Shelf life and biochemical changes of ready-to-eat arils among nineteen Iranian pomegranate cultivars (*Punica granatum* L.) during storage

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Revised: 22 January 2019 / Accepted: 29 January 2019 / Published online: 13 February 2019
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Abstract The objective of this study was to investigate the shelf life of arils and the changes in their biochemical compounds in nineteen Iranian pomegranate cultivars during storage. Fruits were harvested when commercially mature and the arils were removed, packaged and stored at 5 ± 1 °C, at 85–90% relative humidity in a cold room. Samples of the stored arils were examined for biochemical features in temporal checkpoints throughout a storage period that lasted for 35 days. By using the onset of decay as an index, the shelf life of arils varied among cultivars, ranging from 7 days to approximately 21 days. Considering the quality attributes of ready-to-eat arils at the beginning of the experiment, substantial variations were observed among the cultivars with regard to their titratable acidity (0.50–8.47%), total soluble solids (13–18.66 °Brix), DPPH radical scavenging activity (63–87.44%), Gallic-acid-equivalent (2.64–6.95 mg/ml) and ascorbic acid (12.21–75.09 mg/l). In general, the decay of arils gradually increased during storage, but several cultivars—which exhibited a very slow process of decay—contained the highest content of titratable acidity, Gallic-acid-equivalent and total soluble solids (since the signs of decay appeared on around the twenty-first day of storage). In addition, titratable acidity increased slightly by the end of storage, whereas the ascorbic acid content, total soluble solids and Gallic-acid-equivalent were cultivar-dependent

and did not show consistent patterns of change during storage.

Keywords Storage · Aril · Shelf life · Minimal processing

Introduction

The pomegranate is native to Iran, where it was first cultivated in around 2000 B.C. (Levin 1994). It is presently cultivated throughout the world in subtropical and tropical areas such as in India, Turkey, Iran, Spain and China (Holland et al. 2009). Iran is also the world's largest producer, with 600,000 tons of pomegranate fruit produced annually on approximately 65,000 ha of land, while 10% of its pomegranate is exported (Holland and Bar-Ya'akov 2008). The medicinal properties of pomegranate fruits can be found in their peels (Singh et al. 2018b) and arils which suggest that it has the potential to be processed into value-added products with extended shelf lives (Dhinesh and Ramasamy 2016). The pomegranate fruit can be processed into products, including minimally-processed fresh arils and juice. Arils comprise approximately 60% of the total fruit weight. They consist of 80% juice and 20% seeds, while the juice contains approximately 80–85% water and 10% total soluble solids (Shwartz et al. 2009). The hard suture (peel) of pomegranate fruits often makes it unpopular as a table fruit, thereby limiting its consumption as a fresh fruit. In recent years, minimally-processed or ready-to-eat pomegranate arils have become popular due to their ease of consumption, healthiness and desirable sensory characteristics, compared to the whole fruit which is associated with difficulties in taking out the arils manually (Caleb et al. 2013). However, preserving the nutritional and microbial quality of pomegranate arils is a challenge

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because minimally-processed arils can deteriorate easily and lose their appearance, color or texture (Gil et al. 1996). This problem is often exacerbated by the increase in respiration rates, along with elevated levels of ethylene production, active metabolic processes, endogenous enzymatic activity and increased microbial capacity (Leistner and Gould 2012). The major problem of storing the pomegranate is that the fruit gradually loses its water content. This usually leads to the browning of the fruit, the loss of its natural form and the deterioration of its arils (Mirdehghan et al. 2006). Additional disorders can include physiological deterioration, changes in aril color, loss of firmness, and the decrease in vitamin C and acidity. These tend to minimize the consumer's acceptance of the fruit, with respect to juiciness, freshness, and taste. Moreover, decay is another main cause of losses during the postharvest period, even under recommended conditions of storage at 5–8 °C (Roy and Waskar 1997). Ergun (2012) reported that pomegranate arils share a similarity with the whole fruit in that they have a relatively low rate of respiration and ethylene production. It has been noted that minimally-processed pomegranate fruits may be stored for up to 14 days at 7 °C without a substantial loss of quality (DeFilippi et al. 2006). Tehranifar et al. (2010) reported that the biochemical properties of pomegranate fruit are highly dependent on the cultivar and the horticultural practices. Moreover, Caleb et al. (2013) showed that the volatile compounds of pomegranate arils could be cultivar-dependent and the aroma of packaged pomegranate arils could be lost sooner than the expiry of their postharvest shelf life. The diverse and valuable genetic resources of Iranian pomegranates include wild, semi-wild and commercial types which offer opportunities for further selection, based on cultivars with ready-to-eat pomegranate arils that can exhibit longer shelf lives. There is a limited amount of knowledge, within the scientific literature, regarding biochemical characteristics of pomegranate cultivars during long-term storage. The objective of this study was (1) to investigate the shelf life of ready-to-eat arils among 19 pomegranate cultivars in order to select cultivars that have potentials for minimal processing, (2) to find the trend of changes in biochemical attributes during storage, and (3) to illustrate potential correlations between the chemical composition and the shelf life.

Materials and methods

Plant material

The experiment was conducted in the autumn of 2015, at the Agriculture and Natural Resources Research Centre (ANRRC) in Yazd Province, Iran. Nineteen pomegranate

cultivars (i.e. 'Anar Siah', 'Bihaste Ravar', 'Bihaste Sangan Khash', 'Jangali Poost Ghermez Roodbar', 'Khajei Ghasrodasht Fars', 'Malas Pishva Varamin', 'Malas Yazdi', 'Makhmal Malas Shahreza', 'Malas No.1 Saravan', 'Poost Nazok Torosh Abarkuh', 'Poost Sefid Dezful', 'Rabab Poost Ghermez Neyriz', 'Rabab Poost Ghermez Kazeroon', 'Sefid Biardal Borujen', 'Shahsavari Seydan Marvdasht', 'Shirin Jangal Sisangan', 'Shirin Semnan', 'Torosh Goli Naz Behshahr' and 'Torosh Nar Riz Zirab') were used in the study. These cultivars exhibit diverse characteristics of fruit. Two of the cultivars, 'Rabab Poost Ghermez Neyriz' and 'Malas Yazdi', are of high-level commercial value and are cultivated nationally. The rest are of local importance in different provinces across the country, with the exception of 'Torosh Nar Riz Zirab', which is a non-commercial semi-wild type, and was collected from the Darab region to add further diversity to this study. In addition, several important soft-seeded cultivars, i.e. 'Bihaste Khafr Jahrom', 'Bihaste Ravar' and 'Bihaste Sangan Khash' were studied herein. All trees in the experiment received uniform pruning, irrigation and fertilization according to the standard horticultural practices in the region. Fruits were harvested when commercially mature by an experienced horticulturist and were transferred to the pomology laboratory in the Department of Horticultural Sciences, Shiraz University, Shiraz, Iran. Damaged fruits (i.e. with sunburns, cracks, bruises, and cuts in the husk) were discarded, and the remaining fruits which exhibited a healthy outer skin and uniform size were washed with tap water and left to dry. Husks were carefully cut at the equatorial zone with a sharp knife and the arils were manually taken out. The extracted arils were collected in a tray and mixed thoroughly to assure uniformity. After rinsing, the excess water was removed from the surface of arils with a clean paper towel, and the arils were directly placed in rigid polyethylene boxes (15 × 10 × 5 cm) with air tight screw caps. The packaged arils were stored at 5 ± 1 °C and at 85–90% relative humidity for 35 days. For biochemical evaluations, they were sampled on the first, seventh, fourteenth, twenty-first, twenty-eight and thirty-fifth day of storage. Each cultivar comprised 3 replicates, and each box was considered as a replicate. The experiment was completely randomized.

