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ORIGINAL PAPER

Physicochemical and Enzymatic Properties of Five Kiwifruit Cultivars during Cold Storage

Mahboube Zolfaghari · Mohammad Ali Sahari · Mohsen Barzegar · Hamidreza Samadloiy

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Abstract Samples of Abbot, Alison, Bruno, Monty, and Hayward cultivars of kiwifruit (*Actinidia deliciosa*) were obtained from the Iran Research Center of Citrus (Tonekabon, located in north of Iran) and their physicochemical properties were studied during cold storage (at $T=1\pm1$ °C, RH=80±5%) at 0-, 9-, and 18-week intervals. The mean chemical composition of the fruits were as follows: ash=0.66–0.96%, moisture=75.2–84.7%, starch=0.3–7.0%, and ascorbic acid=54.8–261.0; K=125.0–372.0 mg 100 g^{-1} fresh weight, Mg=18.0–32.0 mg 100 g^{-1} fresh weight, Na=1.4–3.1 mg 100 g^{-1} fresh weight, Fe=0.17–0.52 mg 100 g^{-1} fresh weight, Cu=0.04–0.24 mg 100 g^{-1} fresh weight, Zn=0.16–0.49 mg 100 g^{-1} fresh weight, Mn=0.04–0.10 mg 100 g^{-1} fresh weight, and P=25.2–49.3 mg 100 g^{-1} fresh weight; glucose=0.7–2.39%, fructose=1.20–3.13%, and sucrose=0.0–5.8%. At the same time, the values of the parameters °Brix=6.5–14.8% and acidity=1.8–2.5% of the studied cultivars (mutual effects of cultivar and storage time) were investigated. The increase in peroxidase (POX=0.0–6.65 U ml^{-1}) and the decrease in pectinesterase (PE; poor activity to 0) activities were also determined. The statistical analysis showed that the Bruno cultivar had the highest content of ascorbic acid (115.0–261.0 mg 100 g^{-1} fresh weight), which is an important compound in fruits during storage, while Hayward had the best overall quality particularly with regards to its resistance to softening. This study confirms that long-term cold storage at 1±1 °C and 80±5% RH is suitable for maintaining the highest quality of Iranian grown cultivars of kiwifruit.

M. Zolfaghari · M. A. Sahari (✉) · M. Barzegar · H. Samadloiy
Food Technology Department, College of Agriculture,
Tarbiat Modares University,
P. O. Box 14115-111, Tehran, Iran
e-mail: sahari@modares.ac.ir

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Introduction

Cultivation of Kiwifruit *Actinidia deliciosa* was introduced in Iran in 1951–1968 in Mazandaran Province located in the north of the country. The cultivation has expanded to other areas with a mean production of about 60,000 tons over recent years. Kiwifruit is considered a commercially important fruit with export potentials corresponding to 44% of the total kiwifruit production (Anonymous 2006).

After a few studies were conducted in New Zealand, the cultivars with the highest quality as well as the commercial-scale production possibilities were found to be Abbot, Allison, Bruno, Monty, and Hayward (Manolopoulou and Papadopoulou 1998). In Iran, the most commercially important cultivars of Kiwifruit are Hayward, Abbot, Bruno, Monty, and Allison. Kiwifruit can be cold-stored for 4–6 months at 0–4 °C and 80–95% relative humidity (RH), although infrequent softening may occur (Marsh et al. 2004; Antunes and Sfakiotakis 2002).

Kiwifruit contains considerable amounts of acids, sugars, vitamins, polysaccharides, and minerals. Some chemical changes during storage and ripening have been reported. For instance, soluble solid content (SSC) increased markedly during the first 60 days of storage and then remained almost constant (Antunes and Sfakiotakis 2002). In all the cultivars (Hayward, Allison, Monty, and Bruno), a steady increase in SSC was observed during storage at 0 °C, whereas no statistically significant difference was found after 6 weeks storage periods. In addition, the ascorbic acid (AA) content of the fruits decreased slightly during storage

