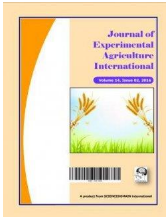

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Postharvest Quality during Refrigerated Storage of 'Nadorcott' Mandarin

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Authors' contributions

This work was carried out in collaboration between all authors. Authors RFFC, PCMF, MBM and RPO designed the study. Author ICN performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors ICN, RFFC, MS, PCMF, MBM and RPO managed the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The aim of this article was to study the suitable storage duration and temperature of Nadorcott mandarin.
Study Design: The experimental design used was the completely randomized design, with two factors: two storage temperatures and four storage durations, with four repetitions for each period, and each repetition counting with 15 fruits.
Place and Duration of Study: The mandarin cv. Nadorcott used were from Rosário do Sul city, Rio Grande do Sul (RS) State, Brazil. Fruits were harvested in commercial maturation, and transported to the Food and Postharvest Laboratory, Embrapa Temperate Climate, Pelotas-RS.
Methodology: Mandarins were stored during 15, 30, 45, and 60 days at refrigerated temperatures of 4°C and 8°C, with two days at 20°C in order to simulate market conditions. The parameters

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analyzed were: total soluble solids content; titratable acidity; the relationship between total soluble solids and titratable acidity; firmness; longitudinal diameter; mass loss; juice yield; skin color; rotting percentage; antioxidant activity; total carotenoids; total phenolic compounds and vitamin C.
Results: Maturity index of 9.97 and 11.52 to 4°C and 8°C, respectively, was obtained. The biggest loss of mass (12.08%) and rotting (18.33%) occurred at 60 days of storage at 8°C. The total phenol content (60.02 mg of gallic/100 g of fresh fruit) and the vitamin C concentration (15.7 mg of ascorbic acid/100 g of fresh fruit) had the highest reduction at 60 days of storage at 8°C.
Conclusion: The 'Nadorcott' mandarin maintained postharvest quality characteristics when stored up to 45 days at 4°C, with relative humidity between 90-95%, and commercialized for 2 days at 20°C.

Keywords: Storage temperature; citrus; conservation.

1. INTRODUCTION

Citrus cultivation was introduced in Brazil in the colonial period and, since then, it became of great importance in the consumption habits [1]. Citrus fruits are among the most appreciated and produced in the world, and Brazil stands out as the second largest producer of mandarins worldwide [2]. The increase in the consumption of in natura fruits and of natural juices is global [3]. Among tangerines, Nadorcott cultivar has stood out because of its good fruit quality and high productivity [4].

The Nadorcott cultivar is a hybrid of "Murcott" tangor, and can reach average annual production of 30 $t.ha^{-1}.year^{-1}$ [5]. Fruit maturation is from mid to late season [5,6]. In Rio Grande do Sul state, harvest period is carried out from July to August. Tangerines can remain in the trees for several weeks after the complete maturation without significant quality loss. Fruits are small to medium in size, weighing 90 to 120 g, thin rind, a very attractive red-orange hue, being moderately easy to peel; intense orange pulp, with good amount of juice [5].

Postharvest fruit conservation has great importance to reach consumers without great quality alterations, such as original nutritional values, appearance, and taste. To achieve this, it is necessary to provide good quality products at harvest, observing the degree of maturation of each species and knowing resistance to refrigerated storage [7]. Adequacy of storage temperature contributes to decrease in respiratory activity of fruit, since it decreases their metabolic activity. Ideal storage temperature will depend on genotype, maturation stage and time-temperature binomial [8].

The aim of this study was to determine the effect of temperature and adequate storage period to the quality of the Nadorcott mandarin cultivar.

2. MATERIALS AND METHODS

The experiment was conducted at the Postharvest Laboratory of the Embrapa Temperate Climate, Pelotas, Rio Grande do Sul State, Brazil. Eight years-old plants of 'Nadorcott' tangerines grafted on *Poncirus trifoliate* rootstock, with 3 m between plants and 6m between lines. At harvest, fruits were selected according to their size, ripeness, and absence of defects and rotting. After cleaned, it was followed by application of carnauba-based wax and vegetal resin before stored.

The treatments consisted on fruits storage in two temperature conditions (4°C and 8°C) and four storage periods (15, 30, 45, 60 days). Each treatment had 4 repetitions, and each repetition containing 15 fruits. Initially, fruits characterization was done by using the same number of repetitions as in treatments. After each storage period, fruits were subjected to 20°C and natural relative humidity for 2 days in order to simulate market conditions.

