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RESEARCH ARTICLE

Effects of harvest date on apple fruit quality at harvesting and after cold storage

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ABSTRACT

The physiochemical changes during the storage in apple fruits (*Malus domestica* Borkh. cv. Fuji) that were harvested on different dates were studied. Fuji apples were harvested from 9 September till 23 October, at five different times and stored at 0±0.5 °C and 95% humidity for 120 days. To determine the best harvest date for maximum quality and storability, physical and chemical parameters were measured at each harvesting time and after 40-day periods until the end of 120 days of storage. The fruit quality parameters at harvest and after storage, depended on the degree of the ripeness at which the apples were picked. Fruits of the first harvest were firmest before and after storage and had the lowest phenolic compounds at the end of storage. First and third harvest date samples had a decrease in phenolic content and total antioxidant activity in end of storage, but the fourth and fifth harvests fruits showed an increase. Total soluble solids and titrable acidity were affected by the harvest date and storage duration. First and second harvest date samples had increased in total soluble solids during 120 days of storage, but it was decreased in third, fourth and fifth harvested samples. The fifth harvest showed more oblate shape for fruits and plus weight loss in storage duration.

Keywords: Harvest date, *Malus* × *domestica,* quality parameters, storage, total phenolic content, total antioxidant activity

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INTRODUCTION

Apple (*Malus domestica* Borkh.) is an important fruit due to its delicious taste with nutritional value (Bokhari, 2002). As a perishable commodity, apples are prone to qualitative and quantitative losses after harvest. The losses may occur during postharvest operations or storage periods and can be as high as 17% of the harvest (Shah et al., 2002).

Fruits and vegetables are rich in bioactive compounds (Duda-Chodak and Tarko, 2007). Today, the positive effects of secondary metabolites on human health is known (Scalbert et al., 2005; Kevers et al., 2011; Siddiqui et al., 2015), and efforts have been made to improve antioxidants contents (Duda-Chodak and Tarko, 2007). Antioxidant capacity and phenolic compounds could be affected by some factors, including the harvest date (Mosel and Herman, 1974; Macheix et al., 1990; Renard et al., 2007; Kevers et al., 2011). In early harvest, the fruits are small with reduced flavor, color, and some unidentifiable characterizes that could have a bad effect on fruit quality after storage such as non-uniform ripening. Kviklienė et al. (2011) reported that in late harvest some of the physiological processes are underway and can complicate storage by making the fruits susceptible to scald, bitter rot and internal breakdown. However, an appropriate harvest date can improve storage life, quality and productivity. Harvesting under optimal physiological conditions ensures good quality at later stages by enhancing a number of quality characteristics, such as extended shelf life, a slower rate of decline in firmness, acidity, and color (Smith, 1987).

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One of the main problems with apple post-harvest in Iran is inappropriate harvest time, because ripe apples are prone to mechanical injury (Hribar et al., 1996). The most important market for fruits (especially apples) in Iran is during the 'Norooz' celebrations, started 21th March. So a lot of apple varieties are stored for 4 or 5 months to meet this selling period.

As a climacteric fruit, apples continue to ripen after harvest, so fruits can be harvested before full ripeness and stored to obtain a good price in the markets (Calder et al., 2002). Kader and Barrett (1996) reported that at the climacteric stage, the rate of flavor component synthesis as organic acids increases, and starch convert to sugars and other flavor components or use for respiration, thereby causing the overall sourness to diminish. Reid and Kader (2002) offer some maturity indexes to estimate the optimum harvest date for various apple cultivars in different countries. These indexes include many parameters such as firmness and percentage of soluble solids to determine the optimal harvest date for growers in order to minimize losses during storage. (Skrzynski, 1996; DeLong et al., 1999). This study investigated changes in apple fruit quality during cold storage to determine the optimum harvest stage for 'Fuji' cultivar in Alborz, Iran. This cultivar has high storability and big market in a world that makes it available for everybody.

MATERIALS AND METHODS

Study site and plant material

This trial was carried out at the facilities of the horticultural research station of Tehran University, Alborz, Iran in 2013. For this experiment, eight years old apple trees (*Malus domestica* Borkh cv. Fuji) that were grafted onto M9 rootstock with uniform size and shape were used. Trees received uniform irrigation and pest management in the experiment duration.

Fruit harvest and sampling

Harvest and measurements of fruit quality parameters were performed 2 to 3 weeks before and after the date of commercial harvest for this cultivar. Apple fruits were harvested from uniform trees at five different dates: 9 September, 19 September, 30 September, 12 October, and 23 October. Within 2 hours after harvesting, uniform sized and shaped fruits without any disorders and infections were selected.

