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Post-harvest conservation of 'Shelly' and 'Omer' mangoes under refrigerated conditions cultivated in the sub-middle of the São Francisco Valley

Conservação pós-colheita de mangas 'Shelly' e 'Omer' sob condições refrigeradas cultivadas no submédio do Vale do São Francisco

Conservación poscosecha de mangos 'Shelly' y 'Omer' en condiciones de refrigeración cultivados en el submedio del Valle del São Francisco

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Abstract
Mango is one of the most important fruits in the world, but its high perishability after harvest limits its commercialization over long distances. Brazil stands out in world production and exports, showing an increasing potential for growth, either with the search for new cultivars or with the advance in the maintenance of fruit quality. Thus, the objective of this research was to evaluate the post-harvest conservation of Israeli mangoes 'Shelly' and 'Omer' stored under refrigerated conditions. The experiment was conducted at the Agricultural Product Storage Laboratory (LAPA), at the Federal University of São Francisco Valley (UNIVASF). The samples received were sanitized, stored for forty days at a temperature of 12 ºC and evaluated at five-day intervals for differences in absorbance (DA index), skin and pulp color (L*, a* and b*), mass loss (ML), dry matter (DM), firmness and soluble solids (SS). The experimental design was completely randomized in a 2 x 9 factorial scheme (cultivars x storage times), with four replications per treatment, except for DM and ML evaluations. Based on the results, the cultivar Omer responded better to the refrigeration condition for post-harvest conservation than Shelly, showing better performance in the evaluation of parameters of firmness, mass loss, dry matter and colorimetry. 'Shelly' performed better in terms of DA index and soluble solids.
Keywords: Storage; *Mangifera indica* L.; Refrigeration; Shelf life; Quality parameters.

Resumo
A manga é uma das frutas mais importantes em todo o mundo, mas sua elevada perecibilidade após a colheita limita sua comercialização em longas distâncias. O Brasil se destaca na produção e exportação mundial, mostrando potencial de crescimento cada vez maior, seja com a busca de novas cultivares ou com o avanço na manutenção da qualidade dos frutos. Dessa forma, o objetivo desta pesquisa foi avaliar a conservação pós-colheita das mangas israelenses 'Shelly' e 'Omer' armazenadas sob condições refrigeradas. O experimento foi conduzido no Laboratório de Armazenamento de Produtos Agrícolas (LAPA), da Universidade Federal do Vale do São Francisco (UNIVASF). As amostras recebidas foram higienizadas, armazenadas durante quarenta dias à temperatura de 12 ºC e avaliadas em intervalos de cinco dias quanto à diferença de absorbância (índice DA), cor da casca e da polpa (L*, a* e b*), perda de

massa (PM), matéria seca (MS), firmeza e sólidos solúveis (SS). O delineamento experimental foi inteiramente casualizado em esquema fatorial 2 x 9 (cultivares x tempos de armazenamento), com quatro repetições por tratamento, exceto para as avaliações de MS e PM. Com base nos resultados, a cultivar Omer respondeu melhor à condição de refrigeração para a conservação pós-colheita do que a Shelly, apresentando melhor desempenho na avaliação dos parâmetros de firmeza, perda de massa, matéria seca e colorimetria. A 'Shelly' desempenhou melhor quanto ao índice DA e aos sólidos solúveis.
Palavras-chave: Armazenamento; *Mangifera indica* L.; Refrigeração; Vida útil; Parâmetros de qualidade.