The parameters evaluated were: Titratable acidity (TA), by using 10 mL of juice and adding 90 mL of distilled water, sample titration was done with aid of a digital burette (Brand®), containing a solution of sodium hydroxide (NaOH) at 0.092N until it reached pH 8.1. The result was expressed in grams of citric acid.100 g^{-1} of juice [9]. Total soluble solids content which was quantified using a digital refractometer (PAL-1, ATAGO), by measuring the refractive index of the sample and with the results expressed in ºBrix [10]. The relationship between total soluble solids and titratable acidity (Maturity Index) [11] was obtained by dividing levels of total soluble solids (°Brix) and titratable acidity (% citric acid). Pulp firmness was obtained by a texturometer (Stable Micro Systems®) using the compression nozzle P/75 with pre-test speed of 1.0 mm/s, test speed of 2.0 mm/s, post-test speed of 10.0 mm/s, 5 kgf, and results were expressed in Newton (N). Mass loss was obtained by difference between initial and final mass, with the result expressed as a percentage (%). The longitudinal diameter was measured with digital caliper in the medium portion of the fruit, with the result expressed in millimeters (mm). The juice yield was calculated by the difference between juice mass and both pulp and rind mass, and expressed as a percentage (%). Rotting percentage was obtained through count of healthy fruits after two-day marketing simulation. Fruit color was measured with colorimeter (Minolta CR-300), with system of reading CIE L*a*b*, proposed by the Comission Internacionale de l' Eclairage (CIE), and the hue or chromatic tonality represented by the Hue angle (Hº), through the arctangent formula b*/a*. The result was expressed in degrees, as seen in Minolta [12]. The antioxidant activity (DPPH) was evaluated by using the methodology proposed by Rufino and co-workers [13], with some modifications. 250 μL of the sample was pipetted and left to react with 3750 μL of DPPH solution diluted in methanol for 24 hours in the dark. Absorbance was obtained at 515 nm and calculated using a gamma linear calibration curve and results were expressed in mg of 100 Trolax/g of fresh fruit. Total carotenoids content was determined by the methodology proposed by Talcott and co-workers [14], and the result obtained was expressed in mg Equivalent β-carotene/100 g of fresh fruit. The total phenol content was determined with the methodology adapted from Swain and Hills [15]. For each test tube, 250 μL of sample was pipetted, 4 ml of ultrapure water and 250 uL of the Folin-Ciocalteau reagent (0.25N) were added, which was maintained for 3 minutes. After that, 500 μL of sodium carbonate (1N) was added and the solution was maintained for 2 hours. Absorbance determinations were done in a spectrophotometer with a wavelength of 725 nm, with the results expressed in mg of Gallic/100 g of fresh fruit. Vitamin C content was determined by means of spectrophotometry using the methodology proposed by Souza (2007), cited by Oliveira [16], with the results expressed in mg of ascorbic acid/100 g of fresh fruit.

The experimental design used was entirely randomized, in factorial scheme, with two factors: temperatures (4°C and 8°C), and storage periods (15, 30, 45 and 60 days). The experimental unit was composed of 15 fruits with four repetitions for each period. The results obtained were submitted to analysis of variance ($p \leq 0.05$) and, in the case of significance, submitted to the minimum significant difference test ($p \leq 0.05$).

3. RESULTS AND DISCUSSION

Fig. 1 shows average values for titratable acidity, total soluble solids content, and maturity index for mandarin cv. Nadorcott. The titratable acidity presented statistical significance only for the isolated factors of time and temperature (Fig. 1A). The total soluble solids did not present significant differences in relation to storage temperature, with significance occurring only when it comes to storage period (Fig. 1 B).

It was observed that temperature of 4°C differed significantly from the highest values to titratable acidity during periods of 15, 30 and 60 days, differing not only at 45 days of storage. The soluble solids content at 30 days of storage showed the greatest concentration, whereas titratable acidity presented simultaneous decrease. It increased again when the soluble solids content decreased at 45 and 60 days. Similar behavior was observed by Brunini and co-workers [17] in oranges cv. Hamlin and Brunini and colleagues [18] with Pera sweet oranges. The researchers associated such performance with loss of water in the oranges. Vale and co-workers [9] associated this phenomenon with the use of soluble sugars as respiratory substrate by the fruit. The highest storage temperature can encourage degradative enzymatic processes, resulting in consumption of sugar and organic acid used as respiratory substrate [19].

