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ORIGINAL PAPER

The postharvest performance of kiwi fruit after long cold storage

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Abstract Conventionally (CG), semi-organically (low chemical, LCG) and organically grown (OG) kiwi fruit was stored at 0° C for 24 weeks. Firmness gradually decreased with storage time regardless of cultivation type, and the rate of softening was slightly higher in OG fruits than those of CG or LCG fruits. Soluble solids content increased with storage time, while acidity decreased in all fruits. Reducing sugar content considerably increased until 12 weeks after storage, while starch content significantly decreased. Rate of fruit decay abruptly increased at middle stage of storage in OG fruits. In 24 weeks after storage, the rate reached 35 %. Most fruits decayed with infection of *Botritis cineria* regardless of cultivation type. Respiration and ethylene contents have peaked at middle stage of storage, and those contents were slightly higher in OG than in CG and LCG fruits. Shelf life of kiwi fruit considerably decreased in OG fruits by increasing fruit decay and softening during storage. Fluorescence measurements showed a difference between the investigated samples, especially in their antioxidant status. The used statistical evaluation confirmed the obtained results. The quenching properties of these samples are correlated with their antioxidant properties and the amount of polyphenols and the decrease in fluorescence intensity.

Keywords Organic fruit · Firmness · Reducing sugar · Decay · Ethylene · Storage · Cultivation system · Antioxidants · Quenching

This article was written in memory of my dear brother Prof. Simon Trakhtenberg, who died in November 2011, who encouraged me and our research group during all his life.

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Introduction

Fruits contain several compounds with antioxidant properties, such as ascorbic acid, carotenoids and polyphenols [1–4]. There are many kiwi fruit cultivars, and the most known is 'Hayward,' which is grown under different conditions: conventional, semi-organic (low chemical, LCG) and organic. Differences in the quality of plants, growing under specific conditions, were discussed in some reports [5–13]. The influence of different cultivation systems and postharvest management on the antioxidant properties of apple, apricot and other plants was investigated [9, 10, 13]. In the cited literature, there are few reports on the differences in the bioactivity between kiwi fruit cultivars grown in conventional and organic conditions [7, 14–17]. Therefore, the postharvest quality attributes such as firmness, acidity, dry matter, sensory aspects, fruit decay and antioxidants after long cold storage of kiwi fruit cultivars were compared after organic, semi-organic and conventional growing

systems. Applied radical scavenging assays for determination of total antioxidant activity were used [18–20]. We are the first to apply a combination of advanced analytical methods including the fluorescence measurements for quality determination.

Materials and methods

Chemicals

Trolox; phenolic standards, HSA, Tris, tris(hydroxymethyl) aminomethane; Folin–Ciocalteu reagent; lanthanum (III) chloride heptahydrate; $FeCl_3 \times 6H_2O$; $CuCl_2 \times 2H_2O$; and 2,9-dimethyl-1,10-phenanthroline (neocuproine) were purchased from Sigma Chemical Co., St Louis, MO, USA. 2, 4, 6-Tripyridyl-*s*-triazine (TPTZ) was from Fluka Chemie, Buchs, Switzerland.

Sample preparation

Kiwi fruit cultivar 'Hayward' was grown under conventional, semi-organic (low chemical) and organic conditions in the orchard Haenam county (longitude 126°15″ and latitude 34°18″), Jeonnam province, Korea, 2013. Mean temperature was about 13–14° C, rainfall—1300 mm, and soil was loam. In fertilization of organic kiwi fruit mature was applied (3 ton per 10 a). The fruits were sprayed three times with biocontrol agents (Seva stop, Poex, white killer, produced in Korea). During the growing process, pesticides or herbicides were not applied. Water drop irrigation (30 ton per week per 10 a) was usually used. Water is related to the dry matter of the fruit, but water stress enhances the phenolic content in plant. Five replicates of five fruits each at their commercial maturity stage (the degree of soluble solids content (SSC) was in the range of 6.8–7.5 %) were used. The samples were treated with liquid nitrogen in order to prevent oxidation of phenolic compounds by freezing and then lyophilized as previously described [5–7]. The bioactive compounds were determined in water extracts of conventional, semi-organic (low chemical, LCG) and organic grown 'Hayward'.

