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Influence of ‘developmental stage’ and ‘variety’ on physicochemical characteristics, total phenolics, and antioxidant activity of melon fruits cultivated in Iran

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A B S T R A C T

Purpose: A study was carried out to investigate the influence of different fruit development stages on the physicochemical attributes, total phenolics, and antioxidant activity of two Iranian melon varieties for optimal harvest time. **Research method:** The research was conducted two times i.e. in 2023 and in 2024. It was a factorial experiment in a Completely Randomized Design (CRD) with four replications. The factors were developmental stage harvest (three stages, viz., 30, 40, and 50 days after fruit set) and variety (two varieties, viz., 'Chaghercheh' and 'Zamcheh'). **Findings:** There were significant differences among the different harvest times in all parameters evaluated for both varieties. The fresh weight and related dimensions, and thickness and percentage of pulp of the fruits increased throughout the developmental stages, while fruit firmness, peel thickness, percentages of peel and seed showed a descending trend in the same period. At 50 days after fruit set, both melon varieties exhibited high levels of total soluble solids and pH, but low titratable acidity, resulting in high maturity index. As the fruits developed and matured, levels of ascorbic acid, total phenolics, and antioxidant activity reduced dramatically in both varieties. Also, statistically significant differences were detected between the two melon varieties in all factors measured. The antioxidant activity positively correlated with total phenolics ($r = 0.910$) and ascorbic acid ($r = 0.891$). **Research limitations:** No limitations were found. **Originality/Value:** Overall, the data of this research revealed that the degree of maturity and the variety are main parameters controlling the physicochemical characteristics, total phenolics, and antioxidant activity of melon. Also, the study provides basis for optimal harvest time for 'Chaghercheh' and 'Zamcheh' melon varieties.

Keywords:

Cucumis melo L., Developmental stage, Maturity index, Variety

INTRODUCTION

Cucumis melo L. commonly known as melon belongs to the Cucurbitaceae family, and is one of the economically most important fruits worldwide (Wang et al., 2023). It is a warm season fruit and extensively cultivated in various parts of the world (temperate, subtropical, and tropical regions) because it's generally adaptable to different climatic and soil environments (Villanueva et al., 2004; Chisari et al., 2008). Fruits are usually consumed fresh as dessert and are also processed into different edibles including salad, fruit juice, ice cream, sweets, and jelly (Wang et al., 2021; Mallek-Ayadi et al., 2022). Melon is also used, traditionally, as medicine (Kolayli et al., 2010; Ibrahim et al., 2016). In recent years, the popularity of melon is mainly due to its high nutritional value and medicinal properties (Vishwakarma et al., 2017; Ezzat et al., 2019; Vanoli et al., 2023). Melon fruits contain vitamins, minerals, water-soluble sugars, carotenoids, flavonoids, phenolic compounds, amino acids, dietary fiber, and other nutrients that are essential for the human health (Ismail et al., 2010; Koubala et al., 2016; Vishwakarma et al., 2017; Zhang et al., 2020; Manchali et al., 2021; Mallek-Ayadi et al., 2022; Singh et al., 2022; Wang et al., 2023). The antioxidant, anti-inflammatory, and antimicrobial properties of melon have been reported (Maietti et al., 2012; Ezzat et al., 2019; Wang et al., 2023).

The quality of melon fruits comprise a range of physical characteristics (fruit size, shape, texture, firmness, etc.) and chemical composition (acidity, sugars, vitamins, carotenoids, flavonoids, volatile compounds, etc.), which are important for consumer acceptability and produce/product marketability (Miccolis & Saltveit, 1991; Villanueva et al., 2004; Beaulieu & Lea, 2007; Ghanbarian et al., 2007; Guler et al., 2013; Falah et al., 2014; Pontes et al., 2021; Vanoli et al., 2023). However, required fruit quality must be achieved before harvest because after harvest all fruit attributes can only be maintained/preserved, not improved. Hence, the importance of stage of harvest with respect to the fruit's development in determining the quality, marketability, and the storage life (Villanueva et al., 2004; Seo et al., 2018; Zulfikar et al., 2020; Vanoli et al., 2023). Various reports show significant variations in physical and chemical properties of different varieties of melon during the different developmental stages of the fruit (Miccolis & Saltveit, 1991; Villanueva et al., 2004; Burger et al., 2009; Ghanbarian et al., 2007; Beaulieu & Lea, 2007; Chisari et al., 2008; Koubala et al., 2016; Zulfikar et al., 2020; Pontes et al., 2021; Li et al., 2025). These varied reports may supply important information to the user/consumer in terms of need for quality fruit. Thus, understanding these variations/changes during fruit development is essential in the direction of optimizing harvesting time for quality produce.

Iran is one of the major world's melons producing and exporting countries; recognized for its diverse and high quality melon fruit varieties. Nevertheless, some of the salient melon varieties of Iran origin, including 'Chaghercheh' and 'Zamcheh' are less known outside Iran. These varieties are widely cultivated in Golestan province, and are major source of income to local farmers. The 'Zamcheh' melon fruit is distinguished by its elliptical shape, smooth and shiny surface, yellow peel color with light green-striped, and creamy yellowish pulp color. The 'Chaghercheh' melon fruit is roughly cylindrical, elongated, netted and rough surfaced, light green peel color with irregular dark green-striped, and pale greenish creamy pulp color. The both varieties are climacteric, resistant to abiotic (drought and salinity stress) and biotic stresses (including fusarium wilt, downy mildew, and powdery mildew), and relatively high yielding. The 'Chaghercheh' and 'Zamcheh' melon varieties are highly popular in Iran due to their refreshing, crunchy, sweet, flavorful, and fragrant fruits properties, thus enhancing their high desirability for the fresh market as well as for processing. The economic, nutritional, and related relevant potentials of these varieties are, however, restricted domestically/nationally.

Despite the increasing domestic patronage of the various melon varieties grown in different regions of Iran, the physical characteristics and chemical composition of some of the melon fruit varieties (particularly ‘Chaghercheh’ and ‘Zamcheh’ varieties) during fruit development have not been evaluated in detail yet. In addition, adequate determination of harvest time vis-à-vis (visa vie) or in relation to stages of the fruit development has widespread application for the fruit’s well-being via production practices including irrigation, fertilization, and management of pests and diseases. The objective of the study was to investigate the influence of different fruit development stages on the physicochemical attributes, total phenolics, and antioxidant activity of two Iranian melon varieties (‘Chaghercheh’ and ‘Zamcheh’) for optimal harvest time.