The maturity index for mandarins cv. Nadorcott presented statistical significance for isolated effects of time and temperature, in which the temperature of 8°C obtained the highest values in all storage period (Fig. 1 C). The relationship between total soluble solids and titratable acidity, which is called maturity index, is widely used in the evaluation of fruits quality. Also, according to the CEAGESP standards [20], for a good acceptance, mandarins must present at least value 10 of maturity index for ‘Murcott’ and 9.5 of maturity index for ‘Ponkan’. For ‘Nadorcott’, the maturity index was higher than those values, reaching 14.08 and 16.47 at 30 days in temperatures of 4°C and 8°C, respectively. Jomori and co-workers [21] found values of approximately 16 in ‘Murcott’ tangor stored up to 30 days at 5°C. Brunini and colleagues [17], working with ‘Hamlin’ oranges, found a maturity index of approximately 14, when stored up to 28 days at 7°C.

Only at 60 days stored at 4°C presented maturity index values below to those of 'Murcott' and 'Ponkan'. The maturity index corresponds to relation between total soluble solid contents and titratable acidity that, beyond determining maturation index, is this component that grants fruits sweetness and acid flavor [22]. During fruit maturation, this relationship tends to increase due to acids decrease and sugar increase contents [23]. This occurred up to 30 days of storage. Also decrease after this period might be related to titratable acidity increase and carbohydrate consumption during respiratory process.

Average values of fruit firmness, mass loss, longitudinal diameter, juice yield, rotting percentage, and rind hue to 'Nadorcott' mandarins are represented in Fig. 2. Interaction among treatment factors for all variables could be observed. Pacheco and co-workers [24] found the importance of physical attributes of fruits for marketing purposes.

