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RESEARCH PAPER

Determination of Shelf-Life of New Satsuma (Rize) Mandarin (*Citrus unshiu* Marc.) Cultivar Candidates Obtained by Clonal Selection

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Abstract

Satsuma (Rize) Mandarin is Türkiye's most widely produced and exported mandarin variety. Due to its early ripeness and seedlessness, Satsuma mandarin (*Citrus unshiu* Marc.) is a popular citrus fruit in domestic and foreign markets. The present study was conducted at Recep Tayyip Erdogan University, Faculty of Agriculture, Department of Horticulture in 2020-2021 to determine the shelf-life of Satsuma mandarin genotypes obtained as a result of clonal selection carried out in Rize province and its districts. The harvested mandarin variety candidates were pomologically analyzed and stored in an environment containing at 15°C ± 1 temperature and 55-60% humidity. The changes in fruit weight (g), fruit juice content (%), rind thickness (mm), total soluble solid (%, TSS), and titratable acid (%, TA) content were examined at one-week intervals during the storage period. It was determined that weight loss (%) and TSS (%) increased steadily, while fruit juice content (%), rind thickness (mm), and titratable acid (%) decreased steadily during storage in all genotypes and control. Also, the differences detected in terms of the properties examined were lower on 7 and 14 days than the initial value, whereas they were higher on 21 days. As a result of the findings, it was determined that the quality losses of mandarin genotypes showed differences during the shelf-life, but they could be stored for 14 days without much loss in quality.

1. Introduction

A total of 161,800,880.88 tons of citrus fruits are produced worldwide on a total area of 10,222,415 ha. Orange is the type with the highest production amount in citrus production. Orange production is followed by mandarin, lemon, and grapefruit. Türkiye ranks 8th in the world with 5,362,615 tons of citrus production in 166,417 ha. Türkiye's citrus production consists of 1,742,000 tons of oranges, 1,819,000 tons of mandarin, 1,550,000 tons of lemon, and 249,000 tons of grapefruit (FAO, 2021). Türkiye Statistical Institute (TSI) has reported that Türkiye's mandarin production were increased in 2020, 2021, and 2022. The most produced mandarin variety in Türkiye is Satsuma mandarin (854,720 tons), with a ratio of 45.90%. Satsuma mandarin is followed by Klemantin (86,121 tons), King (5,793 tons), and other varieties (918,366 tons).

Satsuma mandarin is a low-acid, easy-to-peel, seedless, aromatic, and high-quality variety that ripens earlier than other mandarin varieties. It is suitable for storage and transportation and is popular worldwide (Campbell et al., 2004; Cantuarias-Avilés et al., 2010; Turgutoğlu, 2020). Satsuma mandarin was introduced to Türkiye via Batumi, spread to the Eastern Black Sea region and then spread to areas that can grow in the Aegean and Mediterranean regions.

Cultivation of tropical and semitropical citrus fruits is concentrated in subtropical regions (Davies and Albrigo, 1994). In Türkiye, ecological conditions facilitate the economic cultivation of citrus fruits in the Mediterranean and Aegean Regions (Kaplankıran et al., 2005). However, Satsuma mandarin, also known as Rize mandarin, the most exported fruit in Türkiye, has found the best ecology in the Eastern Black Sea Region, especially in Rize province.

The Black Sea Agricultural Region has 11.8% of Türkiye's fruit production, and the Eastern Black Sea Region ranks 3rd in citrus production after the Mediterranean and Aegean regions (TSI, 2020). Citrus fruits and especially Satsuma (Rize) mandarin, which are in the subtropical fruit group, have found a place to grow individually in home gardens as a border tree in the region, although there are few closed orchards. However, in recent years, it is known that the fruits of the scattered trees are collected and sold at particular sales points in the districts, mandarin jam is also produced in Rize province, and studies have been initiated to establish a mandarin jam factory with increasing demand (Yazıcı et al., 2020).

Fruits maintain their vitality after harvest; in other words, they continue their physiological respiration (Çavuşoğlu et al., 2019). Many factors, such as respiration rate, appropriate harvest time, presence of pathogens, the resistance of the variety to preservation, orchard maintenance conditions, storage temperatures, oxygen, the composition of the packaging atmosphere, and many other factors, affect the shelf-life of fruits. Also, the shelf-life of fresh fruits is shortened due to ethylene, a vital phytohormone associated with the ripening process (Kafa and Canıhoş, 2010; Nayik and Muzaffar, 2014; Çavuşoğlu et al., 2019; Hu et al., 2019).

