

Changes in fruit maturity indices and growth pattern along the harvest season in seedless barberry under different altitude conditions

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Abstract.

BACKGROUND: Barberry fruit is an important source of anthocyanin, and strongly uses for Zereshk Poloe, a delicious diet in Iran.

OBJECTIVE: We are trying to find how fruit quality of barberry is affected under different locations and if sooner harvesting may be possible, which encouraged us to do these studies.

METHODS: The present study was conducted in three different locations (Marvak, Marak and Amirabad with 2079, 1648 and 1480 m altitude) around Birjand, Iran. Fruit sampling was done 66, 98, 122, 155 days after full bloom (DAFB) and also in economical harvesting (EH) date.

RESULTS: The results showed that berry number, fruit fresh weight (FW) and dry weight (DW), juice weight and volume, pH, total acidity (TA), total soluble solids (TSS), maturity index, anthocyanin and total phenols significantly changed with advancement of growing season under different climatic conditions. Interactive effect of sampling time × location indicated the highest pH in Marak and Amirabad and the highest TSS and TSS/TA ratio in Amirabad in EH, and the highest phenols in Marak in 155 DAFB and EH. The highest anthocyanin content accumulated in Marvak, exactly in EH. Using changes in FW, DW and volume of fruit, a double-sigmoidal curve observed for barberry fruit growth.

CONCLUSION: Regarding to obtained data and specially anthocyanin accumulation, we propose regions with higher altitude for seedless barberry cultivation and production because of earlier harvest with more qualified fruit.

Keywords: *Berberis vulgaris*, altitude, anthocyanin, full bloom, fruit growth curves

1. Introduction

Nowadays, seedless barberry (*Berberis vulgaris* L.) has received much attention because of its high level of medicinal properties. This is a medicinal shrub, dicotyledonous and perennial [1, 2], which is cultivated as a domestic plant in south Khorasan province of Iran, since more than 200 years ago. Seedless barberry is an important source of anthocyanin pigments [3]. There are some factors affecting fruit growth and development including cultivar, climate conditions and maturity degrees. Maturity level is an important factor affecting fruit quality [4, 5]. Among climatic factors, temperature is very important and significantly affects some aspects of

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plant growth and development [6]. It was showed that altitude has significant effects on fruit quality of mandarins [7] and ‘pineapple’ guava [8]. There is some evidence about positive effects of cool temperatures on increase of total soluble solids in barberry [9], anthocyanin accumulation in grapevine [10, 11] and improvement of surface color in pomegranate fruit [12]. The average night-temperature is more closely correlated to amount of pigments in fruits, compared with the average day-temperature. Anthocyanin biosynthesis has different patterns including a) accumulation in both skin and flesh, b) accumulation in only skin and c) accumulation in skin as responding to light stimulus [13]. About barberry fruit, and based on findings by Rezvani Moghaddama et al. [3] and Maraki et al. [14], it seems that accumulation of anthocyanin begins with fruit growth stopping (in September), and continues to harvesting time. Harvest time also significantly influences fruit quality parameters. Wang et al. [15] found that immature raspberry fruit has lower TSS and anthocyanin, higher total acidity (TA) and phenols, compared to mature fruits. Rezvani Moghaddama et al. [3] observed that late harvesting lead to more TSS, anthocyanin and pH values in barberry fruit. In pomegranate fruit, results showed that late harvesting resulted to higher fruit weight, juice volume, TSS and anthocyanin content, however, phenols and TA decreased [12]. Personal experiences showed that fruit quality of barberry in some location is higher than others that also lead to earlier harvesting, however, no data was found in this regard. Moreover, there is no report about effects of altitude levels on growth and quality of barberry fruit. In addition, no data was observed on fruit growth curve of barberry. So, the main aims of this experiment were 1) to evaluate the changes in fruit quality during growth season, under different altitude conditions and 2) to determine fruit growth curve of barberry.

2. Material and methods

2.1. Plant selection, heat unit measurement and sampling times

This experiment was conducted on 20-years old seedless barberry (*Berberis vulgaris* L.) trees, in different commercial plantations (Tables 1 and 2) of south Khorasan, Iran, during 2015 and 2016 growing seasons. Study was done on 189 uniform trees (150 ± 20 cm height), planted in 3-4 m \times 2-3 m space. All conventional farm management, pruning, irrigation, and fertilization and manuring were done as needed. Just one-year data presented here, because of high volume of data and also similar trend in both years. Planting soil was deep and loamy. Full bloom and fruit set were recorded during growing season (Table 3). Heat units calculated using temperature data from nearest weather station and data logger (Extech Instruments, Model RHT20, Humidity and Temperature Data logger, USA), based on Wein [16] (1997) as followed:

$$\text{Heat Units (Degree days)} = \frac{(\text{Maximum daily temperature} - \text{Minimum daily temperature})}{2} - T_{\text{base}}$$

T base was the threshold temperature where plant growth started. Regarding to experiments conducted with Maraki et al. [14] and our findings in different locations, T_{base} for barberry fruit was 11 °C. Cumulative heat

Table 1
Characteristics of different locations in this experiment

Location	Latitude	Altitude (m)	Mean Temperature (°C)			Soil	
			Yearly	Day	Night	pH	EC (dS/m)
Marvak	33°7.5'N	2079	20.49	23.87	16.94	8.17	17.62
Marak	32°58.09'N	1648	23.34	31.97	14.69	7.50	16.70
Amirabad	32°56'N	1480	25.01	30.54	22.82	7.80	16.72

Altitude represents rising of each location above the sea level. Mean temperatures obtained from data logger and the nearest weather station.

