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RESEARCH PAPER

Effects of Different Rootstocks on Storage Life and Quality of Loquat Fruit (cv. Gold Nugget)

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Abstract

In this study, the effects of rootstocks on storage life and quality in Gold Nugget loquat grafted on quince, hawthorn and loquat rootstocks were investigated. After harvest, fruit were placed in plastic boxes (2 kg) covered with stretch film and stored for 45 days at 5 ± 0.5°C and 90 ± 5% RH. Weight loss, fruit firmness, total soluble solid, titratable acidity, maturity rate, respiration rate, ethylene production, CO_2 and O_2 concentrations in package, skin colour (L*,a*,b*,C*,h°), decay rate and sensory quality of fruit were determined at 15-day intervals during storage. The same analyzes were repeated for shelf life evaluation after keeping fruit 2 days in ambient condition (20°C and 70±5 RH%). Fruit grown on quince rootstock had the best results for maintaining external appearance, titratable acidity, maturation rate and vivid skin colour. The lowest decay rate and respiration rate during storage were also obtained from this combination. Quince and loquat seedling rootstocks had similar results for sensory quality and decay rate. Covering boxes by stretch film (20 µm) reduced the weight loss in the all the combination of scion/rootstock but, increased pathogens development. These findings revealed that fruit, obtained from the combinations of Gold Nugget variety with quince and loquat seedling rootstocks, can be stored with good quality for 30+2 days at 5°C and 90 ± 5 RH%.

1. Introduction

Loquat (*Eriobotrya japonica* Lindl.), belonging to the Rosaceae family, is a subtropical evergreen fruit-tree and originated from south-eastern China. Loquat is grown in the subtropical regions of China, Japan, India and the Mediterranean countries (Zhang et al., 1990; Cuevas et al., 2003; Ferreres et al., 2009; Polat, 2007; Liguori et al., 2017; CABI, 2020). China is the largest loquat producer country in the world with a production of 650 000 tons (Zheng et al., 2019) followed by Spain, Pakistan and Turkey (Caballero and Fernandez, 2003; TUIK, 2019). The chemical composition of fruit and vegetables may vary depending on the ecological conditions, variety, cultural practices, harvest time and post-harvest processes (Cemeroğlu et al., 2001). At the beginning of fruit orchard establishment, the choosing of appropriate rootstock is crucial for fruit quality and storage (Karaçalı, 2002). The Gold Nugget variety, determined by selection studies, is recommended to producers (Tepe, 2013). Bolat and İkinci (2019) have reported that the rootstocks are used for many different purposes, and affect the grafted variety for many characteristics. Seedling rootstock of loquat (*Eriobotrya japonica* Lindl.) is used widely compared to quince (*Cydonia oblonga* Mill.) and hawthorn (*Crataegus oxyacanthus* L.) in Turkey and worldwide (Polat, 1995; García-Legaz, 2010;

Bermede and Polat, 2011; M.de Almeida et al., 2018). There are some studies about the effect of rootstock on salinity stress in loquat but, no study could be found with regard to fruit quality and storage (López-Gómez et al., 2007). Loquat fruit, in general, are consumed in local markets, because it can not be exported to overseas markets due to quality losses during transportation.

Post-harvest losses in fresh fruit and vegetables have become a serious problem in developing countries (Warjuki and Sutrisno, 1998). The quality losses after harvest may be reduced by using appropriate package and storage techniques. The storage period of loquat fruit, depending on their postharvest physiology, is very short in comparison to other fruit species (Tepe, 2013). Cold storage technique is applied to protect fruit quality and offer higher quality products to the consumer (Qui and Zhang, 1996). The temperature is the most important limiting factor for the storage period of fruit. Kahramanoğlu (2020) reported that low temperature (5 to 7ºC) was very important in reducing postharvest losses and extending storage period of loquat. Most tropical and subtropical fruits are extremely sensitive to low temperatures due to chilling injury. Loquat, a subtropical fruit, is also very sensitive to low temperatures. For example, fruit stored at 5°C are of higher quality than those stored at 0°C and moreover, storage at room temperature can reduce the storage life of fruit by up to 6 days. (Lin, et al., 1999; Zheng et al., 2000; Ding et al., 2002; Cai et al., 2006a,b; Song et al, 2016). Therefore, the cold storage of loquat at low-temperatures limit its postharvest quality and life (Cai et al., 2006c; Xua et al., 2012). The controlled atmosphere, modified atmosphere and polyethylene bags give good results for storage of loquat fruit like other fruit species (Ding et al., 1998; Ding et al., 2002; Amorós et al., 2003; Ding et al., 2006). In Turkey, carton boxes are widely used in the storage and marketing of loquats. Moreover, the plastic or foam plates covered with stretch film are also used for loquats in the grocery chain. The studies about the effect of packaging material on the storage of loquat fruit are very limited. As far as we know, there is no detailed study evaluating the effects of rootstocks on the fruit quality and cold storage of loquat. In this study, the effects of different rootstocks on storage life and quality of loquat fruit cv. Gold Nugget were investigated.

2. Material and Method

2.1. Material

This study was carried out with 16 years old Gold Nugget loquat trees grafted on loquat seedlings (*Eriobotrya japonica* Lindl.), quince (*Cydonia oblonga* Mill.) and hawthorn (*Crataegus oxyacanthus* L.) rootstocks in Antalya/Turkey.