It is known that citrus fruits have a longer shelf-life than other tropical fruits, but if post-harvest processing is not carried out correctly and stored under the appropriate conditions, the amount of marketable fruit will decrease (Strano et al., 2017). It has also been reported that Mandarins (*Citrus reticulata* Blanco) are more sensitive to post-harvest storage than other citrus species (Cohen et al., 1990).

Approximately half of the world's citrus production is for the fresh market. Therefore, the post-harvest shelf-life in non-climacteric citrus fruits is vital to reduce post-harvest losses and extend the time to market. Citrus fruits have a relatively long post-harvest life when kept under the suitable conditions, but they are prone to developing numerous post-harvest disorders that reduce rind quality. The citrus fruit rind contains oil glands filled with essential oils that are easily oxidized. Exposure of fruits to stressful conditions can lead to the breakdown of gland cells and the release of essential oil content, which can cause injury and damage. Furthermore, the rotting of citrus fruits after harvest due to fungal infection is quite common (Lafuente and Zacarías, 2006; Petracek et al., 2007; Lado et al., 2019; Zacarías et al., 2020).

It has been reported that the shelf-life of citrus fruits can be increased by reducing mechanical damage during post-harvest packaging and packaging processes and by expanding cold system transportation (Strano et al., 2017).

To increase the storage and shelf-life of mandarins, the use of UV-C radiation (Shen et al., 2013a), pre-harvest gibberellic acid application (Rokaya et al., 2016a), investigation of packaging packages with different properties (Mahajan et al., 2016), laurel and wax applications (Doğan, 2017), 1% sodium metabisulfite (SMBS) application (Özdemir et al., 2020), post-harvest salicylic acid application (Haider et al., 2020), chitosan and wax applications (Zan and Özdemir, 2022), and hot water dipping (Dündar et al., 2020). The quality can be maintained with these applications, even under normal storage conditions, and they are widely used worldwide (Bisen et al., 2012).

It has been known that preservation and packaging facilities are not sufficient in the Eastern Black Sea region (Akbulut et al., 2017). In Rize province, Satsuma mandarin is sold in special sales places, especially in a very long period after harvest, and applications are not made to increase the storage period. Therefore, the fruits are kept on the tree, and since the harvest period coincides with the winter months, snowfall and adverse weather conditions cause product losses. Some producers keep the mandarin fruits in covered open areas and offer them for sale in parts. No studies have been carried out in the region for Rize mandarin's shelf-life and storage. It has been known that it is crucial to know the shelf-life of the varieties sought, especially in domestic and foreign markets, and to develop appropriate storage and transportation methods in retail sales places such as Rize province. Also, it has been reported that appearance, robustness, and shelf-life are essential for wholesalers and retail producers (Brasil and Siddiqu, 2018). Therefore, the first shelf-life study was carried out in the Rize mandarin, and the results were evaluated in the present study.

Satsuma Mandarin entered our country for the first time in Rize through Russia. Considering that different genotypes have been formed by the vegetative propagation of this mandarin variety until today, it has been accepted that Rize province has an important genetic resource. With two projects completed by Yazıcı et al. (2017, 2021), somaclonal differences in mandarins were determined, and important Satsuma mandarin cultivar candidates for our country were determined. Among these candidates, there are cold-resistant, early, and late varieties and a variety of candidates were identified that could be effective in extending the mandarin season not only for the Black Sea region but also in Türkiye. The present study was conducted at Recep Tayyip Erdogan University, Faculty of Agriculture, Department of Horticulture to determine the shelf-life of new mandarin variety candidates determined by clonal selection in Rize province.

2. Material and Methods

2.1. Plant materials

In the study, eight Satsuma mandarin genotypes were selected by clonal selection from Rize region, grafted on trifoliate rootstock (*P. trifoliata* (L.) Raf.) and established in the orchard with 4×4 m spacing were used as the material, and a registered Satsuma mandarin variety grafted on trifoliate rootstock was used as the control. Mandarin cultivar candidates used as material in this study are high yield and quality cultivar candidates. Among these cultivar candidates, Yu 2 and Tek 1 are early season, Pa 2, Tek 4 and Yu 3 are late season, Tek 3, Tek 8 and İslm are medium late season characteristics.

