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Effects of rootstocks on storage performance of Nova mandarins

Ahmet Erhan ÖZDEMİR[1,*], Öznur DİDİN[1], Elif ÇANDIR[1], Mustafa KAPLANKIRAN[1], Ercan YILDIZ[2]

[1]Department of Horticulture, Faculty of Agriculture, Mustafa Kemal University, Hatay, Turkey

[2]Department of Horticulture, Faculty of Agriculture and Natural Sciences, Uşak University, Uşak, Turkey

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Abstract: In this research, the effects of rootstocks on the storage performance of Nova mandarins grafted on Carrizo citrange, Troyer citrange, or sour orange grown in the ecological conditions of Dörtyol were studied. Fruits were harvested at optimum maturity and kept at 4 °C and 6 °C for 120 days. Changes in weight loss, incidence of fungal decay and physiological disorders, juice content, total soluble solids (TSS), percent fruit with green button, titratable acidity (TA), juice pH, vitamin C content, and rind color (L*, C*, h°) were monitored at 15-day intervals during storage to determine the effects of rootstock on postharvest quality of Nova mandarins. The fruit of Nova mandarin grafted on sour orange and Carrizo citrange had higher weight loss than Troyer citrange. Weight loss from Nova mandarins kept at 4 °C and 6 °C reached 7.71% and 12.21%, respectively, after 120 days of storage. Juice pH, incidence of fungal decay, and physiological disorders increased, while juice content, TA, vitamin C content, percent fruit with green button, and L*, C*, and h° values of rind color decreased in the Nova mandarin cultivar during cold storage. According to the data, the fruits of Nova mandarin grafted on Carrizo citrange, Troyer citrange, or sour orange were stored better at 4 °C than 6 °C. Fruit could be kept at 4 °C for 75 days and at 6 °C for 45 days without any quality deterioration.

Key words: Carrizo, mandarin, rootstock, sour orange, storage, Troyer

1. Introduction

Citrus is a major horticultural crop and commodity worldwide. Citrus species are some of the most important fruit groups for Turkey in terms of production and export quantity. The success of citrus production depends on the availability of suitable rootstocks. In the past, many growers planted sour orange rootstock in Mediterranean regions, including Turkey. However, this rootstock is very sensitive to the tristeza virus (Demirkeser et al., 2009; Kurt et al., 2014); thus, there is a need to evaluate other rootstocks. Kaplankıran et al. (2001) and Demirkeser et al. (2011) suggested the use of Carrizo citrange as rootstock for citrus, except for lemons, in the Aegean and Eastern Mediterranean regions.

Mandarins are becoming increasingly popular among consumers, largely due to easier peeling than other citrus (Obenland et al., 2011). The excellent quality and characteristic flavor of mandarin cultivars are highly prized by some, and if seedless varieties of a larger size can be developed, their popularity will greatly increase (Demirkeser et al., 2009). Although they are preferred by consumers, the recommended storage life under optimum conditions is only 2–4 weeks, less than half that of conventional oranges (Kader and Arpaia, 2002). Tangerines usually have a short postharvest life and could undergo physiological disorders such as chilling injury when stored at low temperatures, with consequent reduction of quality and flavor (D'Aquino et al., 1997). A previous study showed that fruits from Nova mandarin grafted on sour orange could be stored for 60 days at 4 °C and 85%–90% relative humidity (Özdemir et al., 2008). Literature regarding production techniques, appropriate rootstocks, and postharvest fruit characteristics is still scarce.

Temperature management is the most important environmental factor used to maintain quality of fresh horticultural produce after harvest. Low temperatures reduce respiration and water loss, pathogen growth, and decay incidence (Kader, 2002).

The latest trend in the citrus industry is to extend the period in which the markets are supplied with citrus fruit, particularly oranges and mandarins (Demirkeser et al., 2009). Therefore, cold storage performance of Nova mandarins grafted on sour orange, Carrizo, or Troyer citrange grown in the ecological conditions of Dörtyol was evaluated in this study.

* Correspondence: erhan@mku.edu.tr

2. Materials and methods

2.1. Fruit and rootstock material

Fruits of Nova mandarin were obtained from five 8–9-year-old trees grafted on sour orange (*Citrus aurantium* L.), Carrizo, and Troyer citrange (*C. sinensis* (L.) Osb. × *Poncirus trifoliata* (L.) Raf.) rootstocks and planted 7 m × 7 m at the Dörtyol Research Station of the Faculty of Agriculture, Mustafa Kemal University (36°51.10′N, 36°09.57′E; altitude 9 m). The region has a Mediterranean climate with an annual average temperature of 19.1 °C and an annual rainfall of 950 mm (Temiz, 2005; Yener, 2011). The soil of the studied plot is slightly alkaline and soil texture of the experimental area is sandy-loamy (sandy: 646–693, loamy: 245–270, and clay: 64.6–69.4 g kg^{-1}). Subsurface methods of drip irrigation were used in the research plot.