Resumen
El mango es una de las frutas más importantes del mundo, pero su alta perecibilidad después de la cosecha limita su comercialización a largas distancias. Brasil se destaca en la producción y exportaciones mundiales, mostrando un creciente potencial de crecimiento, ya sea con la búsqueda de nuevos cultivares o con el avance en el mantenimiento de la calidad de la fruta. Por lo tanto, el objetivo de esta investigación fue evaluar la conservación poscosecha de los mangos israelíes 'Shelly' y 'Omer' almacenados en condiciones de refrigeración. El experimento fue realizado en el Laboratorio de Almacenamiento de Productos Agrícolas (LAPA), de la Universidad Federal del Valle de São Francisco (UNIVASF). Las muestras recibidas fueron higienizadas, almacenadas durante cuarenta días a una temperatura de 12 ºC y evaluadas a intervalos de cinco días para diferencias en absorbancia (índice DA), color de piel y pulpa (L*, a* y b*), pérdida de masa (PM), materia seca (MS), firmeza y sólidos solubles (SS). El diseño experimental fue completamente al azar en un esquema factorial 2 x 9 (cultivares x tiempos de almacenamiento), con cuatro repeticiones por tratamiento, excepto para las evaluaciones de MS y PM. Con base en los resultados, el cultivar Omer respondió mejor a la condición de refrigeración para conservación poscosecha que Shelly, mostrando mejor desempeño en la evaluación de parámetros de firmeza, pérdida de masa, materia seca y colorimetría. 'Shelly' se desempeñó mejor en términos de índice DA y sólidos solubles.
Palabras clave: Almacenamiento; *Mangifera indica* L.; Refrigeración; Duración; Parámetros de calidad.

1. Introduction

Mango, a fruit of the Asian species Mangifera indica L. belonging to the Anacardiaceae family, is climacteric, has a short shelf life and is commercially one of the most important tropical fruits in the world, occupying the sixth position in world production. (Ebrahimi & Rastegar, 2020; FAOSTAT, 2021). Currently, Brazil is the seventh largest mango producer in the world, with a production of 1,569,011 tons (IBGE, 2021). The São Francisco Valley region stands out in terms of national production, accounting for 87% of the total (Freitas; Marques & Rybka, 2021).

In 2021, 272,560.167 tons of mango were destined for export, making it the most exported Brazilian fruit, and Brazil, its second largest exporter in the world (AGROSTAT/MAPA, 2021; FAOSTAT, 2021). With this sector becoming increasingly important economically, it is necessary to meet the demands of the foreign market, as well as to expand business with it.

Aiming at increasing the foreign purchase of mango produced in Brazil and, producers in the São Francisco Sub-middle Valley are looking for new cultivars of interest to this market, which adapt to the conditions of the region (Araújo et al., 2017) and which allow them to compete in different trades in the world, such as example 'Shelly' and 'Omer', from Israel.

As transport by sea is the most used modal for the export of Brazilian mango (91%) (IBGE, 2021), the use of post-harvest conservation techniques, such as cold, becomes essential for the delivery of quality fruit, with physicochemical aspects preserved at the end of the route.

In this way, the post-harvest characterization of these new cultivars is of paramount importance for the generation of information directed to those who wish to produce and export them with greater security in the optimization of transport and maintenance of the quality of the fruits.

Given the above, the present work aimed to evaluate the effect of refrigeration on the post-harvest conservation of Shelly and Omer mango cultivars during the forty days of storage.

2. Methodology

This research was carried out with mango fruits of the Shelly and Omer cultivars harvested manually in a commercial orchard at Fazenda La Bourdette, located in the municipality of Juazeiro, Bahia state, Brazil (9º 18' 13.5"S, 40º 40' 04.7"W, with an altitude of approximately 380m). The region has a BSwh' climate (semi-arid, megathermal, with a rainy season in the summer) according to the Köppen classification, with an average annual rainfall of 567 mm and an average air temperature ranging from 24.2 °C to 28.2 °C. The experiment was carried out from December 6 2021 to January 14 2022.

After harvesting, the fruits were transported in container boxes to the Agricultural Product Storage Laboratory (LAPA) at the Federal University of São Francisco Valley, Juazeiro – BA campus. After the reception, the mangos were washed with running water, sanitized with a solution of water and sodium hypochlorite (0.01%) for 15 minutes, washed again to remove excess, dried and separated by cultivar, amount to be used in each type of evaluation and storage time evaluated. Then, all the fruits were properly identified and taken to the BOD at a temperature of 12ºC, from there, the first day of analysis began.

The experiment was carried out in a completely randomized design (CRD) in a 2x9 factorial model, where the two cultivars and nine storage times were compared, with four replications per treatment, with the exception only of the evaluations of mass loss and dry matter (8 and 2 repetitions, respectively). Times were 0, 5, 10, 15, 20, 25, 30, 35 and 40 days after harvest.

The physical-chemical analyzes performed were: skin and pulp colorimetry (L*, a* and b*), absorbance difference index (DA index), mass loss, dry matter, firmness and soluble solids.