Measurement of decay percentage

Arils were inspected for decay, and the percentage of decay was recorded on the first, seventh, fourteenth, twenty-first, twenty-eight and thirty-fifth day of storage at 5 °C, as described in Kamel et al. (2015). Here, decay is considered as microbial spoilage, observable shrivels and the browning of arils. The decayed arils of each cultivar were separated at each stage. They were weighed and ascribed to the

whole weight of arils in each box. Decay percentage in each stage was calculated using the following equation:

Decay percentage

$$= \left[\frac{\text{Weight of decayed arils at each stage}}{\text{Arils weight at the beginning of the storage}} \right] \times 100$$

Each value represents the average of three samples.

Measurements of total soluble solids and titratable acidity

The arils from each package were juiced manually per cultivar and replication. The juice was directly analysed in order to measure the total soluble solids (TSS) and titratable acidity (TA). TSS was measured using a hand-held refractometer (Atago NI, Japan) and was expressed as °Brix at 20 °C. TA was determined by titrating aliquots of juice samples (5 ml) to an endpoint pH of 8.2 with 0.1 N NaOH and was expressed as citric acid (g 100 ml⁻¹).

Gallic acid equivalent

The amount of Gallic acid in juice samples was determined using the Folin-Ciocalteu (Folin-C) and by the colourimetric method, as described by Singleton and Rossi (1965). The amount of Gallic acid was determined by a spectrophotometer at 750 nm by adding the Folin-Ciocalteu reagent to the juice sample. Results were expressed as the mean value (mg) of Gallic acid equivalents (GAEs) per ml of crude juice.

DPPH radical scavenging

DPPH radical scavenging was assessed in terms of radical DPPH (2, 2-diphenyl-1-picrylhydrazyl) according to Moon and Terao (1998). Briefly, 0.1 ml of pomegranate juice was mixed with 0.9 ml of 100 mM Tris-HCl buffer (pH = 7.4) to which 1 ml of DPPH (500 µM in ethanol) was added. The control sample was prepared in a similar manner by adding 0.1 ml of distilled water instead of pomegranate juice. The mixtures were shaken vigorously and left to stand for 30 min. The absorbance of the resultant solution was measured at 517 nm with a spectrophotometer. The reaction mixture without DPPH was used for background correction. The DPPH radical scavenging was calculated as the inhibition (%) of DPPH by antioxidants existing in the samples using the following equation:

$$\text{Inhibition (\%)} = \left[1 - \frac{A_{\text{sample}}(517\text{nm})}{A_{\text{control}}(517\text{nm})} \right] \times 100$$

where A sample = Absorbance of sample after 30 min, A control = Absorbance of sample at time = 0 min.

Ascorbic acid

Ascorbic acid was determined by a spectrophotometer against a standard curve using 0.0025% 2,6-dichlorophenolindophenol (DCPIP) dye and 1% metaphosphoric acid (Jalilop and Kumar 1990).

Statistical analysis

Analysis of variance (ANOVA) was performed in SAS Ver. 9.1 (SAS Institute 2003). Differences among the mean values were examined for significance at $P < 0.05$ based on Duncan's multiple range test. Correlations between pairs of traits were estimated based on Pearson's correlation coefficient (PROC CORR) in SAS. The results were expressed as mean $\pm$ standard error (SE).

Results and discussion

Total soluble solids

Changes in TSS values of the fresh arils during cold storage (Table 1) differed significantly among cultivars ($P < 0.05$). At harvest (day 0), TSS varied from 13 to 18.66 °Brix in the cultivars. 'Makhmal Malas Shahreza' (18.66 °Brix) had the highest TSS, while the lowest was recorded in 'Shahsavari Seydan Marvdasht' (13 °Brix). TSS values in this study were higher than those reported by Ghasemnezhad et al. (2015) in several Iranian cultivars. After 7 days of storage, the TSS increased in all cultivars except in 'Sefid Biardal Borujen', 'Jangali Poost Ghermez Roodbar' and 'Makhmal Malas Shahreza.' It is likely that the increase in TSS is related to water loss due to high levels of dehydration in the packages of storage (Ghasemnezhad et al. 2015). From the seventh to the twenty-first day of storage, TSS was observed to decrease in all cultivars. This could probably be attributed to the increase in metabolic activities during storage, activities such as the conversion of soluble sugars into organic acids (e.g. citric, malic, oxalic and succinic acid) which are often accelerated by a high concentration of O₂ (Bhatia et al. 2013).

After 35 days of storage, the TSS of arils in several cultivars, i.e. 'Jangali Poost Ghermez Roodbar', 'Makhmal Malas Shahreza', 'Malas No. 1 Saravan' and 'Poost Nazok Torosh Abarkuh', became slightly higher than the TSS in other cultivars. Our results showed a wide range of TSS values within the Iranian pomegranate germplasm. This genetic diversity could be utilized for breeding programs since the changes in TSS values during storage appeared to be cultivar-dependent.

Table 1 Changes in the total soluble solid (°Brix) of arils in 19 pomegranate cultivars at harvest and following storage