MATERIALS AND METHODS

Experimental site and experimental design

This research was carried out on ‘Chaghercheh’ and ‘Zamcheh’ Iranian melon varieties at Gonbad Kavous University. The site is located on the north eastern part of Iran; 37°14’37’’N latitude, 55°09’57’’E longitude; 52 m above sea level; and enclaved by semi-arid climate. The study was done two times i.e. in 2023 and in 2024. It was a factorial experiment in a Completely Randomized Design (CRD) with four replications (five fruits per replication). The factors were developmental stage harvest (three stages, viz., 30, 40, and 50 days after fruit set) and variety (two varieties, viz., ‘Chaghercheh’ and ‘Zamcheh’).

Experimental material, cultural/field practices, and soil characteristics

The seeds of the melon varieties (‘Chaghercheh’ and ‘Zamcheh’) for the experiment were obtained from Iranian farmers in Gonbad Kavous County, Golestan Province, Iran. Before sowing, seeds were soaked in distilled water for 24 hours after which they were planted in plastic trays at the middle of April in the greenhouse. At 2 to 4 true leaf stage, seedlings were taken to the field for transplanting, which is traditionally practiced by Iranian melon producers. The seedlings were transplanted at a spacing of 0.5 m within rows and 2 m between rows. The plants were grown under drip irrigation and accompanied with cultural practices (including pruning, thinning, and fertigation). Sandy-loam, EC=4.12 dS.m⁻¹, and pH=7.21 characteristics of the experimental soil.

Sampling

In order to obtain homogeneous samples, approximately 500 flowers were tagged at anthesis stage during peak flowering for each variety. These flowers were open-pollinated, and only two fruits per plant were allowed to develop. The developing fruits were hand-harvested at three different developmental stages according to fruit age, namely, 30, 40, and 50 days after fruit set for optimal harvest time to be determined by the physicochemical quality of the fruit at each of the test-developmental stages. Each of the harvest times of the 30, 40, and 50 days after fruit set represented the fruit developmental stages, namely, unripe, half-ripe, and full-ripe, respectively. Fruit samples (consist of 20 fruits per harvest) were collected based to size, shape, peel color, and lack of blemishes in four replicates (five fruits per replication) during all three different developmental stages from both varieties. Melons were transported by a ventilated car to the laboratory soon after harvest, where fruits were inspected carefully for possible damages and samples with defects were discarded. Fruits were washed with running tap water and thoroughly cleaned, and then utilized to the analyses.

Chemicals

All reagents, solvents, and standards used for the analysis were of analytical grade (Merck, Darmstadt, Germany).

Determination of physical characteristics

Twenty fruits of each variety per each developmental stage were individually analyzed for physical characteristics. The procedure of Ghanbarian et al. (2007) was adapted for measurements of physical properties. Fruits were weighed using a digital weighing balance (Veidt, Jiangsu, China). The length and diameter of the fruits were measured with a digital vernier caliper (Mitutoyo, Japan). The measurement of fruit length was determined via measurement of distance between the proximal and distal points of the fruit. The maximum width (normally towards the proximal point) of the fruit, as measured in the direction perpendicular to the polar axis, is defined as the diameter. Fruit firmness was determined by a hand-held penetrometer (8 mm diameter probe) (FT 327, Wagner, USA) on four opposite equatorial sides of each fruit and the results averaged and expressed as Newtons (N). After measuring the whole fruit size, peel was uniformly separated from the fruit using a disinfected stainless steel knife. Also, the length and diameter of seed cavity were measured with a digital vernier caliper as mentioned above. The peel, pulp, and seeds were manually isolated from the fruits, total peel, pulp, and seeds per fruit were measured as explained above. The measurements of the peel and pulp thickness were made using the digital vernier caliper. The moisture content of pulp was estimated gravimetrically by drying at 105°C (AOAC, 2002).

Determination of chemical characteristics

Fresh pulp samples were mashed into a container using a blender (Solac 850, Vitoria, Spain) and the obtained juice was immediately used for the determination of the following parameters. The total soluble solids contents were determined with a digital refractometer (Erma RHB-32, Tokyo, Japan) and results reported in °Brix. The titratable acidity was determined by titration to pH 8.1 with 0.1 M NaOH solution and expressed as mg citric acid per 100 g of fresh weight (AOAC, 2002). The pH measurement was performed using a digital pH meter (Metrohm 780, Herisau, Switzerland) at 21°C. Maturity index was calculated by dividing total soluble solids to titratable acidity. It is responsible for the taste and flavor of melon fruit, acting as a good indicator of fruit ripening. Ascorbic acid was measured directly by UV-Vis spectrophotometry (Cecil CE2041, Cambridge, UK) at a wavelength of 521 nm method developed by Rahman et al. (2007). Briefly, 10 g of blended sample was mixed with 50 ml of metaphosphoric acid (5%)-acetic acid (10%) solution. The mixture was transferred into a 100 ml volumetric flask and was shaken gently until a homogeneous dispersion was obtained. Then it was diluted up to the mark by the metaphosphoric acid (5%)-acetic acid (10%) solution. Then the solution was filtered and the clear filtrate was collected for the determination of ascorbic acid. Results were expressed as mg ascorbic acid per 100 g of fresh weight ($\text{mg}\cdot 100\text{g}^{-1}$ FW).

Determination of total phenolics

Concentration of total phenolics was typically determined using Folin-Ciocalteu assay method, which is often expressed as gallic acid equivalents (GAE) (Singleton et al., 1999). In brief, 1 g of pulp was extracted with 10 ml methanol (85%). Then, 250 μL of this extract was dissolved in a 250 μL of sterile distilled water, and samples were mixed with 2.5 mL of 10-fold-diluted Folin-Ciocalteu reagent and 2 mL of 7.5% sodium carbonate. The mixture was shaken for 1.5 to 2 h before the absorbance was measured by a UV-Vis spectrophotometer

(Cecil CE2041, Cambridge, UK) at 765 nm. The results were expressed as mg gallic acid equivalents per 100 g of fresh weight ($\text{mg}\cdot 100\text{g}^{-1}$ FW).