To evaluate the skin and pulp color were measured the luminosity (L*), the chromaticity on the green (-) to red (+) (a*) color axis, and the chromaticity on the blue (-) to yellow color axis (+) (b*). For this, the Konica Minolta CR-400® portable digital colorimeter with CIE-Lab system was used, with the peel readings always being taken in the same region of the fruit.

The DA index was obtained using a portable spectrophotometer (DA-meter®, Turoni, Italy) that calculates the difference in values given by the light beams emitted with wavelengths of 670 nm (visible) and 720 nm (infrared) (Betemps; Fachinello; Galarça, 2011).

The mass loss was determined with the aid of a semi-analytical balance (BEL Engineering) with a precision of 0.01g, where 8 fruits of each cultivar were weighed from beginning to end of storage.

Dry matter was determined by calculating the percentage difference in fruit mass before and after drying in an oven. Two fruits of each cultivar were used per day of evaluation, and one half of them was removed close to the seed, which was cut to result in a cube. Thin sheets were made from this cubic piece, from which the initial mass of 100g per cultivar was obtained. After that, the samples were taken to the drying oven with circulation and renewal (SOLAB-SL-1021480) at 65ºC for 24h, in the end, the final masses were obtained, and the values were inserted into the dry matter equation.

Firmness readings were obtained in the same region of the fruit, without skin, using a digital penetrometer (Instrutherm PTR-300) with a 5 mm tip, which expressed the values in Newton (N).

Soluble solids were measured with a digital refractometer (Hanna Instruments - HI96804) and expressed in ºBrix. The device was previously calibrated with distilled water and after that, readings were taken with a small amount of pulp juice from each mango.

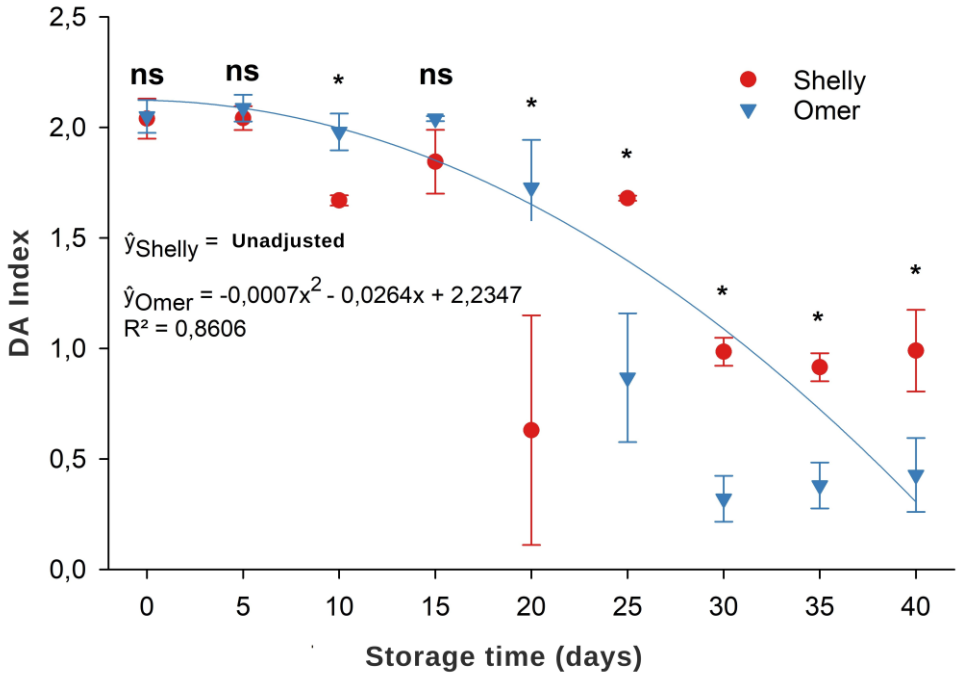
The data collected during the experiment were submitted to analysis of variance (ANOVA), regression and comparison of means by Tukey's test at 5% probability, all in the statistical software R® (version 4.0.2).

3. Results and Discussion

The interaction between cultivars and storage time (C x T) was significant for the parameters DA, ML, Firmness, SS, Color a* and b* of the skin. The other attributes, which in turn did not obtain significant interaction between the sources of variation, were analyzed separately.