2.2. Method

The fruit were picked at optimum harvest time (the greenness of the fruit completely disappeared, which was considered as the mature stage) (Ferreres et al., 2009). Harvested fruits were transferred to laboratory immediately (within one hour), and foreign parts and injured fruits were removed. After homogenization and visual examination, fruit were divided into two lots. The first group was packaged (each containing 25 fruits) in plastic boxes (2 kg) covered with 20 µm thick stretch film (STHF) [O_2 permeability 15300 ± 20%, CO_2 permeability 78000 ± 20%, N_2 permeability 11000 ± 10% ($cm^3\ m^{-2}\ 24hbar^{-1}$) at 38°C and 90% relative humidity]. Second (control) group loquats were placed in same packaging materials without covering STHF. Packaged fruits were stored at 5 C and 90 ± 5% relative humidity (RH) for 45 days (Chong et al., 2006). All treatments and packaging procedures were carried out under sanitary conditions in the laboratory. After cold storage, fruit were kept at 20°C and 70 ± 5% RH for 2 days for shelf-life evaluation. The following chemical and physical analyses were performed at 15-day intervals during cold storage and shelf life.

Weight loss of fruit was measured based on the initial weight and calculated as percent (%) during storage. The weight of each sample group was measured at each analysis day (0, 15, 30 and 45) at the end of cold storage and shelf life. Weight loss during shelf life was calculated from the difference between the initial and final sample weight as percent (%).

The fruit firmness (FF) was measured by Fruit Pressure Tester using stainless steel probe (width: 5 mm) and expressed a Newton (N).

The soluble solid content (SSC) of fruit juice was determined with a refractometer (Digital-Atago Pocket PAL-1) and expressed a percent. For titratable acidity (TA), fruit juice (10 mL) was titrated with 0.1 N sodium hydroxide up to pH 8.1, and results were expressed as percentage.

Maturity rate was calculated by rating of SSC to TA (SSC/TA). Skin colour was measured with a colorimeter (Minolta CR- 400). The colour was evaluated according to the CIE L* (represents brightness-darkness changing from 0 to 100), a* (represents the degree of red-green colour; + a*: red, − a*: green), b* (represents the degree of yellow–blue colour; + b*: yellow, − b*: blue), C* (represents vividity of color) and hº (represents perceived color) system. The chroma (C*) and hue angle (hº) values were calculated by the following formulas; $h° = \tan^{-1}(b^*\ a^{*-1})$, $C^* = [\ (a^*)^2 + (b^*)^2\ ]^{1/2}$. (Koyuncu et al., 2019).

Ethylene production and respiration rate were assessed according to the procedure described by Ding et al. (1998) using Finnigan Trace GC Ultra (Model: K072389201000). Results were calculated as µL ethylene $kg^{-1}\ h^{-1}$ and ml $CO_2\ kg^{-1}\ h^{-1}$ for

Table 1. Changes in weight loss (%), firmness (N), soluble solids content (%), titratable acidity (%) and maturity rate of loquat fruits depending on rootstock, stretch film and storage time during cold storage and shelf life