Cultivars	Storage (days)					
	0	7	14	21	28	35
Anar Siah	13 ± 0.28 ^{hi}	17 ± 0.01 ^{efg}	17 ± 0.11 ^{de}	13.66 ± 0.33 ^{fgh}	14.9 ± 0.03 ^d	–
Bihaste Ravar	15 ± 0.01 ^{efgh}	15.2 ± 0.05 ^h	14.4 ± 0.20 ^h	12 ± 0.01 ⁱ	–	–
Bihaste Sangan Khash	14 ± 0.57 ^{ghi}	15.23 ± 0.23 ^h	14.66 ± 0.35 ^{gh}	12 ± 0.57 ⁱ	–	–
Jangali Poost Ghermez Roodbar	18.33 ± 0.33 ^{ab}	18.66 ± 0.33 ^{abc}	18.55 ± 0.37 ^{ab}	16.66 ± 0.66 ^{bc}	17.76 ± 0.23 ^a	18.43 ± 0.29 ^a
Khajei Ghasrodasht Fars	14.66 ± 0.33 ^{fghi}	17.66 ± 0.88 ^{cdef}	17.66 ± 0.57 ^{bcd}	15.33 ± 0.66 ^{cde}	–	–
Malas Pishva Varamin	15.66 ± 0.66 ^{cdefg}	16.33 ± 0.33 ^{gh}	16.06 ± 0.46 ^{ef}	–	–	–
Malas Yazdi	16 ± 0.57 ^{cdef}	18.66 ± 0.29 ^{abc}	18.33 ± 0.56 ^{abc}	15.33 ± 0.33 ^{cde}	–	–
Makhmal Malas Shahreza	18.66 ± 0.66 ^a	18.33 ± 0.56 ^{abc}	17.33 ± 0.33 ^{cd}	15 ± 0.57 ^{def}	17.53 ± 0.33 ^{ab}	17.13 ± 0.12 ^b
Malas No. 1 Saravan	15.33 ± 0.33 ^{defg}	18.83 ± 0.24 ^{abc}	18.5 ± 0.25 ^{abc}	17 ± 0.01 ^{ab}	17.20 ± 0.11 ^b	12.40 ± 1.4 ^d
Poost Nazok Torosh Abarkuh	15.50 ± 0.28 ^{cdefg}	19.33 ± 0.35 ^a	19.33 ± 0.88 ^a	18.33 ± 0.33 ^a	17.66 ± 0.25 ^{ab}	14 ± 0.54 ^c
Poost Sefid Dezfoul	16.50 ± 0.76 ^{cde}	18 ± 0.57 ^{bcd}	17.8 ± 0.61 ^{bcd}	16.66 ± 0.33 ^{bc}	–	–
Rabab Poost Ghermez Neyriz	14.66 ± 0.33 ^{fghi}	17.66 ± 0.24 ^{cdef}	16.13 ± 0.06 ^{ef}	12.66 ± 0.66 ^{hi}	–	–
Rabab Poost Ghermez Kazeroon	15.66 ± 0.33 ^{cdefg}	18.86 ± 0.06 ^{abc}	18.66 ± 0.24 ^{ab}	14.33 ± 0.33 ^{efg}	–	–
Sefid Biardal Borujen	18.66 ± 0.66 ^a	19 ± 0.01 ^{ab}	18.23 ± 0.03 ^{abc}	16.33 ± 0.33 ^{bcd}	–	–
Shirin Jangal Sisangan	15.33 ± 0.33 ^{defg}	16.73 ± 0.26 ^{fg}	16.06 ± 0.06 ^{ef}	13.33 ± 0.88 ^{ghi}	–	–
Shirin Semnan	14 ± 1 ^{ghi}	17.13 ± 0.06 ^{defg}	15.5 ± 0.11 ^{fg}	12.66 ± 0.33 ^{hi}	–	–
Shahsavari Seydan Marvdasht	13 ± 0.57 ⁱ	17.76 ± 0.39 ^{bcd}	15.83 ± 0.27 ^f	–	–	–
Torosh Goli Naz Behshahr	17 ± 0.57 ^{bcd}	18.60 ± 0.30 ^{abc}	17.86 ± 0.33 ^{bcd}	16.33 ± 0.33 ^{bcd}	16.56 ± 0.31 ^c	–
Torosh Nar Riz Zirab	17.16 ± 0.16 ^{abc}	19.4 ± 0.30 ^a	18.73 ± 0.29 ^{ab}	17.33 ± 0.33 ^{ab}	16.20 ± 0.05 ^c	–

The changes were measured at 7-day intervals for 35 days at 5 °C

Similar letters in each column indicate non-significant differences at $P \leq 0.05$

Titrateable acidity

The results of TA values showed significant differences among the arils of cultivars. These differences were recorded immediately after harvest, through the storage period and at the end of storage (Table 2). The highest and lowest TA values in the arils were observed in ‘Torosh Nar Riz Zirab’ on day 0 (8.47%) and in ‘Bihaste Sangan Khash’ (0.50%), respectively (Table 2). Regarding the changes in TA values of arils during storage, the TA content increased until the end of the storage period, at which time the ‘Torosh Nar Riz Zirab’ had acquired the highest TA value (8.6%) among other cultivars. As mentioned previously, ‘Torosh Nar Riz Zirab’ is a non-commercial, semi-wild pomegranate which is famous for its strong sour taste. Our results are in line with Ghasemnezhad et al. (2015) who reported an increase in the TA of Iranian pomegranate arils under cold storage. It has been suggested that TA and organic acids provide the carbon skeletons for the synthesis of secondary metabolites during storage (Mazza and Miniati 1993). Also, Kannan and Susheela (2002) recently studied the storage behaviour of guava after osmotic dehydration, and reported that the acidity increased in all samples during storage. Acidity is one of the main features

among commercial cultivars which can largely determine the taste and, ultimately, the consumer’s acceptance of pomegranates. Variations in the TA values among such genotypes can provide potentials for breeding new cultivars and fruits of varied tastes.

Radical scavenging activity

The type of cultivar and the duration of storage influenced the radical scavenging activity (RSA) of arils. The RSA ranged from 63% (‘Poost Sefid Dezfoul’) to 87.44% (‘Malas No.1 Saravan’) on the first day of storage. It increased in most cultivars from day 0 to 7, except in ‘Shirin Jangal Sisangan’, ‘Sefid Biardal Borujen’, ‘Rabab Poost Ghermez Kazeroon’, ‘Malas No. 1 Saravan’, ‘Makhmal Malas Shahreza’ and ‘Malas Yazdi’ (Table 3). Similarly, Bhatia et al. (2015) reported that minimally-processed pomegranate arils and juice display an increase in their antioxidant activity until the ninth day of storage. They also suggested that higher levels of antioxidant activity could be a biochemical response to the wounds on fruits during minimal-processing. On the other hand, the DPPH radical scavenging of juice in pomegranate arils of several cultivars (‘Bihaste Sangan Khash’, ‘Jangali Poost

Table 2 Changes in the titratable acidity (%) of arils in 19 pomegranate cultivars at harvest and following storage