Nova mandarin (*C. reticulata* Blanco × (*C. paradisi* Macf. × *C. reticulata*)) on sour orange (*C. aurantium* L.), a hybrid between the Fina clementine and Orlando tangelo, is in high demand in the export market due to its excellent fruit quality. The rind color of Nova is a more attractive reddish orange and its internal quality is extremely high. The color is a deep orange; the segments are very juicy and tender and have a fine sweet flavor. Acid levels are moderate, resulting in a high sugar to acid ratio. Nova is popular with consumers who are ready to pay premium prices only if the fruit is seedless, and seedless fruits are also preferred in European markets. In recent years, production of new mandarin cultivars, e.g. Nova, has been increasing in Turkey (Demirkeser et al., 2009).

2.2. Storage conditions and quality analyses

After 10 days from the time when fruit juice was over 33%, total soluble solid content (TSS) was over 10%, TSS/titratable acid was over 6.5, and 2/3 of the fruit's specific rind color was obtained (Özdemir et al., 2015), the fruit of Nova mandarin was harvested from trees grafted on rootstocks of sour orange, Carrizo, and Troyer citrange. Fruits were stored for 120 days at two different temperatures of 4 °C and 6 °C, at 85%–90% relative humidity.

Weight loss (%) was calculated by subtracting final weight from initial weight. Percentage of fruit with green button (%), incidence of fungal decay (%), and physiological disorders (%) were determined during storage by naked eye. Fruit juice content (%) was extracted with a motor-driven hand reamer and TSS content (%) was assessed in the juice obtained from 10 fruits per replicate after slicing and removing rinds and seeds with a digital refractometer (Atago Model ATC-1E) at 20 °C. Titratable acidity (%) was determined as citric acid equivalent by the potentiometric method. Juice pH value was measured by digital pH meter (WTW Innolab). Fruit rind color (L*, C*, h°) was measured using the CIELAB (L*a*b*) color space with a CR-300 Minolta Chroma Meter (Konica Minolta, Osaka, Japan). Vitamin C (mg 100 mL^{-1}) content (L-ascorbic acid) was determined spectrophotometrically using a Shimadzu UV-1208 spectrophotometer according to the procedure described by Pearson and Churchill (1970) and Çandır and Özdemir (2015). Fruit quality parameters were measured at 15-day intervals during the storage period.

The study was performed over a 2-year period. Data are represented as the mean of 2 experimental years. The experiment was carried out as a factorial experiment in a completely randomized block design with 3 replications per rootstock and temperature during the storage period; each replicate contained 10 fruits and data were analyzed using analysis of variance (ANOVA) by the procedures of statistical software SAS 9.4 (SAS, 2017). Tukey's multiple range test was used for comparing the averages of the variation sources. Analysis of variance was used to examine rootstock effects on fruit quality characteristics. Data for parameters calculated as percentage were arcsine-transformed and analyzed by ANOVA and back-transformed for reporting.

3. Results

3.1. Weight loss

Weight loss increased as storage time extended and reached an average of 16.83% at the end of 120 days (Table 1). Weight loss was higher in fruit from the Nova mandarin cultivar grafted on sour orange (9.77%) and Carrizo citrange (9.66%) than in fruit grafted on Troyer citrange (8.96%). Weight loss was higher at 6 °C (11.21%) than at 4 °C (7.71%).

3.2. Fungal decay

The pathogens causing fungal decay during our study were predominantly *Penicillium* spp. No decay occurred in fruit from all rootstocks at both storage temperatures during 30 days of storage. Then fungal decay increased as storage time extended and reached an average of 12.50% at the end of 120 days (Table 1). The effects of rootstocks on fungal decay were not statistically significant during cold storage. The incidence of fungal decay was higher at 6 °C (3.54%) than at 4 °C (2.55%).

3.3. Physiological disorder

Observed physiological disorders were formation of surface lesions and external discoloration, and formation of brown and/or blacking pit-like depressions in the flavedo, the outer colored part of the peel and senescence. Physiological disorders increased rapidly after 105 and 120 days in fruit on all rootstocks at both storage temperatures. Physiological disorders increased as storage time extended and reached an average of 23.15% at the end of 120 days (Table 1). The incidence of physiological disorders was higher in fruit from the Nova mandarin cultivar grafted on Troyer (4.65%) and Carrizo citrange (4.00%) than in

Table 1. Effects of rootstocks on weight loss, incidence of fungal decay, and physiological disorder in Nova mandarin cultivar during 120 days of storage at 4 °C and 6 °C.