Table 2
Temperature related parameters (Monthly, day, night, and difference between day and night mean temperatures) of different locations in this experiment in 2016

Location	Mean T	Month						
		Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.
Marvak	Monthly	21.10	20.70	22.80	25.00	20.20	20.90	12.70
Marak		15.40	19.50	26.65	28.20	27.70	24.00	21.90
Amirabad		16.85	21.25	28.15	29.80	29.80	26.20	23.00
Marvak	Day	25.88	24.24	26.46	28.68	22.76	23.83	15.21
Marak		22.80	27.50	35.60	36.50	36.30	34.10	31.00
Amirabad		25.66	34.12	36.09	34.62	32.97	27.79	22.50
Marvak	Night	14.58	17.63	19.33	21.44	17.34	17.81	10.46
Marak		8.00	11.50	17.70	19.80	19.20	13.90	12.70
Amirabad		15.77	22.38	28.33	27.56	22.52	24.26	18.90
Marvak	Day & night difference	11.30	6.61	7.13	7.24	5.42	6.02	4.75
Marak		14.80	16.00	17.90	16.70	17.10	20.20	18.30
Amirabad		9.89	11.74	11.09	10.79	10.45	17.50	18.30

Mean T represents mean temperature; Difference represents any difference between day and night temperatures calculating as followed: day-night; difference of day and night temperature calculated via subtraction of night from date temperature.

Table 3
Accumulated heat units (growing degree hours) in each location during the growing season and each harvest date

Location	Full bloom	Fruit set time	Days after full bloom	Accumulative heat unit (GDH)
Marvak	8-May-2016	19-May-2016	66	613.0
			98	988.3
			122	1177.7
			155	1426.7
			168 (E.H.)	1438.0
Marak	19-April-2016	3-May-2016	66	1011.6
			98	1507.8
			122	1889.0
			155	2234.8
			186 (E.H.)	2287.5
Amirabad	13-April-2016	25-April-2016	66	1183.0
			98	1828.5
			122	2314.7
			155	2767.8
			191 (E.H.)	2808.4

GDH: growing degree hours, E. H.: Economical harvesting time.

units calculated via adding all heat units. Fruit sampling were done on 66, 98, 122 and 158 days after full bloom (DAFB) and also in economical harvest for each region (E.H.; 168 DAFB for Marvak, 186 DAFB for Marak, 191 DAFB for Amirabad), to monitor different fruit characteristics. Five shoots on each tree were chosen.

2.2. Measurement of fruit characteristics

Hand-picked fruits transported to Horticultural Lab, University of Birjand, Iran, for more concise evaluations. Many samples of 100 berries were prepared and used for assessments. Berry number (BN) in each cluster, fruit fresh weight (FW), fruit dry weight (DW), fruit volume (FV), chlorophylls a, b and carotenoid were evaluated on 66, 98, 122, 158 DAFB and also in economical harvest. Juice weight and volume, total soluble solids (TSS), total acidity (TA) and their ration (maturity index or TSS/TA juice pH, anthocyanin concentration and total phenol evaluated just on 122 and 158 DAFB and on economical harvesting time in each location. FW and DW assessed with a concise balance with 0.0001 accuracy, FV with method of replacing water, Chlorophyll a and b and carotenoid calculated using method of Arnon [17]. Juice obtained from 100 berries applied for volume and weight. TSS estimated with hand-refractometer (Extech, RF10), TA determined based on citric acid using method of Williams [18]. pH evaluated with digital pH meter (Mettler Toledo, Switzerland). Determination of spectroscopy-based anthocyanin was performed based on the pH difference. The method consists of two buffer systems including potassium chloride and sodium acetate. A 0.025 M solution of potassium chloride buffer with pH=1 was produced using HCl. A 0.4 M solution of sodium acetate buffer with pH=4.5 was produced using acetic acid. Anthocyanin content was estimated as pelargonidin 3-glucoside at 510 nm, and data showed as mg/100 g FW [19]. Estimating total phenol, one g of pulp powder was dissolved in 10 ml of 70% (v/v) aqueous methanol (Merck KGaA, Darmstadt, Germany), shaken for 2 h at room temperature, and centrifuged at $4,000 \times g$ for 10 min. Consequently, the supernatant was separated from the solid particles. Total phenols (TPC) was estimated using Folin-Ciocalteu's (FC) assay with some modifications [20]. A volume of 450 μ l of distilled water was added to 50 μ l of prepared extract. Then 250 μ l of 1 N FC reagent (FC, Merck KGaA, Darmstadt, Germany) was added, vortex-mixed and left to stand for 5 min. Next, 1.25 ml of $Na_2CO_3 \cdot 10H_2O$ (20%, Merck KGaA, Darmstadt, Germany) was added to the mixture and incubated for 40 min under dark conditions in room temperature. Finally, the absorbance was measured at 725 nm using a spectrophotometer (BIOSPEC 1601, SHIMADZU, TOKYO, JAPAN). A calibration curve was prepared using different concentrations of gallic acid (Merck KGaA, Darmstadt, Germany) and results were expressed as mg gallic acid/100 g DW [20].

2.3. Determination of fruit growth pattern

Fruit growth pattern was evaluated during full bloom to economical harvesting. The date of full bloom was considered to be when 80% of the flowers of the tree were opened (Table 3). Fruit samples were taken several times during growth season, started 66 days after full bloom (DAFB) and repeated in dates 32, 56, 92, 102 and E.H (date 102 in Marvak, date 120 in Marak and date 125 in Amirabad), to determine the growth. First fruit collection was performed based on Table 3, when measurable fruit formation occurred. Fruit FW, DW and volume, juice weight and volume, TSS and TA were evaluated on 500 berries based on methods showed above.

2.4. Experimental design and data analysis

The experiment was conducted as factorial (3×5) based on complete block design, with 3 different locations and 5 different harvesting (sampling) times. Three replications, with 21 trees in each, was used (63 trees for each location). Statistical analysis of data was performed using ANOVA to determine statistical differences at $P < 0.05$ and LSD was used for mean comparison. All statistical analyses were performed using SAS version 9.1. Regression analysis was done using excel software.