Cultivars	Storage (days)					
	0	7	14	21	28	35
Anar Siah	0.7 ± 0.02 ^{hi}	0.93 ± 0.07 ^{hiavb}	1.22 ± 0.07 ^h	1.55 ± 0.02 ^g	2.2 ± 0.39 ^d	–
Bihaste Ravar	0.55 ± 0.02 ⁱ	0.96 ± 0.09 ^{ghi}	1.09 ± 0.10 ^h	1.65 ± 0.1 ^g	–	–
Bihaste Sangan Khash	0.50 ± 0.01 ⁱ	1.38 ± 0.46 ^{ghi}	1.35 ± 0.15 ^{gh}	2 ± 0.06 ^{fg}	–	–
Jangali Poost Ghermez Roodbar	2.17 ± 0.18 ^{ef}	2.23 ± 0.27 ^{ef}	3.78 ± 0.28 ^{cde}	2.60 ± 0.19 ^{ef}	4.4 ± 0.05 ^c	3.63 ± 0.28 ^c
Khajei Ghasrodasht Fars	2.51 ± 0.13 ^{def}	2.77 ± 0.14 ^e	3.45 ± 0.17 ^{def}	3.20 ± 0.27 ^c	–	–
Malas Pishva Varamin	1.41 ± 0.01 ^{ghi}	1.77 ± 0.02 ^{gf}	2.50 ± 0.03 ^{efgh}	–	–	–
Malas Yazdi	1.85 ± 0.13 ^{gh}	1.03 ± 0.08 ^{ghi}	2.25 ± 0.39 ^{efgh}	1.92 ± 0.35 ^{gf}	–	–
Makhmal Malas Shahreza	0.64 ± 0.04 ^{hi}	1.34 ± 0.06 ^{ghi}	1.46 ± 0.20 ^{gh}	1.55 ± 0.05 ^g	4.19 ± 0.10 ^c	3.48 ± 0.44 ^c
Malas No. 1 Saravan	3.3 ± 0.68 ^{cd}	4.67 ± 0.33 ^{cd}	4.55 ± 0.17 ^{bcd}	4.30 ± 0.32 ^d	4.02 ± 0.11 ^c	–
Poost Nazok Torosh Abarkuh	2.80 ± 0.47 ^{de}	4 ± 0.22 ^d	3.80 ± 0.05 ^{cde}	3.95 ± 0.27 ^d	4.29 ± 0.14 ^c	4.5 ± 0.28 ^b
Poost Sefid Dezfoul	0.88 ± 0.19 ^{hi}	1.54 ± 0.18 ^{fghi}	2.75 ± 0.14 ^{efgh}	2.12 ± 0.06 ^{fg}	–	–
Rabab Poost Ghermez Neyriz	2.57 ± 0.26 ^{def}	2.92 ± 0.53 ^e	3.15 ± 0.34 ^{defg}	3.20 ± 0.27 ^c	–	–
Rabab Poost Ghermez Kazeroon	1.55 ± 0.18 ^{gh}	1.76 ± 0.05 ^{fgh}	2.67 ± 0.35 ^{efgh}	3.05 ± 0.1 ^e	–	–
Sefid Biardal Borujen	3.97 ± 0.55 ^c	4.98 ± 0.47 ^c	5.75 ± 0.01 ^b	5.12 ± 0.15 ^c	–	–
Shirin Jangal Sisangan	1.35 ± 0.25 ^{ghi}	1.49 ± 0.04 ^{fghi}	2.04 ± 0.11 ^{efgh}	2.21 ± 0.10 ^{fg}	–	–
Shirin Semnan	0.7 ± 0.03 ^{hi}	1.23 ± 0.15 ^{ghi}	1.22 ± 0.04 ^h	1.65 ± 0.04 ^g	–	–
Shahsavari Seydan Marvdasht	0.6 ± 0.01 ⁱ	0.9 ± 0.11 ⁱ	1.70 ± 0.1 ^{fgh}	–	–	–
Torosh Goli Naz Behshahr	5.47 ± 0.49 ^b	7.83 ± 0.22 ^a	9.12 ± 2.09 ^a	6.2 ± 0.2 ^b	7.86 ± 0.39 ^b	–
Torosh Nar Riz Zirab	8.47 ± 0.04 ^a	6.80 ± 0.11 ^b	5.19 ± 0.70 ^{bc}	7 ± 0.66 ^a	8.49 ± 0.30 ^a	8.6 ± 0.01 ^a

The changes were measured at 7-day intervals for 35 days at 5 °C

Similar letters in each column indicate non-significant differences at $P \leq 0.05$

Ghermez Roodbar', 'Malas Yazdi', 'Poost Nazok Torosh Abarkuh' and 'Poost Sefid Dezfoul') increased until the fourteenth day of storage. Then, from day 14 to day 21 of the storage, an incremental trend was observed in the DPPH radical scavenging activity inside the arils of 'Bihaste Ravar', 'Bihaste Sangan Khash', 'Khajei Ghasrodasht Fars', 'Sefid Biardal Borujen', 'Torosh Goli Naz Behshahr' and 'Torosh Nar Riz Zirab'. On the other hand, the DPPH radical scavenging in other cultivars decreased during this period. These results are in agreement with those reported by Ayhan and Eştürk (2009) where the total antioxidant activity in packaged, fresh pomegranate arils increased until the ninth day of storage, but then decreased. The researchers also reported that the exposure of packaged pomegranate arils to an enriched O₂ atmosphere causes their antioxidants to increase until the fifteenth day of storage, and thereafter the antioxidants decrease. In the current study, radical scavenging activity decreased through the period from day 21 to day 28 of the storage, but then again increased through the period from day 28 to day 35 of storage. The decrease in antioxidant capacity, as a result of prolonged aril storage, occurs because O₂ promotes the oxidation of constitutive phenolic compounds (Bhatia et al. 2015). Generally, the DPPH radical

scavenging activity was quite high in almost all of the studied pomegranate cultivars. The changes in RSA through storage were cultivar-dependent.

Gallic acid equivalent

By comparing the conditions at the time of harvest and storage, the Gallic acid equivalent in the arils of the pomegranate cultivars showed significant differences, except on day 35 of the storage (Table 4). The initial GAE ranged from 2.64 mg/ml (in 'Shahsavari Seydan Marvdasht') to 6.95 mg/ml (in 'Sefid Biardal Borujen') (Table 4). In this context, Tehranifar et al. (2010) reported that total phenolic contents in some Iranian pomegranate cultivars range between 295.79 mg/100 ml and 985.37 mg/100 ml in their juice. However, Ghasemnezhad et al. (2015) observed that the Gallic acid equivalent can range between 568.9 and 713.1 mg/100gFW. A rich variety of phenolic compounds (as sources of natural antioxidants) are present in pomegranate peels and arils. These have attracted the attention of many researchers and practitioners in the field of medicine (Singh et al. 2018b). In most fruits, the level of phenolic accumulation depends on the cultivar, the degree of maturity, and environmental factors.