Weight loss (%)	Temperature (°C)						Storage time mean
	4			6			
Storage time (days)	Rootstocks						
	Carrizo citrange	Troyer citrange	Sour orange	Carrizo citrange	Troyer citrange	Sour orange	
15	1.63	1.55	1.92	2.52	2.21	2.39	2.04 h
30	3.04	3.10	3.44	5.04	4.35	4.72	3.95 g
45	4.91	5.12	5.53	8.10	7.17	7.68	6.42 f
60	6.43	6.54	7.17	10.87	9.56	10.15	8.45 e
75	8.16	8.33	9.11	13.76	12.04	11.95	10.56 d
90	9.56	10.02	11.00	16.27	13.91	15.15	12.65 c
105	11.45	11.95	13.14	18.77	15.79	17.59	14.78 b
120	13.12	13.64	15.20	20.82	18.09	20.10	16.83 a
Temperature mean		7.71 b[x]		11.21 a			
Rootstock mean		Carrizo	9.66 a	Troyer	8.96 b	Sour orange	9.77 a
Fungal decay (%)							Mean
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00 d
30	0.00	0.00	0.00	0.00	0.00	0.00	0.00 d
45	0.56	0.56	0.00	1.11	2.22	1.67	1.02 cd
60	0.56	1.11	0.56	1.11	0.00	0.56	0.65 d
75	2.22	1.67	1.67	0.56	2.22	1.11	1.57 cd
90	2.78	2.22	1.67	2.22	0.00	1.67	1.76 c
105	3.89	7.78	5.56	7.78	10.00	6.11	6.85 b
120	8.33	9.44	10.56	15.56	15.56	15.56	12.50 a
Temperature mean		2.55 b		3.54 a			
Rootstock mean		Carrizo	2.92	Troyer	3.30	Sour orange	2.92
Physiological disorders (%)							Mean
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00 e
30	0.00	0.00	0.00	0.00	0.00	0.00	0.00 e
45	0.00	0.00	0.00	0.00	0.56	1.67	0.37 de
60	0.00	0.00	0.56	0.00	0.56	1.11	0.37 de
75	0.56	0.56	0.56	1.67	1.67	6.11	1.85 c
90	0.56	0.00	3.33	2.22	0.56	2.22	1.48 cd
105	3.33	3.89	1.67	5.56	6.11	14.45	5.83 b
120	8.89	11.11	5.56	41.11	49.44	22.78	23.15 a
Temperature mean		1.69 b		6.57 a			
Rootstock mean		Carrizo	4.00 ab	Troyer	4.65 a	Sour orange	3.75 b

[x] Mean separation was performed by Tukey's multiple range test. Rootstock and temperature means (number of replicates = 3) followed by the same letter within a column are not significantly different at $P < 0.005$. Rootstock and temperature means were compared separately for each storage time.

fruit grafted on sour orange (3.75%). The incidence of physiological disorders was higher at 6 °C (6.57%) than at 4 °C (1.69%).

3.4. Fruit juice content

Although fluctuations occurred in fruit juice content during storage, they decreased in fruit on all rootstocks at both storage temperatures at the end of storage time. The initial fruit juice content was an average of 55.88% and decreased to 48.64% at the end of 120 days. Fruit juice content was higher in fruit from the Nova mandarin cultivar grafted on Carrizo citrange (53.87%) than in fruit grafted on Troyer citrange (52.41%) and sour orange (52.20%). The effects of temperature on fruit juice content were not statistically significant during cold storage (Table 2).

3.5. Total soluble solids (TSS) content

Although TSS content decreased and increased during storage, a decrease in TSS content was observed in fruit on all rootstocks at the end of the storage time. The effects of rootstocks on TSS content were not statistically significant during cold storage (Table 2). TSS content was higher at 6 °C (11.80%) than at 4 °C (11.59%).

3.6. Percentage of fruit with green button

Percentage of fruit with green button decreased in fruit on all rootstocks at both storage temperatures at the end of the storage time. The initial percentage of fruit with green button was an average of 100.00% and decreased to 12.59% at the end of 120 days (Table 2). The percentage of fruit with green button was higher in fruit from the Nova mandarin cultivar grafted on Troyer citrange (75.62%) and Carrizo citrange (74.69%) than in fruit grafted on sour orange (73.98%). The percentage of fruit with green button was higher at 4 °C (77.39%) than at 6 °C (72.14%).

3.7. Titratable acidity (TA)

The TA was decreased in fruit on all rootstocks at both storage temperatures at the end of storage time. The initial TA content was an average of 1.09% and it decreased to 0.68% at the end of 120 days. TA content was higher in fruit from the Nova mandarin cultivar grafted on Troyer citrange (0.93%) than in fruit grafted on Carrizo citrange (0.84%) and sour orange (0.82%). The effects of temperature on TA content were not statistically significant during storage (Table 3).