Determination of bioactive compounds and total antioxidant capacities (TACs)

Polyphenols were extracted from the samples with methanol and water (concentration 20 mg/mL) in a cooled ultrasonic bath for 1 h [8, 9]. TPC were determined by Folin–Ciocalteu method with absorbance measurements at 750 nm with spectrophotometer (Hewlett-Packard, model 8452A, Rockville, USA). Total flavonoid content and phenolic acids were determined by an aluminum chloride colorimetric method with some modifications. The absorbance was measured immediately against the blank at 510 nm [5–7, 21, 22].

Texture analysis

The fruits were analyzed for firmness by measuring penetration force in kilogram using a fruit firmness tester (Model KM, Fruit Test Tech, and Japan). Firmness tester has cylinder style shape, the tip diameter is 0.5 mm, the bottom diameter is 10 mm and the length is 20 mm. After peeling, the tester penetrates (punches) the flesh with hand pressing. The mean values of the firmness were expressed as Newtons (N). 1 Newton is 9.8 kg.

Determination of total soluble solids (TSSs), pH, total acidity (TA) and dry matter

The peeled fruits were homogenized and filtered through a cheesecloth in order to obtain a clear juice for determination of TSS (Brix), pH, TA and dry matter. The TSS was measured using a refractometer (Atago Com. Ltd., Tokyo, Japan); pH was estimated with a pH meter. The TA was measured in a 4 mL of juice, diluted to 20 mL of distilled water and titrated with 0.1 N NaOH. The total acidity was expressed as a percentage of citric acid.

Starch and reducing sugar contents, carbon dioxide and ethylene productions

Starch was determined in 10 g of flesh kiwi fruit extracted with 20 mL of 90 % ethanol and filtered through Whatman No. 4 filter paper (110-mm pore size). The extract solution was evaporated, and then 5 mL of 90 % ethanol was added. Starch concentration was obtained from values of absorbance (calibration curve), measured at 525 nm on a spectrophotometer (Hewlett-Packard, model 8452A, USA). Reducing sugar was extracted from juice and analyzed with the modified method of 3.5-dinitrosalicylic acid.

For measurement of carbon dioxide and ethylene production, five fruits were sealed in a 1.8-L glass jar for 24 h, and head space gas was sampled with a 1-mL syringe. Ethylene and respiration contents were determined using gas chromatography (Hewlett-Packard, USA). The amount was calculated as following: CO_2/ethylene content (GC) × g (fruit weight)/kg × 1 (h)/24 h, that means that if the amount of CO_2 from the GC analysis using the standard calibration curve is 15 mL, then multiple by 0.5 fruit weight (if gas was extracted from 500 g, and the used units are kg), then divide by 24 h (1 h unit/24 h of extraction time), and the result is 0.31 mL h^{-1} kg^{-1}. The contents were expressed for CO_2 in mL kg^{-1} h^{-1} and for C_2H_4 in μL kg^{-1} h^{-1}.

Total soluble phenols

Total soluble polyphenols were extracted with water at room temperature and extracted 1 h at concentration 25 mg/mL. The polyphenols were determined by Folin–Ciocalteu method [18, 19] with absorbance measurement at 750 nm (Spectrophotometer, Hewlett-Packard, model 8452A, Rockville, USA). The results were expressed as mg of gallic acid equivalents (GAE) per g dry weight (DW). Total flavonoid content was determined by an aluminum chloride colorimetric method with some modifications. The absorbance was measured immediately against the blank at 510 nm. The extracts of condensed tannins (procyanidins) with 4 % methanol vanillin solution were measured at 500 nm. (+)-Catechin served as a standard for flavonoids and tannins, and the results were expressed as catechin equivalents (CE).

Antioxidant assay/activity

Ferric reducing/antioxidant power (FRAP, μMTE/g) assay measures the ability of the antioxidants in the investigated samples to reduce ferric-tripiridyltriazine (Fe^{3+} TPTZ) to a ferrous form (Fe^{2+}). FRAP reagent (2.5 mL of a 10 mmol ferric-tripiridyltriazine solution in 40 mmol HCl plus 2.5 mL of 20 mmol $FeCl_3 \times H_2O$ and 25 mL of 0.3 mol/L acetate buffer, pH 3.6) of 900 μL was mixed with 90 μL of distilled water and 30 μL of kiwi fruit extract samples as the appropriate reagent blank. The absorbance was measured at 595 nm.

Sensory analysis

Sensory quality was carried out in a sensory laboratory by 12 panelists. Taste quality was evaluated by affective test of appearance, taste (sweetness, sourness, flavor, texture) and total acceptation in Hedonic scale method, which was 1–5 rating scale (1 = severely bad, 2 = bad, 3 = moderate, 4 = good, 5 = excellent).