Table 3 Changes in the DPPH radical scavenging (% DPPHsc) of arils in pomegranate cultivars at harvest time and following storage

Cultivars	Storage (days)					
	0	7	14	21	28	35
Anar Siah	74.69 ± 0.67 ^{de}	83.70 ± 0.56 ^{ab}	80.75 ± 1.59 ^{abc}	79.74 ± 1.17 ^{de}	54.22 ± 2.69 ^{bc}	–
Bihaste Ravar	81.78 ± 0.23 ^{abcd}	81.21 ± 0.87 ^{ab}	50.08 ± 4.60 ^{bc}	81.48 ± 0.29 ^{bcde}	–	–
Bihaste Sangan Khash	80.43 ± 0.62 ^{abcd}	82.77 ± 0.79 ^{ab}	85.68 ± 0.79 ^{abc}	86.44 ± 0.37 ^{abc}	–	–
Jangali Poost Ghermez Roodbar	79.22 ± 1.97 ^{bcd}	80.64 ± 2.58 ^{ab}	82.29 ± 2.45 ^{abc}	79.44 ± 5.01 ^{de}	58.75 ± 0.69 ^{ab}	70.92 ± 0.74 ^b
Khajei Ghasrodasht Fars	81.41 ± 2.54 ^{abcd}	88.03 ± 1.02 ^a	80.66 ± 1.55 ^{abc}	84.34 ± 0.57 ^{abcd}	–	–
Malas Pishva Varamin	85.78 ± 1.43 ^{ab}	87.74 ± 0.68 ^a	79.18 ± 3.33 ^c	–	–	–
Malas Yazdi	82.76 ± 1.16 ^{abc}	82.40 ± 1.83 ^{ab}	85.06 ± 2.18 ^{abc}	84.25 ± 2.65 ^{abcd}	–	–
Makhmal Malas Shahreza	83.59 ± 1.35 ^{abc}	81.34 ± 1.86 ^{ab}	82.71 ± 2.39 ^{abc}	79.37 ± 0.48 ^{de}	59.64 ± 0.75 ^a	79.77 ± 1.66 ^a
Malas No. 1 Saravan	87.44 ± 0.96 ^a	79.32 ± 3.41 ^b	87.07 ± 0.88 ^a	78.91 ± 0.72 ^{de}	61.35 ± 1.44 ^a	73.14 ± 1.25 ^{ab}
Poost Nazok Torosh Abarkuh	81.14 ± 0.39 ^{abc}	81.15 ± 0.26 ^{ab}	86.58 ± 0.85 ^{ab}	79.60 ± 0.61 ^{de}	62.35 ± 0.23 ^a	71.49 ± 2.69 ^b
Poost Sefid Dezfoul	63 ± 6.63 ^f	79.80 ± 4.10 ^b	83.66 ± 1.99 ^{abc}	80.60 ± 0.43 ^{cde}	–	–
Rabab Poost Ghermez Neyriz	81.44 ± 3.78 ^{abcd}	86.32 ± 0.44 ^{ab}	86.11 ± 0.18 ^{ab}	76.92 ± 3.48 ^e	–	–
Rabab Poost Ghermez Kazeroon	81.59 ± 2.65 ^{abcd}	81.16 ± 3.55 ^{ab}	85.85 ± 1.28 ^{abc}	80.86 ± 0.45 ^{cde}	–	–
Sefid Biardal Borujen	86.68 ± 1.08 ^{ab}	80.26 ± 0.48 ^{ab}	86.27 ± 1.88 ^{ab}	88.58 ± 1.85 ^a	–	–
Shirin Jangal Sisangan	83.22 ± 0.55 ^{abc}	81.28 ± 4.93 ^{ab}	86.69 ± 1.42 ^{ab}	84.34 ± 2.65 ^{abcd}	–	–
Shirin Semnan	80.54 ± 0.32 ^{abcd}	85.69 ± 0.09 ^{ab}	–	–	–	–
Shahsavari Seydan Marvdasht	77.64 ± 1.87 ^{cd}	81.58 ± 0.59 ^{ab}	81.97 ± 0.58 ^{abc}	–	–	–
Torosh Goli Naz Behshahr	83.93 ± 1.53 ^{abc}	84.11 ± 2.79 ^{ab}	83.93 ± 2.11 ^{abc}	86.46 ± 1.72 ^{abc}	51.40 ± 0.90 ^c	–
Torosh Nar Riz Zirab	68.85 ± 3.43 ^{ef}	85.06 ± 2.33 ^{ab}	83.40 ± 2.11 ^{abc}	87.45 ± 1.72 ^{ab}	53.19 ± 0.90 ^c	70.93 ± 0.25 ^b

The changes were measured at 7-day intervals for 35 days at 5 °C

Similar letters in each column indicate non-significant differences at $P \leq 0.05$

Moreover, Singh et al. (2018b) reported that the total phenolic compound usually varies among pomegranate cultivars depending on their geographical locations and the fruit peel colour. In the current study, GAE increased significantly from the first day until the fourteenth day after storage in all cultivars. However, different cultivars did not show similar accumulation rates. For example, the Gallic acid equivalent in ‘Torosh Goli Naz Behshahr’ became three times higher than in other cultivars. Thus, different rates of transformation during storage could be expected depending on the cultivar, along with an occasional predominance of phenolic synthesis and degradation (Reyes et al. 2007). In this study, the GAE increased through time. This was observed from the fourteenth to the twenty-first day of storage, except in ‘Jangali Poost Ghermez Roodbar’, ‘Poost Nazok Torosh Abarkuh’, ‘Torosh Goli Naz Behshahr’ and ‘Torosh Nar Riz Zirab’. After 28 days of storage, the highest GAE was recorded in ‘Torosh Goli Naz Behshahr’ (15.87 mg/ml), while other cultivars were not significantly different when comparing their mean GAE values. After 35 days of storage, the GAE in the remaining cultivars did not display significant differences ($P = 0.54$). The variations in GAE during storage were probably due to the changes in TA and TSS contents, which also affected

the total anthocyanin content and total antioxidant activity (Ayhan and Eştürk 2009). These results are in agreement with those reported by Zahran et al. (2015) regarding packaged arils of the ‘Wonderful’ cultivar. The researchers stated that the total phenol content increased through the storage time. However, a decreasing trend in the phenol content of some pomegranate cultivars might be due to the structural breakdown of cells as part of the senescence process during storage. The intensity of this decreasing trend is also cultivar-dependent.