	RS	T	SD 0	15	15+2	30	30+2	45	45+2	Mean of RS/T	Mean of RS	Mean T
WL (%)	Loquat	STHF	-	0.80	1.34	1.16	2.29	1.67	3.00	1.71 a	6.00 C	STHF
		Control	-	4.72	9.07	10.45	13.32	10.36	13.82	10.29 b		1.72 A
	Hawthorn	STHF	-	0.45	1.15	1.31	2.43	2.24	2.51	1.68 a	4.80 A	
		Control	-	3.39	5.39	7.99	9.63	10.40	10.68	7.91 b		Control
	Quince	STHF	-	0.43	1.77	1.45	3.04	1.30	2.54	1.76 a	5.35 B	9.05 B
		Control	-	3.99	7.89	6.60	13.25	8.65	13.27	8.94 b		
		Mean of SD	-	2.29 A	4.44 B	4.83 B	7.33 D	5.77 C	7.64 D			
FF (N)	Loquat	STHF	21.87	25.69	26.58	26.28	25.89	28.15	30.6	26.38 NS	26.18 A	STHF
		Control	21.87	20.89	29.32	26.48	26.08	29.32	27.75	25.99 NS		25.50 NS
	Hawthorn	STHF	23.83	27.75	21.77	24.42	25.79	26.67	28.64	25.61 b	26.28 A	Control
		Control	23.83	25.89	30.20	27.26	25.69	26.09	29.42	26.97 a		
	Quince	STHF	20.00	22.65	22.26	28.93	23.54	25.4	22.65	23.63 b	24.12 B	25.50 NS
		Control	20.00	25.80	26.38	27.75	21.67	25.69	25.3	24.61 a		
		Mean of SD	21.87 D	24.81 C	2.66 B	26.87 A	24.81 C	26.87 A	27.36 A			
SSC (%)	Loquat	STHF	10.90	9.33	9.87	9.60	8.10	9.80	7.47	9.30 a	9.83 A	STHF
		Control	10.90	10.33	10.40	9.20	10.83	11.93	8.87	10.35 b		9.76 A
	Hawthorn	STHF	8.88	10.13	11.13	13.73	10.67	7.95	7.62	10.02 NS	9.88 A	
		Control	8.88	10.47	10.13	11.27	10.87	8.42	8.15	9.74 NS		Control
	Quince	STHF	10.82	9.20	12.27	11.33	8.03	8.52	9.65	9.97 NS	10.15 B	10.14 B
		Control	10.82	10.40	10.67	11.13	10.63	9.92	8.65	10.32 NS		
		Mean of SD	10.20 C	9.98 C	10.74 D	11.04 D	9.86 C	9.42B	8.40 A			
TA (%)	Loquat	STHF	0.76	0.48	0.50	0.46	0.45	0.42	0.34	0.49 a	0.47 B	STHF
		Control	0.76	0.40	0.43	0.37	0.42	0.37	0.36	0.45 b		0.51 NS
	Hawthorn	STHF	0.75	0.48	0.54	0.39	0.50	0.22	0.30	0.45 NS	0.45 B	
		Control	0.75	0.44	0.47	0.42	0.43	0.24	0.42	0.45 NS		Control
	Quince	STHF	0.86	0.77	0.77	0.61	0.56	0.29	0.28	0.59 NS	0.60 A	0.50 NS
		Control	0.86	0.73	0.78	0.47	0.75	0.25	0.37	0.60 NS		
		Mean of SD	0.79 A	0.55 C	0.58 B	0.46 E	0.52D	0.30 G	0.34 F			
MR	Loquat	STHF	15.04	25.28	23.77	25.79	23.46	23.86	19.61	22.40 b	24.04 A	STHF
		Control	15.04	25.73	29.27	21.75	31.83	30.35	25.85	25.69 a		21.38 B
	Hawthorn	STHF	14.36	19.64	19.94	21.01	18.02	23.63	21.79	19.77 b	22.19 B	
		Control	14.36	26.09	24.08	24.82	25.84	32.38	24.76	24.62 a		Control
	Quince	STHF	12.51	12.04	15.98	18.53	14.26	29.85	34.94	19.73 NS	19.93 C	22.78 A
		Control	12.51	14.26	13.75	23.38	14.52	39.11	23.40	20.13 NS		
		Mean of SD	12.89 D	19.63 C	19.42 C	25.05 B	20.05C	32.59 A	24.93 B			

SD: Storage day; T: Treatments; STHF: Stretch film; RS: Rootstock; WL: Weight loss (%); FF: Firmness of the fruit (N); SSC: Soluble solids content (%); TA: Titrable acidity (%); MR: Maturity rate. NS represents non-significance; Means followed by different letters within the same column are significantly different ($p<0.05$). Capital letters show the differences among overall averages and lower case letters represent the differences among the averages for each rootstock/stretch film combinations.

ethylene production and respiration rate, respectively. CO_2 value (%) in the plastic package was measured with a gas analyser (Bühler IR-Analysator Typ 3000 Inj.). O_2 values (%) in the package was measured by Servamex Oxygen Analyzer.

The results were expressed as percentage. The sensory analysis were performed by evaluation panel consisted of 10 members of the research staff who were experienced in sensory analysis of horticultural crops. The hedonic scale was used for external appearance and taste (Erbaş and Koyuncu, 2016). External appearance (scale 1-9): poor quality: 1-3; marketable quality: 3-5; good quality: 7; excellent quality: 9. Taste (scale 1-9): very poor: 1; poor: 3; mild: 5; good: 7; excellent: 9. Determination of fungal agents was assessed according to the procedure described by Kalyoncu et al. (2008). The decay rate (%) was calculated by rating of decayed fruits to the total number of fruits.

The data, obtained from three replicates for each rootstock, was evaluated by one-way analysis of variance (ANOVA). The differences among means (at a significance level of 0.05) were analysed using LSD (Least Significant Difference) test.

3. Results

3.1. Weight loss

The weight losses (WL) of fruit increased, regardless of rootstocks and packaging, throughout the cold storage, and reached to 5.77%. The highest fruit weight loss was obtained from fruit grown on loquat rootstock (6.00%) followed by quince (5.35%) and hawthorn rootstocks (4.80%), respectively. As with the combination of rootstock/stretch film, the difference between averages covered with stretch film (1.72%) and uncovered (9.05%) was statistically significant (Table 1).

3.2. Fruit firmness

Fruit firmness (FF) of loquats during storage is presented in Table 1. The firmness of fruit increased significantly at the end of storage (26.87 N) compared to initial value (21.87 N), contrary to expectations. The FF value of the fruit grown on the quince rootstock (24.12 N) was lower than those grown on the loquat (26.18 N) and hawthorn rootstock (26.28 N). Stretch film treatments did not affect the fruit firmness of loquats. According to mean values of rootstock/stretch film, the loquat rootstock/stretch film combination did not affect the FF value of fruit, while the treatments in other combinations decreased this value.

3.3. Soluble solids content

Soluble solids content (SSC) of fruit, which was 10.20% at the beginning of storage, decreased significantly at the end of cold storage (9.42%) and shelf life (8.40%). The effects of both rootstock and stretch film on SSC were significant. The SSC measured in the control (10.14%) group was higher than the fruits covered with stretch film (9.76%). The average SSC of samples was higher when fruits were grown on quince rootstock (10.15%) compared to hawthorn (9.88%) and loquat (9.83%) rootstocks (Table 1).

