external air on the increase in temperature is due to variations in the thermal properties of conduction, specific heat, and diffusivity, which directly affect the cooling process of the fruit in different positions (Teruel et al., 2003; Dussán-Sarria & Honório, 2005).

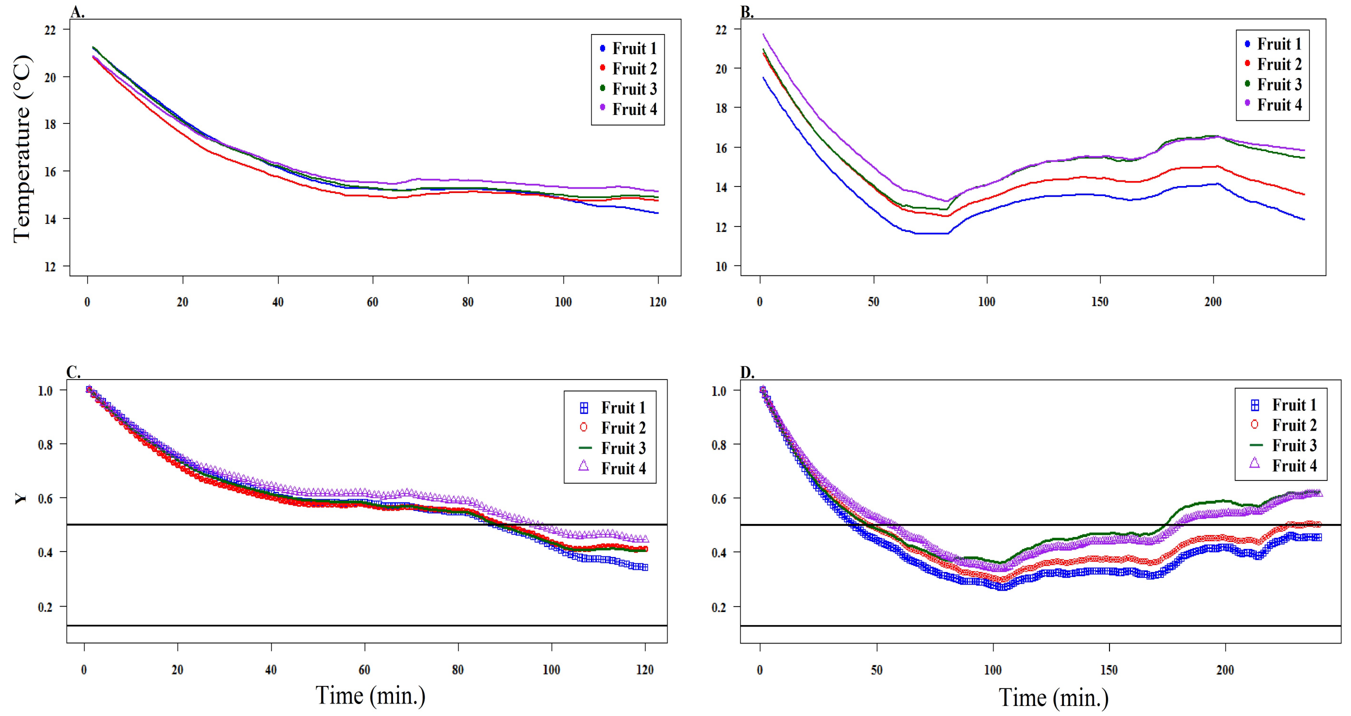

FIGURE 3. Pulp temperature (A and B) and cooling rate (C and D) for 'Rosa' mangoes from different positions on the pallet subjected to 120 or 240 minutes of rapid cooling. Black lines indicate the half cooling time (0.5) and the seven-eighths cooling time (0.125).

For both programs, fruit from positions 2, 3, and 4 accumulated the lowest cooling rates (Figures 3C and 3D). Because of this, after 240 minutes, fruit from positions 3 and 4 showed cooling rates above the HCT (Figure 3D). Furthermore, fruit from position 1 reached the lowest temperatures and the highest cooling rates, because of its closer proximity to the front hole of the package (Figures 3C and 3D). In the process of cooling fruit, there are preferential routes of distribution of cold air, so that in a certain position of the package, greater convective exchanges occur (O'sullivan, 2016). In studies with the cooling of bananas cv. Prata and strawberries, it was found that forced-air heat transfers varied according to the position of the fruit in the packages (Teruel et al., 2003; Mercier et al., 2018).

Table 1 indicates the cooling rates of ‘Rosa’ mangoes submitted to two rapid cooling programs, and under different positions on the pallet. The cooling rates of the fruit ranged from 0.0083 to 0.0108 min^{-1}. ‘Rosa’ mangoes subjected to 120 minutes of cooling under extreme position 4 showed the highest resistance to cold airflow, while mangoes with 240 minutes of cooling at the positions 1 and 2 developed the lowest resistance to airflow.