The DA Index showed a significant difference for cultivars, storage time and the interaction between them. In figure 1, it was possible to observe that there was a reduction in the average values of the two cultivars, a movement already expected based on other works such as those by Betemps et al., (2011), Busatto et al. (2021).

Figure 1 - DA index of 'Shelly' and 'Omer' mangoes as a function of refrigerated storage time.



Fonte: Autores (2022).

This can be explained by the change in the colors of the pericarp, resulting from the degradation of starch and chlorophyll, and from the synthesis of other pigments, as observed in other mango cultivars by Costa et al. (2019). This explanation can be reinforced by the correlation made by the same author with the parameters a* and b* of the peel, which indicates, in addition to the decrease in the green color, an increase in the yellowish color.

It was also noted that 'Omer' presented the DA index with a more uniform behavior over the days than 'Shelly', which even with a decrease in values did not fit the equation, which may have been a consequence of a more heterogeneous maturation of the samples that were evaluated in this time interval.

The analysis of variance allowed us to infer that the skin luminosity (L*) presented a significant difference at the 5% probability level ($p < 0.05$) for the cultivars and for the storage time.

'Shelly' showed higher average peel luminosity compared to 'Omer' (Table 1). This result, as pointed out by Coelho (2021), can be justified by the color of the skin of each cultivar, with the highest averages for the lighter shades and the lowest for the darkest shades.

Table 1 - Means of L* from the peel of 'Shelly' and 'Omer' mango fruits.

Cultivar	L* peel
Shelly	42,95 ± 3,43 a
Omer	34,00 ± 2,86 b

Means followed by the same letter in the column do not differ by Tukey's test ($p \leq 0.05$). Fonte: Autores (2022).

As evidenced by Costa et al. (2019), the mean values of peel L* increased over time of storage for the two cultivars (Table 2), reflecting the increase in clarity, brightness or whiter/lighter spots on the fruit peel (Coelho, 2021).

Table 2 - Parameter L* of 'Shelly' and 'Omer' mango fruit peel as a function of storage time.

Time (days)	Shelly	Omer
	L* peel	
0	43,99 ± 2,38 a	37,01 ± 3,31 a
5	41,01 ± 3,03 a	31,33 ± 2,00 b
10	41,04 ± 2,22 a	32,33 ± 2,16 b
15	41,80 ± 1,76 a	31,73 ± 1,64 b
20	40,99 ± 4,44 a	31,62 ± 1,75 b
25	43,26 ± 6,72 a	34,84 ± 1,74 b
30	44,11 ± 2,52 a	33,91 ± 1,32 b
35	44,86 ± 2,52 a	35,64 ± 1,30 b
40	45,46 ± 1,92 a	37,63 ± 1,30 a

Means followed by the same letter on the line do not differ by Tukey's test ($p \leq 0.05$). Fonte: Autores (2022).

Thus, the highest L* averages were observed in the most advanced stages of fruit maturation, which coincide with the final storage times, where the colors were presented in light shades. The a* values of the shell followed an increase from the beginning to the end of storage, both for 'Shelly' and for 'Omer', where the first presented the highest averages and the second a greater increase (Table 3).

Table 3 - Parameter a* of 'Shelly' and 'Omer' mango fruit peel as a function of storage time.

Time (days)	Shelly	Omer
	a* peel	
0	21,33 ± 1,35 a	10,71 ± 1,40 b
5	28,62 ± 1,12 a	14,69 ± 2,91 b
10	29,81 ± 2,75 a	15,09 ± 1,89 b
15	28,09 ± 1,94 a	12,37 ± 1,24 b
20	32,74 ± 5,99 a	19,28 ± 4,93 b
25	28,49 ± 1,65 a	26,01 ± 2,02 a
30	32,19 ± 3,24 a	25,48 ± 2,29 b
35	34,23 ± 3,24 a	27,63 ± 1,24 b
40	34,04 ± 2,26 a	30,03 ± 2,49 b

Means followed by the same letter on the line do not differ by Tukey's test ($p \leq 0.05$). Fonte: Autores (2022).