Determination of antioxidant activity

Antioxidant activity was determined by the DPPH (1,1-diphenyl-2-picrylhydrazyl) method reported by Ismail et al. (2009). Briefly, 1 g of pulp was extracted with 10 mL methanol (85%). Then, 1 mL of this extract was mixed with 2 mL of DPPH ($0.15 \text{ mmol}\cdot\text{L}^{-1}$) in methanol. The mixtures were shaken vigorously and left to stand for 30 min (under dark condition). The control was prepared by adding 2 mL of DPPH to 1 mL methanol. Absorbance of the resulting solution was measured at 517 nm by a UV-Vis spectrophotometer (Cecil CE2041, Cambridge, UK). The antioxidant activity was calculated using the following equation (1):

$$\text{Antioxidant activity (\%)} = [1 - (\text{Absorbance}_{\text{sample 517 nm}} / \text{Absorbance}_{\text{control 517 nm}})] \times 100 \quad (1)$$

Statistical analysis

Data for the two years' experiments were combined for analysis. Analysis was done by employing the Statistical Analysis System (SAS) software version 9.1 using analysis of variance (ANOVA) and differences among means were determined for significance at $P \leq 0.05$ using Tukey's test. Pearson correlation analysis was performed to identify the relationship between the different physical and chemical characteristics.

RESULTS AND DISCUSSION

Physical characteristics

The influence of different fruit development stages on fruit fresh weight, fruit length, fruit diameter, and fruit length to diameter ratio of two melon varieties is shown in Table 1. The data showed that the fruit fresh weight increased significantly throughout the fruit's developmental stages, with values ranging from 2158.62 to 2941.17 g for 'Chaghercheh' and from 1409.54 to 2438.12 g for 'Zamcheh'. In both varieties, the length and diameter of the fruits increased progressively during fruit development. Also, the length to diameter ratio of fruit showed a decreasing trend with the advance in fruit development for both varieties, while varying from elongated to round shape. Similar results were reported by Miccolis and Saltveit (1991), Villanueva et al. (2004), Ghanbarian et al. (2007), Ahmed (2009), and Koubala et al. (2016) for different melon varieties. The increase in fresh weight and related dimensions of the fruits are typical of the pattern of fruit growth established for many other fruit crops. Both melon varieties showed sigmoidal growth curves, as reiterated by McCollum et al. (1988), and that the increases could be attributed to division and elongation of cells and nutrient accumulation in the fruits (Ghanbarian et al., 2007; Koubala et al., 2016). Variation in fresh weight and related dimensions of the fruit were observed among the two melon varieties and the differences were statistically significant. The maximum fresh weight, length, diameter, and length to diameter ratio of the fruit were found in 'Chaghercheh'. Thus, one can say that there is a close relation between fruit weight and the related dimensions of the fruit. Pontes et al. (2021) indicated that variations in fresh weight, length, diameter, and length to diameter ratio of melon fruit could be influenced by variety, which is in agreement with the present study.

Table 1. Influence of different fruit development stages on fruit fresh weight (FFW), fruit length (FL), fruit diameter (FD), fruit length/diameter (FL/D), and fruit firmness (FF) of two melon varieties.

Varieties	Days after fruit set	FFW (g)	FL (mm)	FD (mm)	FL/D	FF (N)
'Chagherche'	30	2158.62±28.09 ^d	225.51±5.81 ^b	167.95±5.69 ^{bc}	1.34±0.04 ^a	35.43±3.13 ^a
	40	2698.06±31.55 ^b	238.80±6.15 ^{ab}	181.49±6.82 ^{ab}	1.32±0.03 ^{ab}	29.25±2.55 ^{ab}
	50	2941.17±29.70 ^a	244.36±4.66 ^a	189.78±7.72 ^a	1.28±0.05 ^{abc}	20.66±2.12 ^{cd}
'Zamcheh'	30	1409.54±27.04 ^e	174.25±5.87 ^d	145.18±6.36 ^d	1.20±0.04 ^{bc}	28.44±3.16 ^{ab}
	40	2125.61±30.09 ^d	187.78±4.93 ^c	159.99±8.61 ^{cd}	1.17±0.06 ^c	22.28±2.64 ^{bc}
	50	2438.12±25.64 ^c	190.05±6.63 ^c	164.26±6.97 ^{bc}	1.16±0.05 ^c	14.02±2.10 ^d

Data of the two years were combined.

Means in each column with different letters are significantly different ($P < 0.05$); ± standard deviation.

As shown in Table 1, fruit firmness decreased significantly with the advance in fruit development, with values ranging from 35.43 to 20.66 N for 'Chaghercheh' and from 28.44 to 14.02 N for 'Zamcheh'. Similar pattern of changes have been reported for other melon varieties (Miccolis & Saltveit, 1991; Ghanbarian et al., 2007; Beaulieu & Lea, 2007; Chisari et al., 2008). Nishiyama et al. (2007) stated that fruit firmness is an important ripening and quality indicator that consumers use to decide whether to purchase a melon fruit, and that it is also useful in the estimation of harvest maturity and storability. Most fruits begin ripening process by losing firmness due to the dismantling of the fruit cell wall. Chisari et al. (2008) concluded that melon fruit softening during development is as a result of the action of cell wall-degrading enzymes such as polygalacturonase and pectin methylesterase. The present study showed that the values of fruit firmness were significantly different between the two melon varieties studied, which was in agreement with the findings observed by Miccolis and Saltveit (1991), Ghanbarian et al. (2007), and Chisari et al. (2008).

As the fruits advanced in development, length and diameter of seed cavity increased progressively in both varieties. In contrast, the length to diameter ratio of seed cavity had shown a decreasing trend during fruit development (Table 2). In both varieties, the pulp thickness showed significant increase, whereas peel thickness decreased with the advance in fruit development (Table 2). It is assumed that these changes, depending on the developmental stage would be due to increase in the fruit growth rate. Table 2 shows the variations in length and diameter of seed cavity, peel thickness, and pulp thickness observed with the varieties studied. The highest length and diameter of seed cavity, peel thickness, and pulp thickness were observed with 'Chaghercheh'. Pontes et al. (2021) showed that length and diameter of seed cavity, and pulp thickness were different between varieties of melon studied, which is in agreement with the present study.

Table 2. Influence of different fruit development stages on seed cavity length (SCL), seed cavity diameter (SCD), seed cavity length/diameter (SCL/D), pulp thickness (PT), and peel thickness (PeT) of two melon varieties.