3.8. Juice pH

Juice pH fluctuated during storage, but an increase occurred in fruit on all rootstocks at both storage temperatures at the end of storage time. The initial juice pH was an average of 3.27 and increased to 3.59 at the end of 120 days. Juice pH was higher in fruit from the Nova mandarin cultivar grafted on Troyer (3.35) and Carrizo citrange (3.34) than in fruit grafted on sour orange (3.31). The effects of temperature on the juice pH value were not statistically significant during cold storage (Table 3).

3.9. Vitamin C content (L-ascorbic acid)

Vitamin C content decreased in fruit on all rootstocks at both storage temperatures at the end of storage time. The initial vitamin C content was an average of 45.75 mg 100 mL^{-1} and decreased to 35.64 mg 100 mL^{-1} at the end of 120 days (Table 3). Vitamin C content was higher in fruit from the Nova mandarin cultivar grafted on sour orange (40.98 mg 100 mL^{-1}) and Carrizo citrange (40.65 mg 100 mL^{-1}) than in fruit grafted on Troyer citrange (40.34 mg 100 mL^{-1}). Vitamin C content was higher at 6 °C (41.07 mg 100 mL^{-1}) than at 4 °C (40.24 mg 100 mL^{-1}).

3.10. Rind color

Fruit rind color L* values of Nova mandarins decreased during storage time in fruit on all rootstocks at both storage temperatures. Fruit rind color L* values of Nova mandarins were an average of 64.55 at harvest and decreased to 58.66 at the end of cold storage period (Table 4). L* values were higher in fruit from the Nova mandarin cultivar grafted on Troyer (62.97) than in fruit grafted on Carrizo citrange (62.46) and sour orange (62.21). L* values were higher at 4 °C (63.12) than at 6 °C (61.98).

Fruit rind color C* values decreased in fruit on all rootstocks at both storage temperatures at the end of storage time. Initial fruit rind color C* values were an average of 74.15 and decreased to 63.69 at the end of 120 days. The effects of rootstocks on C* values were not statistically significant during cold storage (Table 4). C* values were higher at 4 °C (71.31) than at 6 °C (68.98).

Fruit rind color h° values of Nova mandarins decreased during storage in fruit on all rootstocks at both storage temperatures. The fruit rind color h° values of Nova mandarins were an average of 65.54° at harvest and decreased to an average of 62.28° at the end of cold storage period (Table 4). Rind color h° values were higher in fruit from the Nova mandarin cultivar grafted on Troyer (64.45°) than in fruit grafted on Carrizo citrange (63.43°). Fruit rind color h° values at 4 °C (64.17°) were higher than at 6 °C (63.55°).

4. Discussion

Quality parameters were affected by rootstock and temperatures during storage. According to Grierson and Ben-Yehoshua (1986), weight loss is the most important factor in quality loss of citrus fruit after harvest. It is reported that if weight loss exceeds 10% of the product's total weight, it will lose its marketable characteristics (Grierson and Wardowski, 1978). In addition, Pekmezci (1984), Waks et al. (1985), and Gürgen et al. (1995) reported that weight loss of 2%–3% per month may occur at relative humidity of 85%–90% under appropriate storage temperature in citrus. According to our findings, weight loss in the Nova mandarins at 6 °C was above these limits during storage. However, our data on weight loss are in agreement with

Table 2. Effects of rootstocks on juice content, total soluble solids, and percent green buttoned fruit in Nova mandarin cultivar during 120 days of storage at 4 °C and 6 °C.