in all cultivars (Manolopoulou and Papadopoulou 1998). Titratable acidity also decreases during storage (Marsh et al. 2004). At harvest, most of the carbohydrate content in kiwifruit is in the form of starch, which is almost completely hydrolyzed to simple sugars during storage (Jordan et al. 2000). The starch content of ripened fruits is low and contributes little to the total carbohydrate. The concentration of starch in unripe kiwifruit ranges from 1% to 4% of the fresh weight, while glucose, fructose, and sucrose in unripe kiwifruit are 2.8–2.3%, 2.4–2.1%, and 1.6–1.3% of the fresh weight, respectively (Jordan et al. 2000). However, the potassium content in kiwifruits is high while its manganese content is low compared to other minerals (Ca, Mg, Na, Fe, Cu, and Zn) (Plaza et al. 1992). Enzyme activities (e.g., peroxidase and pectinesterase) have an important role in quality deterioration of the processed products and their activities have been determined during ripening (Marangoni et al. 1995; Llano et al. 2003).

An extensive research program has been undertaken in Tarbiat Modares University to assess the characteristics and commercial qualities of kiwifruit in Iran. The objective of this study was to examine changes in the physicochemical compositions of five cultivars grown in Iran (i.e., Abbot, Allison, Bruno, Monty, and Hayward) during cold storage at 1±1 °C and 80±5% RH for a period of 18 weeks.

Materials and Methods

Materials

Samples of kiwifruit (Abbot, Allison, Bruno, Monty, and Hayward cultivars usually picked for storage and/or export at the same maturity and firmness) were obtained from the Tonekabon region in the north of Iran (mean temperature= 2–30 °C, mean sea elevation=60 m, annual rain fall= 1,200–1,300 mm, longitude=51°09′, and latitude=36°43′). The samples (10 kg of each cultivar) were harvested during October from the research farm of Iran Research Center of Citrus Fruits. They were then transferred (under cold condition, near 0 °C, and reached the laboratory after 5 h) and kept in cold storage (1±1 °C and 80±5% RH) in the university laboratory in appropriate baskets (suitable panniers). The cultivation conditions were the same for all the fruits. To prepare samples for analysis, all fruits were initially washed in cold water of 5 °C temperature, then peeled and sliced. All chemical reagents used were of analytical grade (Merck, Germany).

Physicochemical Properties

The ash and moisture measurements were carried out following the AOAC method (AOAC 1990). The SSC, known as Brix,

Table 1 Physicochemical properties of the five kiwi fruit cultivars grown in Iran during 18 weeks cold storage

Cultivars	Time storage (weeks)	Ash (% fresh weight)	Moisture (%)	Total soluble solids (°Brix)	Acidity (%)	pH	Ascorbic acid (mg 100 g^{-1} fresh weight)	Total soluble solids/acidity
Abbot	0	0.72±0.02CDE	81.22±1.21DCB	9.53±0.21H	2.41±0.00A	3.07±0.01EDC	184.61±12.79B	3.95±0.28
	9	0.69±0.01DE	81.76±1.72CB	16.97±0.15ECD	1.99±0.14CD	3.06±0.01ED	76.50±9.66ED	8.53±0.64
	18	0.69±0.06DE	79.90±0.19DC	17.27±0.15C	2.07±0.20CB	2.95±0.01G	57.91±7.16E	8.34±0.81
Allison	0	0.96±0.47A	79.70±3.28D	14.83±0.40F	2.49±0.07A	3.05±0.03E	236.30±6.39A	5.95±0.23
	9	0.84±0.03CAB	75.22±0.78E	19.60±0.20B	2.33±0.10A	2.82±0.01J	112.54±15.18C	8.41±0.37
	18	0.84±0.06CAB	75.17±0.45E	20.90±1.15A	2.30±0.20AB	2.99±0.01F	92.45±23.11CD	9.09±0.94
Bruno	0	0.72±0.02CDE	80.43±0.40CD	10.93±0.38G	2.35±0.08A	3.14±0.02B	261.09±7.73A	4.65±0.23
	9	0.63±0.1E	80.22±0.03CD	17.13±0.15C	2.27±0.04AB	2.92±0.01GH	121.22±9.22C	7.55±0.15
	18	0.78±0.05CDB	80.13±0.47DC	17.73±0.21C	1.877±0.22CD	2.88±0.01I	115.02±11.72C	9.84±1.16
Monty	0	0.68±0.07DE	84.72±0.88A	6.50±0.26J	1.99±0.04CD	3.32±0.01A	122.15±0.00C	3.27±0.15
	9	0.77±0.06CDB	82.94±0.78AB	16.20±0.26E	1.75±0.14D	3.04±0.05E	71.31±5.61ED	9.26±0.80
	18	0.87±0.10AB	84.01±1.01A	17.03±0.11CD	1.76±0.04D	3.09±0.01DC	57.30±14.18E	9.68±0.23
Hayward	0	0.71±0.11CDE	80.42±0.23CD	8.13±0.15I	1.77±0.04D	3.10±0.01BC	106.68±23.09C	4.59±0.24
	9	0.66±0.05DE	80.37±0.33CD	16.33±0.06ED	1.92±0.04CD	2.88±0.01IH	60.55±13.04E	8.50±0.18
	18	0.73±0.05CDE	79.60±0.46D	17.70±0.26C	2.06±0.04CB	2.93±0.02G	54.80±13.56E	8.59±0.18

