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Postharvest quality of new quince cultivar and promising genotype (*Cydonia oblonga* Mill.) in response to harvesting time and length of the cold storage period

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ABSTRACT

Purpose: The aim of this study was to determine the most appropriate harvesting time and to evaluate the storage period of some new quince cultivar and the promising genotype. **Research method:** The fruits of 'Isfahan' and 'Behta' cultivars along with NB4 promising genotype were harvested on 6th, 14th, and 21st October from Isfahan Agricultural Research Station, Iran. The fruits were transferred to the storage and placed at a temperature of 0±1°C and relative humidity of 90±5%. Traits were evaluated at harvesting time and also at one-month intervals for five months after storage using a factorial experiment based on a completely randomized design. **Main findings:** The highest percentage of total soluble solids (TSS) was obtained in the third harvesting time and after five months of storage for 'Isfahan'. The highest firmness was obtained at the first harvesting time without storage for 'Behta'. 'Isfahan' at the time of the second and third harvest showed the highest total phenol content and 'Behta' at the first harvest and five months after storage showed the lowest value of this trait. The most weight loss was observed in 'Isfahan' in the third harvest and the fifth month of storage. Experimental treatments had no effect on pectin content. The highest surface browning was observed in the third harvest and the fifth month of storage. **Research limitations:** No limitations were found. **Originality/Value:** The best harvest time for 'Isfahan', 'Behta', and NB4 was similarly 193 days after flowering. As well as storage of these fruits for four months is recommended.

INTRODUCTION

Quince (*Cydonia oblonga* L.) belongs to the Rosaceae family. This species is known as a native of Iran and its distribution centers are the forests of northern Iran from Astara to Katoul Gorgan and the middle latitudes of northern Iran (Abdollahi, 2021). The first program to collect of native cultivars and genotypes in Iran was conducted by Ghasemi (2002) in Isfahan province. 'Behta' new cultivar is one of these cultivars that have been considered in recent years due to its desirable quality, high productivity, and relative tolerance to fire blight (Abdollahi, 2019). NB4 promising genotype is also one of the genotypes that are being introduced due to the high fruit quality and quantity (Tatari & Abdollahi, 2021).

The beneficial effects of quince fruit as a source of pectin (Moradi et al., 2016) and antioxidant compounds (Wojdylo et al., 2013) have been previously reported. Quince is a climacteric fruit that is usually harvested from October to November in the Northern hemisphere (Sharma et al., 2011). In climacteric fruits, an increase in respiration occurs at the ripening time, therefore if the temperature of storage is reduced, the respiration of the fruit will be slowed down and the fruit ripening will be delayed and the storage period of the fruit will be increased (Luengwilai & Beckles, 2013). Firmness and TSS are two important qualitative factors in determining the maturity and harvest time of fruit that change during storage. Water loss occurs during long-term storage and leads to reduced economic benefits due to reduced fruit weight and leads to increased fruit shrinkage (Veraverbeke et al., 2003). Pectin is a complex polysaccharide composed mainly of polygalacturonic acid and it is an important compound in the cell wall that is usually dissolved when the fruit ripens (Acikgoz, 2011). One of the major problems during the marketing of quince cultivars is the enzymatic browning, which leads to postharvest physiological disorders. This physiological disorder is caused by pre-harvest and harvest conditions as well as storage conditions (Kuzucu & Sakaldas, 2008). Browning occurs due to polyphenol oxidase activity (Holderbaum et al., 2010). During enzymatic browning, phenolic compounds such as chlorogenic acid are oxidized to the quinone by polyphenol oxidase. Then quinone is converted to melanin by a non-enzymatic polymerization process, which results in the destruction of the fruit and the formation of yellow or brown pigments. Phenolic compounds are substrates of polyphenol oxidases (Awad & De Jager, 2000).

The quince fruit has a shelf life of more than three months (Gunes et al., 2012). According to the results of a study, cold storage of fruit significantly reduced fruit waste. Also, with the delay in harvesting time and increasing the storage period in the cold storage, fruit firmness decreased and the surface browning increased (Gunes, 2008). Depending on the cultivar or genotype, the quince fruit can be stored at a temperature of 2±1°C and relative humidity of 80-90% (Moradi et al., 2017).

With increasing cold storage period, fruit weight loss of the 'Gorton' quince cultivar increased. Prolonged harvesting time and increased storage period reduced the fruit firmness and increased the surface browning. In 'Gorton', most TSS was obtained in the second harvest and after 135 days of cold storage (Gunes, 2008). Fruit weight loss of 'Esme' quince cultivar increased after six months of storage with prolonged harvesting time. TSS in the third harvest increased and the TA decreased after six months of storage (Kuzucu & Sakaldas, 2008).

Fruits harvesting at the suitable time is one of the most important factors before harvest for reducing storage rot and fruit waste in the postharvest period, so determining the correct harvesting time is very important. In production areas of quince, production density occurs in October; therefore, it is necessary to store additional products (Kuzucu & Sakaldas, 2008). Due to the lack of widespread cultivation of quince in the world, the qualitative traits of this fruit in storage and postharvest damage have not been extensively studied (Moradi et al., 2017). Considering that 'Behta' and NB4 are new genetic materials of quince in Isfahan province, it is necessary to determine the most appropriate harvesting time and storage period for them.