Varieties	Days after fruit set	SCL (mm)	SCD (mm)	SCL/D	PT (mm)	PeT (mm)
'Chagherche'	30	174.73±2.47 ^b	114.88±3.42 ^{bc}	1.52±0.05 ^a	49.21±1.87 ^b	2.70±0.03 ^a
	40	182.44±2.50 ^{ab}	124.58±4.12 ^{ab}	1.46±0.04 ^{ab}	53.32±1.42 ^{ab}	2.68±0.05 ^a
	50	189.30±2.78 ^a	131.38±3.90 ^a	1.44±0.05 ^{ab}	55.31±1.69 ^a	2.64±0.03 ^a
'Zamcheh'	30	127.76±3.01 ^{de}	94.96±3.34 ^d	1.35±0.04 ^{bc}	48.78±1.69 ^b	2.27±0.04 ^b
	40	133.75±2.69 ^{cd}	103.82±3.87 ^{cd}	1.30±0.05 ^c	52.72±1.83 ^{ab}	2.21±0.05 ^b
	50	136.46±3.08 ^c	106.17±4.04 ^{cd}	1.28±0.04 ^c	54.05±1.62 ^a	2.18±0.03 ^b

Data of the two years were combined.

Means in each column with different letters are significantly different ($P < 0.05$); ± standard deviation.

Table 3. Influence of different fruit development stages on pulp fresh weight (PFW), pulp percentage (PP), peel fresh weight (PeFW), peel percentage (PeP), seed fresh weight (SFW), seed percentage (SP), and pulp moisture content (PM) of two melon varieties.

Varieties	Days after fruit set	PFW (g)	PP (%)	PeFW (g)	PeP (%)	SFW (g)	SP (%)	PM (g.100g ⁻¹)
'Chagherche'	30	1333.80±35.61 ^d	61.78±2.12 ^d	617.57±29.05 ^a	28.61±2.42 ^a	207.25±12.67 ^b	9.60±0.67 ^a	90.72±1.92 ^a
	40	1825.98±32.34 ^b	67.67±1.77 ^{cd}	632.95±31.58 ^a	23.46±1.80 ^{ab}	229.12±20.14 ^a	8.49±0.74 ^b	88.18±1.96 ^{ab}
	50	2069.09±38.39 ^a	70.34±2.19 ^{bc}	635.56±32.65 ^a	21.61±1.92 ^{abc}	236.52±17.25 ^a	8.04±0.69 ^b	84.45±1.78 ^b
'Zamchek'	30	1002.93±42.71 ^e	71.21±2.09 ^{bc}	300.36±26.66 ^c	21.25±2.03 ^{abc}	106.25±15.36 ^c	7.53±0.63 ^b	91.19±1.98 ^a
	40	1624.27±28.89 ^c	76.41±2.10 ^{ab}	369.53±24.93 ^{bc}	17.44±1.87 ^{bc}	121.80±19.12 ^c	5.73±0.60 ^c	88.54±1.77 ^{ab}
	50	1932.79±45.68 ^{ab}	79.40±2.02 ^a	379.41±35.09 ^{bc}	15.56±1.66 ^c	125.91±18.98 ^c	5.17±0.58 ^c	86.28±1.64 ^{ab}

Data of the two years were combined.

Means in each column with different letters are significantly different ($P < 0.05$); \pm standard deviation.

In both varieties, the pulp percentage increased significantly, while percentages of peel and seed declined significantly during fruit maturity (Table 3), as previously reported for different melon varieties studied (Villanueva et al., 2004; Ghanbarian et al., 2007; Koubala et al., 2016). More than half of the whole fruit weight recorded during the many stages of fruit development consisted of the pulp. As shown in Table 3, there were significant differences between the two varieties in terms of their pulp, peel, and seed percentages. The highest percentage of pulp was found with 'Zamchek' (mean of 75.77%), while 'Chaghercheh' had the highest peel and seed percentages (mean of 24.56% and 8.71%, respectively). In other words, the pulp percentage was inversely correlated to peel and seed percentages. These results agree with those previously reported by Villanueva et al. (2004), and Ghanbarian et al. (2007).

The results in this experiment showed that the pulp moisture content decreased significantly throughout fruit development in both varieties (Table 3), which was consistent with previous reports (Villanueva et al., 2004; Ghanbarian et al., 2007; Koubala et al., 2016). This decrease in pulp moisture content during fruit development may be due to accumulation of reserve nutrients in the pulp. A variation in pulp moisture content was observed with the two varieties, and the highest level of pulp moisture obtained with 'Zamchek' (Table 3). Similar data were noted for other melon varieties (Villanueva et al., 2004; Ghanbarian et al., 2007).

Because of its bigger size, 'Chaghercheh' is recommended for the local fresh market/consumption. It is also recommended for distant markets due to its highest firmness and peel thickness records. On the other hand, 'Zamchek', which recorded a higher pulp percentage and least percentages of peel and seed, is necessarily highly recommended for the food processing industry.

Total soluble solids, titratable acidity, pH, and maturity index

Significant increases in total soluble solids content were observed from 7.81 to 14.07 °Brix for 'Chaghercheh', and from 8.79 to 16.23 °Brix for 'Zamchek' along the fruit developmental stages (Fig. 1). This trend has been reported previously (Miccolis & Saltveit, 1991; Villanueva et al., 2004; Ghanbarian et al., 2007; Beaulieu & Lea, 2007; Chisari et al., 2008; Pontes et al., 2021). This could be due to the hydrolysis of starch to soluble sugars during fruit maturation. As the fruit developed and matured progressively, titratable acidity level decreased significantly (Fig. 2), while pH value increased rapidly (Fig. 3) in both varieties. Several authors have recorded similar data (Villanueva et al., 2004; Ghanbarian et al., 2007; Beaulieu & Lea, 2007; Chisari et al., 2008; Aminah & Anna, 2011; Koubala et al., 2016;

Pontes et al., 2021). Burger et al. (2003) stated that the changes in concentrations of titratable acidity and pH during fruit development processes are related to the developmental changes in organic acid levels. In line with the present study, titratable acidity inversely correlated with pH, as reported by Ghanbarian et al. (2007), and Pontes et al. (2021). With both varieties, the maturity index increased progressively as fruit development advanced (Fig. 4), which was consistent with previous reports by Villanueva et al. (2004), and Ghanbarian et al. (2007). This could be attributed to an increase in total soluble solids content and a decrease in titratable acidity level (Miller et al., 2020).