Different letters in the same column show significant differences at $P<0.01$ (mutual effects of cultivar and storage time)

was measured by refractometer (DR-A1, Atago, Japan). Titratable acidity was also estimated by titration with 0.1 N NaOH using 5% phenolphthalein, and the pH was measured by a pH meter (Metrohm, Switzerland). The ascorbic acid measurements were made following the indophenol dye titration method (Manolopoulou and Papadopoulou 1998).

About 2 g of the sample was placed in a test tube, 10 ml of diethyl ether was added, and then the mixture was placed in an ultrasonic bath (for 1 h). After removing the fat, the defatted samples were mixed with 10 ml ethanol 80% (two times for removing soluble sugar) at 80 °C. Following this, the given samples were dried, 15 ml H_2SO_4 0.15 M was added and the mixture was heated at 100 °C for 1 h. The hydrolyzed samples were centrifuged and filtrated. The hydrolysate was mixed with 9,10-dihydro-9-oxoanthracene (anthrone) under acidic conditions (0.1 g 100 ml^{-1} of 76% sulfuric acid), heated for 10 min, and then cooled. A blank was prepared with distilled water instead of the sample extract. The absorbance was determined at λ_{max} 620 nm using a spectrophotometer (PDA-UV/Vis, Sinco, South Korea). The concentration of glucose was calculated from the standard curves plotted using glucose solutions of known concentrations ($r^2 \leq 0.99$). The starch levels (g/100 g fresh weight) were determined by multiplying glucose concentrations by the conversion factor 0.9 (Regina and Beatrize 2005).

Sugar Analysis

The soluble sugars (glucose, fructose, and sucrose) were determined by high-performance liquid chromatography (HPLC) as follows: 30 g of the sample was weighed into the sample cup of a mixer (Sanyo, Japan) and 100 ml of 80% ethanol was added. The samples were ground for 6 min and mixed with ethanol–water and then stirred by a magnetic stirrer on a water bath (60 °C) for 30 min to dissolve all the sugars. The mixtures were filtered through Whatman No. 2 and then 0.45 μm Millipore filter. Sugar analysis was carried out by a HPLC system with integrator (Waters, USA), a pump (600E, Waters, USA), a Rheodyne 7125i six-way injector with 20 μl sample loop, and a refractive index detector (2414, Waters, USA). A column (High-Performance Carbohydrate Cartridge, 5 μm, 4.6×250 mm, Ireland) was used for the separation. The clarified extract was injected into the HPLC system with the quantity of 20 μl. HPLC elution was carried out at 40 °C using acetonitrile/water (70:30 *v*/*v*) at the flow rate of 1.2 ml min^{-1} as the mobile phase. Calculating the concentrations was done on the basis of the external standard method (Bernardez et al. 2004).

Mineral Elements Analyses

An inductively coupled plasma atomic emission spectrometer (Vista-pro, Varian, Australia) was used to determinethe mineral elements (Ca, K, Mg, Na, Fe, Cu, Zn, Mn) and P in kiwi according to the previously reported methods. The operating conditions were as follows: plasma power, 1,200 W; coolant gas flow, 15 min^{-1}; auxiliary gas flow, 1.5 l min^{-1}; nebulizer pressure, 220 kPa; sample uptake rate, 1 ml min^{-1}. Then, the spectral data tables were used to identify the most sensitive wavelengths for each element. The emission lines chosen were the most sensitive lines, having no interferences from the other elements in the group. Calibration was achieved using four synthetic multielement (Ca, K, Mg, Na, Fe, Cu, Zn, Mn, and P) standards, prepared using aliquots of the 1,000 ppm of each element standard solutions (Sahari et al. 2007).