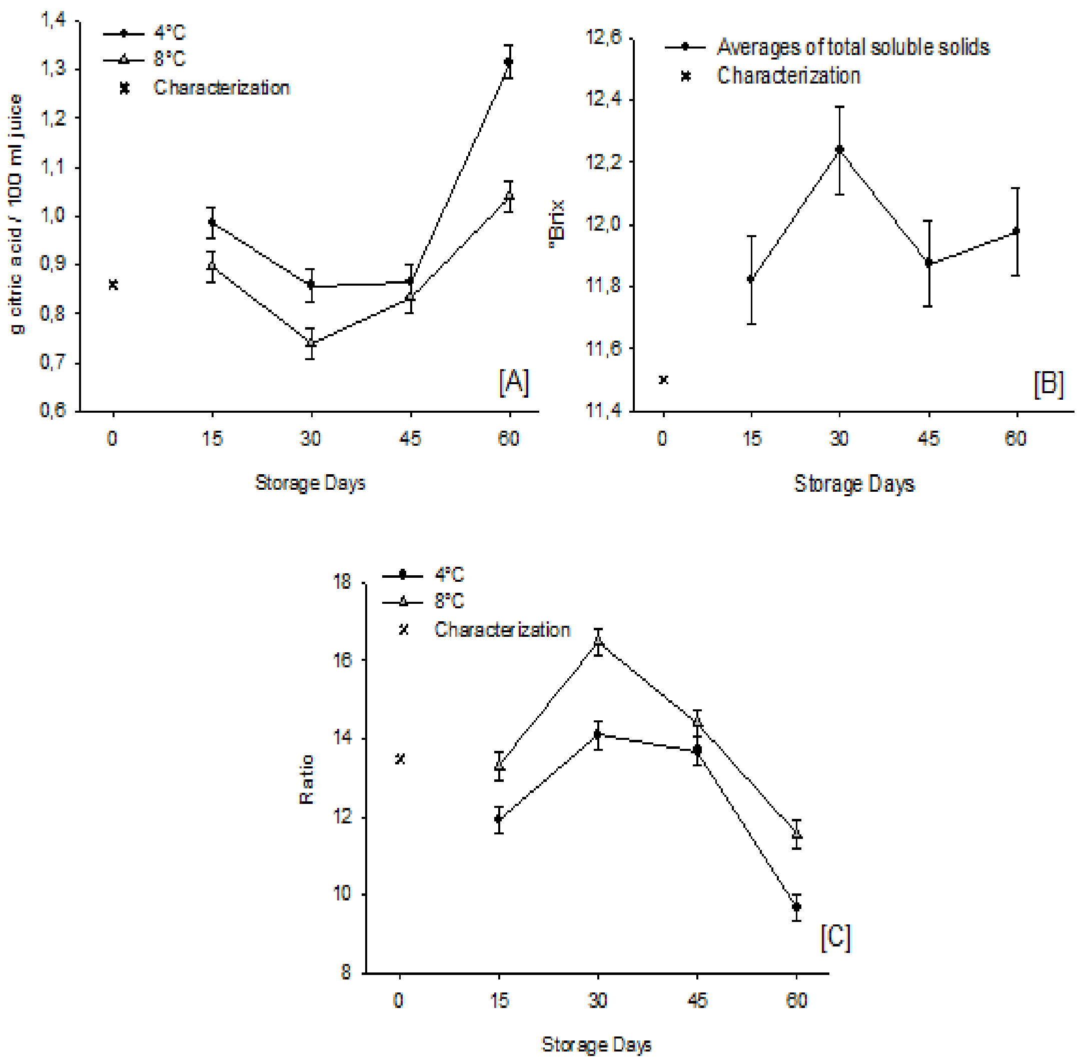

Fig. 1. Average titratable acidity (A), total soluble solids (B), soluble solids ratio and titratable acidity (C) of mandarins cv. Nadorcott in different storage periods. Vertical bars: DMS test ($p \leq 0.05$)