2.2. Methods

The harvested fruit samples of each mandarin genotype were divided into four groups, and the first group was initially subjected to pomological analyses, then stored at 15°C ± 1 temperature and 55-60% humidity. To determine the quality losses in the fruit samples during the shelf period, weight loss (%), TSS (%), titratable acid content (%), fruit juice content (%), rind thickness (mm) changes were determined at one-week intervals on the 2nd group on day 7, 3rd group on day 14 day and 4th group on day 21. The experiment was established according to the factorial experimental design in randomized plots with three replicates. The data obtained from the experiment was analyzed with the JMP statistical package program, and the LSD ($P<0.05$) multiple comparisons test was applied to determine the differences between the means.

Weight loss was calculated in percentile for each treatment in each analysis period by comparing the initial weight with a precision balance of 0.01 g. Rind thickness was determined by cutting the fruits transversely from the equator and measuring the flavedo and albedo thickness with the help of calipers. The fruit juice was weighed individually by squeezing the juice of each fruit. After the pulp weight was determined, the pulp content % was calculated. The TSS content was determined in percentile using a hand refractometer after the juices were filtered through the cheesecloth. Titratable acid (TA) content was calculated in % citric acid by titrating the juice samples with 0.1 N NaOH.

3. Results and Discussions

3.1. Weight loss

The weight losses of fruit samples of different mandarin genotypes after three weeks of storage at 15°C ± 1 temperatures and 55-60% humidity is given in Table 1. According to the statistical analysis results, the differences between shelf periods and genotypes in terms of weight losses were found to be statistically significant ($P< 0.05$). As seen in Table 1, weight losses increased in all mandarin types in parallel with the increase in shelf period. During the 21-days shelf-life, the lowest weight loss was found in Tek 1 (18.78%), İslm (18.84%), and Control (19.75%) fruit groups, followed by Tek 4 (22.06%), Tek 3 (22.08%), Pa 2 (23.20%), and Yu 2 (26.57%). The highest weight loss was found in the Yu 3 (31.55%) and Tek 8 (28.27%) mandarin genotypes. It was also reported by different researchers (Dal and Gözen, 2010; Yadav et al., 2010; Kaur and Kumar, 2014; Rokaya et al., 2016b; Majahan et al., 2016; Zan and Özdemir, 2022) that weight loss in fruits increases in parallel with the shelf period.

Dal and Gözen (2010) reported that the weight loss of three different types of Satsuma mandarins, which were applied to wax and kept at 20 ±1°C and 55-60% humidity for 10 days, was 8.46-8.97-10.09% in the control plants. Kaur and Kumar (2014) determined the shelf-life of Kinnow mandarins and the weight loss as 21.22% on day 15 and 33.33% on day 30. Rokaya et al. (2016a) examined the effects of post-harvest treatments on the shelf-life and quality of mandarins (*Citrus reticulata* Blanco) and found that the weight loss of mandarins stored for four weeks at 14ºC - 18ºC and 45% - 73% humidity was 21% in untreated fruits. Majahan et al. (2016) determined that the rate of weight loss in Kinnow mandarin increased during the shelf period, and the weight loss was 15% on day 21. Pekmezci (1984) determined that Satsuma mandarins can be successfully stored for 2-2.5 months at 3ºC and 85-90% relative humidity. In the study, it was also reported that the thin rind of mandarins accelerated their weight loss.

3.2. Fruit juice content

Changes in the fruit juice value during the shelf-life of Rize mandarin genotypes are given in Table 2. At the beginning of the shelf-life, the average fruit juice content was determined to be 40.95% and 35.30% at the end of the 21-day shelf-life. During the shelf-life period, Yu 2, İslm, Tek 1, Tek 3, Tek 4, Tek 4, Tek 8, and Pa 2 genotypes showed a decrease in the fruit juice values, whereas the Yu 3 and control genotypes showed an increase. Both genotypes and shelf-life changes in the fruit juice values were statistically significant ($P< 0.05$). Similar to the results obtained in the present study, Kaur and Kumar (2014) determined the fruit juice content in Kinnow mandarins to be 45% on day 15th day and 43.95% on 30th day. Rokaya et al. (2016a) reported that the juice content of mandarins for four weeks decreased from 47.26% to 34.65%. During the shelf-life of the genotypes, there was a regular increase in the fruit juice values in İslm, Tek 1, Tek 3, and Tek 8 genotypes, whereas fluctuations were observed in Control, Yu 2, Yu 3, Pa 2, and Tek

Table 1. Weight loss (%) of genotypes during storage.