3.4. Titratable acidity

At harvest, the titratable acidity (TA) of loquats changed between 0.75% (hawthorn) and 0.86% (quince). Acidity contents of loquats decreased significantly over time in all fruits obtained from trees grafted on different rootstocks. Stretch film treatment did not affect the amount of TA but, the acidity content of fruits grown on quince rootstock (0.60%) was significantly higher than those of Loquat (0.47%) and hawthorn (0.45%) rootstocks (Table 1).

3.5. Maturity rate

Maturity rate (MR) of all treated fruits increased in parallel with increasing storage period (from 12.89 to 32.59). The MR values of loquats in stretch film covered boxes were lower compared to control group in all rootstocks, especially in hawthorn. The highest maturity rate was obtained from the fruits grown on loquat rootstock (24.04) followed by the fruits grown on the hawthorn (22.19) and quince rootstocks (19.93), respectively. The effects of stretch film, rootstock and storage periods on MR were significant (Table 1).

3.6. Respiration rate

There was no statistically significant difference between the respiration rates (RR) measured at the end of cold storage and the values determined at harvest. However, the respiration rate value (26.14 ml CO_2 kg^{-1} h^{-1}), determined by keeping the fruits in room conditions for 2 days, was significantly higher than the value determined at the end of the cold storage (23.65 ml CO_2 kg^{-1} h^{-1}). Stretch film treatments did not affect the respiration rates**.** Respiration rate of fruits grown on loquat rootstock was remarkable higher (26.97 ml CO_2 kg^{-1} h^{-1}) than other rootstocks (hawthorn: 23.45 and quince: 22.19 ml CO_2 kg^{-1} h^{-1}) (Table 2).

3.7. Ethylene production

In cold storage and shelf-life studies, the effects of rootstock, stretch film and storage period on ethylene production (EP) were statistically significant. The maximum ethylene production (1.55 µL kg^{-1} h^{-1}) was found at the beginning of storage. Stretch film treatments significantly increased the ethylene production. The ethylene value, which was 1.31 µL kg^{-1} h^{-1} in control group, was measured as 1.46 µL kg^{-1} h^{-1} in stretch film treatments. The highest ethylene production was determined in fruits grown on quince rootstock (1.78 µL kg^{-1} h^{-1}), while fruits grown on hawthorn rootstock gave the lowest value (1.03 µL kg^{-1} h^{-1}) followed by fruits grown on loquat rootstock (1.61 µL kg^{-1} h^{-1}). Rootstock / package combination had no significant effect on ethylene production (Table 2).

3.8. Gas composition of the package

The O_2 and CO_2 concentrations in the package were statistically affected by storage time and rootstock during cold storage. The gas composition in the package changed during cold storage. The initial O_2 content (21 ± 0.1%) of packages decreased to 10.02% at the 15th day of storage and changed between 5.81% and 6.77% in the rest of the cold storage period. The average initial CO_2 concentration increased and reached to a peak value of 3.19% in the first 30 days of cold storage. In the shelf life studies carried out by keeping the fruits in room conditions for 2 days, the O_2 and CO_2 concentrations increased significantly compared to the cold storage. The loquat rootstocks gave the lowest O_2 (9.56%) value, followed by quince (10.36%) and hawthorn (10.56%) rootstocks, respectively. The lowest CO_2 value (1.97%) was measured in fruits obtained from quince rootstock (Table 3).

3.9. Fruit colour

Colour is an important quality parameter in loquat fruit and directly affects its market value. Colour changes of loquat fruits during storage are presented in Table 4. As it can be seen in Table 4, all fruit skin color values fluctuated, in general, over time showing differentiations according to cold storage and shelf life conditions. However, a*, b* and C* values increased at the end of cold storage compared to the beginning of storage. Moreover, L* value decreased, and hº value did not change. While the C* and a* values decreased significantly, L* and hº values increased, and b * values remained the same in fruits kept in room conditions for 2 days after cold storage. The packaging treatments did not

Table 2. Changes in respiration rate (ml CO_2 kg^{-1} h^{-1}) and ethylene productions (µL kg^{-1} h^{-1}) of loquat fruits depending on rootstock, stretch film and storage time during cold storage and shelf life

	RS	T	SD 0	SD 45	SD 45+2	Mean of RS/T	Mean of RS	Mean of T
RR (ml CO_2 kg^{-1} h^{-1})	Loquat	STHF	26.33	25.32	29.13	26.93 NS	26.97 A	STHF
		Control	26.33	28.23	26.45	27.00 NS		24.48 NS
	Hawthorn	STHF	23.16	24.42	26.88	24.82 a	23.45 B	
		Control	23.16	21.93	21.13	22.07 b		Control
	Quince	STHF	21.17	22.19	23.66	21.68 NS	22.19 B	23.98 NS
		Control	21.17	19.82	27.13	22.71 NS		
		Mean of SD	23.55 B	23.65 B	26.14 A			
EP (µL kg^{-1} h^{-1})	Loquat	STHF	1.66	1.62	1.57	1.62 NS	1.61 B	STHF
		Control	1.66	1.65	1.53	1.61 NS		1.46 A
	Hawthorn	STHF	1.11	0.94	0.98	1.01 NS	1.03 C	
		Control	1.11	1.11	0.95	1.05 NS		Control
	Quince	STHF	1.89	1.78	1.63	1.77 NS	1.78 A	1.31 B
		Control	1.89	1.81	1.65	1.78 NS		
		Mean of SD	1.55 A	1.48 B	1.39 C			