Juice content	Temperature (°C)						Storage time mean
	4			6			
Storage time (days)	Rootstocks						
	Carrizo citrange	Troyer citrange	Sour orange	Carrizo citrange	Troyer citrange	Sour orange	
0	56.82	55.44	55.38	56.82	55.43	55.38	55.88 a
15	55.20	54.37	56.35	57.78	56.69	54.93	55.89 a
30	52.79	52.79	54.73	53.32	50.92	51.76	52.72 bc
45	55.87	55.29	55.26	57.80	56.18	56.06	56.08 a
60	53.81	54.50	52.80	55.55	54.23	51.46	53.72 b
75	51.94	49.20	50.98	52.60	51.98	47.82	50.75 d
90	51.11	49.26	53.08	52.65	46.71	47.45	50.04 de
105	51.21	50.97	48.42	55.75	52.55	51.36	51.71 d
120	46.42	46.25	48.18	52.17	50.70	48.15	48.64 e
Temperature mean		52.53[x]		53.12			
Rootstock mean		Carrizo	53.87 a	Troyer	52.41 b	Sour orange	52.20 b
Soluble solids content (%)							Mean
0	11.70	11.70	11.57	11.70	11.70	11.57	11.66 bc
15	11.37	11.50	11.40	11.67	11.50	11.30	11.46 cd
30	11.70	11.47	11.70	11.17	11.55	11.40	11.50 cd
45	12.47	12.00	12.33	12.13	12.73	12.10	12.29 a
60	11.50	11.90	11.73	11.87	12.03	12.13	11.86 b
75	11.78	11.65	11.97	11.57	11.30	11.23	11.58 cd
90	11.63	11.33	11.40	12.03	12.02	12.38	11.80 b
105	10.43	10.93	11.57	11.77	11.87	12.10	11.44 d
120	11.50	11.23	11.43	11.75	11.78	12.23	11.66 bc
Temperature mean		11.59 b		11.80 a			
Rootstock mean		Carrizo	11.65	Troyer	11.68	Sour orange	11.75
Green buttoned fruit (%)							Mean
0	100.00	100.00	100.00	100.00	100.00	100.00	100.00 a
15	100.00	100.00	100.00	100.00	100.00	100.00	100.00 a
30	100.00	100.00	100.00	100.00	100.00	100.00	100.00 a
45	96.67	100.00	98.33	90.00	90.00	90.00	94.17 b
60	85.56	91.67	91.67	83.89	87.78	88.89	88.24 c
75	85.00	90.00	87.22	80.56	81.11	76.11	83.33 d
90	82.22	75.56	78.33	72.78	66.67	58.33	72.31 e
105	25.56	30.00	27.78	15.00	20.00	15.00	22.22 f
120	15.56	15.00	13.33	11.67	13.33	6.67	12.59 g
Temperature mean		77.39 a		72.14 b			
Rootstock mean		Carrizo	74.69 ab	Troyer	75.62 a	Sour orange	73.98 b

[x] Mean separation was performed by Tukey's multiple range test. Rootstock and temperature means (number of replicates = 3) followed by the same letter within a column are not significantly different at $P < 0.005$. Rootstock and temperature means were compared separately for each storage time.

Table 3. Effects of rootstocks on titratable acidity, juice pH value, and vitamin C content in Nova mandarin cultivar during 120 days of storage at 4 °C and 6 °C.

Titratable acidity (%)	Temperature (°C)						Storage time mean
	4			6			
Storage time (days)	Rootstocks						
	Carrizo citrange	Troyer citrange	Sour orange	Carrizo citrange	Troyer citrange	Sour orange	
0	1.10	1.15	1.01	1.10	1.15	1.01	1.09 a
15	1.05	1.14	1.00	0.95	1.11	1.00	1.04 b
30	0.97	1.00	1.01	0.87	1.08	0.90	0.97 c
45	0.93	0.98	0.91	0.78	0.96	0.80	0.89 d
60	0.86	0.90	0.80	0.73	0.90	0.74	0.82 e
75	0.85	0.85	0.77	0.76	0.93	0.74	0.82 e
90	0.74	0.85	0.70	0.76	0.85	0.71	0.77 f
105	0.66	0.70	0.64	0.70	0.73	0.68	0.69 g
120	0.60	0.74	0.60	0.65	0.83	0.68	0.68 g
Temperature mean		0.87[x]		0.86			
Rootstock mean		Carrizo	0.84 b	Troyer	0.93 a	Sour orange	0.82 b
Juice pH value							Mean
0	3.31	3.27	3.24	3.31	3.27	3.24	3.27 e
15	3.16	3.13	3.07	3.12	3.18	3.12	3.13 f
30	3.23	3.24	3.11	3.05	3.09	3.02	3.12 f
45	3.24	3.24	3.18	3.37	3.32	3.31	3.27 e
60	3.33	3.29	3.24	3.33	3.32	3.33	3.31 d
75	3.32	3.43	3.42	3.39	3.34	3.36	3.38 c
90	3.39	3.42	3.39	3.43	3.38	3.38	3.40 c
105	3.50	3.56	3.60	3.50	3.53	3.49	3.53 b
120	3.64	3.66	3.57	3.57	3.58	3.52	3.59 a
Temperature mean		3.34		3.33			
Rootstock mean		Carrizo	3.34 a	Troyer	3.35 a	Sour orange	3.31 b
Vitamin C content (mg 100 mL^{-1})							Mean
0	44.77	44.82	47.66	44.77	44.82	47.66	45.75 a
15	43.06	43.22	45.22	44.02	43.61	44.79	43.99 b
30	41.36	41.62	42.78	43.27	42.40	41.91	42.22 c
45	40.39	40.98	41.76	42.71	42.88	41.25	41.66 cd
60	39.42	40.35	40.74	42.14	43.35	40.60	41.10 d
75	38.38	39.79	39.30	40.98	40.63	39.95	39.84 e
90	37.34	39.22	37.86	39.83	37.91	39.30	38.58 f
105	37.24	35.92	37.15	38.21	36.62	37.51	37.11 g
120	37.15	32.61	36.44	36.60	35.33	35.72	35.64 h
Temperature mean		40.24 b		41.07 a			
Rootstock mean		Carrizo	40.65 ab	Troyer	40.34 b	Sour orange	40.98 a