Genotypes	Shelf life			Average (Genotypes)
	7th day	14th day	21st day	
Control	11.80	16.27	31.17	19.75 d
Yu 2	12.68	32.19	34.84	26.57 b
Yu 3	14.02	35.44	45.02	31.55 a
Pa 2	8.05	27.33	34.23	23.20 bd
İslm	10.91	15.04	30.58	18.84 d
Tek 1	10.20	15.92	30.21	18.78 d
Tek 3	13.99	20.18	32.06	22.08 cd
Tek 4	7.88	23.85	34.46	22.06 cd
Tek 8	14.05	21.86	41.80	25.90 bc
Average (Storage period)	11.50 c	25.14 b	37.01 a	

LSD 5% =3.53 (Storage period), LSD 5% =6.11 (Genotypes), LSD 5% = N.S. (Genotypes×Storage period)

Table 2. Changes in the fruit juice values (%) in genotypes during storage.

Genotypes	Shelf life				Average (Genotypes)
	Inception	7th day	14th day	21st day	
Control	40.23 fj	52.50 a	37.84 gk	37.05 gm	41.65 ab
Yu 2	41.92 eg	33.45 lp	46.61 cd	34.62 kp	38.90 cd
Yu 3	34.80 kp	47.45 c	40.40 eh	39.62fı	40.32 bc
Pa 2	34.89 kp	33.18 mp	31.86 np	34.17 kp	33.27 f
İslm	43.96 df	44.43 ce	36.36 hm	36.32 ım	40.02 bc
Tek 1	41.81 eg	39.75 fı	35.31 jo	34.20 kp	37.52 de
Tek 3	40.50 fı	36.40 hm	36.34 hm	30.68 p	35.73 e
Tek 4	52.31 a	31.60 op	45.62 cd	35.70 ın	43.31 a
Tek 8	38.15 gm	37.28 gl	37.07 gm	35.35 jo	36.72 e
Average (Storage period)	40.95 a	39.56 b	38.60 b	35.30 c	

LSD 5% =1.35 (Storage period), LSD 5% =2.03 (Genotypes), LSD 5% =4.06 (Genotypes×Storage period)

Table 3. Changes in rind thickness (mm) of genotypes during storage.

Genotypes	Shelf life				Average (Genotypes)
	Inception	7th day	14th day	21st day	
Control	2.45	2.85	1.91	1.66	2.21 b
Yu 2	2.89	2.41	2.37	1.98	2.41 a
Yu 3	3.22	2.10	1.87	1.64	2.20 b
Pa 2	2.46	2.18	2.04	1.70	2.10 c
İslm	2.35	1.93	1.93	1.40	1.90 d
Tek 1	2.75	2.17	2.15	1.89	2.24 b
Tek 3	2.90	2.28	2.28	2.06	2.40 a
Tek 4	2.53	2.39	2.07	1.72	2.17 bc
Tek 8	2.54	2.16	2.02	1.75	2.11 c
Average (Storage period)	2.68 a	2.29 b	2.07 c	1.76 d	

LSD 5% =0.13 (Storage period), LSD 5% =0.19 (Genotypes), LSD 5% = N.S. (Genotypes×Storage period)

4 genotypes. It has been reported that fluctuations were observed in the fruit juice content during storage (Rokaya et al., 2016b; Didin et al., 2018; Dündar et al., 2018; Özdemir et al., 2020; Güvenç and Dündar, 2021; Zan and Özdemir, 2022). These fluctuations were associated with the moisture loss of the fruit rind and solubility of compounds other than carbohydrates-sugars (Echeverria and Ismail, 1990; Özdemir et al., 2020; Zan and Özdemir, 2022).