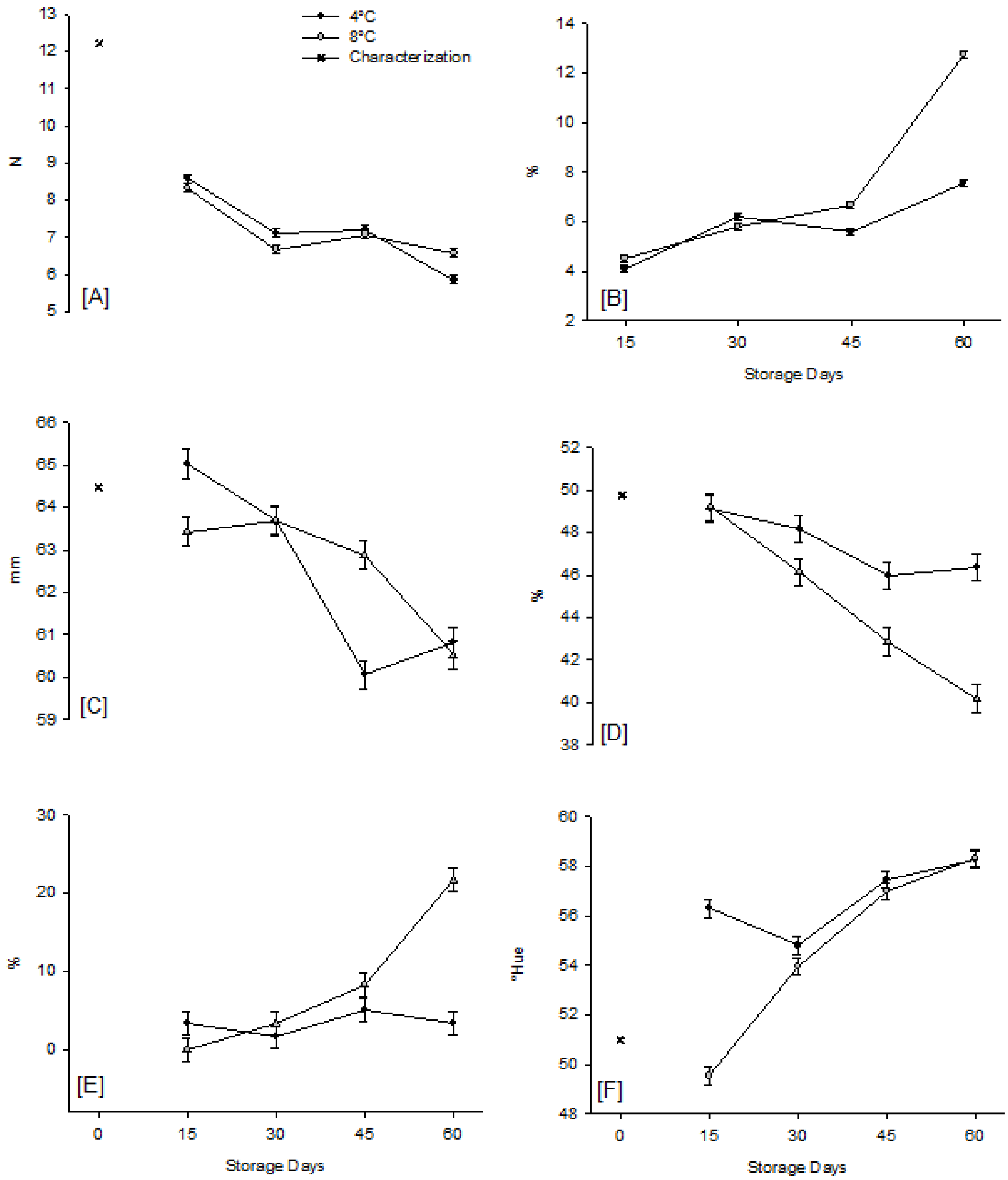

Fig. 2. Mean values of fruit firmness (A), mass loss (B), longitudinal diameter (C), juice yield (D), rotting percentage (E) and shade (F) of 'Nadorcott' mandarin in different storage durations. Vertical bars: DMS test ($p \leq 0.05$)

Firmness had greater value for fruits stored at 4°C up to 45 days (Fig. 2), inverting their behavior after this period. Fruits with low firmness present less resistance to transport, storage, and handling, and were, therefore, rejected by consumers [24]. Decrease in firmness values might be related to pectic substances solubilization. During maturation, there is a conversion of insoluble pectin to soluble pectin, which softens fruit and decreases their resistance, as explained by Chitarra and Chitarra [7]. During cold storage, enzymes that are influenced by temperature can lead to release calcium from cell walls, inducing protopectin solubilization, which results in a fruit firmness decrease [25].

Mass loss increased with the longest storage period for fruits stored at both temperatures (Fig. 2 B), but increased significantly from 45 up to 60 days in fruits stored at 8°C, reaching approximately 12.5%. According to Agostini and co-workers [26], it must be considered that loss of fresh mass in fruits, when superior 10%, impairs or hinders their commercialization *in natura*. These losses are associated mainly with fruits dehydration. This is one of main causes of deterioration, resulting in quantitative and qualitative losses [9]. This behavior was already expected considering that part of water content in fruits is lost due to transpiration process, which reflects, throughout storage, in wilting, mass and consistency losses [23].

Longitudinal diameter of 'Nadorcott' fruits decreased throughout refrigerated storage, ranging from 5 mm to 3 mm at temperatures of 4°C and 8°C, respectively (Fig. 2 C). This behavior was expected since diameter is related to firmness and mass loss. According to marketing standards established by the Brazilian Program for Horticulture Modernization adopted by CEAGESP [20], 'Nadorcott' mandarin is inserted in group with less than 70mm diameter.

Juice yield for this cultivar decreased approximately 10% when stored at 8°C, and around 3% when stored at 4°C up to 60 days (Fig. 2 D). This behavior might be related to mass loss which occurred during storage and also to rotting percentage found during this period, considering that when fruits were subjected to 8°C storage, rotting percentage was higher, reaching 20% of losses (Fig. 2).

Commercially, this value becomes impracticable, raising production costs and affecting the final product quality. Felicio and co-workers [27] did not find rotting in 'Murcott' fruits stored up to 8 weeks at 1°C and 4°C. They attributed these good results to three main factors: good orchard phytosanitary control, low storage temperature that might have contributed to pathogens suppression, and fruit immersion in sanitizing solution. By observing the storage duration, we can highlight importance of low storage temperature. It was observed that, up to 60 days at 4°C, resulted in approximately 3% of contaminated fruit, thus showing that low temperatures are effective in control of pathogens.

The largest variation in rind hue occurred in the first 15 days of storage in fruits submitted to temperatures of 4°C showing higher values of Hue angle, and showing the same behavior up to 30 days, but with less difference in Hue between temperatures (Fig. 2 F). After this period there were no significant differences for Hue angle between two storage temperatures. According to Borguini [28], Hue angle corresponds to colors variation ranging from blue (270º) to red (0º), passing through yellow (90º) and green (180º). In this work, data obtained varied 54.14 in characterization of fruits up to approximately 58 at the end of experiment. This result showed that mandarins kept orange-colored hue close to beginning of the study.