[x] Mean separation was performed by Tukey's multiple range test. Rootstock and temperature means (number of replicates = 3) followed by the same letter within a column are not significantly different at $P < 0.005$. Rootstock and temperature means were compared separately for each storage time.

Table 4. Effects of rootstocks on rind color L*, C*, and h° values in Nova mandarin cultivar during 120 days of storage at 4 °C and 6 °C.

L* values	Temperature (°C)						Storage time mean
	4			6			
Storage time (days)	Rootstocks						
	Carrizo citrange	Troyer citrange	Sour orange	Carrizo citrange	Troyer citrange	Sour orange	
0	64.11	64.99	64.26	64.18	64.72	65.02	64.55 a
15	63.25	63.74	63.17	63.30	63.79	63.97	63.53 bc
30	63.36	64.33	62.90	63.05	63.90	63.59	63.52 bc
45	63.74	64.87	63.28	63.53	64.68	64.27	64.06 ab
60	63.71	64.31	62.62	62.71	63.95	63.40	63.45 c
75	63.46	63.99	61.78	61.92	62.62	62.68	62.74 d
90	63.43	64.08	61.83	60.21	60.48	60.61	61.77 e
105	62.73	62.88	60.16	58.75	59.09	60.11	60.62 f
120	62.40	61.49	59.28	56.36	55.56	56.88	58.66 g
Temperature mean		63.12 a[x]		61.98 b			
Rootstock mean		Carrizo	62.46 b	Troyer	62.97 a	Sour orange	62.21 b
C* values							Mean
0	76.31	75.06	75.09	72.80	72.23	73.43	74.15 a
15	72.29	72.40	72.33	72.17	71.80	72.63	72.27 b
30	72.37	72.77	72.08	72.39	72.10	72.72	72.40 b
45	69.84	70.42	69.06	69.74	69.72	70.07	69.81 d
60	71.68	71.87	70.42	70.24	71.21	71.09	71.08 c
75	71.71	71.53	69.01	68.86	69.23	70.13	70.08 d
90	74.15	73.75	71.50	66.33	66.35	67.59	69.95 d
105	71.53	70.97	68.36	65.00	64.08	67.21	67.86 e
120	68.41	66.19	64.21	61.82	59.38	62.14	63.69 f
Temperature mean		71.31 a[x]		68.98 b			
Rootstock mean		Carrizo	70.42	Troyer	70.06	Sour orange	69.95
h° values							Mean
0	65.84	66.02	65.79	64.35	65.52	65.76	65.54 a
15	63.97	64.72	64.22	63.26	64.67	64.44	64.22 b
30	63.95	65.24	64.05	63.27	64.56	64.22	64.22 b
45	61.88	63.39	61.74	60.93	62.49	62.17	62.10 c
60	64.03	65.16	63.70	62.95	64.55	63.90	64.05 b
75	64.05	65.53	63.63	63.00	64.19	63.71	64.02 b
90	64.87	65.65	64.36	62.75	63.85	63.45	64.15 b
105	64.59	65.87	63.88	63.02	63.77	64.01	64.19 b
120	62.62	62.91	61.06	62.43	61.96	62.69	62.28 c
Temperature mean		64.17 a		63.55 b			
Rootstock mean		Carrizo	63.43 c	Troyer	64.45 a	Sour orange	63.71 b

[x] Mean separation was performed by Tukey's multiple range test. Rootstock and temperature means (number of replicates = 3) followed by the same letter within a column are not significantly different at $P < 0.005$. Rootstock and temperature means were compared separately for each storage time.

the work of Agabbio et al. (1985) in Tardivi di Ciaculli mandarins; Ağar and Kaşka (1992), Gül (1996), Dündar and Göçer (2001), Özdemir et al. (2007), and Özkaya (2007) in Minneola tangelo; Pekmezci (1984), Pekmezci et al. (1997), and Ağar and Kaşka (1994) in Clemantine mandarins; Agabbio et al. (1999) in Malvasio mandarins; Pekmezci (1984), Ağar and Kaşka (1994), Şen (2004), and Şen and Karaçalı (2005) in 'Satsuma' mandarins; Gonzales-Aguilar et al. (1997) and D'Aquino et al. (2005) in Fortune mandarins; D'Aquino et al. (1997), Ragone (1999), Salvador et al. (2006), Özdemir et al. (2008), and Karaşahin et al. (2014) in Nova mandarins; Özkaya (2007) and Özdemir et al. (2008) in Robinson mandarins; and Özdemir et al. (2005, 2008, 2016) in Fremont mandarins. It has been reported that the lowest weight loss occurred in the fruit from Valencia and Washington Navel orange cultivars grafted on Troyer and Carrizo citrange during storage (Akpınar, 1990). Similarly, Gürgen et al. (1995) reported that the lowest weight loss occurred in fruit from the Marsh Seedless grapefruit cultivar grafted on Troyer citrange during storage.