Ascorbic acid content

There were significant differences in the ascorbic acid content of arils among different cultivars. These differences in contents were highlighted by comparisons between their status at the time of harvest and after 7, 14, 21, 28 and 35 days of storage (Table 5). The highest and lowest ascorbic acid contents were observed in ‘Khajei Ghasrodasht Fars’ (75.09 mg/l) and in ‘Rabab Poost Ghermez Neyriz’ (11.90 mg/l), respectively. Sayyari et al. (2010) reported that the ascorbic acid in pomegranate juice can range between 10 and 36 mg 100 g⁻¹. The changes in ascorbic acid content during storage was cultivar-

Table 4 Changes in the Gallic acid equivalent (mg/ml juice) of arils in 19 pomegranate cultivars at harvest time and following storage

Cultivars	Storage (days)					
	0	7	14	21	28	35
Anar Siah	5.57 ± 0.27 ^{abcd}	8.22 ± 0.21 ^c	7.93 ± 0.86 ^{abcd}	8.55 ± 0.37 ^{bcd}	–	–
Bihaste Ravar	3.69 ± 0.55 ^{efg}	5.52 ± 0.06 ^{efgh}	6.19 ± 0.84 ^d	7.27 ± 0.78 ^{de}	–	–
Bihaste Sangan Khash	5.57 ± 0.52 ^{abcd}	3.68 ± 0.23 ^{hi}	8.67 ± 0.44 ^{abc}	9.31 ± 0.37 ^{abc}	–	–
Jangali Poost Ghermez Roodbar	4.68 ± 0.39 ^{cdef}	6.29 ± 0.23 ^{cdefg}	8.09 ± 0.17 ^{abcd}	7.64 ± 0.91 ^{cde}	7.14 ± 0.78 ^b	8.40 ± 0.58 ^a
Khajei Ghasrodasht Fars	3.79 ± 0.14 ^{efg}	6.86 ± 0.33 ^{cdef}	7.33 ± 0.32 ^{cd}	8.10 ± 0.07 ^{bcd}	–	–
Malas Pishva Varamin	3.04 ± 0.26 ^{fg}	4.45 ± 0.33 ^{fhi}	6.25 ± 0.42 ^d	–	–	–
Malas Yazdi	3.98 ± 0.13 ^{defg}	5.91 ± 0.67 ^{defg}	8.56 ± 0.65 ^{abc}	9.68 ± 0.65 ^{ab}	–	–
Makhmal Malas Shahreza	4.59 ± 0.04 ^{def}	6.30 ± 0.38 ^{cdefg}	6.74 ± 0.51 ^{cd}	8.03 ± 0.47 ^{bcd}	6.39 ± 0.40 ^b	7.86 ± 0.56 ^a
Malas No. 1 Saravan	6.29 ± 0.44 ^{abc}	8.01 ± 0.18 ^{cd}	8.07 ± 0.03 ^{abcd}	8.40 ± 0.07 ^{bcd}	6.32 ± 0.75 ^b	–
Poost Nazok Torosh Abarkuh	6.57 ± 0.23 ^{ab}	8.03 ± 0.08 ^{cd}	7.02 ± 0.51 ^{cd}	6.37 ± 0.61 ^e	9.00 ± 0.60 ^b	6.32 ± 0.79 ^a
Poost Sefid Dezfoul	5.29 ± 0.15 ^{bcd}	10.07 ± 0.68 ^b	9.66 ± 0.84 ^a	10.81 ± 0.65 ^a	–	–
Rabab Poost Ghermez Neyriz	4.43 ± 0.53 ^{def}	5.22 ± 0.41 ^{fgh}	7.73 ± 0.19 ^{bcd}	9.31 ± 0.30 ^{abc}	–	–
Rabab Poost Ghermez Kazeroon	4.27 ± 0.27 ^{defg}	6.24 ± 0.21 ^{cdefg}	8.09 ± 0.86 ^{abcd}	8.18 ± 0.37 ^{bcd}	–	–
Sefid Biardal Borujen	6.95 ± 0.60 ^a	7.29 ± 0.47 ^{cdef}	8.25 ± 0.31 ^{abc}	8.76 ± 0.45 ^{bcd}	–	–
Shirin Jangal Sisangan	4.85 ± 0.24 ^{cde}	7.68 ± 0.32 ^{cde}	6.77 ± 0.48 ^{cd}	7.27 ± 0.52 ^{de}	–	–
Shirin Semnan	4.76 ± 0.36 ^{cde}	5.71 ± 0.06 ^{efgh}	6.82 ± 0.73 ^{cd}	7.20 ± 0.69 ^{de}	–	–
Shahsavari Seydan Marvdasht	2.64 ± 0.23 ^g	3.23 ± 0.26 ⁱ	7.45 ± 0.42 ^{cd}	–	–	–
Torosh Goli Naz Behshahr	4.42 ± 0.11 ^{def}	12.02 ± 1.16 ^a	9.63 ± 1.09 ^{ab}	8.76 ± 0.61 ^{bcd}	15.87 ± 0.39 ^a	–
Torosh Nar Riz Zirab	5.30 ± 0.19 ^{bcd}	7.62 ± 0.38 ^{cde}	7.80 ± 0.14 ^{abcd}	6.10 ± 0.19 ^e	7.46 ± 0.78 ^b	8.68 ± 0.58 ^a

The changes were measured at 7-day intervals for 35 days at 5 °C

Similar letters in each column indicate non-significant differences at $P \leq 0.05$

dependent. For example, the ascorbic acid content of ‘Malas Pishva Varamin’ and ‘Rabab Poost Ghermez Neyriz’ increased significantly during storage, whereas it decreased in the cultivars ‘Jangali Poost Ghermez Roodbar’, ‘Khajei Ghasrodasht Fars’, ‘Malas Yazdi’, ‘Makhmal Malas Shahreza’, ‘Poost Sefid Dezfoul’, ‘Sefid Biardal Borujen’, ‘Shahsavari Seydan Marvdasht’, ‘Torosh Goli Naz Behshahr’ and ‘Torosh Nar Riz Zirab’ at the end of the storage period. Our results are in agreement with those by Yassin and Tayel (2009) who reported that the ascorbic acid content of ‘Balady’ pomegranate fruits showed irregular trends of change during cold storage. Moreover, Karav et al. (2015) suggested that reductions in the ascorbic acid content did not completely parallel the changes in total antioxidant capacity, despite the high correlation between these values at the beginning of storage. Silva et al. (2015) showed that the variations in ascorbic acid content have a cubic effect, with a strong tendency to increase from the third to the fifteenth day of storage. Furthermore, they reported a decrease in ascorbic acid content at the end of storage which probably resulted from a decrease in metabolism and the occurrence of fruit senescence, accompanied by an intense loss in fruit freshness and acidity.

Decay percentage

There were significant differences in the decay percentage of arils in different cultivars after 7, 14, 21 and 28 days of storage (Table 6). After 7 days of storage, the arils of some cultivars began to show symptoms of decay, and the highest percentage of decay was observed in the ‘Shahsavari Seydan Marvdasht’ (43.33%). Between the seventh and fourteenth day of storage, the decay percentage increased in all cultivars except in the ‘Jangali Poost Ghermez Roodbar’, ‘Malas Yazdi’, ‘Makhmal Malas Shahreza’, ‘Malas No. 1 Saravan’, ‘Torosh Goli Naz Behshahr’ and ‘Torosh Nar Riz Zirab’ which exhibited no decay during the mentioned time span. The maximum decay percentage was observed in ‘Shahsavari Seydan Marvdasht’ (86.66%).