Table 2 Sugars (glucose, fructose, and sucrose) and starch contents of the five kiwi fruit cultivars grown in Iran during 18 weeks cold storage (in g 100 g^{-1} fresh weight)

Cultivars	Time storage (week)	Glucose	Fructose	Sucrose	Starch
Abbot	0	1.59±0.01CB	1.89±0.07E	3.87±0.07B	3.20±0.88D
	9	2.10±0.18A	2.75±0.32B	3.39±0.22B	0.96±0.45FG
	18	1.18±0.00EFD	1.66±0.00GFE	0.00±0.00E	0.30±0.15G
Allison	0	1.57±0.26CD	1.76±0.08FE	5.81±1.31A	2.58±0.41DE
	9	2.13±0.26A	3.13±0.42A	5.03±0.43A	0.81±0.15FG
	18	1.52±0.02ECD	1.93±0.01DE	0.00±0.00E	0.34±0.19G
Bruno	0	1.07±0.34F	1.83±0.06FE	3.80±0.54B	5.78±0.22B
	9	1.99±0.14AB	2.57±0.06BC	1.32±0.42CD	1.84±0.46FE
	18	1.21±0.00ECFD	1.62±0.01GFE	0.00±0.00E	0.55±0.21G
Monty	0	0.67±0.02G	1.42±0.08GH	1.01±0.02CD	4.71±0.95C
	9	2.39±0.11A	3.11±0.12A	0.64±0.08E	1.68±0.55FE
	18	1.15±0.00EF	1.67±0.01GFE	0.00±0.00E	0.79±0.31FG
Hayward	0	1.18±0.13EF	1.22±0.04H	3.92±0.11B	7.01±0.56A
	9	1.31±0.13ECFD	2.26±0.02DC	1.57±0.09C	1.29±0.50FG
	18	1.13±0.01EF	1.54±0.00GFH	0.00±0.00E	0.53±0.10G

Different letters in the same column show significant differences at $P<0.01$ (mutual effects of cultivar and storage time)

Enzymatic Activity Determination

The tissue cylinders were homogenized within 4 min immediately after cutting in an ice-cooled mixer (Vancouver, Canada) containing phosphate buffer (pH=7.0) and maintaining the temperature at 4 °C, according to the procedure of Fuster et al. (1994). The soluble peroxidase (POXsol; EC 1.11.1.7) was estimated after extraction with 0.05 M phosphate buffer (Merck, Darmstadt, Germany), and the total peroxidase activity (POXtot) was measured after additional extraction with 1 M NaCl (Merck, Germany) solution enabling the extraction of the ionically bound enzyme fraction. The peroxidase activity was assayed at 25 °C using guaiacol (Merck, Darmstadt Germany) as substrate and absorbance recording at 470 nm for at least 1 min (Marangoni et al. 1995; Llano et al. 2003).

The pectinesterase (PE; EC 3.1.1.11) activity was determined according to the method of Kimball (1999). Accordingly, the measurement of the change of acid concentration or pH can be used as an estimate of the reaction rate or the enzymatic activity. The change in pH of a fruit juice sample is detected from the amount of pectin naturally present in it. The acid formation rate can be calculated in pectinesterase units according to:

PE

$$\mathrm{R{-}(CO)OCH_3 + H_2O \rightarrow RCOOH + CH_3OH} \quad (1)$$

$$R = k(\text{acid}) = (\text{volume titrated})(\text{NaOH normality})/(\text{sample volume})(\text{reaction time}) \quad (2)$$

$$\text{Pectinesterase unit (PEU)} = (0.05\ \text{N NaOH})(0.10\ \text{mL of NaOH})(10\ \text{mL of sample})(\text{min}).$$

Most juices have PEU values from 1×10^{-6} to 1×10^{-4}. Levels much higher than this are susceptible to gelation and/or cloud loss depending on pH and other related conditions. If the recorded pH is regained in 2.5 min or less (or lower than PEU=1×10^{-6} to 1×10^{-4}), the PE activity is poor. Unavailability of pH 7 (or reaction time=∞) and then by substitution into Eq. 2 we will have: limit of Eq. 2→0 (Kimball 1999).