MATERIALS AND METHODS

Plant materials

This research was conducted in Isfahan Agricultural Research Station, Iran in 2018 and 2019. The experiment was carried out on 'Behta' cultivar and NB4 promising genotype as well as 'Isfahan' (control) that were grafted on hawthorn seedling rootstock. In April, the flowering time of cultivars and genotype was recorded and when 85-90% of the flowers opened, the time of full bloom was recorded separately for each cultivar and genotype so that the harvesting time could be reported based on the number of days after full bloom. Harvesting was done on 6th, 14th, and 21st October. The fruits of each cultivar and genotype were randomly harvested from three trees (three replications) and transferred to the cold storage with a temperature of 0±1°C and relative humidity of 95%. At the harvesting time and also at intervals of one month and for five months, some quantitative and qualitative characteristics (as follows) of stored fruits were examined.

Evaluated traits

Three days after removing the fruits from storage and storing them at 20°C, the fruit surface browning was recorded. So that without browning or very low browning, low browning, medium browning, high browning, and very high browning were considered 0-10%, 10-30%, 50-30%, 70-50%, and 90-70%, respectively. To evaluate the percentage of decay in each replication, the average decay of fruits was observationally recorded. Each test plot was weighed before transfer to the cold storage and weighed again after that. By calculating the difference between primary and secondary weight, weight loss percentage was calculated in each test plot. To determine the fruit firmness, a penetrometer (model EFFEGI, Italy, plunger diameter 11.1 mm, depth 7.9 mm) was used and the applied force was recorded as kg/cm^2. Total soluble solids (TSS) was measured using an ATAGO N-1α refractometer made in Japan. Titratable acidity (TA) was reported by titration of extracted juice with sodium hydroxide (0.1 N) up to pH 8.1 and expressed as a percent of malic acid (Roussos et al., 2011). The taste index (TSS/TA) was obtained by dividing TSS by TA. The pectin in the samples was measured by the weighting method and by determining calcium pectinate (Thakur et al., 1996). The total phenol content of fruit juices was measured using the Folin-Sikalcho method (Singleton & Rossi, 1965). The absorbance of the samples was determined at 765 nm wavelength with spectrophotometer model T80 UV/Visible, then compared with the standard of gallic acid and expressed as mg gallic acid per 100 grams of fresh weight.

Statistics design

Obtained results were analyzed using a factorial experiment with tree factors (tree cultivars and genotype, three harvesting time, and duration of storage in six levels) based on a completely randomized design with three replications and 10 samples per replicate during two years. Due to the non-significance of Bartlett's test, a combined analysis was performed for an average of two years. For two traits, surface browning and decay percentage, data normalization was performed with the ArcSin formula using Excel software. Analysis of data was performed by ANOVA method using statistical software SAS (version 9.1) and mean comparisons using LSD.

RESULTS

Flowering time

Results showed that similar to 'Isfahan', 'Behta' and NB4 were also late flowering and had a good flowering overlap with 'Isfahan' (Table 1). Due to higher temperatures in 2019, flowering occurred earlier than in 2018.

The effect of treatments on the evaluated traits

According to Table 2, none of the evaluated traits were affected by year × cultivar × storage time × harvesting time. The effect of cultivar × harvesting time × storage period on weight loss, TSS, taste index, firmness, and total phenol content was significant. TA was affected by harvest time × cultivar and storage period × cultivar. The effect of harvest time × duration of storage on surface browning was significant. Storage period had a significant effect on the percentage of decay. Pectin content was not affected by the applied treatments. The effect of year was significant on some traits.

Table 1. Flowering time of quince cultivars and promising genotype in 2018 and 2019.

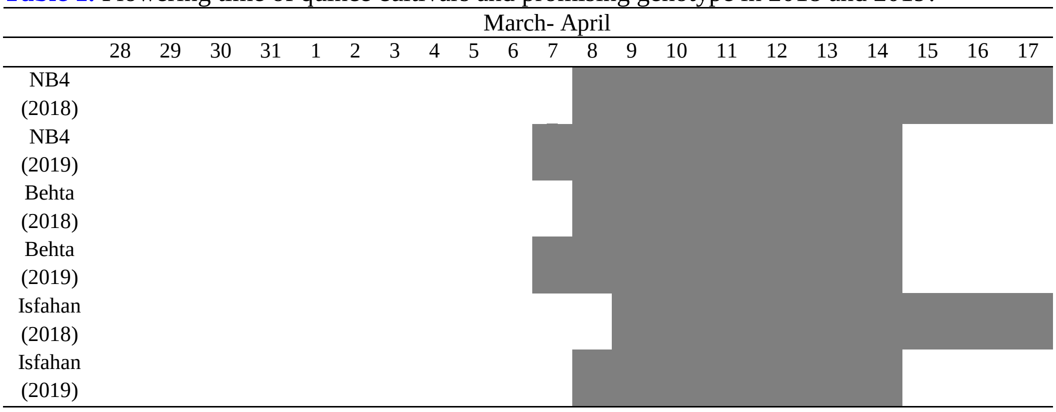

Table 2. Combined analysis of variance for effect of year, harvesting time, cultivar and duration of storage on measured characteristics.