Despite the difference among treatments, reduction in coloration intensity was not so serious. It was observed a small variation until the end of study, and it was insufficient to affect the fruits commercial acceptance. Brunini and co-workers [17], in experiments with 'Hamlin' oranges, noticed that temperature and storage duration showed little interference in this parameter. However, Felicio and colleagues [27] observed a different behavior in their study of 'Murcott' tangor. They found that a decrease in Hue angle was more evidenced when fruits were stored at 4°C instead of 1°C. It is worth remembering that each species or cultivar responds differently. Therefore, when it comes to 'Nadorcott', small color variation in cold storage is intrinsic to the cultivar.

Citrus generally show in their constitution several compounds with antioxidant action, such as ascorbic acid, carotenoids, and total phenolic compounds [28]. In Fig. 3, averages for antioxidant capacity, total phenolic compounds, total carotenoids, and vitamin C content of 'Nadorcott' mandarins are presented.

The antioxidant capacity showed a higher decrease in the first 15 days of storage (Fig. 3). It showed a significant difference between temperatures, with fruits kept at 8°C presented higher decrease of antioxidant capacity when compared to fruits kept at 4°C at 60 days of storage. This performance could be related to difference in chemical composition, such as phenolic compounds, ascorbic acid, and carotenoids [29]. However, antioxidant compounds may be lost during the storage period, which affects the antioxidant capacity of the food [30].

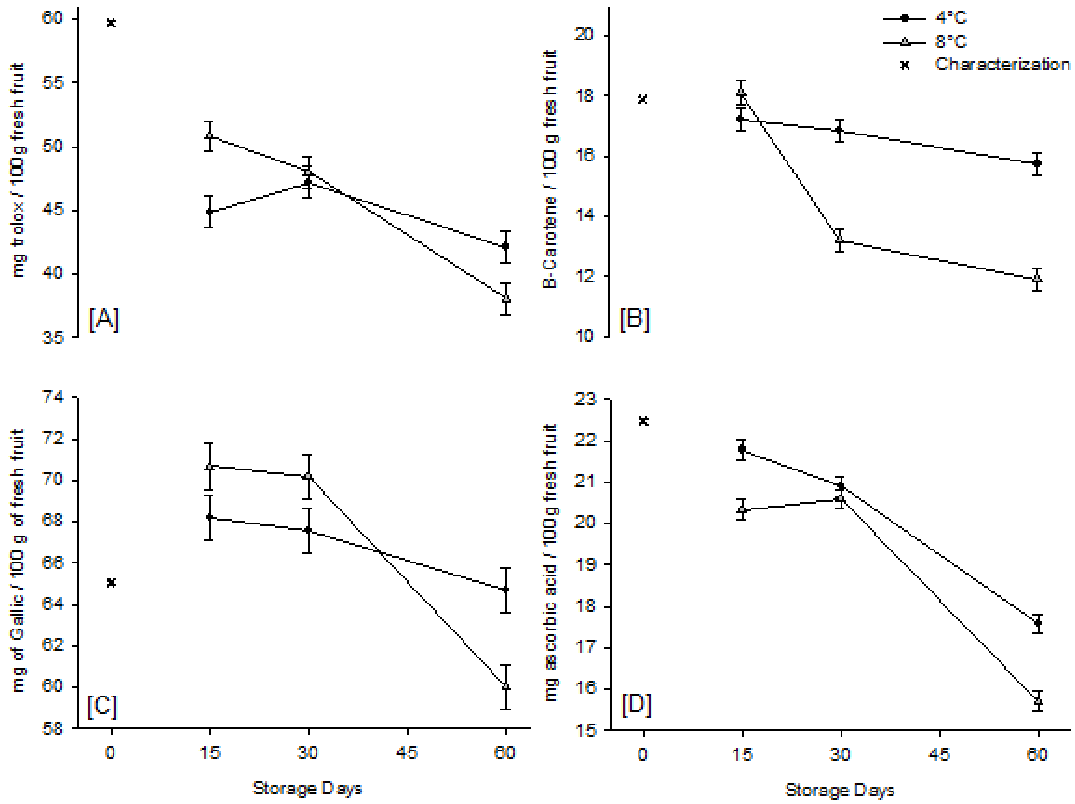

Fig. 3. Average of antioxidant activity (A), total carotenoids (B), total phenolic compounds (C) and vitamin C content (D) of 'Nadorcott' tangerines in different storage durations and temperatures. Vertical bars: DMS test (p≤0.05)