Statistical Analysis

The data were analyzed by the analysis of variance in randomized complete blocks using the SPSS software. All the analyses were repeated three times.

Table 3 Minerals (mg 100 g^{-1} fresh weight) of the five kiwi fruit cultivars grown in Iran during 18 weeks cold storage

Cultivars	Time storage (week)	Ca	K	Mg	Na	Fe	Cu	Zn	Mn	P
Abbot	0	42.726±0.485H	327.600±0.400C	20.555±0.162G	1.588±0.022I	0.413±0.015E	0.185±0.006C	0.162±0.004K	0.051±0.001I	38.209±0.001C
	9	47.516±0.165FG	286.162±0.790FG	25.518±0.061D	1.490±0.031J	0.169±0.0005L	0.193±0.001C	0.190±0.001I	0.051±0.000I	36.179±0.039D
	18	48.460±0.400F	271.200±1.733H	21.128±0.065G	1.651±0.003H	0.356±0.002G	0.206±0.001B	0.491±0.001A	0.076±0.000C	32.655±0.229G
Allison	0	79.590±1.590B	372.271±2.530A	32.799±0.548A	2.475±0.004DE	0.521±0.001A	0.037±0.018I	0.308±0.002C	0.062±0.000G	42.221±0.115B
	9	78.650±0.396B	293.589±14.141F	26.601±0.034C	2.520±0.040DC	0.463±0.006C	0.189±0.001C	0.267±0.001E	0.068±0.001E	42.335±0.320B
	18	82.830±1.230A	304.420±1.189E	29.566±0.235B	2.658±0.004C	0.488±0.001B	0.241±0.001A	0.387±0.001B	0.087±0.000B	49.292±0.050A
Bruno	0	54.500±2.250D	284.290±1.140FG	25.209±0.872D	2.482±0.005DE	0.354±0.001G	0.207±0.003B	0.202±0.001H	0.042±0.000L	31.296±0.073I
	9	56.163±0.733D	187.290±2.061I	19.512±0.056H	2.490±0.042DE	0.325±0.001H	0.089±0.001H	0.323±0.001G	0.043±0.001K	25.175±0.005J
	18	65.359±0.432C	290.850±4.350F	26.780±0.087C	2.439±0.004E	0.388±0.001F	0.168±0.001DE	0.275±0.001D	0.071±0.000D	36.364±0.040D
Monty	0	46.220±0.020G	322.590±5.411CD	21.210±0.027G	1.444±0.008J	0.290±0.004J	0.126±0.001G	0.247±0.005F	0.046±0.000J	33.149±0.459F
	9	45.630±0.395G	315.890±0.969D	23.077±0.022F	1.832±0.049G	0.381±0.001F	0.173±0.001D	0.237±0.001G	0.095±0.000A	32.067±0.002H
	18	45.510±0.020G	357.850±0.050B	24.425±0.021E	2.081±0.015F	0.304±0.001I	0.164±0.001FDE	0.274±0.001D	0.063±0.000F	0.355±0.355E
Hayward	0	52.210±0.680E	279.890±0.387HG	18.977±0.219H	2.046±0.001F	0.470±0.002C	0.154±0.001F	0.186±0.001I	0.050±0.001I	32.082±0.296H
	9	64.870±0.150C	125.450±2.160J	23.560±0.017F	2.953±0.046B	0.431±0.001D	0.159±0.001F	0.178±0.001J	0.051±0.000I	33.218±0.009F
	18	66.520±0.780C	330.478±0.570C	21.085±0.118G	3.080±0.015A	0.256±0.002K	0.131±0.000G	0.232±0.006G	0.060±0.001H	36.394±0.191D

Different letters in the same column show significant differences at $P<0.01$ (mutual effects of cultivar and storage time)

Results and Discussion

The content for ash, moisture, soluble solids, and ascorbic acid, in addition to the physicochemical properties such as pH and acidity, of the five kiwifruit cultivars grown in Iran during 18 weeks of cold storage are presented in Table 1.