TABLE 1. Cooling rates for ‘Rosa’ mangoes submitted to rapid cooling programs and under different positions on the pallet.

Fast Cooling Program (min)	Fruit Location on the Pallet	C_{exp} (min^{-1})	C_t (min^{-1})	R^2_t	R^2_{aj}	Error
			0.0054[1]	0.78	0.78	0.85
	Fruit 1	0.0103	0.0054[2]	0.78	0.77	0.86
			0.0113[3]	0.99	0.99	0.20
			0.0046[1]	0.67	0.66	0.93
	Fruit 2	0.0108	0.0046[2]	0.67	0.66	0.93
			0.0115[3]	0.99	0.99	0.12
120			0.0048[1]	0.73	0.72	0.90
	Fruit 3	0.0103	0.0049[2]	0.73	0.72	0.90
			0.0110[3]	0.99	0.99	0.11
			0.0042[1]	0.71	0.71	0.81
	Fruit 4	0.0093	0.0042[2]	0.71	0.70	0.82
			0.0100[3]	0.99	0.99	0.13
			0.0019[1]	0.14	0.13	1.48

	Fruit 1	0.0104	0.0019[2]	0.14	0.12	1.48
			0.0125[3]	0.84	0.84	0.64
			0.0017[1]	0.13	0.13	1.53
	Fruit 2	0.0097	0.0017[2]	0.13	0.12	1.53
			0.0114[3]	0.88	0.88	0.57
240			3.9559×10^{-5}(1)	9.27×10^{-5}	-0.01	1.59
	Fruit 3	0.0088	3.9557×10^{-5}(2)	9.27×10^{-5}	-0.02	1.61
			0.0105[3]	0.86	0.85	0.61
			0.0007[1]	0.03	0.03	1.65
	Fruit 4	0.0083	0.0007[2]	0.03	0.02	1.65
			0.0096[3]	0.91	0.91	0.50

C_{exp} - experimental cooling coefficient; C_t - theoretical cooling coefficient; R^2_t - theoretical coefficient of determination; R^2_{aj} - adjusted theoretical coefficient of determination. [1]linear model (y = ax+b); [2]logarithmic model (y = a + m*(x+(1/h)*log((1+exp(-h*(x-l)))/(1+exp(l*h)); [3]exponential model (y = a*exp(-k*x)+b*x +c).

In a study with the cooling of different cultivars of sweet corn, Cortbaoui et al. (2006) found that products cooled in positions perpendicular to the airflow achieved cooling rates distinct from those achieved by products cooled in positions parallel to the flow. When investigating cooling behavior with oranges, Wu et al. (2019) found that packages from the top pallet layer were the fastest cooled.

Figure 4 indicates the theoretical cooling rate according to the experimental cooling rate for ‘Rosa’ mangoes submitted to 120 minutes and 240 minutes of rapid cooling. The theoretical cooling rates were shown to have a high mathematical fit with the experimental cooling rates, and the heat loss showed an exponential response. The developed models can be used in future predictions of cooling rates within the commercial cooling system of ‘Rosa’ mangoes.