Total carotenoid content of Nadorcott cultivar was higher than contents found in its progenitor 'Murcott', as demonstrated by several authors [31,21]. All 'Nadorcott' fruits stored at 4°C presented more carotenoid content after 15 days of storage (Fig. 3 B). And this result differed to fruits stored at 8°C, which presented a sudden decrease in carotenoids level. This fact could be related to increase in metabolic activity in mandarins stored at 8°C, which caused acceleration in degradation of these compounds, due to their susceptibility to oxidation [21].

Phenolic compounds are widely found in plants and belong to a diversified group of phytochemicals derived from phenylalanine and tyrosine. Those are compounds that originate from secondary metabolism and are essential to plants growth and reproduction [32].

When it comes to 'Nadorcott' mandarins, phenolic contents decreased during storage (Fig. 3C), showing a higher value in fruits stored at 8°C until the 30 days of storage, and at 60 days it was reversed. A sharp decrease in phenolic compounds was observed at the end of study. It can be attributed to type of compound that is predominant in sample, and it may be related to enzymatic activity, blocking the oxidation, or, unrelated to enzymatic activity, interacting with free radicals and being consumed by this reaction [32].

Concerning the vitamin C content, only significant effect isolated from duration and temperature was observed. A decrease in vitamin C content, from harvest up to the end of storage period, was observed (Fig. 3). Presence of vitamin C in fruits is an important aspect that influences consumption of fresh fruits [33]. Vitamin C is known by its antioxidant and functional potential and it occurs naturally in fruits in the form of L-ascorbic acid, which, in mandarins, is present on an average of 20 to 50 mg for 100 mL of juice [34].

'Nadorcott' mandarins that showed concentration around 20.50 mg of L-ascorbic acid in the beginning of experiment, got to less than 16 and 18 mg of vitamin C when stored for 60 days at 4°C and 8°C, respectively. This shows that the most effective storage temperature was 4°C when it comes to maintain ascorbic acid content in all storage periods. Reduction in the vitamin C content is usually observed after harvest because it is a natural antioxidant involved in antioxidant reactions that are processed during fruit senescence, due to its metabolic processes, manly respiration [27,17]. Agostini and co-workers [25] attributed reduction of vitamin C content in cold storage to the highest storage temperature, which may lead to early senescence, consuming ascorbic acid on oxidative reactions.

There is no research in the literature on the storage of citrus cultivar nadorcott refrigerated, denoting the novelty and originality of this study. Citrus fruit can be a particularly advantageous model for studying the senescence of woody perennial fruits. After harvest, citrus fruit remains animate and active. The senescence of non-climacteric citrus fruit is a gradual physiological change process with dysfunction or malfunction of the fruit tissues in response to water, nutrient and temperature stresses, which ultimately affects the fruit quality [35].

Citrus Metabolic Pathway Network and correlation networks were constructed to explore the modules and relationships of the functional genes/metabolites. They found that the different flesh-rind transports of nutrients and water due to the anatomic structural differences among citrus varieties might be an important factor that influences fruit senescence behavior. They modeled and verified the citrus senescence process. As fruit rind is directly exposed to the environment, which results in energy expenditure in response to biotic and abiotic stresses, nutrients are exported from flesh to rind to maintain the activity of the whole fruit. The depletion of internal substances causes abiotic stresses, which further induces phytohormone reactions, transcription factor regulation and a series of physiological and biochemical reactions [35].

4. CONCLUSION

‘Nadorcott’ mandarin maintained postharvest quality characteristics when stored up to 45 days at 4°C, with relative humidity between 90-95%, and commercialized for 2 days at 20°C. Overtime, there has been significant progress in the areas of postharvest physiology and postharvest technology of citrus fruit. By understanding and using these developments, the postharvest handling system can be improved, which will help to improve the profitability of industry. While, many challenges in the area of postharvest are still to be tackled, our current state of postharvest losses can be minimized by application of the principles of postharvest management. On the basis of the current knowledge about citrus postharvest and in order to extend the fruits shelf-life, one of the future challenge could be identified: and optimization of both cold storage room and refrigerated container for citrus.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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