The ash content at harvesting ranged from 0.68% to 0.96% of the fresh weight, and cultivars of Allison and Monty had the highest (0.96% of the fresh weight) and the lowest (0.68% fresh weight) ash content, respectively. Cultivars of Monty, Abbot, Bruno, and Hayward did not show significant difference in ash content after harvesting. The given results here were higher than that of the Hayward cultivar in New Zealand (Mainland 1998) and similar or higher (0.44–0.73%) than the values reported by Castaldo et al. (1992). These differences probably pertain to the kiwi cultivars' agroclimatic and environmental conditions. In all the cultivars, at 9 and 18 weeks of storage, the ash content changed significantly. Yet, the differences among theses cultivars were not significant.

Water was the main constituent in fruits and varied from 75.2 to 84.7. The Monty and Allison cultivars had the highest (84.7%) and lowest (79.7%) moisture content, respectively, which fall within the moisture range of the New Zealand Hayward cultivar (Anonymous 2006). The Allison, Abbot, Bruno and Hayward cultivars did not show significant difference in moisture after harvesting. In all the cultivars, the moisture did not change significantly at 9 and 18 weeks of storage.

At harvesting, SSC (°Brix) ranged from 6.50 to 14.83, and the Allison, Bruno, Abbot, Hayward, and Monty cultivars had the highest and lowest SSC, respectively.

Table 4 POX and PE activities of the studied kiwi fruit cultivars grown in Iran during 18 weeks cold storage

Cultivars	Time (week)	POX activity (U ml^{-1})	PE activity
Abbot	0	0.00	Poor activity
	9	0.40±0.06D	0
	18	5.31±0.06B	0
Allison	0	0.00	Poor activity
	9	1.31±0.02C	0
	18	4.23±0.09C	0
Bruno	0	0.00	Poor activity
	9	2.03±0.09A	0
	18	6.65±0.23A	0
Monty	0	0.00	Poor activity
	9	1.50±0.06B	0
	18	5.42±0.12B	0
Hayward	0	0.00	Poor activity
	9	0.47±0.03D	0
	18	2.34±0.03D	0

Different letters in the same column show significant differences at $P<0.01$ (mutual effects of cultivar and storage time)

Table 5 Comparison of some physicochemical properties of Iranian kiwifruit cultivars with other countries

Country	Characteristics												
	Ash (% fresh weight)	Moisture (%)	Total soluble solids (°Brix)	Acidity	pH	Ascorbic acid (mg 100 g^{-1} fresh weight)	Starch (% fresh weight)	Glucose (% fresh weight)	Fructose (% fresh weight)	Sucrose (% fresh weight)	Reference
Iran											
Abbot	0.72	81.22	9.53	2.41	3.07	184.61	3.20	1.59	1.89	3.87	Present study
Allison	0.96	79.70	14.83	2.49	3.05	236.30	2.58	1.57	1.76	5.81	
Bruno	0.72	80.43	10.93	2.35	3.14	261.09	5.78	1.07	1.83	3.80	
Monty	0.68	84.72	6.50	1.99	3.32	122.15	4.71	0.67	1.42	1.01	
Hayward	0.71	80.42	8.13	1.77	3.10	106.68	7.01	1.18	1.22	3.92	
Greece											
Allison	–	–	11.54	–	–	127	–	–	–	–	Manolopoulou and Papadopoulou, 1998
Bruno	–	–	11.24	–	–	161.6	–	–	–	–	
Monty	–	–	11.32	–	–	70.4	–	–	–	–	
Hayward	–	–	11.72	–	–	110.2	–	–	–	–	
New Zealand											
Hayward	–	–	12.6	–	–	–	1.19	2.81	3.01	1.52	Jordan et al. 2000
Hayward	–	–	–	1.25–1.48	–	–	–	–	–	–	Marsh et al. 2004
Hayward	–	84	–	–	–	–	–	–	–	–	Anonymous 2006
Hayward	–	–	–	–	–	114	–	–	–	–	Hendrik et al. 1992
Hayward	–	–	–	–	3.4–4.2	80–120	–	1.13–3.66	1.20–3.52	0.2–3.36	Esti et al. 1998
Italy											
Hayward	0.57	–	14.03	1.47	3.31	–	–	4.2	4.7	–	Castaldo et al. 1992

The SSC content had a statistically significant increase ($P<0.01$) during the storage time at 9 and 18 weeks in all the five cultivars of kiwifruit. This result confirms the finding that SSC increases at ripening (Park et al. 2006, Antunes and Sfakiotakis 2002; Tavarani et al. 2008).