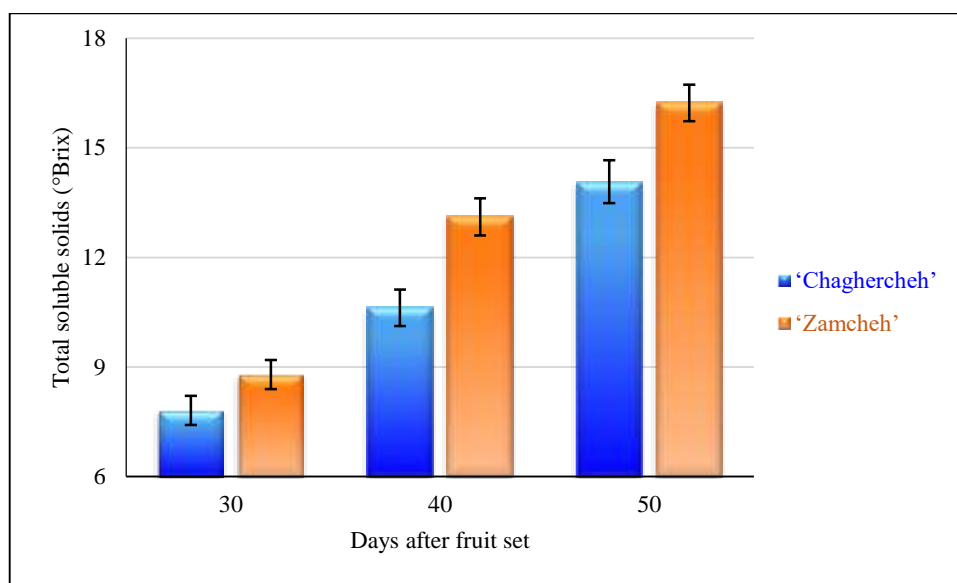


Fig. 1. Influence of different fruit development stages on content of total soluble solids of two melon varieties (Data of the two years were combined; the vertical bars represent standard error of the means).

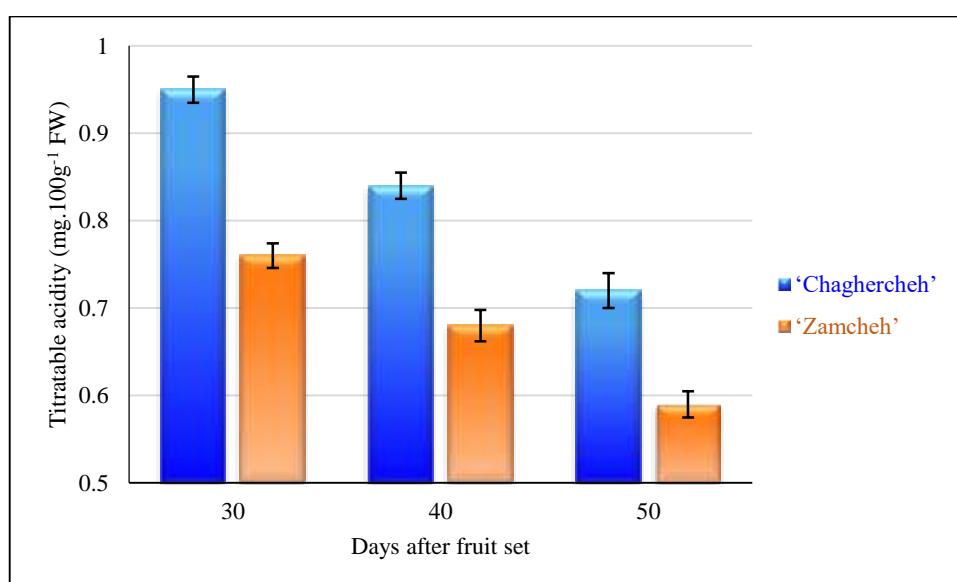


Fig. 2. Influence of different fruit development stages on content of titratable acidity of two melon varieties (Data of the two years were combined; the vertical bars represent standard error of the means).

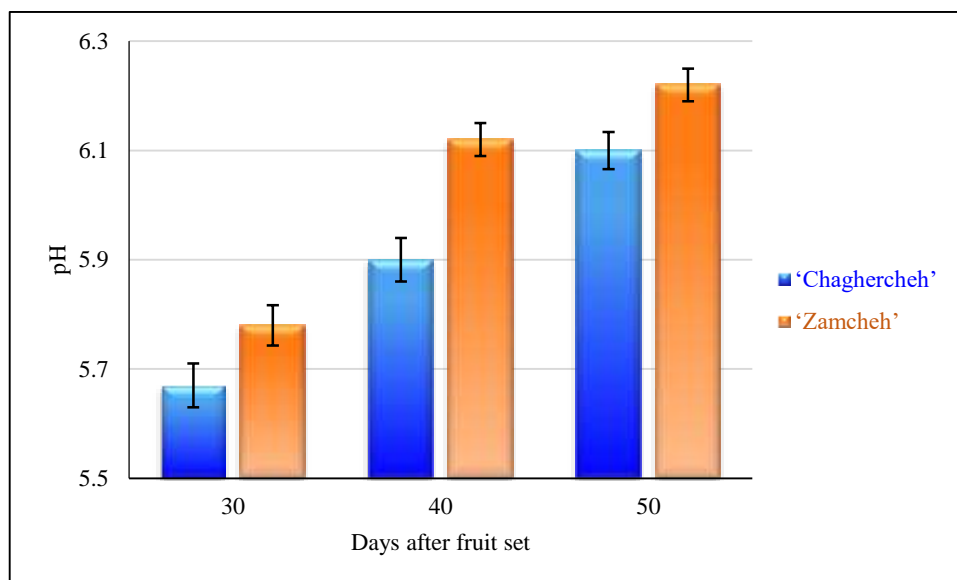


Fig. 3. Influence of different fruit development stages on content of pH of two melon varieties (Data of the two years were combined; the vertical bars represent standard error of the means).

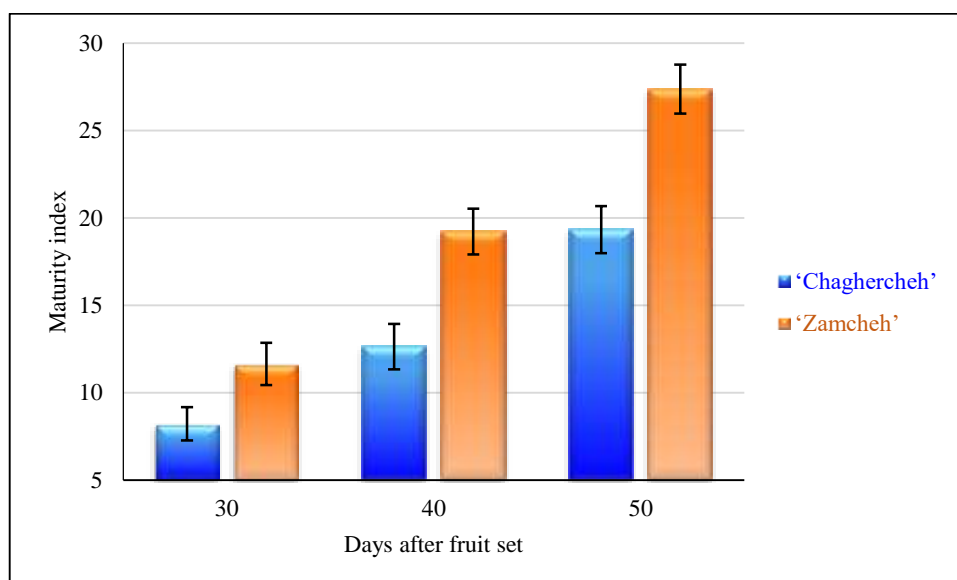


Fig. 4. Influence of different fruit development stages on maturity index of two melon varieties (Data of the two years were combined; the vertical bars represent standard error of the means).