ST: Storage Time; T: Treatments; STHF: Stretch film; RS: Rootstock (%); RR: Respiration rates (ml CO_2 kg^{-1} h^{-1}); EP: Ethylene production; (µL kg^{-1} h^{-1}); NS represents non-significance; Capital letters show the differences among overall averages, and lower case letters represent the differences among the averages for each rootstock/stretch film combinations

Table 3. Changes in CO_2 and O_2 ratio (%) of loquat fruits depending on rootstock and storage time during cold storage and shelf life

	RS	SD 0	SD 15	SD 15+2	SD 30	SD 30+2	SD 45	SD 45+2	Mean of RS
O_2 (%)	Loquat	21.00	8.47	11.67	6.00	4.80	5.90	9.00	9.56 A
	Hawthorn	21.00	10.93	9.43	7.97	6.10	4.97	13.53	10.56 AB
	Quince	21.00	10.67	9.27	6.33	6.40	7.67	11.13	10.36 AB
	Mean of SD	21.00 C	10.02 B	10.12 B	6.77 A	5.80	6.18 A	11.22 B	
CO_2 (%)	Loquat	0.03	4.90	4.90	3.17	2.50	3.63	2.53	2.87 A
	Hawthorn	0.03	2.27	2.27	1.90	5.60	3.07	4.93	3.03 A
	Quince	0.03	2.30	2.30	4.50	2.10	1.93	2.07	1.97 B
	Mean of SD	0.03 C	3.16 A	3.16 A	3.19 A	3.40	2.88 AB	3.18 A	

SD: Storage day; RS: Rootstock; O_2: Oxygen ratio (%); CO_2: Carbondioxide ratio (%); NS represents non-significance; Capital letters show the differences among overall averages. and lower case letters represent the differences among the averages for each rootstock/stretch film combinations

have an effect on the L* value. However, the a*, b*, C* values increased, and the hº value decreased depending on packaging. Rootstocks had no effect on hº value but, L*, a*, b*, C* values were higher in fruits grown on quince rootstock compared to those grown on other rootstocks.

3.10. Decay rate

Decay rate (DR) was statistically affected by storage time, rootstock and stretch film during storage. While there was no decayed fruit on the 15th day of cold storage, the decay rate on the 45th day was 16.67%. Keeping fruits at 20°C and 70 ± 5% relative humidity for 2 days for shelf life evaluation and applying stretch film significantly increased decay rate. The highest decay rate was determined in fruits (9.76%) grown on hawthorn rootstock followed by loquat (8.41%) and quince rootstocks (7.46%), respectively (Table 5). *Phytophthora* spp. has been identified as a fungal agent causing infection in fruits.

3.11. Sensory analysis

Storage time and rootstocks significantly affected the external appearance and taste of fruits during cold storage and shelf life period. The external appearance and taste scores of fruits decreased in cold and room conditions, as the storage time increased. Fruits with good quality (score ≥ 7) were only obtained on the 30th day of storage. While the highest external appearance score (7.06) was obtained from fruits grown on quince, loquat rootstock gave the highest taste score (6.79). The lowest external appearance and taste scores (6.30 and 5.95, respectively) were obtained from fruits grown on hawthorn rootstock during storage (Table 6).

4. Discussion

Weight loss of horticultural product is a crucial commercial parameter for storage as it directly refers to the decrease in product weight (Bülüç and Koyuncu, 2020). In the present study, the weight loss of fruits increased with prolonged storage duration. This change was higher in shelf life condition in comparison with cold storage as expected (Table 1). It is known that, the main reason for increasing of weight loss is water loss from the fruit throughout the storage period. The shelf life of loquat is very short due to its high water

Table 4. Changes in L*. a*. b*. hº and C* values (CIEL* a*b*) of loquat fruits depending on rootstock, stretch film and storage time during cold storage and shelf life