The acidity results also showed significant statistical difference among the Abbot, Allison, and Bruno cultivars, as well as the Monty and Hayward cultivars. The acidity ranged from 1.77% to 2.49% at harvesting in all the five cultivars, and its content decreased statistically ($P<0.01$) during the storage time (at 9 and 18 weeks). The same phenomenon was also observed in some other fruits and vegetables (Park et al. 2006; Sahari et al. 2004; Marsh et al. 2004). As previously reported, during storage, the most important organic acids in fruits are converted to each other (with different pK_a values) (Marsh et al. 2004).

The °Brix/acid ratio is a way to evaluate objectively the optimum harvesting time for several fruits. It is calculated by dividing the sugar content of the fruit, expressed as degrees Brix, by its acid percentage. This value range was between 3.27±0.15 and 9.84±1.16 in Monty and Bruno cultivars, respectively (Table 1). These values are lower than those for the Italian kiwifruits (Castaldo et al. 1992).

At harvesting, the pH ranged from 3.05 to 3.32. The pH value in all the five cultivars fluctuated with storage and ripening duration. This finding corroborates the previously published results (Sahari et al. 2004; Park et al. 2006).

The comparison of the average ascorbic acid content at different storage times (0, 9, and 18 weeks) also showed significant decrease, and after harvesting, its content ranged from 261.09 to 106.68 mg 100 g^{-1} fresh weight. The Bruno and Hayward cultivars had the highest ascorbic acid content (261.09 mg 100 g^{-1} fresh weight), which confirms the finding of Cotter et al. (1991), and the lowest ascorbic acid content (106.68 mg 100 g^{-1} fresh weight). The decrease in the ascorbic acid content during storage complies with many previously published results (Agar et al. 1999; Manolopoulou and Papadopoulou 1998; Sahari et al. 2004; Tavarani et al. 2008).

Table 2 shows the sugar (glucose, fructose, and sucrose) and starch content of the five kiwifruit cultivars grown in Iran during the cold storage time (0, 9, and 18 weeks).

Sucrose was the main sugar in the cultivars at harvesting, and its content ranged from 1.01% to 5.81% of the fresh weight. The highest and lowest contents of sucrose were in the cultivars of Allison (5.81% of the fresh weight) and Hayward and Abbot (3.92 and 3.87% of the fresh weight), respectively. Its content at 18 weeks storage showed significant decrease because, after 9 weeks, sucrose almost completely converted to glucose and fructose. At harvesting, the lowest and highest glucose and fructose contents were as follows: 0.67% and 1.22% to 1.59% and 1.89% of the fresh weight, respectively. The highest and the lowest content of glucose and fructose were observed in the Abbot cultivar with 1.59% and 1.89% of the fresh weight. The Monty cultivar had the lowest content of glucose (0.67% of the fresh weight), and the Hayward cultivar had the lowest content of fructose (1.22% of the fresh weight). After 9 weeks of storage, the content of glucose and fructose increased, but at 18 weeks of storage, their amounts decreased approximately to the initial values due to the consumption in enzymatic reactions. This result confirms the finding of Esti et al. (1998), which showed that the level of fructose and glucose were higher than that of sucrose. Also, during storage, starch is hydrolyzed to other sugars such as glucose and fructose. A large proportion of the dry matter value can be related to the soluble sugars present in the ripe fruit (Jordan et al. 2000; Gallego and Zarra 1998; Burdon et al. 2004; Adao et al. 2005). At the same time, the content of starch after storage decreased. After harvesting, its content ranged from 2.58 to 7.01, and the highest and lowest contents were in the Hayward and Allison cultivars, respectively.