Significant differences were observed with the two melon varieties for total soluble solids, titratable acidity, pH, and maturity index results (Fig. 1, 2, 3, 4). The highest total soluble solids, pH, and maturity index values were found with 'Zamcheh', while 'Chaghercheh' recorded the highest titratable acidity level. Previous researches have also reported variable ranges of total soluble solids, titratable acidity, pH, and maturity index readings (Villanueva et al., 2004; Ghanbarian et al., 2007; Beaulieu & Lea, 2007; Chisari et al., 2008; Tomaz et al., 2009; Kolayli et al., 2010; Aminah & Anna, 2011; Guler et al., 2013; Bianchi et al., 2016; Li et al., 2019; Pontes et al., 2021; Mallek-Ayadi et al., 2022), which was consistent with readings of the current study. Thus, variety type plays an important role in terms of total soluble solids, titratable acidity, pH, and maturity index capacities of the melon fruit. Both varieties were suitable for the fresh market/consumption and as well for

processing, such as in the production of juice, since all are of high levels of total soluble solids and low titratable acidity content.

Ascorbic acid

A significant decrease in the level of ascorbic acid was observed during the later stages of the fruit development processes for both varieties (Fig. 5). Similar developmental changes were noted by Beaulieu et al. (2007), Koubala et al. (2016), and Zulfikar et al. (2020). Also, the concentration of ascorbic acid varied significantly in both varieties (Fig. 5). At 50 days after fruit set, the value of ascorbic acid was 19.47 mg.100g⁻¹ FW for 'Chaghercheh', and 17.80 mg.100g⁻¹ FW for 'Zamcheh'. Previous studies have also presented variable ranges of ascorbic acid results in context for other melon varieties (Fundo et al., 2018; Miller et al., 2020; Mallek-Ayadi et al., 2022; Pontes et al., 2021).

Ascorbic is an important reactive oxygen species (ROS) scavenger during fruit development, due to its powerful antioxidant character (Zheng et al., 2022; Arabia et al., 2024). Increased ROS production is mainly predominant in fruits during the transition of chloroplast into chromoplast, at the latest stages of fruit ripening, and massively produced during over-ripening (Wheeler et al., 2015; Maruta et al., 2016; Munoz & Munne-Bosch, 2018; Decros et al., 2019). In this research, ascorbic acid content had shown a decreasing trend during the fruit development, especially at the latest stages. As mentioned above, the latest stages of the fruit ripening processes were accompanied by a rise in ROS production. Thus, the reduction of ascorbic acid concentration during the latest stages of the fruit development processes could be due to the increased accumulation of ROS, leading to oxidation of ascorbic acid. This oxidation is achieved by increasing the expression of ascorbate peroxidase (APX) enzyme, and conversion of ascorbic acid to monodehydroascorbic acid and dehydroascorbic acid (Van Aken, 2021; Zheng et al., 2022; Arabia et al., 2024). Based on these findings, the ascorbic acid content was significantly affected by variety. This may be related to differences in the expression levels of genes related to ascorbic acid synthesis and metabolism in both varieties, as reiterated by Zheng et al. (2022).

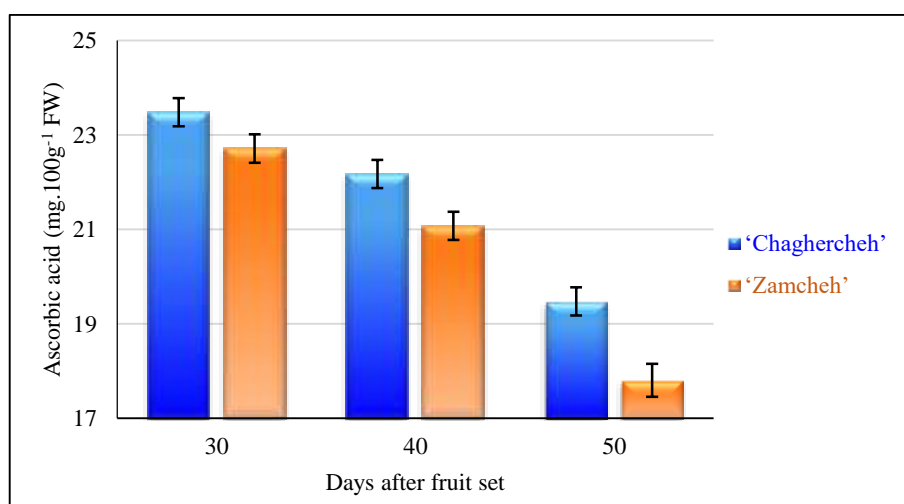


Fig. 5. Influence of different fruit development stages on content of ascorbic acid of two melon varieties (Data of the two years were combined; the vertical bars represent standard error of the means).