3.3. Rind thickness

Regarding rind thickness, the differences between storage periods and genotypes were found to be statistically significant ($P < 0.05$). The rind thickness of the genotypes decreased throughout the shelf-life analysis. The rind thickness, which was 2.68 mm at the beginning, was determined to be 1.76 mm on day 21. At the end of the shelf period, the rind thickness was 2.41 mm in Yu 2 and 2.21, 2.41, 2.20, 2.10, 1.90, 2.24, 2.40, 2.17, 2.11 in control, Yu 2, Yu 3, Pa 2, İslm, Tek 1, Tek 3, Tek 4 and Tek 8, respectively.

Different researchers have also reported a decrease in fruit rind thickness during storage (Wang et al., 2019; Shahzad et al., 2022). Shahzad et al. (2022) reported that the rind thickness of Tango mandarin was 1.99 mm at the beginning of the storage period and became 1.73 mm at the end

Table 4. Changes in the TSS content (%) of genotypes during storage.

Genotypes	Shelf life				Average (Genotypes)
	Inception	7th day	14th day	21st day	
Control	8.40 e	8.80 c	8.60 d	8.80 c	8.65 b
Yu 2	7.80 h	8.20 f	8.40 e	8.47 de	8.22 c
Yu 3	8.60 d	8.80 c	9.00 b	9.20 a	8.90 a
Pa 2	7.40 j	7.60 ı	7.60 ı	7.20 k	7.45 f
İslm	8.00 g	8.00 g	8.00 g	8.20 f	8.05 d
Tek 1	7.20 k	7.40 j	7.20 k	7.40 j	7.30 g
Tek 3	8.00 g	8.00 g	8.00 g	8.10 g	8.02 d
Tek 4	7.80 h	7.80 ı	7.80 ı	8.00 g	7.85 e
Tek 8	8.20 f	8.00 g	8.31 e	8.40 e	8.22 c
Average (Storage period)	7.93 d	8.06 c	8.10 b	8.20 a	

LSD 5% = 0.05 (Storage period), LSD 5% =0.08 (Genotypes), LSD 5% =0.16 (Genotypes×Storage period)

Table 5. Changes in TA content (%) of genotypes during storage.

Genotypes	Shelf life				Average (Genotypes)
	Inception	7th day	14th day	21st day	
Control	1.00 eg	0.93 ıj	0.92 ıj	0.77 qs	0.91 de
Yu 2	0.96 gı	0.74 s	0.99 eg	0.87 km	0.89 e
Yu 3	1.14 a	1.01 df	1.06 bc	1.06 bc	1.07 a
Pa 2	0.98 fh	0.98 fh	0.96 gı	0.91 jk	0.96 c
İslm	1.04ce	1.12 a	1.05 cd	0.94 hı	1.04 b
Tek 1	0.83 np	0.85 mo	0.83 mp	0.79 pr	0.83 f
Tek 3	0.98 fh	0.84 mp	0.81 oq	0.75 rs	0.84 f
Tek 4	0.90 jl	0.90 jl	1.10 ab	0.80 oq	0.92 d
Tek 8	0.96 gı	0.86 ln	0.98 fh	0.84 mo	0.91 de
Average (Storage period)	0.97 a	0.91 b	0.97 a	0.86 c	

LSD 5% = 0.02 (Storage period), LSD 5% =0.02 (Genotypes), LSD 5% =0.05 (Genotypes×Storage period)

of the storage period. Wang et al. (2019) have reported that the rind thickness of pomelo (*Citrus grandis* Osbeck) varieties decreased during storage on the tree and with the storage period in the closed storage environment.