Source of Variation	Degrees of freedom (df)	Traits				
		Weight loss (%)	TSS (%)	TA (%)	TSS/TA	Firmness (kg/cm^2)
Year	1	944.74**	705.19**	0.02*	1609.52**	0.31**
Replication (year)	4	30.06	28.24	0.04	174.96	1.17
Harvesting time	2	87.13**	287.90**	0.60**	4599.27**	4.61**
Cultivar	2	79.14**	188.12**	1.70**	6495.23**	23.48**
Storage period	5	2855.71**	511.85**	1.01**	4080.60**	27.94**
Harvesting time×Cultivar	4	1.85^{ns}	91.62**	0.02**	627.70**	0.44**
Harvesting time×Storage period	10	9.97*	70.12**	0.01^{ns}	168.63**	0.13**
Storage period×Cultivar	10	13.57**	97.46**	0.01**	48.55^{ns}	0.28**
Storage period× Harvesting time×Cultivar	20	6.82*	95.88**	0.006^{ns}	52.80*	0.09**
Harvesting time×Year	2	1.37^{ns}	0.37^{ns}	0.0001^{ns}	1.19^{ns}	0.0008^{ns}
Cultivar×Year	2	0.36^{ns}	0.19^{ns}	0.0001^{ns}	24.29^{ns}	0.0006^{ns}
Storage period×Year	5	118.46**	0.43^{ns}	0.0008^{ns}	16.00^{ns}	0.0006^{ns}
Cultivar× Harvesting time×Year	4	2.14^{ns}	0.56^{ns}	0.0001^{ns}	2.48^{ns}	0.0005^{ns}
Storage period× Harvesting time×Year	10	14.17**	2.10^{ns}	0.0007^{ns}	2.16^{ns}	0.0005^{ns}
Storage period×Cultivar×Year	10	3.53^{ns}	0.73^{ns}	0.0005^{ns}	3.06^{ns}	0.0006^{ns}
Storage ×Cultivar× Harvesting time×Year period	20	9.17^{ns}	2.06^{ns}	0.0002^{ns}	2.73^{ns}	0.0006^{ns}
Error	212	5.24	0.41	0.006	28.73	0.003
C.V.	-	23.89	4.30	13.02	19.35	1.77

Table 2. Continued. Combined analysis of variance for effect of year, harvesting time, cultivar and duration of storage on measured characteristics.

Source of Variation	Degrees of freedom (df)	Traits			
		Pectin (g/100 g)	Total phenol (mg/100 g (FW	Fruit decay (%)	Fruit browning (%)
Year	1	475.26^{ns}	16.46^{ns}	0.027^{ns}	0.00001^{ns}
Replication (year)	4	478.09	592.70	0.046	0.001
Harvesting time	2	492.96^{ns}	8368.48**	0.026^{ns}	0.002*
Cultivar	2	480.76^{ns}	25775.43**	0.0008^{ns}	0.0006^{ns}
Storage period	5	502.60^{ns}	25301.50**	0.13**	0.004**
Harvesting time×Cultivar	4	476.81^{ns}	439.83**	0.0009^{ns}	0.00005^{ns}
Harvesting time×Storage period	10	480.58^{ns}	98.28**	0.008^{ns}	0.009*
Storage period×Cultivar	10	478.72^{ns}	1575.40**	0.004^{ns}	0.0006^{ns}
Storage period× Harvesting time×Cultivar	20	479.28^{ns}	180.15**	0.001^{ns}	0.0004^{ns}
Harvesting time×Year	2	479.67^{ns}	1.59^{ns}	0.009^{ns}	0.0000003^{ns}
Cultivar×Year	2	475.94^{ns}	1.37^{ns}	0.012^{ns}	0.00001^{ns}
Storage period×Year	5	478.38^{ns}	3.96^{ns}	0.012^{ns}	0.00005^{ns}
Cultivar× Harvesting time×Year	4	479.55^{ns}	2.69^{ns}	0.009^{ns}	0.00001^{ns}
Storage period× Harvesting time×Year	10	478.14^{ns}	2.33^{ns}	0.005^{ns}	0.00002^{ns}
Storage period×Cultivar×Year	10	478.82^{ns}	2.58^{ns}	0.007^{ns}	0.00003^{ns}
Storage period×Cultivar× Harvesting time×Year	20	477.84^{ns}	2.37^{ns}	0.007^{ns}	0.000009^{ns}
Error	212	478.18	14.43	0.007	0.0004
C.V.	-	18.93	8.87	15.82	4.21

Weight loss

In each cultivar and genotype, weight loss gradually increased with prolonged storage period and harvesting times (Table 3). The highest weight loss was related to the third harvest of 'Isfahan' in the fifth month of storage (21.71%). Under similar conditions, 'Behta' and NB4 had a weight loss of 20.54% and 20.2%, respectively. The value of this trait in 2018 was more than in 2019 (Table 4).