Storage and quality measurements

Fruits were stored at 0±0.5 °C and 95% humidity for 120 days. For each harvesting date and for 40-day periods of storage, 16 fruits were selected randomly (four replicates for each treatment and four replicate for sampling), to determination of dry matter, firmness, soluble solids content, pH, TA, fruit shape, TAA and total phenolic compounds.

Soluble solids content in expressed juice from fresh fruit was measured with a hand refractometer (% Brix). Firmness was measured with a penetrometer (model FT-327) with 0.8-cm diameter probe (Pocharski et al., 2000). Sixteen fruits in each treatment were used for determining weight loss. The initial weight of each fruit was recorded at harvesting time, and the average of weight loss in all the treatments was calculated every 40 days. The weight loss (%) was calculated by:

$$\text{Fruit weight loss (\%)} = (\text{fruit initial weight} - \text{fruit final weight} / \text{fruit initial weight}) \times 100.$$

Fruit juice was extracted by juicers and the pH was determined with an electronic pH meter on 10 ml of fruit juice in 40 mL of stirred deionizer water. Fruits length and width were measured by digital calipers, and fruit shape was measured by the length to width ratio. TA was measured on juice extracted from the composite sample of segments by titration to an end point of pH 8.1 with 0.1 M NaOH.

Total Antioxidant activity and phenolic content measurements

The total phenolic content in the apple samples was measured by a modified colorimetric Folin-Ciocalteu method (Ough and Amerine, 1988). About 0.5 g of fruit flesh and 0.5 mL Folin reagent were added to the test tube separately, 8 mL deionizer water and 1 mL sodium carbonate was added to the Folin. Then 0.5 g fruit sample was homogenized with 4 mL methanol, and the mixture was centrifuged at 9500 for 20 min, 0.5 mL of this methanol extract added to Folin solution and allowed to react for 90 min, and the absorbance was read at 765 nm with a spectrophotometer (SHIMADZU, model UV-1700, Japan). The measurement was compared to the standard curve of Gallic acid solution and expressed in mg of Gallic acid equivalents (GAE/100g) of samples. Total antioxidant activity was measured by using the method of Faniadis *et al*. (2010) as this method 0.5 g of fruit tissue homogenized with 4 mL of 80% methanol. The mixture was centrifuged at 9500 rpm for 20 min. Then, 3.4 mL of solution DPPH (1-diphenyl-2-picrylhydrazyl) was added to 100 µL methanol extract, and after two hours of exposure in darkness, the absorbance was read at 520 nm on the spectrophotometer. The capability of TAA was calculated using the following equation:

$$\text{Antioxidant activity \%} = (A_{520}\ \text{sample}/A_{520}\ \text{blank}) * 100$$

Statistical Analysis

The data were analyzed as a factorial experiment with a completely randomized design based on five harvesting time and four storage time measurements with four replicate of each treatment and four replicate for sampling. Mean of interactions were assessed for differences by Duncan multiple Range test and SPSS (Statistical Package for the Social Sciences) testing Statistical computer software.

RESULTS

The TSS content of apple fruit was significantly affected by storage duration and harvest date interaction (Table 1). First, second and third harvested fruits showed an increase in TSS during storage. But in fourth and fifth harvested samples, fruits in the first 40 days, had highest TSS (TSS decreased during storage) (Table 2).

Table 1: Results of two-way analysis of variance (ANOVA) for the effects of harvest date and maintaining days in cold storage on Fuji apple cultivar quality parameters

Source Of Variation	Mean square								
	TSS	Firmness	pH	TA	Dry matter	Weight loss	L/W (Fruit shape)	Total phenolic content	TAA
Harvest date	6.582 ns	5.540 *	0.307 **	0.060 *	19.748 ns	2.134 **	0.005*	140.1671 ns	1760.892 *
Storage	9.726 ns	33.037 **	0.183 **	0.005 *	59.023 **	9.143 *		1794.492 **	318.485 *
H.d * S	6.722 *	1.509 *	0.026 **	0.025 ns	25.253 *	0.485 ns		584.867 *	2676.810 *
Error	2.683	0.245	0.007	0.002	7.423	0.252	0.004	60.081	414.071

Note: * and ** are significant in 0.05 and 0.01 respectively. ns is non-significant.