3. Results and discussion

3.1. Evaluation of the effects of sampling date and location on growth and quality

The full bloom (FB) time was different for studied locations and earlier FB observed in Amirabad, followed by Marak and Marvak. Earlier fruit set obtained in Amirabad (12 DAFB), followed by Marak (14 DAFB) and Marvak (11 DAFB). The season length (from full bloom to economical harvest) ranged from 168 days in Marvak to 191 days in Amirabad. Moreover, different heat unit (HU) accumulated in each location and the highest and lowest HU observed in Amirabad and Marvak, respectively (Table 3).

Simple effect of location and sampling time were not significant on chlorophyll a, b and carotenoid contents (data not shown). Results (Table 4) expressed significant reduction in berry number per bunch (BN) about 6.57% in two-final harvesting times, compared with first sampling (66 DAFB). Berry number is related to the number of any meristems formed previously, and many factors such as fruitlets abscission may be effective. The highest BN observed with Marvak (by 12.36% more than Amirabad), which may be related to higher ovule longevity and better fruit setting. As season progressed, an increasing trend observed in fruit FW, fruit DW and fruit volume (FV) that was in agreement with Arena and Curvetto [21] and Rezvani Moghaddam et al. [3] on barberry, and may be resulted from photosynthetic activities, assimilate transport into fruits, biomass accumulation within berries, and fruit growth and development. Regression analysis indicated an exponential increment for FW, DW and FV in all locations, as more heat unit accumulated (Figs. 1–3). Although approximately 3.5 times increase in FW obtained between dates 66 and E.H., however, not significant changes observed in fruit FW since date 155 onward. The highest values for fruit FW and DW observed in Marak (5.03 g FW) and Amirabad (1.43 g DW), respectively. FW differences between Marvak (lower FW) and Marak (higher FW) was 102%, and DW between Marvak (lower DW) and Amirabad (higher DW) was 53.76%. From date 66 to 155, a significant increase observed in FW/DW, however, a reducing trend indicated then after. The highest FW/DW obtained in Marak (4.30), compared with others (Table 4) that may be related to more juice content or lower biomass accumulation within berries. Fruit volume significantly increased from date 66 to E.H. and the highest volume observed in Marvak, compared with other locations (Table 4). Sugiura et al. [22] and Candir et al. [23] on persimmon found

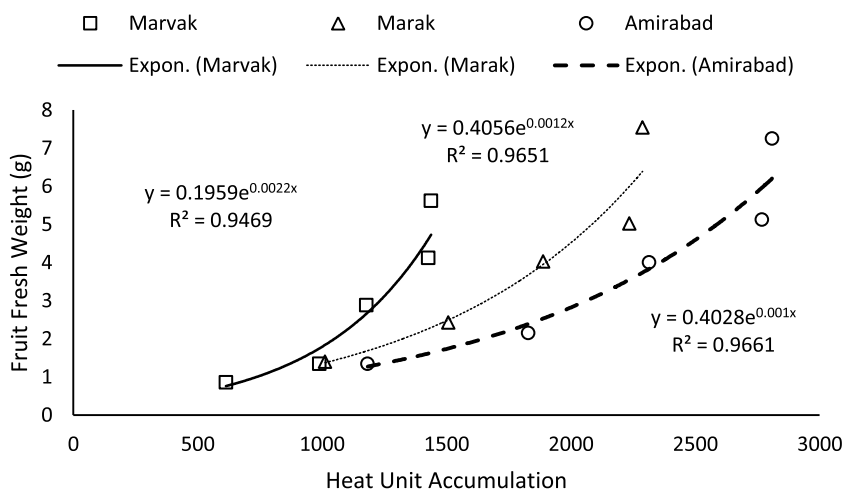


Fig. 1. Changes of fruit FW based on heat unit accumulation.

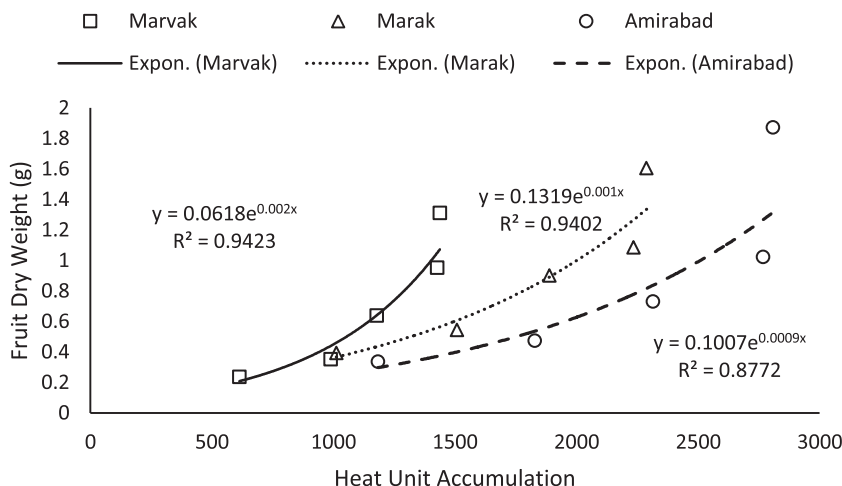


Fig. 2. Changes of fruit FD based on heat unit accumulation.