	RS	T	SD							Mean of RS/T	Mean of R	Mean of T
			0	15	15+2	30	30+2	45	45+2			
L*	Loquat	STHF	54.79	54.95	60.29	63.00	61.29	56.82	58.39	58.50 b	59.26 B	STHF
		Control	58.61	58.61	60.95	64.98	62.34	57.31	57.25	60.01 a		
	Hawthorn	STHF	58.10	58.10	60.64	61.71	61.43	52.85	60.64	59.07 b	59.61 B	60.00 NS
		Control	58.59	58.59	60.69	63.26	60.58	58.71	60.69	60.16 a		Control
	Quince	STHF	56.86	60.57	60.71	67.03	62.35	54.40	59.78	60.24 b	60.79 A	59.77 NS
		Control	57.98	61.96	60.68	67.89	61.97	57.07	61.76	61.33 a		
		Mean of SD	57.49 E	58.80 D	60.66 BC	64.64 A	61.66 B	56.19 F	59.75 C			
a*	Loquat	STHF	24.07	23.48	24.69	23.63	25.40	27.69	23.49	24.72 a	23.42 B	STHF
		Control	23.35	21.33	20.96	20.41	22.84	25.38	18.61	22.13 b		24.37 A
	Hawthorn	STHF	22.99	21.86	24.27	21.69	24.27	24.74	23.42	23.48 NS	23.36 B	
		Control	23.92	22.30	22.03	22.66	22.03	26.39	21.69	23.24 NS		Control
	Quince	STHF	22.91	22.25	26.69	23.99	27.53	24.62	25.73	24.91 a	24.22 A	22.96 B
		Control	23.53	22.62	23.35	23.48	23.96	25.42	21.42	23.53 b		
		Mean of SD	23.46 CD	22.28 D	23.67 C	22.64 D	24.34 B	25.71 A	22.39 D			
b*	Loquat	STHF	47.60	45.67	46.92	45.76	45.56	49.80	49.81	47.30 a	45.69 B	STHF
		Control	40.45	40.72	44.99	41.35	45.21	47.30	48.53	44.08 b		46.52 A
	Hawthorn	STHF	41.16	44.27	47.02	38.86	47.02	47.05	47.94	44.76 b	45.57 B	
		Control	44.85	46.27	45.47	45.16	45.47	50.91	46.60	46.39 a		Control
	Quince	STHF	47.50	46.12	47.81	42.74	47.86	50.65	49.71	47.49 NS	46.94 A	
		Control	46.04	46.65	44.16	44.67	45.76	50.86	46.56	46.39 NS		45.62 B
		Mean of SD	44.60 C	44.95 BC	46.06 B	43.09 D	46.15 B	49.43 A	48.19 A			
hº	Loquat	STHF	63.13	62.13	62.23	62.72	60.84	60.81	64.73	62.37 b	62.81 NS	STHF
		Control	60.04	60.02	64.99	63.77	63.20	61.75	69.03	63.26 a		
	Hawthorn	STHF	60.80	62.47	62.68	60.75	62.67	64.11	63.94	62.49 b	63.02 NS	62.29 B
		Control	61.83	62.66	64.23	63.39	64.20	63.46	65.11	63.55 a		Control
	Quince	STHF	64.19	63.57	60.83	60.66	60.09	62.17	62.64	62.02 b	62.50 NS	
		Control	62.90	63.24	62.13	62.28	62.37	62.62	65.28	62.98 a		63.26 A
		Mean of SD	62.15 B	62.35 B	62.85 B	62.26 B	62.23 B	62.49 B	65.12 A			
C*	Loquat	STHF	53.35	51.65	53.02	51.51	52.16	57.04	55.08	53.40 a	51.40 B	STHF
		Control	46.72	47.02	49.64	46.13	50.67	53.70	51.98	49.41 b		52.54 A
	Hawthorn	STHF	47.14	49.91	52.92	44.53	52.92	53.18	53.37	50.57 NS	51.24 B	
		Control	50.85	52.09	50.56	50.53	50.55	57.34	51.43	51.91 NS		Control
	Quince	STHF	52.76	51.52	54.76	49.02	55.22	56.36	55.98	53.66 a	52.84 A	
		Control	51.71	52.26	49.97	50.47	51.66	56.88	51.25	52.03 b		51.11 B
		Mean of SD	50.42 D	50.74CD	51.81 BC	48.70E	52.19B	55.75A	53.18 B			

SD: Storage day; T: Treatments; STHF: Stretch film; RS: Rootstock (%); L: Lightness; a* red; b*: yellow; C*: Chroma; h°: Hue angle
NS represents non-significance; Capital letters show the differences among overall averages. and lower case letters represent the differences among the averages for each rootstock/stretch film combinations.

Table 5. Changes in decay rate (%) of loquat fruits depending on rootstock, stretch film and storage time during cold storage and shelf life

RS	T	SD						Mean of RS/T	Mean of RS	Mean of T
		15	15+2	30	30+2	45	45+2			
Loquat	STRF	0.00	2.86	3.81	11.43	19.05	20.00	9.52 NS	8.41 AB	STRF
	Control	0.00	0.95	2.86	6.66	16.19	17.14	7.30 NS		10.64 B
Hawthorn	STRF	0.00	2.86	3.81	6.67	30.48	31.43	12.54 b	9.76 B	
	Control	0.00	2.86	0.95	4.76	16.19	17.14	6.98 a		Control
Quince	STRF	0.00	0.95	1.91	10.48	10.48	35.24	9.84 b	7.46 A	
	Control	0.00	0.00	0.95	3.81	7.62	18.09	5.08 a		6.45 A
	Mean of SD	0.00 A	1.74 A	2.38 A	7.30B	16.67 C	23.18 D			

Table 6. Changes external appearance and taste of loquat fruits depending on rootstock, stretch film and storage time during cold storage and shelf life