The decay percentage in all cultivars increased considerably in the interim between the fourteenth to the twenty-first day of storage. At this time, the decay percentage ranged from 3.33 to 100% among cultivars. After 21 days of storage, cultivars such as ‘Malas Pishva Varamin’ and ‘Shahsavari Seydan Marvdasht’ exhibited 100% decay. After 28 days of storage, all cultivars decayed completely, with the exception of ‘Malas No. 1 Saravan’, ‘Makhmal

Table 5 Changes in the ascorbic acid (mg/l) content of arils in pomegranate cultivars at harvest and following storage

Cultivars	Storage (days)					
	0	7	14	21	28	35
Anar Siah	54.36 ± 4.09 ^{cb}	14.93 ± 2.09 ^{efg}	33.72 ± 0.90 ^{bcdef}	67.36 ± 0.92 ^a	–	–
Bihaste Ravar	58.87 ± 8.59 ^b	17.36 ± 1.18 ^{de}	29.48 ± 4.09 ^{efg}	23.72 ± 0.90 ^{fg}	–	–
Bihaste Sangan Khash	57.36 ± 0.91 ^b	15.09 ± 0.45 ^{ef}	29.78 ± 5.24 ^{efg}	58.27 ± 6.63 ^b	–	–
Jangali Poost Ghermez Roodbar	27.66 ± 5.0 ^{de}	32.81 ± 4.54 ^c	24.03 ± 4.03 ^{gh}	49.48 ± 7.73 ^c	13.72 ± 0.90 ^{bc}	8.27 ± 2.72 ^{ab}
Khajei Ghasrodasht Fars	75.09 ± 2.72 ^a	17.66 ± 1.89 ^{de}	32.81 ± 3.27 ^{cdef}	70.09 ± 0.91 ^a	–	–
Malas Pishva Varamin	14.63 ± 0.90 ^f	15.60 ± 1.04 ^{ef}	31 ± 5.45 ^{defg}	–	–	–
Malas Yazdi	73.72 ± 5.45 ^a	22.51 ± 6.05 ^d	34.33 ± 7.62 ^{bcdef}	32.51 ± 6.82 ^{de}	–	–
Makhmal Malas Shahreza	54.49 ± 0.91 ^c	60.39 ± 7.73 ^a	27.66 ± 3.67 ^{fg}	38.57 ± 3.19 ^d	4.93 ± 0.52 ^c	14.93 ± 4.09 ^a
Malas No. 1 Saravan	15.09 ± 1.36 ^f	50.09 ± 3.63 ^b	41.3 ± 3.19 ^b	60.09 ± 1.81 ^b	27.06 ± 2.73 ^a	–
Poost Nazok Torosh Abarkuh	13.12 ± 0.52 ^f	61.60 ± 9.1 ^a	34.93 ± 3.19 ^{bcdef}	53.72 ± 0.91 ^{bc}	14.33 ± 3.67 ^{bc}	4.93 ± 2.28 ^b
Poost Sefid Dezfoul	32.81 ± 4.54 ^d	17.06 ± 2.77 ^{de}	36.75 ± 0.52 ^{bcd}	21.30 ± 1.38 ^g	–	–
Rabab Poost Ghermez Neyriz	11.90 ± 3.63 ^f	15.84 ± 0.52 ^{ef}	23.72 ± 4.35 ^{gh}	35.09 ± 3.18 ^{de}	–	–
Rabab Poost Ghermez Kazeroon	31.90 ± 5.45 ^d	5.84 ± 2.28 ^{hi}	39.48 ± 1.38 ^{bc}	71.0 ± 3.27 ^a	–	–
Sefid Biardal Borujen	70.39 ± 4.29 ^a	6.45 ± 1.57 ^{hi}	4.63 ± 0.90 ^j	13.12 ± 2.28 ^h	–	–
Shirin Jangal Sisangan	12.51 ± 0.52 ^f	6.90 ± 0.45 ^{hi}	28.27 ± 2.40 ^{fg}	31.0 ± 7.76 ^c	–	–
Shirin Semnan	12.21 ± 0.52 ^f	8.87 ± 0.50 ^{gh}	13.72 ± 0.91 ⁱ	–	–	–
Shahsavari Seydan Marvdasht	18.27 ± 5.45 ^{ef}	10.54 ± 1.36 ^{ghf}	17.66 ± 1.38 ^{hi}	–	–	–
Torosh Goli Naz Behshahr	51.0 ± 9.45 ^{bc}	9.48 ± 1.04 ^{ghf}	38.87 ± 1.38 ^{bcd}	28.27 ± 1.81 ^{ef}	10.39 ± 1.38 ^{bc}	–
Torosh Nar Riz Zirab	70.09 ± 17.27 ^a	32.27 ± 0.90 ^c	52.51 ± 4.66 ^a	12.81 ± 1.81 ^h	17.36 ± 2.02 ^{ab}	12.0 ± 2.0 ^{ab}

The changes were measured at 7-day intervals for 35 days at 5 °C

Similar letters in each column indicate non-significant differences at $P \leq 0.05$

Malas Shahreza', 'Jangali Poost Ghermez Roodbar', 'Poost Nazok Torosh Abarkuh', 'Anar Siah', 'Torosh Nar Riz Zirab' and 'Torosh Goli Naz Behshahr'. By the end of storage (35 days), some relatively healthy arils were still observed in some cultivars such as 'Jangali Poost Ghermez Roodbar', 'Makhmal Malas Shahreza', 'Poost Nazok Torosh Abarkuh' and 'Torosh Nar Riz Zirab'.

Food decay and the production of mycotoxins by fungal spoilage cause considerable amounts of economic loss and serious health problems for consumers (Singh et al. 2018a). Decay is a major factor that can limit the long-term storage of pomegranate arils. It is also a major cause of postharvest loss. Such damages could be incurred by pathogens such as *Botrytis cinerea*, *Aspergillus niger*, *Penicillium spp.* and *Alternaria spp.* (D'Aquino et al. 2010). Our results showed that the number of damaged arils increased significantly among all cultivars during the storage period. These results are consistent with those reported by Ghasemnezhad et al. (2015) concerning pomegranate arils. Moreover, the biochemical properties of fruits such as their pH and TA have important effects on the microbial count and the shelf-life of fresh-cut fruits. Ghasemnezhad et al. (2015) suggested that the use of resistant genotypes can be the most concrete approach for the maintenance of quality and the control of

decay in pomegranate arils. Interestingly, the peel extract of pomegranate has shown a broad-spectrum of antimicrobial activity against bacteria and fungi. High levels of polyphenols in the pomegranate peel, particularly punicalagin and ellagic acid, are mostly responsible for antimicrobial properties (Singh et al. 2018a).