TSS and taste index

The highest percentage of TSS was obtained in the third harvest of 'Isfahan', so that TSS in this cultivar, four and five months after storage was 18.83% and 18.16%, respectively (Table 3). After that, 'Behta' in the third harvest and four months after storage had TSS equal to 17.83%. The lowest amount of TSS belonged to NB4. The amount of TSS in this genotype at the first harvest (October 6) was 10.16% and after one month of storage was 11.5%, which was equal to TSS in the first harvest of 'Behta'. In general, the third harvest and longer storage increased the percentage of TSS.

The highest taste index was 73.33, which belonged to 'Isfahan' that had been stored for five months in cold storage. Under similar conditions, the taste index in 'Behta' and NB4 were 48.19 and 41.25, respectively. NB4 at the first harvesting time and one month after storage showed the lowest taste index with averages of 9.5 and 12.2, respectively (Table 3). TSS and taste index in 2019 was significantly higher than in 2018 (Table 4).

Table 3. Mean comparison of cultivar, duration of storage and harvesting time on weight loss, TSS, firmness and total phenol ± SD in two years.

Cultivar	Harvesting time	Duration of storage (Month)	Weight loss (%)	TSS (%)	Taste index	Firmness (kg/cm^2)	Total phenol (mg/100 gFW)
NB4	1	At harvest	-	10.16±1.72	9.5±1.75	4.36±0.16	56.71±3.83
NB4	1	1	2.73±2.78	11.5±1.87	12.2±2.42	4.06±0.09	40.25±5.21
NB4	1	2	4.64±2.34	12.83±1.72	15.2±2.46	3.21±0.10	43.2±3.66
NB4	1	3	8.88±2.18	14.5±1.87	19.91±3.32	2.86±0.13	23.09±3.83
NB4	1	4	14.01±2.82	15.66±2.16	22.36±5.35	2.52±0.12	17.74±3.52
NB4	1	5	17.18±3.67	15.83±1.72	26.88±4.88	2.28±0.04	3.51±1.12
Behta	1	At harvest	-	11.5±1.87	12.84±2.22	4.95±0.11	33.99±3.69
Behta	1	1	4.23±2.59	11.83±1.72	14.76±3.22	4.69±0.09	35.82±4.82
Behta	1	2	6.42±2.05	13.16±1.72	19.35±2.50	4.47±0.09	25.52±11.67
Behta	1	3	12.81±4.32	15.16±1.72	23.26±4.71	4.06±0.16	21.57±4.93
Behta	1	4	16.06±4.43	15.83±1.72	27.54±4.98	3.69±0.11	11.53±4.58
Behta	1	5	16.65±4.99	16.16±1.72	30.5±3.98	3.27±0.14	2.68±0.66
Isfahan	1	At harvest	-	13.5±1.87	17.97±1.87	4.56±0.10	98.21±3.61
Isfahan	1	1	3.78±3.12	13.83±1.72	20.03±3.51	4.14±0.15	73.02±5.45
Isfahan	1	2	6.38±2.98	14.5±1.87	24.94±3.43	3.69±0.16	58.41±3.47
Isfahan	1	3	9.91±3.17	15.5±1.87	33.41±4.29	3.3l±0.16	32.44±5.27
Isfahan	1	4	12.84±3.50	15.83±1.72	33.47±6.86	2.89±0.12	11.64±3.91
Isfahan	1	5	18.77±5.54	16.33±1.86	45.27±8.24	2.46±0.14	5.37±2.14
NB4	2	At harvest	-	10.83±1.72	11.25±2.07	4.3±0.22	69.52±4.09
NB4	2	1	2.68±2.33	12.16±1.72	16.27±2.46	3.7±0.20	60.67±5.05
NB4	2	2	4.94±0.89	13.83±1.72	21.18±4.25	3.19±0.12	54.73±4.43
NB4	2	3	12.36±3.58	14.5±1.87	21.78±2.62	2.89±0.09	46.49±4.45
NB4	2	4	14.05±3.72	15.16±1.72	23.54±3.28	2.71±0.17	29.24±4.37
NB4	2	5	19.005±6.27	16.16±1.72	31.75±4.87	2.53±0.07	10.98±3.64
Behta	2	At harvest	-	12.83±1.72	14.88±2.45	4.87±0.18	46.76±4.59
Behta	2	1	4.51±2.17	14.16±1.72	19.08±3.21	4.47±0.20	42.5l±4.64
Behta	2	2	10.33±5.12	15.5±1.87	22.83±2.99	3.94±0.16	30.79±4.09
Behta	2	3	14.12±3.81	15.5±1.87	23.5±3.93	3.64±0.12	24.11±3.57
Behta	2	4	17.01±1.78	15.83±1.72	28.22±4.72	3.33±0.11	15.73±3.70
Behta	2	5	19.12±2.31	16.33±1.86	36.66±5.41	2.98±0.12	14.62±4.88
Isfahan	2	At harvest	-	13.16±1.72	21.53±3.19	4.51±0.09	103.32±5.38
Isfahan	2	1	4.06±2.03	13.5±1.64	24.75±2.94	4.09±0.20	80.61±3.84
Isfahan	2	2	6.64±3.27	15.16±1.72	28.72±4.70	3.55±0.18	73.01±5.48
Isfahan	2	3	11.94±3.08	16.16±1.72	37.66±5.40	2.88±0.20	59.37±4.05
Isfahan	2	4	15.64±5.35	16.83±1.72	37.83±5.76	2.35±0.12	40.59±6.16
Isfahan	2	5	18.09±4.73	10.83±1.72	33.19±7.53	2.11±0.18	12.69±3.51
NB4	3	At harvest	-	11.83±1.72	13.68±2.04	3.72±0.24	84.36±4.14
NB4	3	1	5.02±2.36	12.83±1.72	17.26±2.91	3.1±0.12	69.25±4.20
NB4	3	2	7.01±1.83	13.83±1.72	21.53±5.26	2.8±0.10	62±5.77
NB4	3	3	11.77±3.22	14.83±1.72	24.66±5.49	2.55±0.09	45.99±4.61
NB4	3	4	15.06±5.55	15.83±1.72	33.77±6.85	2.34±0.11	32.45±3.75
NB4	3	5	20.2±4.7	16.5±1.62	41.25±13.01	2.1±0.12	21.81±5.28
Behta	3	At harvest	-	15.83±1.72	20.77±3.05	4.57±0.10	47±4.71
Behta	3	1	5.36±1.81	16.16±1.72	22.76±3.29	4.39±0.13	45.97±4.84
Behta	3	2	9.63±2.30	16.83±1.72	25.43±3.81	4.005±0.08	32.24±4.39
Behta	3	3	14.49±3.63	17±1.54	28.37±5.79	3.73±0.15	25.76±3.96
Behta	3	4	18.22±5.38	17.83±1.72	38.74±9.72	3.34±0.20	19.98±4.55
Behta	3	5	20.54±3.47	17.5±1.64	48.19±4.92	2.88±0.15	15.54±3.80
Isfahan	3	At harvest	-	16.5±1.87	30.22±4.23	3.92±0.12	101.64±4.67
Isfahan	3	1	3.56±2.27	16.83±1.72	39.16±5.02	3.72±0.14	85.79±3.84
Isfahan	3	2	4.5±2.62	17.16±1.72	46.19±10.26	3.39±0.16	74.17±3.42
Isfahan	3	3	11.67±4.36	17.5±1.64	50.83±7.85	2.89±0.12	57.63±4.61
Isfahan	3	4	18.68±7.01	18.16±1.72	55.55±9.58	2.47±0.16	44.22±3.48
Isfahan	3	5	21.71±4.98	18.83±1.32	73.33±17.51	2.1±0.14	36.12±4.16
LSD (0.05)			0.85	0.09	0.46	0.007	0.43