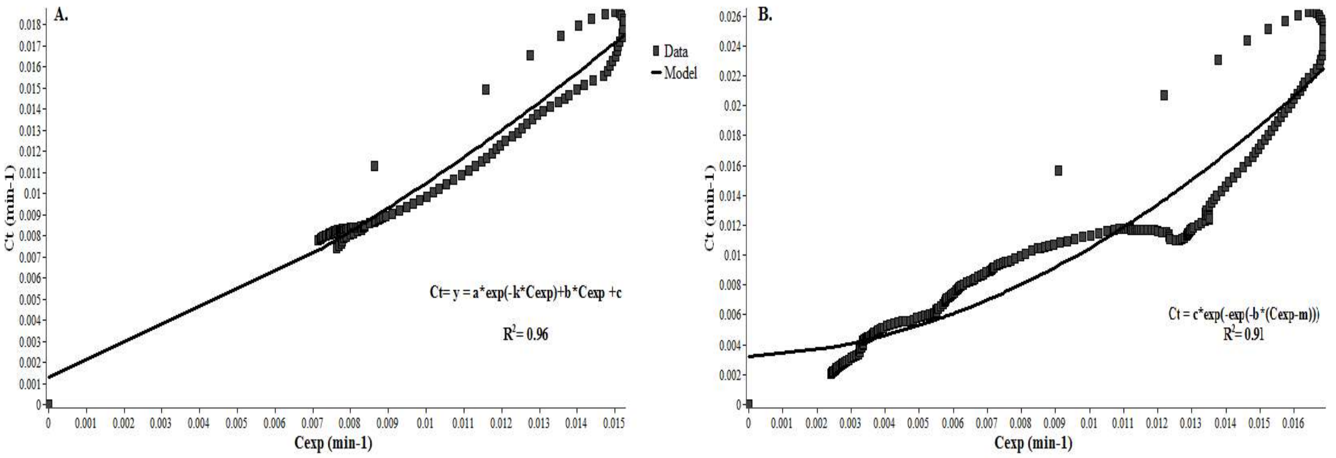

FIGURE 4. Theoretical cooling rate according to experimental cooling rate for ‘Rosa’ mangoes submitted to 120 minutes (A) or 240 minutes (B) of rapid cooling.

In terms of distribution, temperatures were uniform at the beginning of cooling ($\bar{Y} = 1$), when $\omega_{120\text{-}240min} = 0$ and increased until HCT ($\bar{Y} = 0.5$), when $\omega_{120min} = 0.4$ and $\omega_{240min} = 0.075$. The quantification of temperature changes by the values $\alpha_{120\text{-}240min} = 0$, at the beginning, and $\alpha_{120min} = 25$ in addition to $\alpha_{240min} = -10$, at the end of cooling, shows that the pallet subjected to the 120 minutes program was transported to the cold chamber with a greater number of warmer fruits, even though the predominance of $\varepsilon_{120min} = 0$ values indicates that a more even distribution between warm and cool temperatures occurred for most of the program (Figure 5).

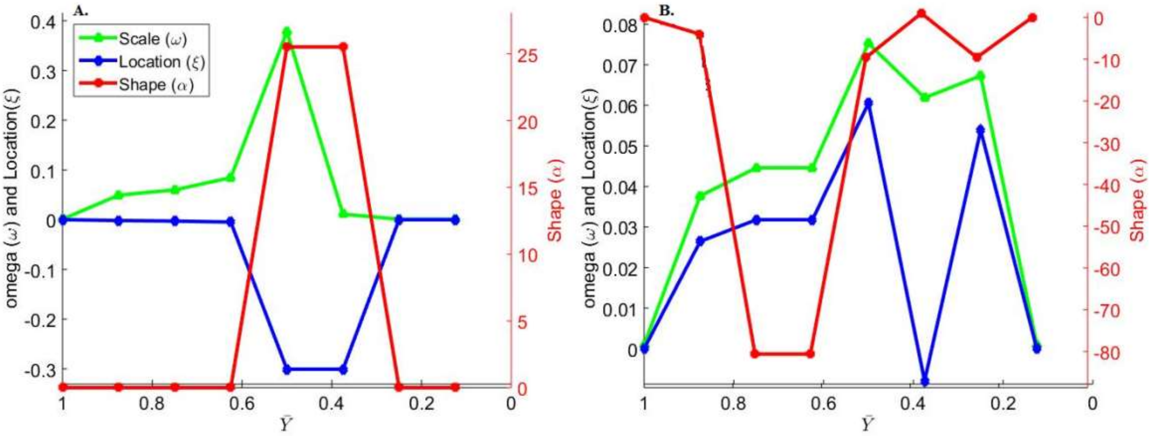

FIGURE 5. Skew-normal distribution of temperatures by mean (ε), standard deviation (ω), and shape (α) values with Ȳ = 1; 0.875; 0.75; 0.625; 0.5; 0.375; 0.25; and 0.125 for 'Rosa' mangoes subjected to 120 minutes (A) or 240 minutes (B) of rapid cooling.

According to Olatunji et al. (2017), heterogeneous temperature distributions in cooling systems can occur due to factors related to fruit size and packing in locations more preferential to the direction of airflow, as well as errors in thermal measurement equipment.

There were no significant differences ($p > 0.05$) between the rapid cooling programs for the quality parameters: weight, which ranged from 530 to 550 g, pH, which showed an average limit of 4.1, and epidermis color after storage, followed by 3 days of shelf life at 20ºC (Figure 6).

The advanced stages of ripening impacted the absence of significant differences in the quality parameters. Most cellular metabolic activities related to texture, pigment deposition, acidity changes, sugar conversion, and production of aromatic volatile chemical compounds were stabilized (Goulao & Oliveira, 2008; Mossad et al., 2016; Nordey et al., 2016). Rapid cooling programs and cold storage kept reduced water loss and extended fruit shelf life (Brosnan & Sun, 2003).