	RS	T	SD							Mean of RS/T	Mean of R	Mean of T
			0	15	15+2	30	30+2	45	45+2			
EA	Loquat	STRF	8.47	8.60	8.00	6.80	6.13	5.13	5.47	6.94 NS	6.99 A	STRF
		Control	8.47	8.00	8.20	7.13	6.13	5.80	5.47	7.03 NS		6.84 NS
	Hawthorn	STRF	7.87	7.73	7.37	7.63	5.80	4.13	4.47	6.43 NS	6.30 B	
		Control	7.73	7.53	8.07	7.80	3.93	4.93	3.27	6.18 NS		Control
	Quince	STRF	8.60	8.60	8.20	8.27	5.27	7.60	3.60	7.16 NS	7.06 A	6.72 NS
		Control	8.60	8.53	7.87	5.60	7.13	4.13	6.80	6.95 NS		
		Mean of SD	8.29 A	8.17 A	7.95 A	7.21 B	5.73C	5.29 CD	4.84 D			
TAS	Loquat	STRF	8.80	7.80	7.13	7.27	4.80	5.80	4.47	6.58 NS	6.79 A	STRF
		Control	8.80	8.47	8.13	8.47	4.80	6.13	4.13	6.99 NS		6.28 NS
	Hawthorn	STRF	8.27	7.33	6.60	5.13	4.60	4.60	3.93	5.78 NS	5.95 B	
		Control	8.27	8.13	5.93	6.33	5.60	3.93	4.60	6.11 NS		Control
	Quince	STRF	8.80	8.80	7.47	7.80	5.47	4.47	2.47	6.47 NS	6.54 A	
		Control	8.80	8.13	7.80	8.13	4.80	4.80	3.80	6.61 NS		6.57 NS
		Mean of SD	8.62 A	8.11 A	7.19 B	7.18 B	5.01C	4.96 C	3.90 D			

content comparison with other fruit species. Similarly, previous studies demonstrated that the high weight losses in loquats were observed due to water loss during storage (Ding et al., 1998; Ding et al., 2002; Ertürk et al., 2005; Park et al., 2005; Cai et al., 2006a; Amoros et al., 2008; Liguoria et al., 2017). Stretch film application clearly decreased the weight loss in loquats during storage (Table 1) as found in previous studies (Ertürk et al., 2005; Çandir et al., 2011).

In this study, in parallel with the increasing storage period, fruit firmness of loquats increased due to the elastic structure of fruit skin as a result of water loss. Talhouk et al. (1999) reported that stretch film treatments increased fruit firmness of loquats during storage. Our results showed that the effect of stretch film treatments on fruit firmness varied depending on rootstocks. Similar to our results, Zhang et al. (2011) indicated that the fruits obtained from different rootstock/scion combinations showed different characteristics. The highest fruit firmness was measured in the combination of Gold Nugget/hawthorn. This can be explained by the differences in the compatibility of rootstock/scion.

It has been reported that different rootstocks have different effects on the formation of taste, dry matter and acidity in fruits (Koyuncu and Çalhan, 2010). The effect of packaging material, storage time and their interactions on SSC during cold storage and shelf life was statistically significant. The SSC value peaked on the 30th day of storage. The higher SSC during shelf life studies can be attributed to the higher water loss from loquat depending on high temperature, as reported by Koyuncu et al. (2019). The SSC of control samples increased proportionally as storage time increased due to higher water loss. Ding et al. (1998) reported that the total acidity of loquat fruits decreased rapidly in the first 5 days of storage and then slowed down. In the present study, there was a similar decrease in TA during storage. Ambient condition increased TA compared to cold storage (Table 1). This increase is thought to be due to an increase in metabolic activity and decay rate. Stretch film treatment had no effect on TA content of loquat. Rootstocks affected TA contents, and the highest one was measured in fruits grown quince rootstock. The MR of fruits obtained from trees on loquat rootstock was significantly higher than those of other rootstocks (Table 1). Rootstocks affect the grafted variety in terms of many characteristics (Bolat and İkinci, 2019). According to results in our study; there is a correlation between ripening rate and SSC and TA value (Table 1). These differences can be attributed to different effects of rootstock and varieties.

While there was no difference between the respiration rates measured at the end of the cold storage and the values determined at the beginning, the respiration rate of fruits increased in room condition (Table 2). It is known that high storage temperature is predominant factor for increasing respiration rate. Ding et al. (1998b) indicated that the respiration rate of loquats was significantly higher at 20ºC in comparison with 1ºC. In the present study, the suppressing effect of low temperature in cold storage on respiration rate of loquat fruits is accordance with the findings of this researcher. The fruits that have higher respiration rate have a shorter post-harvest life (Karaçalı, 2002). Therefore, fruits obtained from Gold nugget and loquat seedlings combination may not be advised for long-term storage when respiration rate is considered only. Wang et al. (2010) have expressed that the ethylene production of loquats, as a non-climacteric fruit, is at a low level during post-harvest ripening. Similar to the findings of Ding et al. (1998a), we determined that ethylene production of loquats decreased with increasing storage period. The ethylene production in cold storage was lower than room condition (Table 2).