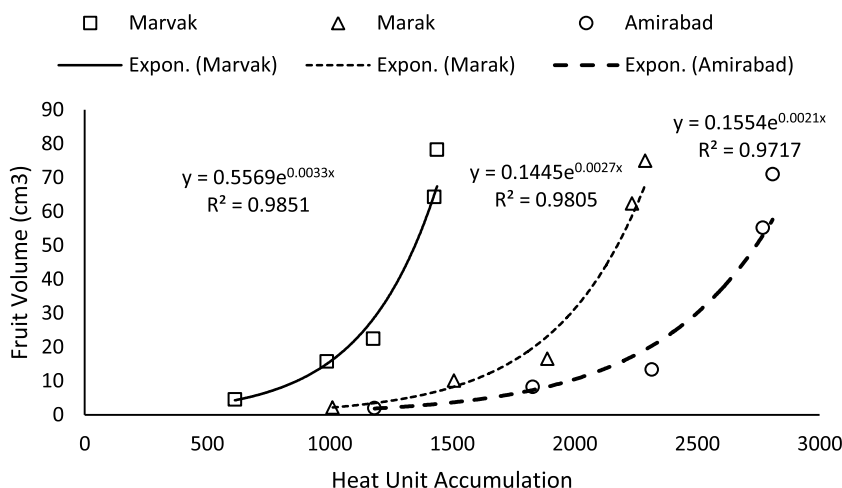


Fig. 3. Changes of Fruit volume based on heat unit accumulation.

that cool night is responsible for more fruit growth and development. However, based on regression analysis (Figs. 1–3), we suggest the effectiveness of cumulative heat unit on barberry fruit growth and development. Interaction between location and harvesting time on chlorophyll a, b and carotenoid content of fruits, BN, FW and DW of fruit, were not significant (data not shown).

Earlier harvesting could be done, because of no significant change of juice volume and density between dates 155 and E.H. On the other hand, juice weight (JW) significantly increased with season progression (by 94.10% between 122 and E.H) and the highest JW observed on E.H. which may be related to solid accumulation within berries. Regarding to locations, the highest juice weight (by 69.68% higher than Marvak) and volume (by 66.02% higher than Marvak) observed in Amirabad, followed by Marak (by 28.57% juice weight and by 26.69% juice volume higher than Marvak) and Marvak (Table 5).

Table 4

Changes in berry number, fruit weight and volume of barberry under different locations and during growing season

Variable	Berry Number Per Bunch	Fruit F.W. of 100 fruits (g)	Fruit D. W. of 100 fruits (g)	F. W./D. W. ratio	Fruit V. of 100 fruits (ml)
Sampling Time (DAFB)					
66	27.83a	1.20b	0.32d	3.75c	8.67e
98	29.00a	1.98b	0.46c	4.30b	34.06d
122	28.83a	3.64a	0.76c	4.79a	52.39c
155	26.08b	4.93a	1.07b	4.61a	181.86b
Economical H.	26.00b	5.39a	1.46a	3.69c	224.22a
Location					
Marvak	29.69a	2.49c	0.93c	2.68b	37.05a
Marak	27.38b	5.03a	1.17b	4.30a	33.24b
Amirabad	26.02b	4.35b	1.43a	3.04b	29.95b

DAFB: days after full bloom in which 50% flowers are open; Economical H: economical harvesting in each location; F. W.: fresh weight; D. W.: dry weight; Fruit V.: fruit volume. Mean values in each column followed by the same letter are not significantly different by the LSD ($P < 0.05$).

Table 5

Changes in juice related characteristics of barberry under different locations and during growing season

Variable	Juice weight of 100 fruits (g)	Juice Volume of 100 fruits (ml)	Juice density of 100 fruits (mg/ml)
sampling time (DAFB)			
122	6.78c	7.38b	0.9115b
155	12.11b	11.29a	1.0707a
Economical Harvest	13.16a	12.08a	1.0903a
Location			
Marvak	8.05c	7.83c	1.0137a
Marak	10.35b	9.92b	1.0182a
Amirabad	13.66a	13.00a	1.0406a

DAFB: days after full bloom in which 50% flowers are open. Mean values in each column followed by the same letter are not significantly different by the LSD ($P < 0.05$).

As season progressed, an elevating trend observed in pH (by 18.93%), TSS (by 46.24%) and TSS/TA (by 741.28%) that was in agreement with Rezvani Moghaddam et al. [3] on barberry. TA significantly decreased with season progression (by 86%) that was in agreement with Candir et al. [23] on persimmon, Rezvani Moghaddam et al. [3] on barberry and Kulkarni and Aradhya [24] on pomegranate fruit (Table 6). On date 122, an acceptable taste with approximately 15% TSS and 0.5% TA observed that was in agreement with Rezvani Moghaddam et al. [3] on barberry, however, better quality (higher TSS and lower TA) obtained as season progressed (E.H.). Biale [25] on evaluation of some tropical and subtropical fruits suggested that any increases in TSS attributed to starch hydrolysis into simple sugars. These components are produced from hydrolyzing sucrose to glucose and fructose [21]. Reduction of TA was coincided with TSS increment that was in agreement with Kulkarni and Aradhya [24] on pomegranate fruit. Yoon et al. [26, 27] on apple and cherry found that there was a positive correlation between acid phosphatase activity and the TSS/TA ratio. The highest juice pH observed in Marak and Amirabad, and the highest TA obtained in Marvak and Marak. The highest TSS and TSS/TA (by 43.75% higher than Marvak and by 73.32% higher than Marak) indicated in Amirabad. Regarding to data presented in Table 2, it seems that TA significantly affected by night temperatures ($R^2 = 0.62$) and cool nights may be the

Table 6
Changes in pH, total acidity (TA) and Total soluble solids (TSS) of barberry under different locations and during growing season

Variable	pH	TA (%)	TSS (%)	TSS/TA ratio
sampling time (DAFB)				
122	2.622c	0.5050a	15.83c	37.3c
155	2.984b	0.2177b	20.25b	120.0b
Economical H.	3.166a	0.0756c	23.15a	313.8a
Location				
Marvak	2.873b	0.3330a	20.40b	144.2b
Marak	2.925a	0.3072a	17.43c	119.6b
Amirabad	2.973a	0.1582b	21.39a	207.3a

DAFB: days after full bloom in which 50% flowers are open; Economical H: economical harvesting in each location. Mean values in each column followed by the same letter are not significantly different by the LSD ($P < 0.05$).