Table 4. Mean comparison of year on weight loss, TSS, TA, taste index and firmness.

Year	Weight loss (%)	TSS (%)	TA (%)	Taste index	Firmness (Kg/cm^2)
2018	11.29a	13.41b	0.608b	25.47b	3.4b
2019	7.87b	16.36a	0.625a	29.93a	3.46a
LSD	1.69	0.81	0.06	4.08	0.33

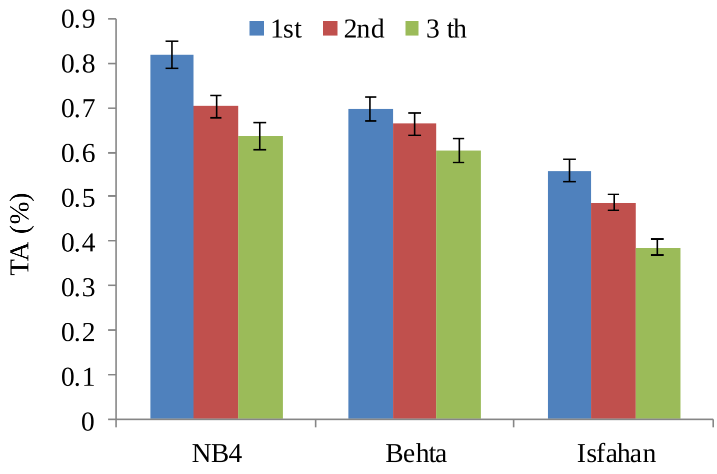

Fig. 1. Effects of cultivar and harvesting time on TA percentage.