Table 6 Comparison of minerals (mg 100g^{-1} fresh weight) of Iranian kiwifruit cultivars with other countries

Mineral elements Country	Ca	K	Mg	Na	Fe	Cu	Zn	Mn	P	Reference
Iran										
Abbot	42.726	327.600	20.555	1.588	0.413	0.185	0.162	0.051	38.209	Present study
Allison	79.590	372.271	32.799	2.475	0.521	0.037	0.308	0.062	42.221	
Bruno	54.500	284.290	25.209	2.482	0.354	0.207	0.202	0.042	31.296	
Monty	46.220	322.590	21.210	1.444	0.290	0.126	0.247	0.046	33.149	
Hayward	52.210	279.890	18.977	2.046	0.470	0.154	0.186	0.050	32.082	
New Zealand										
Hayward	27.00	171.97	9.30	6.75	0.74	0.15	0.22	0.07	–	Plaza et al. 1992
Italy										
Hayward	21.4	300.4	12.3	3.7	–	–	–	–	19.3	Castaldo et al. 1992
FAO										
Hayward	–	236	17	4	0.3	–	0.5	–	–	Anonymous 2006

Table 3 shows the mineral elements (Ca, K, Mg, Na, Fe, Cu, Zn, Mn) and P of the five kiwifruit cultivars grown in Iran during cold storage (0, 9, and 18 weeks).

Potassium was the main mineral element in all the studied cultivars while Mn was the minor mineral element (Castaldo et al. 1992; Mainland 1998). The Allison cultivar had the highest Ca, K, Fe, Zn, Mn, and P contents (79.590, 372.271, 0.521, 0.308, 0.062, and 42.221 mg 100 g^{-1} fresh weight, respectively) and the lowest Cu content (0.037 mg 100 g^{-1} fresh weight). Hayward had the lowest K and Mg contents (279.890 and 18.977 mg 100 g^{-1} fresh weight, respectively). The Bruno cultivar had the highest Na and Cu contents (2.482 and 0.207 mg 100 g^{-1} fresh weight, respectively) and the lowest Mn and P contents (0.042 and 31.296 mg 100 g^{-1} fresh weight, respectively). The lowest contents of Na and Fe were in the Monty cultivar, and the lowest Ca and Zn content were in the Abbot cultivar. In all the cultivars of kiwifruit, the contents of mineral element changed significantly after cold storage ($P<0.01$). The differences in mineral composition can be attributed to the genetic factor of the studied cultivars. Mn, Zn, Cu, Fe, and Na content was very low, while K, Ca, Mg, and P content was very high, which are considered safe for consumption. These values are similar to or even higher than the previously reported results. The content of the mineral elements in all the cultivars varied with storage and ripening duration.

Table 4 shows the peroxidase and pectinesterase activities of the five kiwifruit cultivars grown in Iran during cold storage (0, 9, and 18 weeks).

The statistical results showed that the POX activity in all the cultivars was zero at harvesting and its activity at week 18 had significantly increased. The Bruno and Abbot cultivars had the highest and the lowest POX activities, respectively. POX is found in most plant tissues and has various functions related to fruit ripening, including cell wall synthesis, changes in the cell wall plasticity, lignifications, degradation of indole-3-acetic acid, and anthocyanin breakdown. It seems that the changes of the chemical composition during storage can lead to increased activity of POX (Llano et al. 2003; Perez-Tello et al. 2001). Also, the PE activity in all the cultivars at harvesting was poor, and at weeks 9 and 18, it was zero with Hayward being the slowest to soften in storage. PE activity is usually linked to chemical changes in cell wall–middle lamella structure occurring during market requirements and thermal treatment of the kiwifruit tissue. The apparent quality of Hayward (the commercially preferred cultivar) was more acceptable than those of the other cultivars, which confirm the findings of Cotter et al. (1991) and Thorp et al. (1990). This enzyme shows optimal activity around 55–65 °C (Llano et al. 2003); so, in this study, PE activity remained constant during cold storage (1±1 °C).

Some physicochemical properties of Iranian kiwifruits were compared with cultivars grown under different conditions (Tables 5 and 6).

Conclusion

The changes in the physicochemical attributes indicate some differences among the cultivars studied, and cold storage (at 1±1 °C, RH=80±5%) seems to be a good method for maintaining quality during long-term storage. The Bruno cultivar showed a high ascorbic acid content, which is an important nutritional component in fruits, while Hayward had a higher apparent quality, which is an important factor for resistance to softening. At week 18 of storage, POX and PE activities initially increased and then decreased. These results confirm that long-term cold storage at 1±1 °C and 80±5% RH is suitable for maintaining the highest quality of the cultivars grown in Iran, especially, Hayward cv. Hayward had the best overall quality particularly in terms of its resistance to softening.

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