In general, cultivars could be divided into three groups, depending on the temporal point at which the symptoms of decay become visible. The first group comprises cultivars which exhibit a long shelf life (in which the decay starts from around the twenty-first day). Ranked by their resistance to decay, these cultivars are 'Malas No. 1 Saravan', 'Jangali Poost Ghermez Roodbar', 'Makhmal Malas Shahreza', 'Poost Nazok Torosh Abarkuh', 'Torosh Nar Riz Zirab' and 'Torosh Goli Naz Behshahr', respectively. The second group is characterized by a moderate shelf life (in which the decay starts from around the fourteenth day). These are 'Bihaste Sangan Khash', 'Bihaste Ravar', 'Anar Siah', 'Poost Sefid Dezfoul', 'Shirin Jangal Sisangan', 'Malas Yazdi', 'Rabab Poost Ghermez Neyriz' and 'Sefid Biardal Borujen', respectively. The third group consists of cultivars with a short shelf life (in which the decay starts from around the seventh day). They are 'Malas Pishva Varamin', 'Shahsavari Seydan Marvdasht', 'Shirin

Table 6 Changes in the decay percentage (cumulative) of arils in 19 pomegranate cultivars at harvest time and following storage

Cultivars	Storage time (days)					
	0	7	14	21	28	35
Anar Siah	0	0	30 ± 8.81 ^{bc}	36.66 ± 5.54 ^g	50 ± 0.01 ^{cb}	100 ^a
Bihaste Ravar	0	0	43.33 ± 6.12 ^b	91.66 ± 1.66 ^{ab}	100 ^a	–
Bihaste Sangan Khash	0	0	40.0 ± 5.77 ^{bc}	100 ^a	–	–
Jangali Poost Ghermez Roodbar	0	0	0	11.66 ± 1.66 ^{hi}	26.66 ± 3.21 ^{ef}	73.3 ± 12 ^b
Khajei Ghasrodasht Fars	0	26.66 ± 3.12 ^b	33.33 ± 6.81 ^{bc}	66.66 ± 3.33 ^{cdef}	100 ^a	–
Malas Pishva Varamin	0	36.6 ± 5.211 ^a	73.33 ± 3.14 ^a	100 ^a	–	–
Malas Yazdi	0	0	26.66 ± 5.52 ^{bcd}	60 ± 10 ^{def}	100 ^a	–
Makhmal Malas Shahreza	0	0	0	16.66 ± 3.33 ^{hi}	36.66 ± 6.66 ^{de}	78.33 ± 4.40 ^b
Malas No. 1 Saravan	0	0	0	3.33 ± 3.52 ⁱ	20.0 ± 0.12 ^f	80.0 ± 5.77 ^b
Poost Nazok Torosh Abarkuh	0	0	1.66 ± 1.66 ^e	23.33 ± 3.24 ^{gh}	40.0 ± 5.77 ^{cd}	80.0 ± 5.57 ^b
Poost Sefid Dezfoul	0	0	10.0 ± 2.81 ^{de}	35.0 ± 0.01 ^g	100 ^a	–
Rabab Poost Ghermez Neyriz	0	0	20.0 ± 5.77 ^{cde}	73.33 ± 12.01 ^{cde}	100 ^a	–
Rabab Poost Ghermez Kazeroon	0	23.33 ± 3.33 ^b	25.0 ± 3.33 ^{bcd}	76.66 ± 0.21 ^{bcd}	100 ^a	–
Sefid Biardal Borujen	0	0	26.66 ± 3.20 ^{bcd}	83.33 ± 3.33 ^{abc}	100 ^a	–
Shirin Jangal Sisangan	0	0	23.33 ± 8.87 ^{cd}	53.33 ± 8.81 ^f	100 ^a	–
Shirin Semnan	0	11.66 ± 1.66 ^c	20.0 ± 5.77 ^{cde}	56.66 ± 8.81 ^{ef}	100 ^a	–
Shahsavari Seydan Marvdasht	0	43.33 ± 3.01 ^a	86.66 ± 6.63 ^a	100 ^a	–	–
Torosh Goli Naz Behshahr	0	0	0	26.6 ± 3.33 ^{gh}	53.33 ± 3.33 ^b	100 ^a
Torosh Nar Riz Zirab	0	0	0	10.0 ± 5.77 ^{hi}	50.0 ± 0.2 ^{bc}	100 ^a

The changes were measured at 7-day intervals for 35 days at 5 °C

Similar letters in each column indicate non-significant differences among cultivars at $P \leq 0.05$

Semnan', 'Rabab Poost Ghermez Kazeroon' and 'Khajei Ghasrodasht Fars'.

So far, the commercial success of ready-to-eat pomegranate arils has been limited, which is primarily due to their short shelf life and their susceptibility to decay. A correct selection of cultivars is very important when processing fresh cut fruits because cultivars can widely differ in terms of their physical traits (e.g. texture and skin-color), biochemical features (e.g. nutritional value and flavour) and browning potential. These differences manifest themselves particularly during storage and postharvest handling (Florkowski et al. 2009). The selection of appropriate cultivars, along with an appropriate level of maturity at harvest, followed by proper storage conditions, can be considered as important factors that determine the shelf life of fresh-cut fruits (Florkowski et al. 2009).

There were positive correlations between the shelf life of arils and the TSS ($r = 0.48$; $P \leq 0.001$), GAE ($r = 0.45$; $P \leq 0.001$) and TA ($r = 0.43$; $P \leq 0.001$) (Fig. 1). Interestingly, cultivars with the highest contents of TA, GAE and TSS had the longest shelf lives during storage. These cultivars are 'Malas No. 1 Saravan', 'Jangali Poost Ghermez Roodbar', 'Makhmal Malas Shahreza', 'Poost Nazok Torosh Abarkuh', 'Torosh Nar Riz Zirab' and 'Torosh Goli

Naz Behshahr'. Pertinent to this context, Kazemi et al. (2011) reported that the TA value is directly related to the content of organic acids in the fruit, which is an important parameter in maintaining the quality of fruits. Haminiuk et al. (2012) reported that phenols have excellent properties as food preservatives, since they contribute to the protection against pathological disturbances. The fruit peel of pomegranate is generally believed to contain phenols.

Conclusion

Based on the initial symptoms of decay observed in the arils following storage, the cultivars in this study could be classified into three categories which indicate that the shelf life of arils are either short, moderate or long. All of the biochemical attributes that were measured in the fresh arils underwent changes during storage. The TA increased slightly in the fruits of all cultivars, while the changes in many other features were cultivar-dependent. These features were the ascorbic acid content, TSS and GAE which did not follow consistent patterns of change. In general, the variations in shelf life and the varied levels of changes in other quality attributes during storage can provide

Fig. 1 Correlations between GAE, TA, TSS and the starting point of decay in the pomegranate arils of 19 cultivars

opportunities for future breeding programs on superior cultivars. Such opportunities can be strengthened by realizing good correlations between shelf life and specific values of the biochemical content. Ultimately, researchers can explore new ways of maintaining the edible quality of ready-to-eat arils and other minimally-processed pomegranate products for longer durations.

Funding This research is funded by Shiraz University (the affiliated institute of the authors) and there is no external funding for this research.

Conflict of interest The authors declare that they have no conflict of interest.

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