The increment of 'Omer' was greater in relation to 'Shelly' due to different variations in the pigmentation of the peel of each of the two cultivars. The red color of the 'Shelly' peel does not indicate fruit ripening, but it is correlated with higher values of anthocyanin and flavonoids (Sivankalyani et al., 2016), which explains the higher averages.

There was a significant difference in the b* colorimetry of the peel which indicates the transition from blue (-b*) to yellow (+b*), for the interaction of cultivars with time (Carvalho, 2022). This is the main value related to the yellowing of the fruits, being directly linked to the synthesis of carotenoids during ripening (Coelho, 2021).

In the results shown in Table 4, it is possible to see that 'Shelly' presented higher averages in relation to 'Omer' over the storage period, showing a greater presence of yellow in its peel. Both cultivars show a similar range of mean values with slight superiority for 'Shelly'.

Table 4 - Parameter b* of 'Shelly' and 'Omer' mango fruit peel as a function of storage time.

Time (days)	Shelly	Omer
	b* peel	
0	16,08 ± 0,90 a	5,97 ± 0,33 b
5	15,95 ± 1,46 a	6,33 ± 1,89 b
10	14,83 ± 1,78 a	5,93 ± 1,22 b
15	16,94 ± 1,22 a	5,12 ± 1,50 b
20	21,72 ± 1,73 a	11,18 ± 1,00 b
25	18,52 ± 1,10 a	9,54 ± 0,55 b
30	16,74 ± 1,44 a	7,99 ± 1,34 b
35	18,75 ± 1,73 a	8,13 ± 1,00 b
40	22,49 ± 2,16 a	7,54 ± 2,07 b

Means followed by the same letter on the line do not differ by Tukey's test ($p \leq 0.05$). Fonte: Autores (2022).

The L* coordinate of the pulp showed a significant difference only for the storage time variation source, where the averages had a slight decrease up to 20 days and then increased (Table 5), an opposite effect to that observed in other studies.

Table 5 - Parameter L* of 'Shelly' and 'Omer' mango fruit pulp as a function of storage time.

Time (days)	Shelly	Omer
	L* pulp	
0	73,86 ± 3,23 a	75,72 ± 4,16 a
5	68.04 ± 3,70 a	68,59 ± 1,07 a
10	65.48 ± 2,65 a	67.47 ± 4,33 a
15	68.41 ± 2,82 a	64.61 ± 5,76 a
20	65.97 ± 5,68 a	64.66 ± 3,43 a
25	78.10 ± 2,46 a	81.22 ± 2,09 a
30	75.02 ± 2,29 a	78.52 ± 1,07 a
35	76.01 ± 2,46 a	78.75 ± 1,08 a
40	76.59 ± 3,77 a	79.76 ± 3,05 a

Means followed by the same letter on the line do not differ by Tukey's test ($p \leq 0.05$). Fonte: Autores (2022).

Costa et al. (2016), through the results obtained for the luminosity of the pulp of coated 'Palmer' fruits, associated the levels of this measure with the water content in the fruit and with its ripening, which results in greater reflection of the initially incident light, and smaller as the pulp darkens (Serpa et al., 2014), different from what was noticed in this work.

This effect contrary to what was expected may have occurred due to a non-representative reading of the samples with visually confirmed maturation, since the analyzes were performed on different fruits on each evaluation day.

The pulp variable a*, as well as the luminosity, was statistically different only for the storage time, and showed an initial aptitude for the loss of green color and change to red (-a* to +a*), indicated in Table 6, but later it showed some non-uniformity in the means.

Table 6 - Parameter a* of 'Shelly' and 'Omer' mango fruit pulp as a function of storage time.

Time (days)	Shelly	Omer
	a* pulp	
0	- 6,76 ± 1,09 a	- 6,07 ± 1,06 a
5	- 4,92 ± 1,74 a	- 4,41 ± 0,79a
10	- 3,97 ± 1,47 a	- 1,89 ± 3,22 a
15	- 4,20 ± 1,05 a	- 3,72 ± 0,69 a
20	- 0,31 ± 3,89 a	- 3,29 ± 1,11 a
25	- 4,28 ± 1,33 a	- 5,54 ± 1,13 a
30	- 1,06 ± 2,75 a	- 4,24 ± 0,37 b
35	- 3,41 ± 2,75 a	- 4,54 ± 1,33 a
40	- 4,21 ± 1,22 a	- 4,43 ± 1,08 a

Means followed by the same letter on the line do not differ by Tukey's test ($p \leq 0.05$). Fonte: Autores (2022).