Consistent with our results, fungal decay increased during storage in mandarins (Pekmezci, 1984; Ağar and Kaşka, 1992, 1994; Gül, 1996; D'Aquino et al., 1997; Pekmezci et al., 1997; Schirra and D'Hallewin, 1997; Ragone, 1999; Şen, 2004; Şen and Karaçalı, 2005; Hong et al., 2007; Özkaya, 2007; Özdemir et al., 2005, 2008; Karaşahin et al., 2014) at different temperatures (Ragone, 1999; Özdemir et al., 2007, 2016; Obenland et al., 2011) and with different rootstocks (Özdemir et al., 2016). Similarly, Akpınar (1990) reported that the impact of rootstocks on the incidence of fungal decay was not statistically significant during cold storage in fruit from Valencia and Washington Navel orange cultivars.

Similarly, Özdemir et al. (2016) reported that physiological disorders were higher in the mandarin fruit from the Fremont mandarin cultivar grafted on Carrizo citrange than in fruit from Fremont mandarin grafted on sour orange during storage. It is known that similar physiological disorders, in the form of blackening on the fruit rind surface, increased during storage in many studies on mandarin (Pekmezci, 1984; Ağar and Kaşka, 1992, 1994; Gül, 1996; D'Aquino et al., 1997; Pekmezci et al., 1997; Ragone, 1999; Şen, 2004; Salvador et al., 2006; Özdemir et al., 2005, 2007, 2008; Özkaya, 2007).

Fruit quality characteristics varied according to rootstock type. Higher juice content was obtained from fruit harvested on Carrizo citrange than those from other rootstocks after 120 days of storage. Similarly, Özdemir et al. (2016) reported that fruit from the Fremont mandarin cultivar grafted on Carrizo citrange had higher juice content than fruit grafted on sour orange during storage. The decrease in juice content during storage was reported in previous studies on mandarin (Pekmezci, 1984; Ağar and Kaşka, 1992, 1994; Gül, 1996; Pekmezci et al., 1997; Agabbio et al., 1999; Ragone, 1999; Şen, 2004; Şen and Karaçalı, 2005; Özdemir et al., 2005, 2007, 2008; Özkaya, 2007; Ladaniya, 2011). Similarly, Gürgen et al. (1995) reported that the highest juice content occurred in fruit from the Marsh Seedless grapefruit cultivar grafted on Troyer citrange during storage. Moreover, it has been reported that the highest juice content occurred in fruit from Valencia and Washington Navel orange cultivars grafted on Carrizo and Troyer citrange during storage (Akpınar, 1990).

TSS content was higher in fruit stored at 6 °C than in fruit stored at 4 °C. Özdemir et al. (2016) reported similar results; the tendency was characterized by an increase followed by a decrease during storage, and decreases occurred at the end of the storage time. These increases and decreases could be due to solubilization of compounds other than carbohydrates/sugars (Echeverria and Ismail, 1990) or, to some extent, a concentration effect. Hydrolysis of cell wall constituents could also possibly contribute to the increase in degrees Brix (Burns, 1990). It has been reported in previous studies that the TSS content of mandarins decreased during storage (Pekmezci, 1984; Ağar and Kaşka, 1992, 1994; Gül, 1996; Pekmezci et al., 1997; Ragone, 1999; Şen, 2004; Şen and Karaçalı, 2005; Salvador et al., 2006; Özdemir et al., 2005, 2007, 2008; Özkaya, 2007; Ladaniya, 2011; Karaşahin et al., 2014). Unlike our findings, Obenland et al. (2011) reported that TSS content increased during 7 weeks of storage in Owari and W. Murcott mandarins. Tietel et al. (2012) reported that the effect of the variations between temperatures on TSS content were considered statistically insignificant during 4 weeks of storage in Or and Odem mandarins.