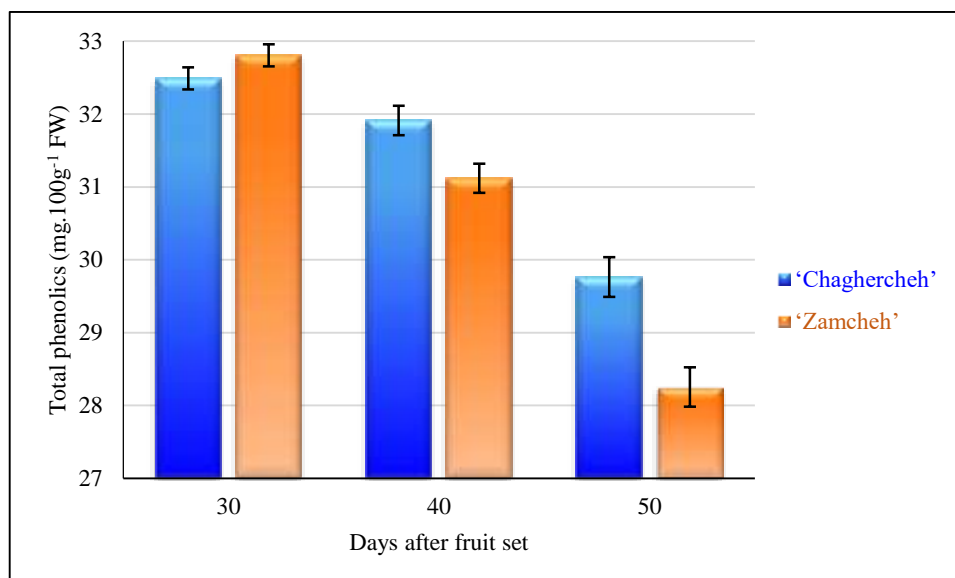


Fig. 6. Influence of different fruit development stages on content of total phenolics of two melon varieties (Data of the two years were combined; the vertical bars represent standard error of the means).

Total phenolics

Total phenolics content decreased significantly with the advance in fruit development for both varieties (Fig. 6). Previous researches have also stated that total phenolics levels decreased substantially during the fruit growth period in other melon varieties (Koubala et al., 2016; Chisari et al., 2008; Aminah & Anna, 2011; Motomura et al., 2018). Significant difference in total phenolics concentrations were observed between the two varieties (Fig. 6). The contents of total phenolics were higher with 'Chaghercheh' (29.76 mg.100g⁻¹ FW) than with 'Zamcheh' (28.25 mg.100g⁻¹ FW), at 50 days after fruit set. In other studies, different values of total phenolics have been reported for different melon varieties (Chisari et al., 2008; Ismail et al., 2010; Koubala et al., 2016; Miller et al., 2020; Mallek-Ayadi et al., 2022; Wang et al., 2023) reiterating the effect of variety on the evolution of total phenolics contents in the melon.

Phenolic compounds are usually involved in defense responses to biotic and abiotic stresses in the plant (Kumar et al., 2023). They also play crucial roles in various physiological processes including growth, fertility, coloring, aroma, and flavor of fruit (Balasundram et al., 2006). Phenolic compounds not only play critical roles in plant physiology, but also are vital for nutrition and health of human due to their antioxidant, antimicrobial, anti-inflammatory, and anti-proliferative properties (Dai & Mumper, 2010; Derong et al., 2016; Matsumura et al., 2023). During the fruit development processes, levels of total phenolics trended downward. This decrease might be related to reduction in phenolic compounds synthesis or to increases in the expression of enzymes involved in catabolism of phenolic compounds with consequent conversion to other substances (Machado et al., 2013; Zhang et al., 2022). In addition to ripeness, differences in total phenolics contents were highly dependent on the variety. This may be related to variations in the biosynthesis of phenolic secondary metabolites in both varieties, as mentioned by Wang et al. (2023).

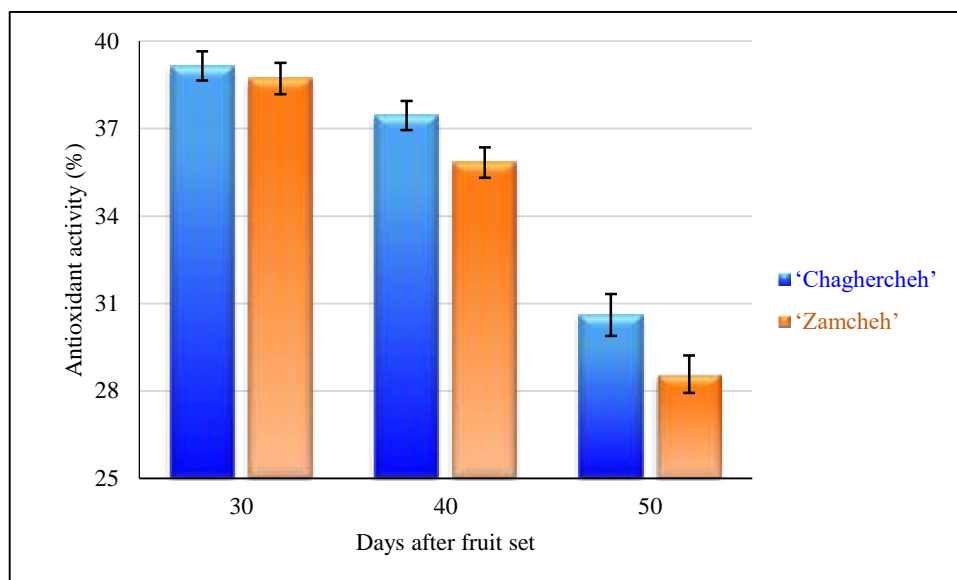


Fig. 7. Influence of different fruit development stages on antioxidant activity of two melon varieties (Data of the two years were combined; the vertical bars represent standard error of the means).

Antioxidant activity

Significant changes in antioxidant activity were recorded during melon fruit ripening process in both varieties (Fig. 7). The highest antioxidant activity occurred at 30 days after fruit set, but as the ripening proceeded, a decreasing trend was observed in both varieties. Previous studies have also presented that antioxidant activity differed markedly throughout fruit development period in other melon varieties (Aminah & Anna, 2011; Koubala et al., 2016; Zulfikar et al., 2020). As shown in Figure 7, there were significant differences in antioxidant activity between the two varieties. At 50 days after fruit set, the antioxidant activity was 30.61% for 'Chaghercheh' and 28.57% for 'Zamcheh'. Several authors have also recorded variable ranges of antioxidant activity for other melon varieties (Aminah & Anna, 2011; Maietti et al., 2012; Koubala et al., 2016; Motomura et al., 2018; Zulfikar et al., 2020; Miller et al., 2020; Manchali et al., 2021; Wang et al., 2023). Variety type also plays an important role in antioxidant activity of melon fruit.