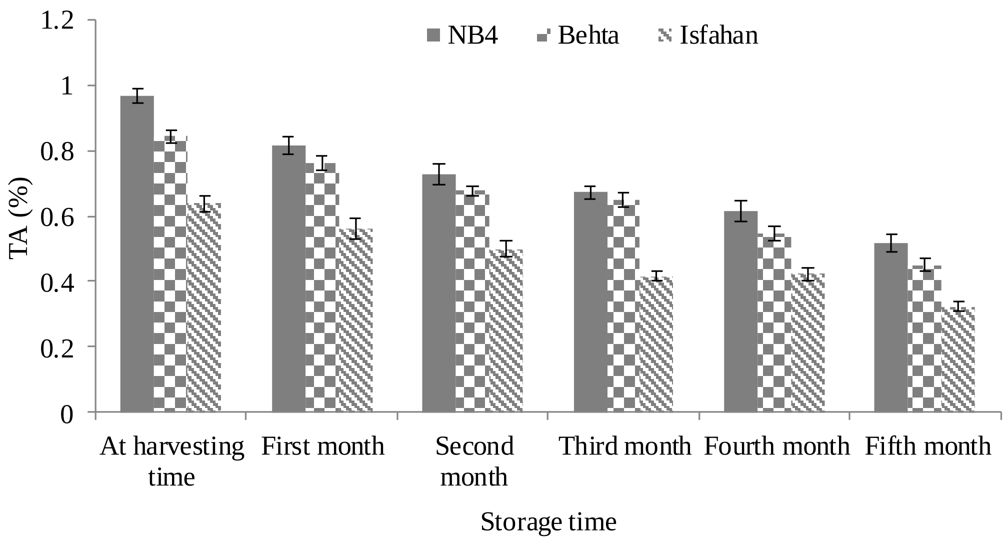

Fig. 2. Effects of cultivar and storage period on TA percentage.

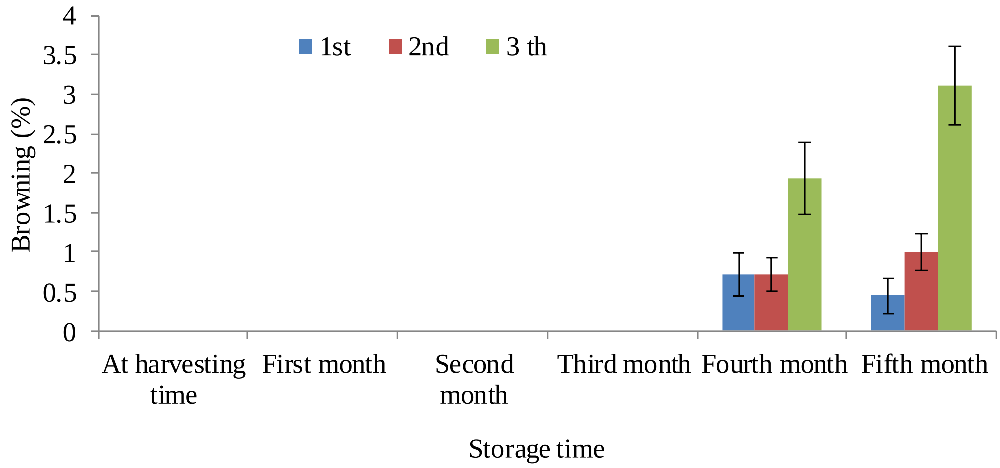

Fig. 3. Effects of storage period and harvesting time on browning percentage.

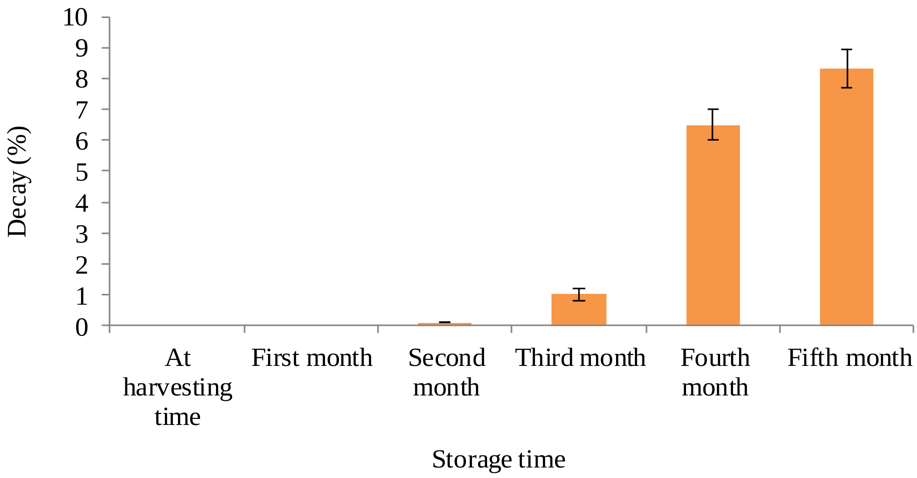

Fig. 4. Effects of storage period on decay percentage.

Firmness and total phenols

According to Table 3, the highest fruit firmness was at harvesting time. The highest firmness belonged to 'Behta' at the first and second harvesting time as well as one-month storage after the first harvest with averages of 4.95, 4.87, and 4.69 kg/cm^2, respectively. The lowest fruit firmness was related to 'Isfahan' and NB4 in the third harvest and after five months of storage (2.1 kg/cm^2). In general, delay in harvest and longer storage reduced the fruit firmness. Fruit firmness in the second year was significantly higher than the first year (Table 4).

Most of the total phenol content belonged to 'Isfahan'. The total phenol content in this cultivar at the second and third harvest was 103.32 and 101.64 mg/100g, respectively. The lowest total phenol belonged to 'Behta' in the first harvest and after five months of storage with an average of 2.68 mg/100gFW (Table 3).