Harvest date and storage periods and their interaction had a significant effect on fruit firmness (Table 1). The highest fruit firmness was recorded in the first and second harvest dates, and the softest were in fifth date harvested fruits (in zero day of storage). Changes in fruit firmness during the 120 days of storage at 0±0.5 °C are shown in Table 2. After 40 days in cold storage the firmness of apple fruit from all harvested times, declined considerably, and after that (after 80 days of storage), its changes were slight (Table 2).

Table 2: The effects of harvest date and maintaining days in cold storage on some quality parameters of Fuji apple cultivar

Harvests	Storage	TSS (% Brix)	Fruit firmness (kg/cm^3)	Fruit pH	Organic acid (TA) mg/100mL	Dry matter (%)
Harvest 1 (9 September)	0 day storage	9.15 defg	9.25 a	4.15 i	2.76 a	11.08 bc
	40 day storage	8.8 efg	4.97 bcd	4.23 g	2.6 b	10.78 bc
	80 day storage	10.5 bcdefg	5.7 b	4.29 f	2.46 c	11 bc
	120 day storage	12.5 ab	5.15 bcd	4.2 h	2.2 ef	11.96 abc
Harvest 2 (19 September)	0 day storage	9.78 cdefg	8.55 a	4.24 g	2.6 b	14.39 ab
	40 day storage	11.56 abcd	5.14 bcd	4.236 g	2.46 c	14 ab
	80 day storage	11 abcde	4.53 cdef	4.45 d	2.36 d	14.33 ab
	120 day storage	12 abc	4.06 f	4.5 c	2.16 fg	11.44 abc
Harvest 3 (30 September)	0 day storage	9.2 defg	8.375 a	4.4 e	2.56 b	9.78 c
	40 day storage	13 a	4.95 bcde	4.13 i	2.43 c	12 abc
	80 day storage	13 a	5.28 bc	4.50 c	2.26 ef	11.62 abc
	120 day storage	11 abcde	4.13 f	4.55 b	2.03 h	11 bc
Harvest 4 (12 October)	0 day storage	9.3 defg	8.15 a	4.42 e	2.33 d	14 ab
	40 day storage	8.2 g	4.71 cdef	4.55 b	2.43 c	13 abc
	80 day storage	8.91 efg	4.87 bcde	4.56 b	2.33 d	12.79 abc
	120 day storage	8.5 fg	4.69 cdef	4.73 a	2.23 e	12.08 abc
Harvest 5 (23 October)	0 day storage	10.6 bcdef	5.04 bcd	4.42 de	2.26 e	15.16 a
	40 day storage	9.46 defg	4.4 def	4.55 b	2.13 g	13 abc
	80 day storage	9.45 defg	4.02 f	4.74 a	2.03 h	10.66 bc
	120 day storage	9.5 defg	4.14 ef	4.72 a	1.86 i	10 c

Note: The means were separated by Duncan multiple range test at $p \leq 0.05$.

Fruit juice pH was significantly affected by both treatments and their interaction, (Table 1). Fourth and fifth harvested fruits, at the beginning and end of the 120 days of storage, had higher pH levels (Table 2). During the storage periods, the pH increased and in the last round storage had reached its highest level. Fruits of the first harvest date had the lowest changes in pH during the storage.

Fruit juice TA declined during cold storage in all treatments (Table 2). As shown in Table 2, TA content of late harvested fruits was lower than those harvested at an earlier date.

Table 2 shows the change in dry matter for the apples throughout the harvest dates with 120 days of storage duration. The dry matter content increased gradually during the different harvest dates, starting from the 9th of September. After 40 days maintaining in cold storage, the dry matter for the fruits from fourth and fifth harvested dates decreased significantly (13.71% and 34.04% respectively).

Fruits of the fifth harvest date had the highest weight loss during the storage and the second harvest date had the least. Weight loss in 40 to 80 days of storage, in fruits from the first, second, and third harvests increased significantly. In all harvest dates, except the first and second harvest samples, weight loss decreased after 80 days (Table 3).