Erkan et al. (2005) reported an increase in CO_2% and a decrease in O_2% in different package during storage of loquat. In the present study, the O_2 concentration decreased significantly during storage period, while CO_2 level increased showing similarity to the findings of Erkan et al. (2005). In the present study, O_2 and CO_2 concentrations measured at the end of the cold storage were 6.18% and 2.88%, respectively. In shelf life studies, O_2 concentration of package was relatively higher compared to cold storage (Table 3). This increase is thought to be due to the change in gas permeability of the packaging with temperature. According to our results, it can be said that fruits grown on loquat rootstock provides lower O_2 concentration depending on high respiration rate during cold storage (Table 2 and 3).

Fruit colour is important for the determining of maturity stage at harvest as well as for consumer preference after harvest (Besada et al., 2010). The L*, b* and C* values could be taken into consideration for the evaluation of yellow-coloured fruits. The L* value, represents brightness-darkness changing from 0 to 100, of loquats fluctuated during storage and decreased at the end of cold storage (56.19) compared to initial value (57.49). However, it increased at the end of shelf life in all rootstock combinations (except for loquat-control) and reached to 59.75. The best result for L* value was obtained from quince rootstock (60.79) followed by hawthorn (59.61) and loquat (59.26) (Table 4). The findings of Ding et al. (1998a, 2002) related to colour change are accordance with the present study. The b* values of fruits fluctuated during storage and increased at the end of storage compared to initial values both in cold storage and room condition (Table 4). This change indicates the alteration of skin colour from green to yellow during storage. Our results are similar to those reported by Ertürk et al. (2005), who indicated that b* values of loquats increased throughout the storage period. In the present study, the best bright yellow color, preferred by consumers, was observed in loquats grown on quince rootstock during storage. Stretch film treatments caused to increase the b* value of fruit skin (Table 4). The C* values (represents vividity of colour) tended to rise with the increasing storage period in all treatments during cold storage as well as shelf life period. Similar trend was also observed by Cao et al. (2011) in loquat fruits throughout cold storage. The highest C* value (52.84) was obtained from loquat fruits grown on quince rootstock followed by loquat seedling (51.40) and hawthorn (51.24). This can be explained by the differences in the compatibility or relationship between scion and rootstock.

Loquat is susceptible to various postharvest diseases after harvest (Pareek**,** 2014). By keeping the relative humidity high in storage, water loss of fruit can be limited but, if it is too high, the decay rate increases (Gezginç et al., 2005). The result of the present study showed that decay rate increased due to *Phytophthora* spp. infection at the end of storage compared to the beginning. However these changes remained within acceptable limits (2.38%) up to 30th day of storage in cold conditions. Stretch film treatment and room conditions increased decay rate in fruits. While decay rate in boxes covered with stretch film remained within acceptable limits up to 30th day of the storage, it increased rapidly after this period, and was higher at the end of the storage compared to the control (Table 5). Ertürk et al. (2005) reported that the fungal spoilage in loquats started on the 60th day, and there was no decay in control fruits during the storage. Our results related to stretch film are supported by the fact that loquat fruits are susceptible to decay at high humidity conditions. Decay rate in fruits grown on hawthorn rootstock was higher than those of other rootstocks (Table 5). This result can be explained by the effect of rootstocks on the nutrition content and disease resistance of fruit.

According to the sensory analysis results, which are very effective in making decision to terminate the storage period, there was a significant decrease in the external appearance and taste values at the end of the storage compared to the beginning (Table 6). Poor taste can be caused by the accumulation of metabolites (acetic aldehyde, ethanol, ethyl acetate) in fruits (Gerçekçioğlu et al., 2008). Çandır et al. (2011) reported a decrease in taste and aroma values on the 45th day of storage in loquats. On the other hand, Ding et al. (2002) found that loquats could be stored with good quality for 2 months at 5°C. According to the sensory evaluation results, in the present study, loquat fruits grown on quince rootstock can be stored with good quality for 30+2 days at 5°C (Table 6). These results, different from the above mentioned literature findings, are thought to be due to the variety, rootstocks, packaging and storage conditions. Ambient conditions caused a significant decrease in both external appearance and taste scores during storage. Stretch film treatment, widely used in the long-term storage of fruits, did not affect sensory quality of fruits in cold storage. The sensory quality change of loquats in our study is accordance with the findings of Ertürk et al. (2005) up to 30th day of cold storage. The external appearance and taste scores determined in the hawthorn rootstock were generally lower than the other rootstocks. Quince and loquat seedling rootstock, which gave better results during storage, can be recommended for loquat growing. Similar results were also reported by Pio et al. (2007).

5. Conclusion

The findings of the present study showed that quince rootstocks may be more suitable than the others, especially hawthorn rootstock, for some quality parameters during storage. Although loquats grown on three rootstocks gave different results in terms of storage life and quality, the best result for acidity, maturation rate, respiration rate, skin colour, decay rate, and external appearance were obtained from quince during storage. Loquat seedling rootstocks also gave good results for sensory quality and decay rate, showing similarity to quince. While the fruit colour of the fruits grown on hawthorn rootstock was, relatively, pale yellowish-green, quince rootstock gave vivid yellow skin colour. Stretch film application reduced the weight loss in all the combination of scion/rootstock but, increased pathogens development. The disease agent causing decay, especially after 30th day of storage, was *Phytophthora* spp. Fruits grown on quince and loquat seedling rootstocks can be stored with good quality for 30+2 days at 5°C and 90 ± 5 RH%.

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