The highest and lowest TA was observed in the first harvest of NB4 genotype (0.81%) and the third harvest of 'Isfahan' (0.38%), respectively. 'Behta' had a moderate level of TA in all harvests compared to 'Isfahan' and NB4. In the studied two cultivars and one genotype, the amount of TA decreased with prolonged harvesting time (Fig. 1). The value of this trait in 2019 was more than in 2018 (Table 4).

The effect of cultivar and storage period on TA is shown in Figure 2. In all studied genetic material, TA decreased with increasing storage period. In all storage periods, NB4 and 'Isfahan' had the highest and the lowest TA, respectively and 'Behta' was in the middle.

Surface browning was affected by harvesting time and storage period (Fig. 3). No surface browning was observed until three months after storage. The amount of this trait started from the fourth month of storage. Harvested fruits in the first and second harvest and after the fourth and fifth months of storage did not have a significant difference in the percentage of fruit browning, but in the third harvest, the percentage of surface browning in fruits with 5 months storage was more than the amount of this trait in fruits with 4 months storage.

The effect of storage period on the percentage of fruit decay (Fig. 4) showed that for two months after storage, no decay was observed in the fruits. From the third month, decay occurred and reached its maximum in the fifth month.

DISCUSSION

Weight loss

Water loss during storage resulting in weight reduction that had a negative effect on fruit appearance (Pasquariello et al., 2013). In this research, weight loss increased with prolonged storage period and harvesting times. In agreement with the present study, other studies have also indicated an increase in water loss and a decrease in fruit weight with increasing shelf life. For example, with increasing cold storage period, fruit weight loss increased in 'Gorton' quince cultivar (Gunes, 2008). Also, the fruit weight loss of 'Esme' quince cultivar after six months of storage in the first, second and third harvest was 9%, 10.5%, and 11.5%, respectively (Kuzucu & Sakaldas, 2008). The rate of weight loss was different among studied genetic materials in this research (Table 3). Burdon and Klark (2001) stated that the difference in weight loss between different cultivars was due to differences in fruit storage conditions, the fruit minerals, and the ratio of fruit surface to fruit volume.

TSS and taste index

The soluble sugars (sucrose, fructose, and glucose) contents resulting from the hydrolysis of starch during ripening, are determined by evaluation of concentration of total soluble solids (Etienne et al., 2013). In general, the third harvest and longer storage increased TSS (Table 3). Similarly, Arzani and Mousavi (2008) showed that Asian pears had high levels of sucrose at harvest, which after storage, sucrose was converted to simpler sugars, and the percentage of TSS increased. It has been reported that the increase in TSS during storage is not only related to the accumulation of sugar but also the increase and decrease of other substances such as acids, soluble pectins, and phenolic compounds (Amodio et al., 2007). The quality characteristics of the fruit after harvest and during storage changes that are effectively affected by the cultivar (Moradi et al., 2017). In this study, TSS was significantly different among 'Behta', 'Isfahan', and NB4. Gorji Chakespari et al. (2010) also reported significant differences in TSS between 'Shafiabadi' and 'Golab Kohanz' apple cultivars (11.1% and 8.75%, respectively). The difference in TSS between these two apple cultivars was due to genetic differences and the effect of environmental conditions in which these cultivars grew. In the present study, the differences among 'Behta', 'Isfahan', and NB4 in addition to genetic differences can be due to the different origins of these plants. In another study, TSS in 'Isfahan' cultivar in the last harvest and after five months of storage was 16.20% and at the first harvesting time was 14.75%, which is less than the values reported in the present study (Mosharraf & Ghasemi, 2004). Deficiency of water resources in recent years in Isfahan, Iran, which leads to an increase in the concentration of cell sap in tissues, can be the reason for the higher values of TSS in the current study.

In the genetic materials of this research, increasing the storage period and prolonging the harvesting time led to an increase in the taste index (Table 3). In another study, quality index and taste index increased with prolonging apples fruit storage (Ahmad et al., 2021).

Firmness and total phenols

Delay in harvesting time and prolonged storage reduced the fruit firmness (Table 3). Similarly, in the 'Yali' pear, the fruit firmness decreased during storage (Chen et al., 2006). In the 'Esme' quince, the fruit firmness in the third harvest decreased rapidly and after six months of storage reached 3 kg/cm^2. The highest firmness was observed in the first harvest, which was 12.5 kg/cm^2 (Kuzucu & Sakaldas, 2008). Fruit firmness depends on the structure and composition of the cell wall (Valero & Serrno, 2010). The fruit ripening and senescence leads to the dissolution of the middle septum and the loss of cell wall cohesion. The activity of hydrolyzing enzymes increases and the firmness of the fruit tissue reduces. Under these conditions, the susceptibility of the fruit to postharvest disorders depends on the degree of fruit maturity at harvesting time (Raese & Drake, 2000). On the other hand, the property of sucrose polysaccharides also causes firmness. During cold storage, climacteric fruits continue to ripen, and extensive changes are made by enzymes in the cell wall polysaccharides, and sucrose is converted to simpler sugars. Thus, with the ripening of the fruit, the amount of sucrose and firmness of the fruit is reduced (Jan & Rab, 2012). As mentioned, the studied fruits in this research had different firmness (Table 3). In other studies, differences in fruit firmness of apple cultivars have been reported. For example, the fruit tissue of 'Red Delicious' was much firmer than that of 'Golden Delicious'. The firmness of 'Gol Shahi' was higher than 'Red Delicious', 'Golden Delicious' and 'Abbasi' in the Khorasan region, Iran (Hoseini Farahi et al., 2008). The effect of harvesting time on fruit firmness after storage has also been reported by Konopacka and Plocharski (2002).