Ntsoane et al. (2019) also identified the same change in pulp a* averages with advancing storage period in 'Shelly' fruits, which occurs due to the loss of greenish tones and the gain of more orange tones (Costa et al., 2021). The non-uniformity can also be explained by the heterogeneity of the samples and their non-correlation with the visually observed maturation.

In the analysis of the average values of b*, there was a significant difference only for the cultivars, showing that the yellowness of the pulp of the samples did not vary significantly over the days of storage, similar to what was observed by Costa et al. (2021) for 'Ataulfo'.

The cultivar 'Shelly' showed a higher mean value (Table 7) in relation to 'Omer'. These results can be justified by the intrinsic characteristics of maintaining the color of the pulp of each cultivar.

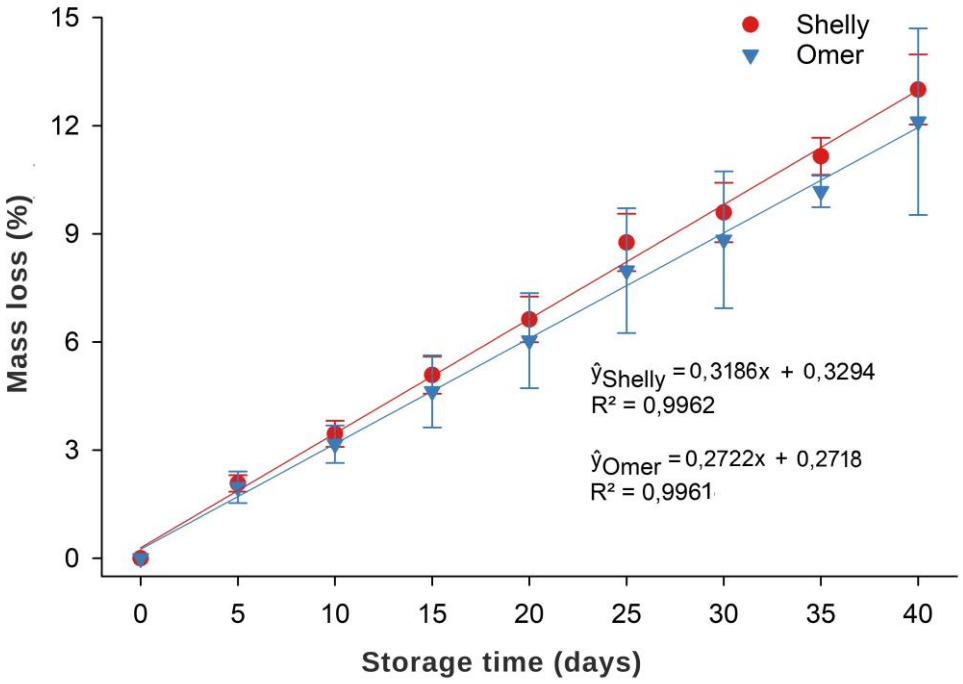
Table 7 - Means of b* of 'Shelly' and 'Omer' mango fruit peel.

Cultivar	b* pulp
Shelly	56,11 ± 6,90 a
Omer	41,96 ± 7,79 b

Means followed by the same letter in the column do not differ by Tukey's test ($p \leq 0.05$). Fonte: Autores (2022).

The cultivars and storage time differed statistically in terms of mass loss, different from the interaction between these sources of variation. As expected, over the days there was an increase in the loss of fruit mass (Figure 2), a trend also reported by Ebrahimi and Rastegar (2020).

Figure 2 - Mass loss of 'Shelly' and 'Omer' mangoes from 0 to 40 days after harvest, under refrigerated conditions.



Fonte: Autores (2022).

'Shelly' showed a higher percentage of mass loss compared to 'Omer' (Table 8).