The green button, which is a sign of vitality in citrus fruit, is infected especially by *Alternaria* ssp. As storage time extended, the green color of the button turned brown or black, and it fell off the fruit. In agreement with our study, the percentage of fruit with green button decreased during storage in previous studies on mandarin (Ağar and Kaşka, 1992, 1994; Gül, 1996; Özdemir et al., 2005, 2007, 2008, 2016; Karaşahin et al., 2014). Akpınar (1990) reported that the impacts of rootstocks on percentage of fruit with green button were not statistically significant during cold storage of orange fruit cultivars Valencia and Washington Navel.

Fruit from Troyer citrange had higher acid content than fruit from other rootstocks. It was previously reported that as storage time extended, the TA content of mandarins decreased (Pekmezci, 1984; Agabbio et al., 1985, 1999; Ağar and Kaşka, 1992, 1994; Gül, 1996; D'Aquino et al., 1997, 2005; Gonzales-Aguilar et al., 1997; Pekmezci et al., 1997; Schirra and D'Hallewin, 1997;

Ragone, 1999; Şen, 2004; Özdemir et al., 2005, 2007, 2008; Şen and Karaçalı, 2005; Salvador et al., 2006; Özkaya, 2007; Ladaniya, 2011; Obenland et al., 2011; Tietel et al., 2012; Karaşahin et al., 2014). Similarly, it has been reported that the lowest decrease in TA content occurred in the fruit from Valencia and Washington Navel orange cultivars grafted on Carrizo and Troyer citrange during storage (Akpınar, 1990). Moreover, Özdemir et al. (2016) reported that the lowest decrease in TA content occurred in the fruit from the Fremont mandarin cultivar grafted on Carrizo citrange during storage. Unlike our findings, Gürgen et al. (1995) reported that the lowest decrease in TA content occurred in the fruit from the Marsh Seedless grapefruit cultivar grafted on Yuzu and sour orange during storage. Consistent with our results, other authors reported increases in pH values of mandarins during storage (Ağar and Kaşka, 1992, 1994; Gül, 1996; D'Aquino et al., 1997; Özdemir et al., 2005, 2008, 2016; Özkaya, 2007; Karaşahin et al., 2014).

Temperature management after harvest is the most important factor for maintaining the vitamin C content of fruits and vegetables; losses are accelerated at higher temperatures and with longer storage durations. However, some chilling-sensitive crops show more losses in vitamin C content at lower temperatures. Conditions favorable to water loss after harvest result in a rapid loss of vitamin C, especially in leafy vegetables (Seung and Kader, 2000). Consistent with our results, the vitamin C contents of mandarins decreased during storage (Pekmezci, 1984; Ağar and Kaşka, 1992; D'Aquino et al., 1997; Pekmezci et al., 1997; Şen, 2004; Şen and Karaçalı, 2005; Özkaya, 2007; Ladaniya, 2011; Karaşahin et al., 2014). Ascorbic acid and acidity dropped considerably while TSS showed little change in Kinnow fruit stored at 5 °C (Mahajan et al., 2006). According to our data, the impacts of sour orange and Carrizo citrange rootstocks on vitamin C content were similar and higher than other rootstocks during cold storage. However, Akpınar (1990) reported that vitamin C content was higher in the fruit from Valencia and Washington Navel orange cultivars grafted on sour orange than in those grafted on Carrizo citrange. Moreover, Özdemir et al. (2016) reported that vitamin C content was higher in Fremont mandarin grafted on sour orange than in those grafted on Carrizo citrange.

As the storage time extended, L* values decreased and the fruit lost a bit of its brightness. Brightness loss is generally caused by physiological deteriorations, especially peel browning. The brightness was better maintained in Nova mandarin fruit grafted on Troyer citrange and at 4 °C. As the storage time extended, C* values decreased, but the impacts of rootstocks on fruit rind color C* values were statistically significant during the cold storage. As the h° value decreases from 90° to 0°, the fruit rind color changes from yellow to red; from 180° to 90°, it changes from green to yellow. The h° value is given as the angle value of a* and b* values; it is reported that the hue value can give the best interpretation regarding a* and b* values (Voss, 1992). Consistent with our results, L*, C*, and h° values decreased during storage of mandarin fruit (Ağar and Kaşka, 1992; Şen, 2004; Şen and Karaçalı, 2005; Özdemir et al., 2007, 2008; Özkaya, 2007; Tietel et al., 2012; Karaşahin et al., 2014). Unlike our findings, Özdemir et al. (2016) reported that the impacts of rootstocks on fruit rind color L* and h° values were not statistically significant during cold storage.

Our data indicated that Nova mandarin fruits were stored better at 4 °C than 6 °C. When we considered 3 criteria (weight loss, physiological deterioration, and fungal deterioration) together with a 10% loss limit, Nova mandarin fruit grafted on Carrizo citrange, Troyer citrange, or sour orange could be kept at 4 °C for 75 days and at 6 °C for 45 days without any quality deterioration.

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