Table 7
Interactive effect of sampling time \times location on pH, total acidity (TA) and total soluble solids (TSS) of Barberry fruit

Variable		pH	TA (%)	TSS (%)	TSS/TA
Location	Sampling Time (DAFB)				
Marvak	122	2.630d	0.7030a	16.70d	24.3e
	155	2.910c	0.2145d	20.05c	99.7d
	E.H.	3.080b	0.0815e	24.45a	308.6b
Marak	122	2.542e	0.5197b	13.90e	26.8e
	155	3.028b	0.3260c	17.95d	55.2d
	E.H.	3.205a	0.0758e	20.45c	276.7b
Amirabad	122	2.693d	0.2923c	16.87d	60.7d
	155	3.015b	0.1128e	22.75b	205.2c
	E.H.	3.213a	0.0695e	24.55a	356.1a

DAFB: days after full bloom in which 50% flowers are open; E. H.: economical harvesting in each location. Mean values in each column followed by the same letter are not significantly different by the LSD ($P < 0.05$).

cause of higher TA in Marvak and Marak, compared with Amirabad, which was in agreement with findings of Kozai et al. [28] on passion fruit.

Interaction between location and harvest time showed significant influence on pH, TA, TSS and TSS/TA (Table 7). The highest juice pH obtained in Marak and Amirabad on date E.H. (date 186 and 191, respectively), which resulted to sourest berries in Marvak (by 4% more than Marak and by 4.3% more than Amirabad). This results were in agreement with findings of Chandra and Todaria [29], Arena and Curvetto [21] and Rezvani Moghadam et al. [3]. Disregard to location, the lowest TA showed in final harvesting (date 168 and 186 for Marvak and Marak, respectively, and date 155 and 191 for Amirabad). It is clear that produced fruits in Marvak and Marak are less acidity on E.H., however reducing acidity started earlier in Amirabad (since date 155). The highest TSS observed in Marvak (24.45%) and Amirabad (24.55%) and the lowest rate indicated in Marak (20.45%) that may be related to late accumulation of soluble solids in fruits. On the other hand, the highest TSS/TA ratio observed in Amirabad on date 191, followed with Marvak (on date 168) and Marak (on date 186). TSS/TA ratio can be used as harvest index for human consumption, and the best index observed in Amirabad at later harvest (Table 7).

Table 8
Changes in anthocyanin and phenols of barberry fruit under different locations
and during growing season

Variable	Anthocyanin (mg/l)	Phenol (mg galic acid/100 g dry weight)
Sampling Time (DAFB)		
122	5.00b	74.46b
155	240.00a	95.50a
Economical Harvest	251.00a	92.92a
Location		
Marvak	271.00a	71.41b
Marak	111.00b	119.68a
Amirabad	103.00b	71.80b

DAFB: days after full bloom in which 50% flowers are open. Mean values in each column followed by the same letter are not significantly different by the LSD ($P < 0.05$).

Table 9
Interactive effect of sampling time \times location on anthocyanin and phenols of Barberry fruit

Sampling Time (DAFB)	Anthocyanin (mg/100 g FW)			Phenol (mg Gallic acid/100 g DW)		
	122	155	E. H.	122	155	E. H.
Location						
Marvak	16.00c	345.00b	485.00a	73.17b	72.08b	68.97c
Marak	6.00c	110.00c	217.00b	75.80b	142.44a	140.80a
Amirabad	4.00c	264.00b	281.00b	74.41b	71.99b	69.00c

DAFB: days after full bloom in which 50% flowers are open; E. H.: economical harvesting in each location. Mean values in each column followed by the same letter are not significantly different by the LSD ($P < 0.05$).

Both anthocyanin and phenol contents (Table 8) significantly increased between dates 122 and 155, indicating that barberry fruits may be ready to harvest during this period that was in agreement with Rezvani Moghaddam et al. [3] on barberry. Anthocyanin accumulation in E.H. was 49.2 times more than date 122 (Table 8). Arena and Curvetto [21] stated that allocation of carbon into biomass is responsible of fruit growth and development. Regarding to significant changes in FW before date 122 (Table 4) and also significant changes occurred in anthocyanin since after, we suggest allocation of carbon into biosynthesis and production of secondary metabolites. The highest anthocyanin content obtained in Marvak, followed with Marak and Amirabad (by 144% and 163.10% higher than Marak and Amirabad, respectively). Koshita et al. [30] and Choi et al. [31] stated that low temperatures induce anthocyanin synthesis in various plants, although in cold temperatures, it is light dependent and in the absence of light, low temperatures prevent anthocyanin biosynthesis. Saure [32] and Marais et al. [33] found that low autumnal temperatures promote anthocyanin biosynthesis. As data showed in Table 2, cool autumnal (October) temperatures obtained in Marvak (Mean temperature of 12.70 °C). Compared to the average day temperature, average night temperature is more closely correlated to amount of fruit pigments (Table 2) in Marvak ($R^2 = 0.93$). Recent research works demonstrated that low temperatures (15°C) increase anthocyanin content in grape berry skin synergistically with light, which important on the expression of related genes [34]. Recently, crosstalk between a sugar-induced gene and an ABA signaling gene has been reported [35]. Koshita et al. [30] found that ABA level of grapevine fruit under lower night-time temperature is two times higher than higher night-time condition. Here, an increasing trend observed with TSS and anthocyanin in Marvak, which