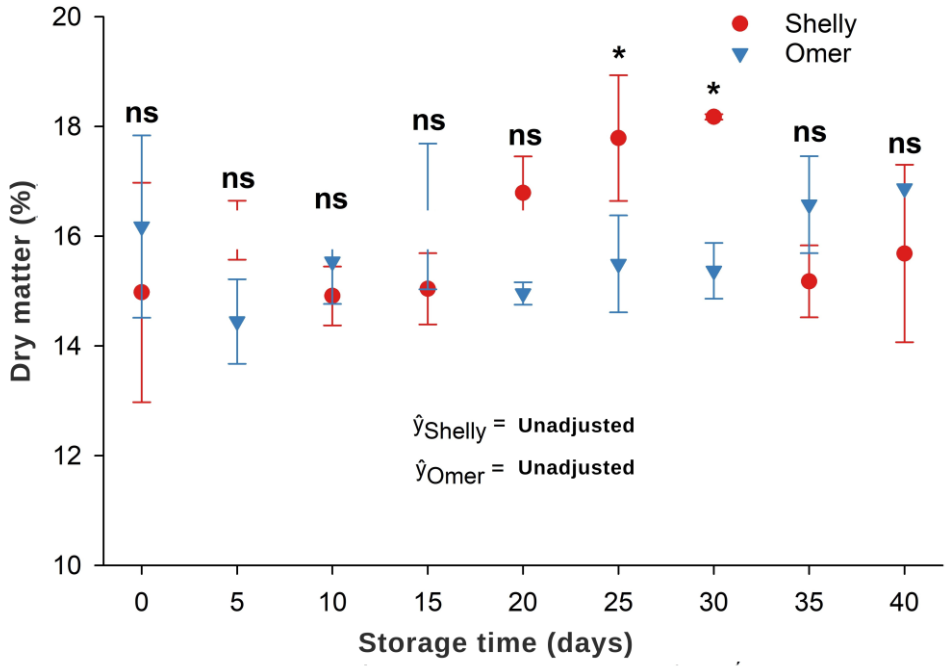
Table 8 - Mass loss of 'Shelly' and 'Omer' mangoes after 40 days of cold storage.

Cultivar	Mass loss (%)
Shelly	6,64 ± 4,17 a
Omer	6,10 ± 4,02 b

Means followed by the same letter in the column do not differ by Tukey's test ($p \leq 0.05$). Fonte: Autores (2022).

The interaction of cultivars with storage time was significant for dry matter, where “Omer” presented the smallest variation of the averages during storage (Figure 3). The means of both cultivars did not fit the equation, so it was not possible to observe trends.

Figure 3 - Dry matter of 'Shelly' and 'Omer' mangoes from 0 to 40 days after harvest, under refrigerated conditions.

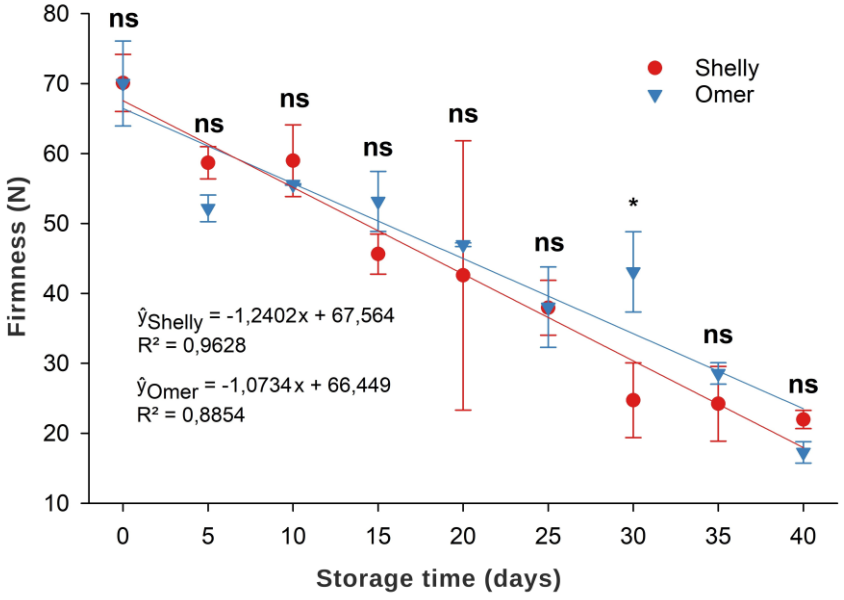


Fonte: Autores (2022).