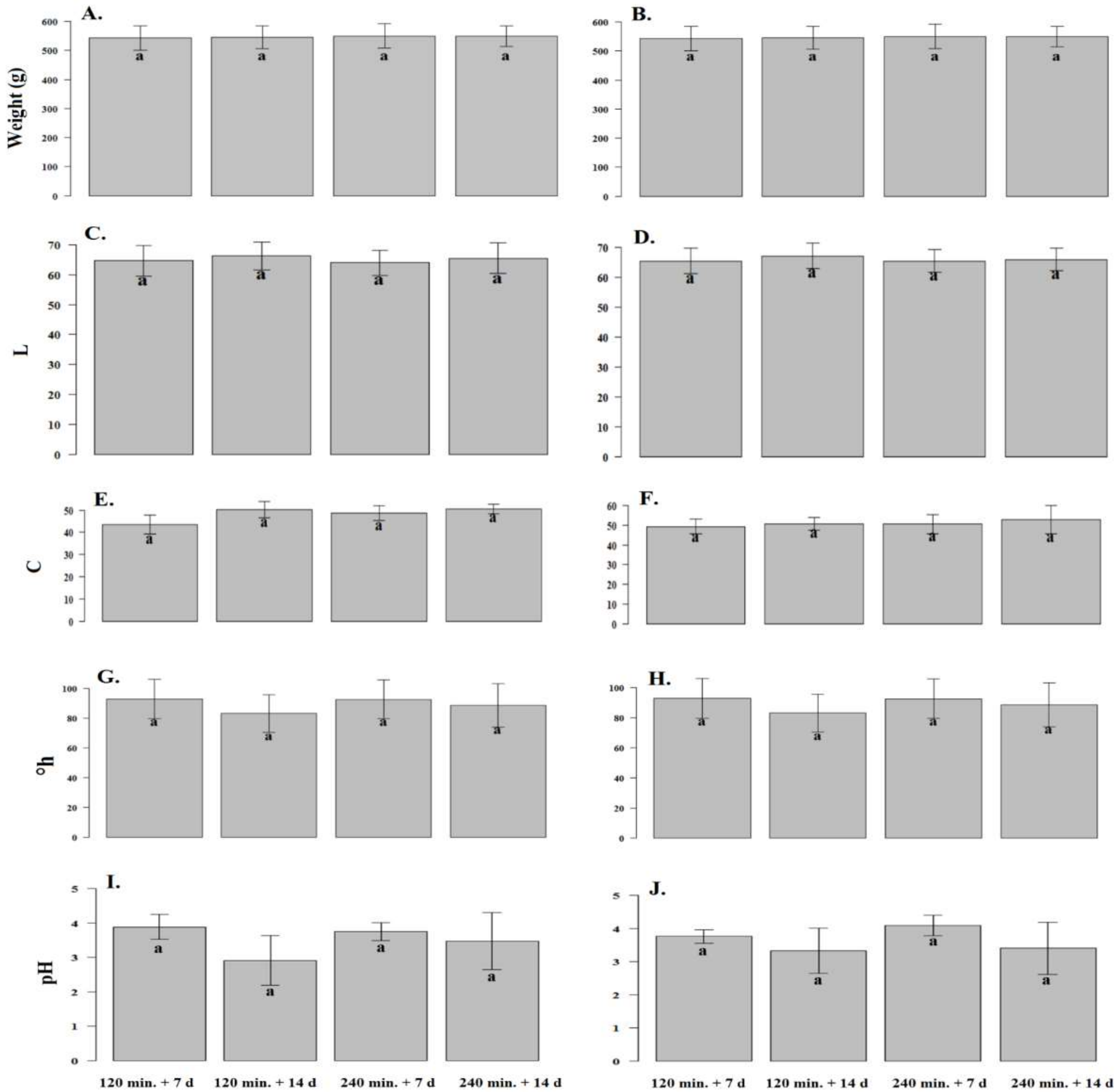

FIGURE 6. Effects of rapid cooling programs (120 or 240 minutes) on weight, brightness, chromaticity, hue angle, and pH of 'Rosa' mangoes after storage (7 or 14 days) (A, C, E, G, I), and 3 days of shelf life at 20ºC (B, D, F, H, J). Bars followed by different letters differ statistically according to Tukey's test at 5% significance ($p \leq 0.05$). L - luminosity; C - chromaticity; °h - hue angle; min - minutes; d - days.

CONCLUSIONS

Pulp temperatures and cooling rates varied according to the position of 'Rosa' mangoes in relation to the cold airflow directed at the pallets with a 120-minute or 240-minute rapid cooling program. Both studied rapid cooling programs associated with cold storage of 7 or 14 days, and a shelf life of 3 days at 20ºC did not affect fruit weight, pH or epidermis color.

The absence of significant differences among the quality parameters indicates that the 120-minute program may be the most satisfactory choice for the rapid cooling process, in view of the reduction in energy costs and the reduction of the dwell time of the mango in the cold chain.

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