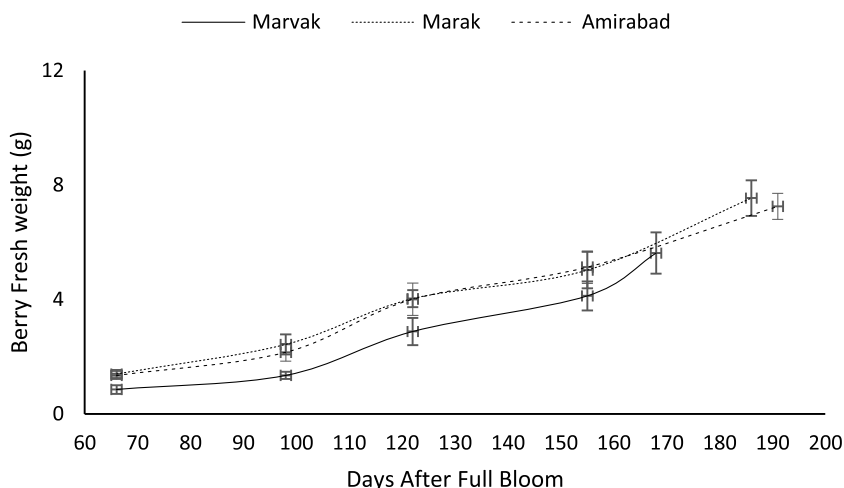


Fig. 4. Changes in barberry fresh weight during growth season. Data represent means \pm SE.

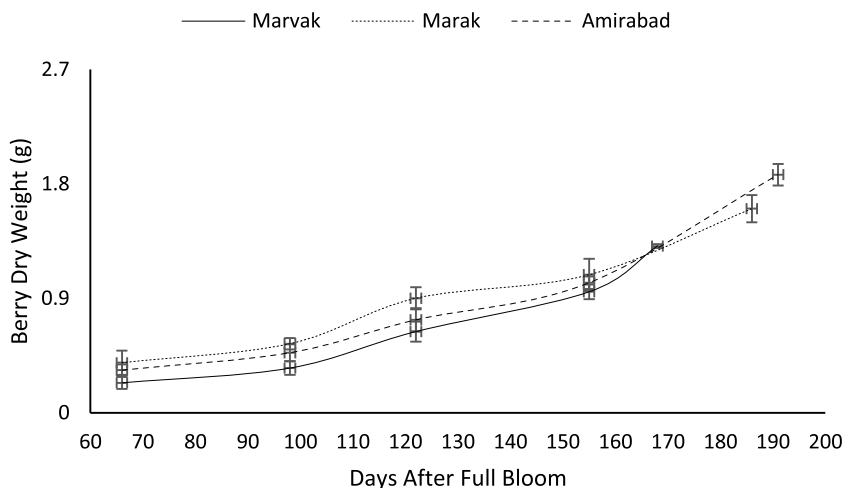


Fig. 5. Changes in barberry dry weight during growth season. Data represent means \pm SE.

may be related to cool night temperature and was in agreement with Hunter et al. [36] in grapevine. Total phenol content increased by 26.67% since date 122 to 155. The increment of this variable was disagreement with Kulkarni and Aradhya [24] on pomegranate and with Bashir and Abu-Goukh [37] on guava fruit. The highest phenols observed in Marak (by approximately 67% more than others), followed with Amirabad and Marvak. We think that cool night and high day-night differences in Marak ($R^2 = 0.87$) may be responsible for more accumulation of phenols within berries (Table 8).

Interaction between location and harvest time showed the highest anthocyanin in Marvak on the final harvest, however, this variable increased with time. The highest phenol observed in Marak on dates 155 and 186 (Table 9). Some phenols are substrates for enzymatic browning. A reduction in the phenol content accompanied with fruit development, may reduce the incidence of enzymatic browning [24]. A decrease in phenol also coincided with an increase in anthocyanin pigments (Table 9).

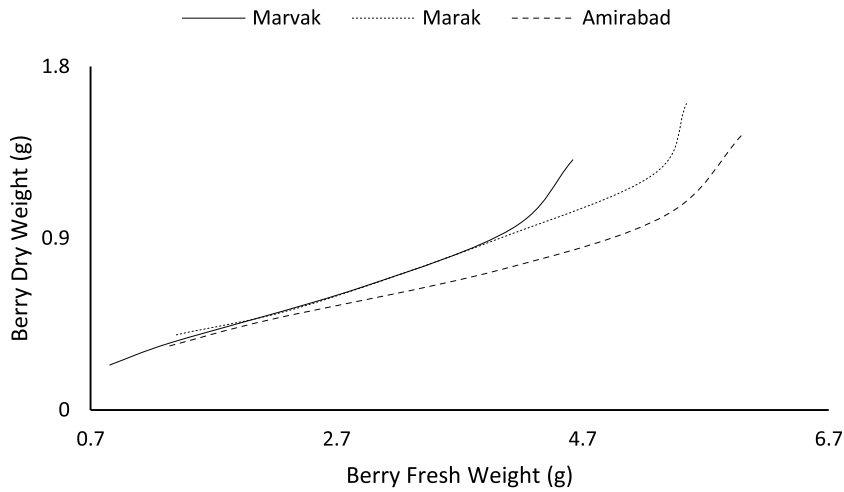


Fig. 6. Changes in dry weight during vs. fresh weight of fruit.