The range of values for this measure was similar to that found by Hor et al. (2020) (14% to 22%) for the 'Kent' variety, also being close to the recommendations of Freitas et al., (2021) for dry matter contents in cvs. Tommy Atkins, Palmer and Keitt, cultivated in the São Francisco Valley, which vary from 13.7% to 16.1%).

The firmness of the fruit of the two cultivars decreased with the passage of time and advancement of maturation (Figure 4), as expected, which resulted in a change in the consistency and texture of the pulp.

Figure 4 - Firmness of 'Shelly' and 'Omer' fruits from 0 to 40 days after harvest, under refrigerated conditions.

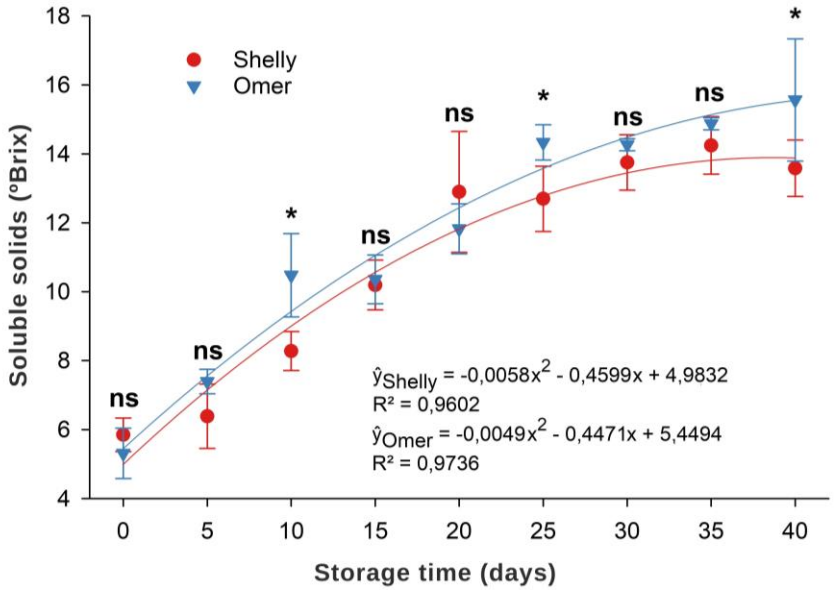


Fonte: Autores (2022).

This decline was also observed in other studies with mangoes cvs. Shelly, Omer, (Silvankalyani et al., 2016; Haseeb et al., 2020). This behavior occurs due to the increase in enzymatic activity related to the hydrolysis of starch, the degradation of pectin and other carbohydrate compounds from the cell wall, in addition to the loss of water from the cells (Vilas Boas et al., 2004; Hossain et al., 2014; Khaliq et al., 2017).

Soluble solids were significantly increased as the days of storage of the fruits of the two evaluated cultivars increased (Figure 5). 'Omer' showed higher averages compared to 'Shelly', reaching peaks of 16.2 ºBrix on the last day of evaluation and 14.3 ºBrix on the penultimate day, respectively.

Figure 5 - Soluble solids (ºBrix) of 'Shelly' and 'Omer' fruits from 0 to 40 days after harvest, under refrigerated conditions**.**



Fonte: Autores (2022).

It was expected that this factor would present the propensity shown, since it was also observed by Sudheeran et al. (2018) on 'Shelly' mango and by several other authors on different mango cultivars.

The SS values may vary according to the cultivar within a range of 12 to 18.1 ºBrix in the main cultivars produced in Brazil (Batista et al., 2015), which includes the data of the two cultivars of the present study. Sivankalyani et al. (2016) working with ‘Shelly’ and Haseeb et al. (2020) with ‘Omer’, also found similar values.

4. Conclusion

The results obtained showed that, in general, the cultivar Omer presented a better response to the condition of cold storage, characterizing better conservation of quality attributes.

'Shelly' had a smaller decrease in DA index and a smaller increase in SS, showing less degradation of chlorophyll and starch compared to 'Omer'.

'Omer' was superior in mass conservation, and showed less variation in the percentage of dry matter and in the color parameters that were possible to infer.

For future studies, it is suggested to determine the ideal harvest point of both cultivars for maritime export, aiming at a better uniformity of the stages of maturation in post-harvest conservation.

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