According to Table 3, the lowest total phenol was observed in the third harvest after five months of storage. Other researchers have shown that total phenol levels gradually decreased with the long-term storage of fruits (Gorji Chakespari et al., 2010; Castro-Lopez et al., 2016). The amount of phenol in fruits and vegetables after harvest can be reduced or increased, which depends on the harvesting time and storage conditions (Kalt, 2005). Phenylalanine aminolysis is one of the main enzymes in the production of phenolic compounds so that an increase or decrease in the activity of this enzyme can be associated with an increase or decrease in phenolic compounds (Lemoine et al., 2007).

TA, browning, and decay

With the prolongation of the harvesting time and storage period, TA decreased (Fig. 1 and 2). A large volume of fruit at the beginning of fruit development belongs to organic acids, so fruits have a high pH before ripening due to the presence of organic acids. With the fruit ripening, most of the organic acids are broken down or converted into other organic acids or sugars and increase the sweetness of the fruit (Hudina & Stampar, 2004). In the present study, there was no significant difference among the fruit of 'Behta', 'Isfahan' and NB4 in TA, but other researchers have reported differences in TA among different cultivars (Gorji Chakespari et al., 2010; Mosharaf & Ghasemi, 2004).

In this study, surface browning was affected by harvesting and storage period (Fig. 3). Browning started in the fourth month of storage and increased in the fifth month. Contrary to the findings of this study, in the studied quince collection by Abdollahi (2012), surface browning was observed in some fruits after two months of storage. According to his report, 20 to 30% of the fruits after a few months turned brown. Surface browning in the third harvest of 'Esme' quince cultivar was higher than the previous harvests and eventually reached 70% (Kuzucu & Sakaldas, 2008). Arzani and Mousavi (2008) reported that increased levels of sugars and organic acids delay fruit browning. Therefore, higher TSS in the fruit of genetic materials can delay browning in this study.

The results of the present study did not show any difference in the percentage of browning among the fruit of 'Behta', 'Isfahan' and NB4, but in the studied cultivars and genotypes by Abdollahi (2012), there were significant differences in the rate and severity of browning in storage. So that SVS1 and SVS2 quince genotypes from Isfahan showed great sensitivity to browning. It seems that the significant difference in the results is due to differences in studied genetic materials in the present study compared to 40 cultivars and genotypes studied by Abdollahi (2012) as well as differences in the status of mother trees and storage conditions.

The effect of storage period on the decay percentage (Fig. 4) showed that decay occurred from the third month and reached its highest rate in the fifth month. Evaluation of quince genotypes in different parts of Iran showed that produced fruits in wetter regions have more fruit decay, while produced quince fruits in drier areas have smoother skin and are more marketable. This indicates that the quince tree is more compatible with lowland areas with semi-arid climates (Abdollahi, 2012).

More heat and less humidity in 2019 than in 2018 led to the production of smaller fruit and less fruit water content in the second year. Decreasing fruit water content in 2019 caused less weight loss and firmer fruit this year. An increase in the concentration of cell sap in tissues in the second year can be the reason for the higher values of TSS and taste index in 2019 (Table 4).

According to the mentioned results and the study of TSS, TA and other traits of 'Behta', 'Isfahan' and NB4 as well as considering that the number of days after full bloom is an important indicator to determine the fruit ripening, the best harvesting time for 'Isfahan', 'Behta' and NB4 is the third harvest (21^{th} October). In this study, 193 days after full bloom is the best time to harvest for 'Isfahan', 'Behta', and NB4. Flowering time may change every year depending on environmental conditions, especially temperature, but the period of fruit growth (number of days from full bloom to ripening) is almost constant for each cultivar. Other researchers have used the number of days after full bloom for the determination of harvesting time of different quince cultivars in different areas. For example, Gunes (2008) reported that the appropriate harvesting time for 'Gorton' in Mashhad, Iran was 191 days after the full bloom stage. Mosharraf and Ghasemi (2004) also reported the best harvesting time for 'Isfahan' was 180 days after flowering and the most desirable period for storage of this cultivar was five months after storage.

Although all studied fruits with prolonged storage showed a higher taste index, in the last month of storage, they were soft and had an undesirable taste due to storage. So, storing these fruits is not recommended for more than four months. In this time antioxidant properties and total phenolic content will reduce as well as surface browning and decay will increase.

CONCLUSION

According to the results, the best harvesting time for 'Isfahan', 'Behta', and NB4 was 193 days after full bloom. Cold storage for four months is advisable for these fruits.

Conflict of interest

The author has no conflict of interest to report.

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