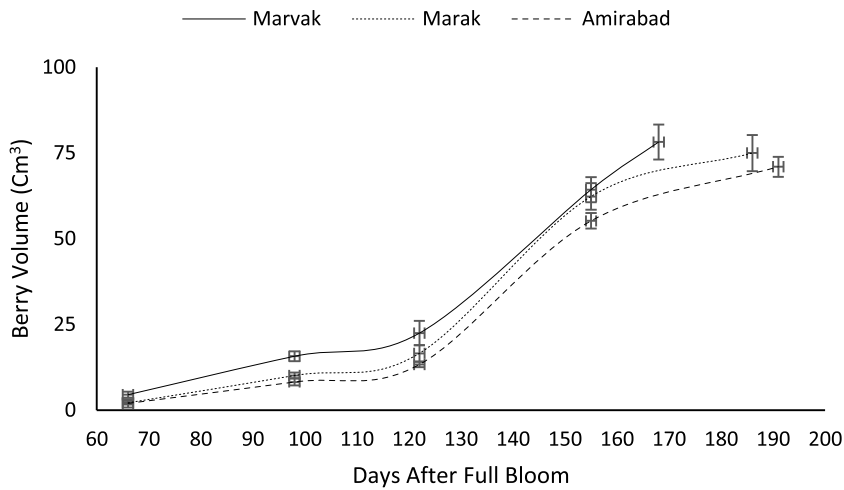


Fig. 7. Changes in barberry volume during growth season. Data represent means \pm SE.

3.2. Fruit growth curve

Fruit growth pattern (Figs. 4–8) studied with using fruit fresh weight (FW), fruit dry weight (DW) and fruit volume (FV). Fruit FW in all three locations initially increased slowly up to 98 DAFB and then became faster for a period of time, up to 122 (first rise), then the rate of growth continued slowly (up to 155) and again increased (up to E.H., second rise) (Fig. 4). A similar trend observed for fruit DW (Fig. 5). Both FW and DW indicated double-sigmoid growth pattern. Evaluation of DW vs. FW showed an increasing trend for this ratio, which observed faster increase of DW in final growth of barberry fruit (Fig. 6). Fruit volume also showed double-sigmoidal growth pattern (Fig. 7). During 66 to 98 DAFB a slow growth and then first rise observed, followed by a steady state during 98 to 122 DAFB. Second rise was much faster (between dates 98 to 155) and finally, slowly increase in growth was reached (Fig. 7). In all locations, two rise were observed in FW, DW and FV that

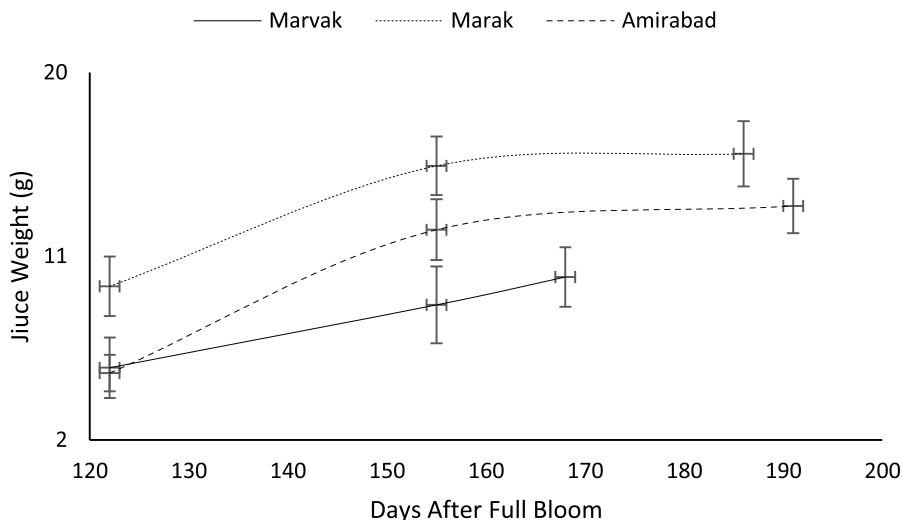


Fig. 8. Changes in barberry juice weight during growth season. Data represent means \pm SE.

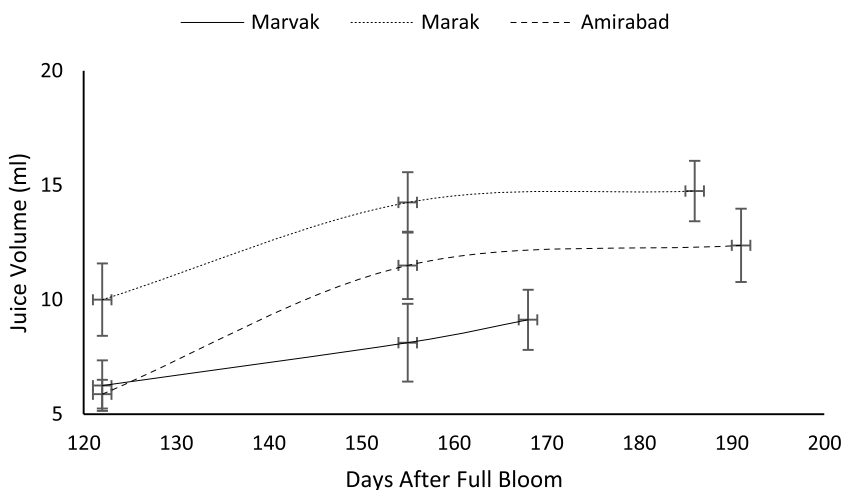


Fig. 9. Changes in barberry juice volume during growth season. Data represent means \pm SE.

was in agreement with Coombe [38] and Worrell et al. [39, 40], who stated that some stone fruits (peach, plum, apricot) and non-stony fruits (grape, fig, currant, soursop, bread fruit) have double-sigmoidal growth curves. In double-sigmoidal tri-phasic growth, there are two periods of rapid growth increase that are separated by a period of slow or suspended growth, similar to findings presented here.