Table 3: The effects of harvest date and maintaining days in cold storage on some quality parameters of Fuji apple cultivar

Harvests	Storage days	Fruit weight loss (%)	Fruit shape (length to width ratio)	Total phenol content (mg/100g FW)	Total antioxidant activity (%)
Harvest 1 (9 September)	0 day storage	0 h	0.89 ab	52 b	8 b
	40 day storage	0.91 fg		51.29 b	8.05 b
	80 day storage	1.5 cdefg		49.46 b	7.95 b
	120 day storage	1.3 defg		40.35 c	6.5 c
Harvest 2 (19 September)	0 day storage	0 h	0.84 bc	43 bc	10.55 a
	40 day storage	0.87 g		39.91 c	11.56 a
	80 day storage	1.13 efg		40.00 c	9.5 b
	120 day storage	1.12 efg		50.44 b	8.6 b
Harvest 3 (30 September)	0 day storage	0 h	0.96 a	52 b	9.5 ab
	40 day storage	1.8 cdf		44.26 bc	9.55 ab
	80 day storage	1.9 bcd		38.88 c	9.63 ab
	120 day storage	1.65 cde		45.02 bc	9.36 ab
Harvest 4 (12 October)	0 day storage	0 h	0.77 c	60 b	8 b
	40 day storage	1.55 cdefg		80 a	8.2 b
	80 day storage	1.61 cdef		87 a	8.91 b
	120 day storage	1.18 efg		85 a	9 b
Harvest 5 (23 October)	0 day storage	0 h	0.77 c	63 b	10.6 a
	40 day storage	2.60 ab		78.17 a	9.46 ab
	80 day storage	2.68 a		75 a	10.45 a
	120 day storage	2.20 abc		80 a	12.23 a

Note: The means were separated by Duncan multiple range test at p ≤ 0.05.

The effect of the date of harvest on fruit shape (length to width ratio) was significant (Table 1). As shown in Table 3, fourth and fifth harvest dates had fruits, which were more oblate than the three earlier harvests (low length to width ratio) (Table 3).

At harvest (zero day of storage), fourth and fifth harvested fruits showed higher contents of total phenolic compounds (Table 3). Total phenolic compounds increased by storage only in the fourth and fifth harvests. Total phenolic content, in first, second and third harvests showed a significant decrease during the storage.

The fruits of the fifth harvest date had the highest antioxidant activity in both the beginning and the end of the storage duration (Table 3). Except for the fourth and fifth harvests, the remaining harvested samples showed a decrease in the TAA in storage duration and this decrease was significant in the first and second harvests.

DISCUSSION

These results demonstrated that harvest time and length of time that the Fuji apples were in cold storage, significantly affects quality and storability of Fuji apple fruits. The TSS of apples and other fruits is an important quality factor which determines the fruit taste (TSS/TA ratio) (Weibel et al., 2004). The increase in TSS could be attributed to the breakdown of starch into sugars (Kvikliene and Valiuskaite, 2009). Since, TSS percentage was a function of total dissolved solids and moisture content of the fruit, the increase in TSS could be due to the concentration of soluble solids in moisture loss (Farooq et al., 2012). Decrease in fruit firmness after 40 days of storage may be due to the high activity of the enzymes evolve in the cell wall collapse as fruit ripeness and therefore affects the storability (Kvikliený et al., 2011). TA of the fruits, depends on the rate of metabolism, especially respiration which consumes organic acids (Ghafir et al., 2009). Apples continue to lose water after harvest, resulting in weight loss (Al-Obeed and Horhash 2006). It has been reported earlier that percent weight loss generally increased with increasing storage duration. The weight loss in fruits depends on the nature and the amount of wax on the surface of the fruit and respiration rate (Veravrbeke et al., 2003). Thus, the relative low rate of weight loss for up to 90 days of storage indicated that the wax layer may have been undamaged for 90 days in this cultivar. And damage to this layer after this time of storage could be the major reason responsible for high weight loss (Gavlheiro et al., 2003). The loss of moisture and subsequent weight loss also depends on the water content of the fruit (Banarus et al., 1994). Second harvested fruits, had lowest weight loss during the storage that may be due to the appropriate formation in the wax layer (compared to the first harvested fruits) and low respiration rate as compared to the over- ripe fruits (compared with the fourth and fifth harvested fruits).

Increase in fruit size, TSS and a reduction in fruit firmness indicates advanced maturity and improve fresh eating quality of the late harvested apples, but decreases their storability (Farooq et al., 2012). Another aim of this study was to improve antioxidants efficiency and restore it in fruits and prevent their wastes. High content of phenolic compounds and TAA in late harvests fruits suggested that a late harvest could have beneficial effects on the phytochemical content of Fuji apples. In this respect it can be said that the fifth and fourth harvested fruits (harvested at 12 and 23 October) have a high content of total antioxidant and total phenols at beginning and at the end of 120 days of storage. Unripe apples (harvested at 9 and 19 September) together constitute a lower source of total phenolic and total antioxidant content and more decrease in storage duration too. So it can be said that storage of ripe Fuji apple fruits (rather than unripe fruits) could save fruit pro-health value.

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