The antioxidants, natural or synthetic forms, are the most important compounds that scavenge free radicals (Zehiroglu & Sarikaya, 2019). Natural antioxidants such as vitamins, carotenoids, and polyphenolic compounds, are constituents of many fruits and vegetables, for which fruits and vegetables are often regarded as important foods (Shebis et al., 2013; Zehiroglu & Sarikaya, 2019; Miller et al., 2020). The antioxidants have drawn increasing attention due to their marked effects in the prevention of various diseases caused by oxidative stress such as cancer, anaemia, and cardiovascular diseases (Vaibhav et al., 2011). The data of this study confirmed that the antioxidant activity declined, along with a decrease in total phenolics and ascorbic acid contents, as the fruits developed and matured. Thus, it can be concluded that antioxidant activity is positively correlated with the levels of ascorbic acid and total phenolics, as previously indicated by Dai and Mumper (2010), and Matsumura et al. (2023). Decrease in antioxidant activity throughout fruit development could be due to reduction levels of ascorbic acid and total phenolics. Antioxidant activity differed markedly between the two varieties, which can be explained with differences in contents of antioxidants such as ascorbic acid and phenolic compounds.

Correlation analysis

Pearson correlation coefficients of physical and chemical characteristics of two melon varieties at different fruit developmental stages are shown in Figure 8. Fruit fresh weight had a perfect positive correlation with fruit length ($r = 0.856$), fruit diameter ($r = 0.872$), seed cavity length ($r = 0.839$), and seed cavity diameter ($r = 0.8012$). Maturity index had a significant positive correlation with total soluble solids ($r = 0.969$) and pH ($r = 0.899$), but a significant negative correlation with titratable acidity ($r = -0.906$) and fruit firmness ($r = -0.896$). Antioxidant activity positively correlated with total phenolics ($r = 0.910$) and ascorbic acid ($r = 0.891$). Similar findings have been reported by Li et al. (2011), Miller et al. (2020), and Wang et al. (2023).

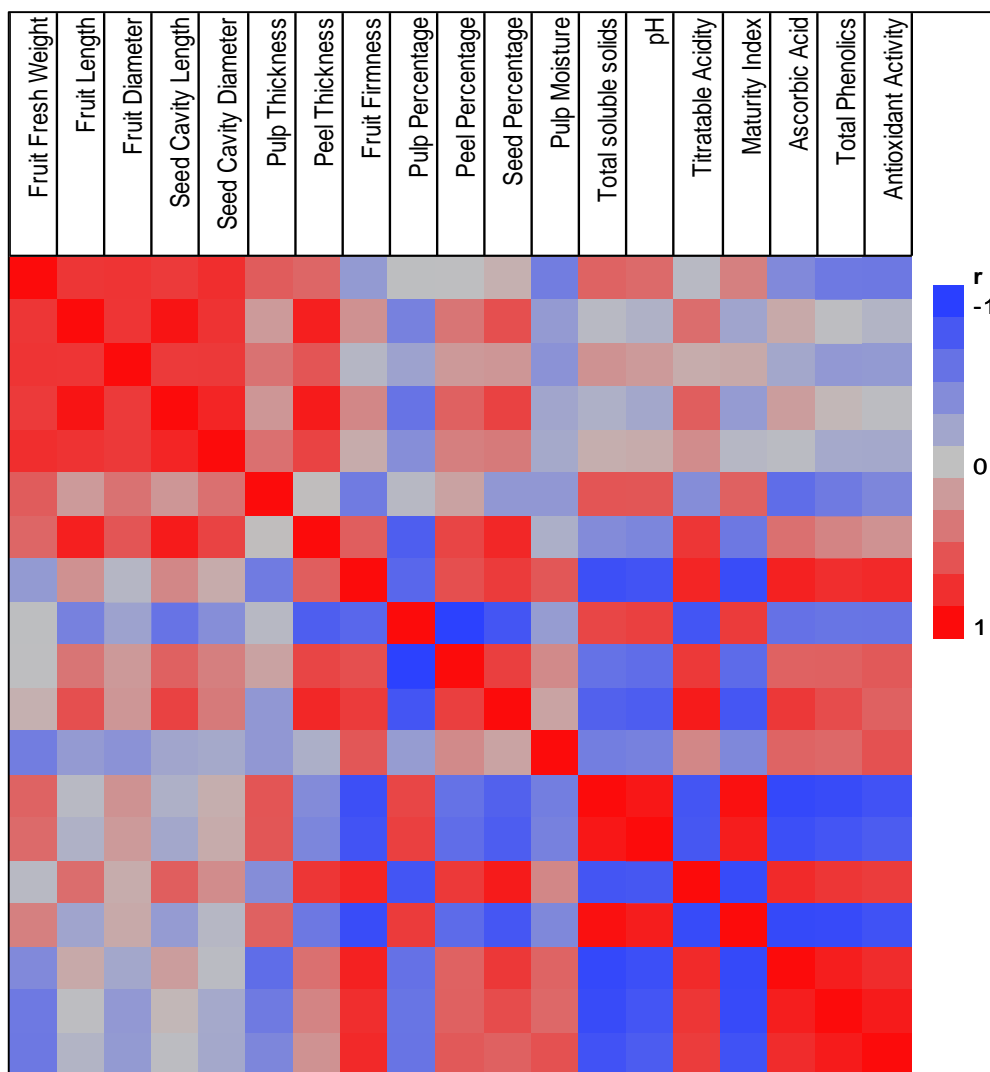


Fig. 8. Heat map of Pearson's correlation coefficients among the physical and chemical characteristics of two melon varieties (Gradient color barcodes at the right indicate the minimum value in blue and the maximum in red).

CONCLUSIONS

The findings of this experiment showed that the different fruit developmental stages significantly influenced the physicochemical characteristics, total phenolics, and antioxidant activity of melon fruit. These changes, from fruit set to ripening, clearly explained its growth, development, and maturation stages of melon fruit. Both varieties showed identical evolution trends throughout their growth and development. The period between 40 and 50 days after fruit set seemed to be the most active time of fruit ripening in both varieties; a finding that will enhance growers' efforts towards appropriate harvest time for quality produce. Statistically significant differences were observed between the two melon varieties in all factors evaluated. Since the two varieties used in this research were grown in the same location with similar agronomic practices, any observed variations would have been due to the genetic constitution of the varieties studied. The antioxidant activity showed a perfect positive correlation with total phenolics ($r = 0.936$) and ascorbic acid ($r = 0.869$). The study provides basis for optimal harvest time for 'Chaghercheh' and 'Zamcheh' melon varieties. The study also highlights the transportation abilities, processing abilities, and related postharvest qualities relevant to industry. Some of the findings from the study are also a call on breeders' efforts towards improved cultivars/varieties of melon for the horticulture industry. However, since there are many melon cultivars/varieties in Iran which are consumed fresh or processed locally, more studies on the physical and chemical properties and other related research efforts are required to improve on them to meet export market qualities.

Conflict of interest

The authors have no conflict of interest to report.

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