Certain biochemical measurements provide indices for changes in fruit growth and development, including pH, acidity, sugar and starch, relative density as sucrose gradient, and fatty acid content in fruit, seed, or embryo and NAD-dependent sorbitol dehydrogenase [41–43]. Extractable juice obtained 122 DAFB onward. Juice weight and volume increased in all locations during 122 to 155 DAFB, however, with the exception of Marak and Amirabad (Figs. 8 and 9). About TSS (Fig. 10), a similar trend observed for both Marak and Amirabad that

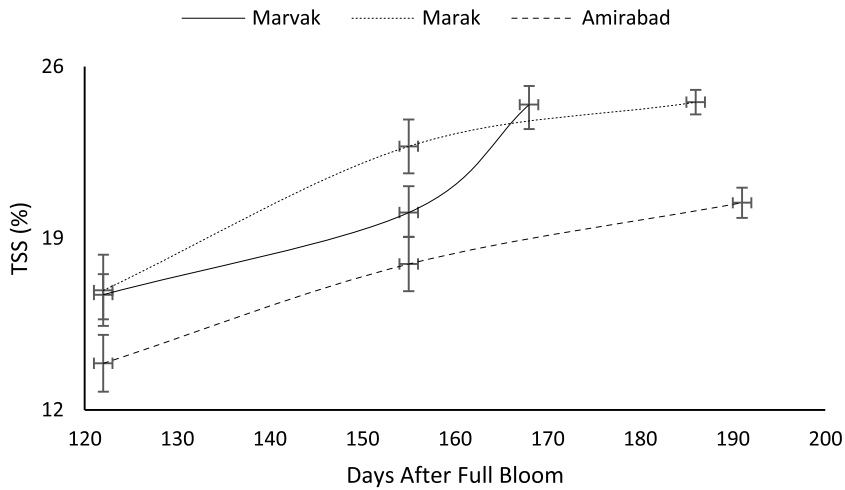


Fig. 10. Changes in barberry TSS during growth season. Data represent means \pm SE.

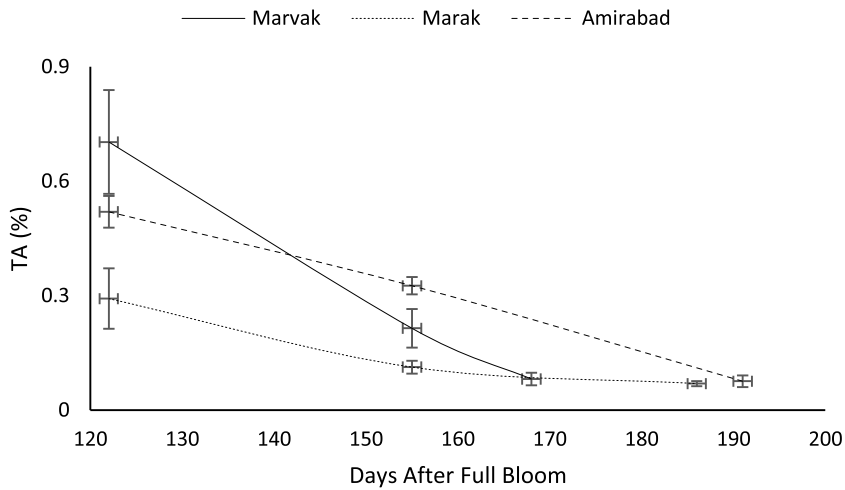


Fig. 11. Changes in barberry TA during growth season. Data represent means \pm SE.

initially increased from date 122 to 155. Figure 11 showed fast reduction of TA in all location during date 122 to 155. Evaluation of TA vs. TSS also showed a reducing manner for TA, as TSS increased (Fig. 12).

4. Conclusion

The study revealed that fruit maturity and improvement of quality may be dependent to the altitude, harvesting date and conditions created by altitude. Harvesting date was different in each location and earlier harvest obtained as altitude increased (in Marvak with higher altitude). Heat unit accumulation exponentially affected all aspects of fruit growth. We found a differences of 23 days in harvest time among different locations, which is very important from economical aspects. Altitude also improved fruit quality characters and more anthocyanin accumulated in

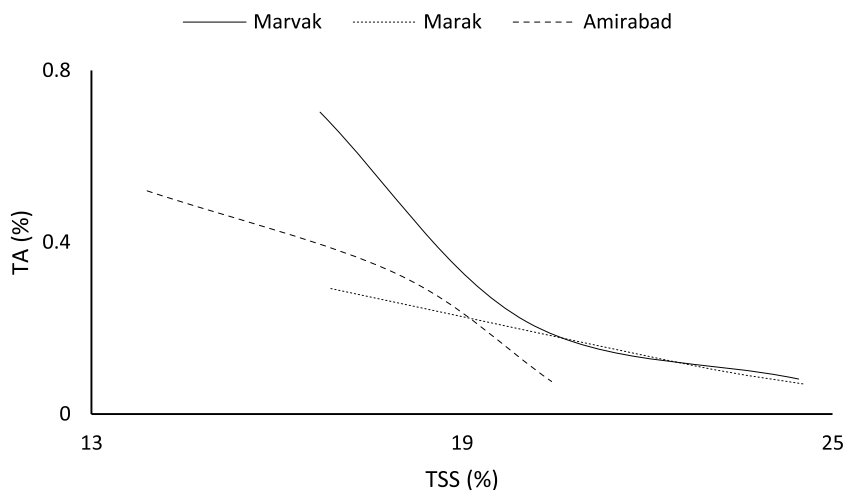


Fig. 12. Changes in TA vs. TSS of fruit during growth season.

berries produced in Marvak. Regarding to growth pattern studies, a double-sigmoidal growth pattern observed for barberry fruit. From the above observations, high qualified barberry fruit production and earlier harvest may be obtained if cultivation be done at altitudes higher than 2000 m from sea level.

Conflict of interest

None to report.

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