3.4. Total soluble solid (TSS) content

The differences between mandarin genotypes in terms of TSS, storage periods, genotypes, and genotype × storage period interactions were found to be statistically significant ($P < 0.05$). During the shelf-life of the Satsuma mandarin genotypes, the average TSS content increased from 7.93% at the beginning to 8.20% at the end of day 21. At the end of the shelf-life, the highest TSS content among genotypes was determined in Yu 3 (8.90%), followed by Control (8.65%), Yu 2 (8.22%) and Tek 8 (8.22%). The genotypes with the lowest TSS content were determined in Tek1 (7.30%) and Pa 2 (7.45%) (Table 4). Camilla et al. (2016) stated that water loss during storage increased the sugar content in the fruit. In shelf-life studies, it has been reported by many researchers that the TSS content increases during shelf-life (Kim et al., 1998; Şen and Karaçalı, 2005; Altuntaş et al., 2009; Dal and Gözen, 2010; Yadav et al., 2010; Çalhan et al., 2012; Kaur and Kumar, 2014; Rokaya et al., 2016a; Dündar et al., 2018). Şen and Karaçalı (2005) reported that 'Satsuma' mandarin generally did not change the TSS value and slightly decreased the TA value in the post-harvest period. Zan and Özdemir (2022) have reported that, on day 90 of Owari Satsuma mandarin stored in natural refrigerated storage and cold storage, the TSS value increased to 11.06% in natural refrigerated storage and 10.90% in cold storage. Rokaya et al. (2016a) have reported that the TSS content of the *Citrus reticulata* Blanco mandarin fruits increased during the shelf period, and the TSS value, which was 10.92% at the beginning, increased to 12.88% at the end of storage. In another study conducted to determine the shelf-life of Kinnow mandarins, Kaur and Kumar (2014) reported that the TSS content was 12.20% on day 15 and 12.53% on day 30. Our findings were similar to those of these studies. According to Pantastico, changes in sugars are insignificant and slow in fruits that do not show climacteric properties. Although their amounts increase slightly at the beginning of storage, they decrease in long-term storage (Özdemir and Dündar, 1999). In our study, there was an increase in the amount of TSS before the 7th and 14th storage days and a decrease in some genotypes on the 21st day.

3.5. Titratable acid (TA)

After the analysis of the titratable acid content of the genotypes during the shelf-life, it was observed that while the initial average was 0.97%, it decreased to 0.86% on day 21. At the end of the 21-day period, it decreased to 0.86%. In terms of titratable acid content, the differences between storage periods, genotypes, and genotype × storage period interactions were found statistically significant ($P < 0.05$) (Table 5).

At the end of the shelf period, the highest titratable acid content was determined in Yu 3 (1.07%), followed by İslm (1.04%), Pa 2 (0.96%), Tek 4 (0.92%), Tek 8 (0.91%) and Control (0.91%), and Yu 2 (0.89%). The genotypes with the lowest acid content were Tek 1 (0.83%) and Tek 3 (0.84%). Also, all genotypes showed a decrease in titratable acid content during the storage period. Many researchers have also reported that the acid content of Satsuma mandarin decreases in post-harvest storage conditions (Şen and Karaçalı, 2005; Hong et al., 2007; Tietel et al., 2010; Santos et al., 2010; Shen et al., 2013b; Özdemir et al., 2020; Zan and Özdemir, 2022).

Dal and Gözen (2010), in their shelf-life study on three different Satsuma mandarin genotypes, determined that TA values were decreased on day 10 of the shelf period and decreased to 1.30%-1.57%-1.67%. Zan and Özdemir (2022) determined that the titratable acid value of Owari Satsuma mandarin in natural refrigerated storage was 1.10% and 0.92% on day 90 in cold storage. Rokaya et al. (2016a) determined that the juice acid ratios of mandarins were 0.86%-0.75%-0.65%-0.53% on weeks 1, 2, 3, and 4 during the shelf-life, respectively. Yadav et al. (2010), in their study on Kinnow mandarins, found that the fruit juice acidity decreased from 0.64% to 0.57% in the control groups during the shelf-life. In their study to determine the shelf-life of the same variety, Kaur and Kumar (2014) determined the acid ratios as 0.58% on day 15 and 0.47% on day 30 of the shelf-life period.

4. Conclusion

The present study was carried out to determine the shelf-life of eight satsuma genotypes obtained by selection. As a result of the study, it was determined that shelf-life varied depending on both the storage period and the genotypes. Losses occurred in the fruit weights of the genotypes during the storage period. The highest weight loss (37.01%) was detected on day 21. Among the genotypes, the highest weight loss was found in the Yu 3 genotype (45.02%). During the shelf period, the fruit juice values of the fruits generally increased, whereas the rind thickness decreased. There was a continuous decrease in the titratable acid values. As a result of the findings, it was determined that the quality losses of mandarin genotypes showed differences during the shelf-life, but they could be stored for 14th days without much loss in quality.

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