Fluorometric measurements

Fluorometric measurements were used for the evaluation of antioxidant properties of water kiwi fruit extracts. Two-dimensional (2D-FL) and three-dimensional (3D-FL) fluorescence measurements were recorded on a model FP-6500, Jasco spectrofluorometer, serial N261332, Tokyo, Japan, equipped with 1.0-cm quartz cells and a thermostat bath, and the excitation and emission slits were set at 5 nm while the scanning rate was 1200 nm min^{-1}. For the fluorescence measurement, kiwi fruit extracts were added to a 1.0-cm quartz cell manually using a micro-injector. The concentrations of kiwi fruit extracts were 0.1 mg/mL. The corresponding fluorescence emission spectra were then recorded in the range of 300–500 nm upon excitation at 280 nm in each case. The three-dimensional fluorescence spectra were measured under the following conditions: The emission wavelength was recorded between 250 and 500 nm, the initial excitation wavelength was set at 200 nm with an increment of 5 nm, and the other scanning parameters were just the same as those for the 2D-fluorescence emission spectra.

Statistical analysis

Simple comparisons of mean values were made by Student's t test, and level of significance was accepted at $p \leq 0.05$. Stepwise and canonical discriminant analysis (CDA) was used to investigate and select the best physicochemical indices to monitor changes and differences between kiwi fruit cultivars during cold treatment. CDA recognition ability test was calculated as the percentage of correctly classified samples in the priori defined categories. Statistical analysis of experimental data was performed by statistical package Unistat version 6.0 (Unistat, London, United Kingdom).

Results and discussion

Texture analysis

The physicochemical properties of kiwi fruit (Table 1) changed at cold storage during 24 weeks. The firmness (N) of 'Hayward' during 24 weeks changed from 40–42 to 6.22–5.65. Dry matter (%) for 'Hayward' at 24th week was similar (Table 1). Texture is usually used in sensory evaluation for fruits, but we measured firmness with as an index of softening. Shelf life in kiwi fruit is determined by the degree of softening. Kiwi fruits are softened when the firmness reached below 5 N [23–27]. Our results were in line with others that delayed storage at non-chilling temperature and ethylene treatment advanced the ripening of 'Hayward' and resulted in increased low-temperature breakdown incidence [28, 29]. Significant fruit softening and decreased TA were observed without ethylene production in intact fruit stored at low temperature for 1 month, but not in fruit stored at room temperature. Repeated 1-MCP treatments (twice a week) failed to inhibit the changes that occurred in low-temperature storage. These observations indicate that low temperature modulates the ripening of kiwi fruit in an ethylene-independent manner, suggesting that kiwi fruit ripening is inducible by either ethylene or low-temperature signals [30]. Kiwi fruit was stored at 0 °C for 12 weeks, followed by 6 days of shelf life at 20 °C. Fruit ripened and softened slowly during storage at 0 °C. At the end of

Table 1 Changes in basic characteristics of conventional, semi-organic and organic 'Hayward' kiwi fruit during cold storage

Time of storage (weeks)	Growing conditions	Firmness (N)	Dry matter (%)	Sensory value	Soluble solids (%)	Acidity (%)	pH	Reducing sugars (%)	Starch (%)	Fruit decay	C_2H_4 production	CO_2 production
0	Conventional	40.01 ± 1.95^{a}	15.23 ± 0.85^{d}	1.33 ± 0.29^{a}	7.20 ± 0.31^{a}	1.33 ± 0.02^{a}	3.21 ± 0.01^{a}	10.32 ± 0.73^{a}	36.32 ± 2.90^{a}	0	19.32 ± 1.33^{a}	2.11 ± 0.12^{ab}
	Semi-organic	42.20 ± 1.99^{a}	15.32 ± 0.22^{d}	1.50 ± 0.10^{a}	7.02 ± 0.31^{a}	1.42 ± 0.03^{a}	3.13 ± 0.02^{a}	11.57 ± 0.67^{a}	36.17 ± 3.33^{a}	0	19.00 ± 0.86^{a}	1.50 ± 0.10^{ab}
	Organic	39.32 ± 2.00^{a}	15.35 ± 0.22^{d}	1.33 ± 0.29^{a}	6.82 ± 0.31^{a}	1.39 ± 0.04^{a}	3.32 ± 0.04^{a}	11.33 ± 0.96^{a}	36.33 ± 2.32^{a}	0	17.32 ± 2.36^{a}	1.33 ± 0.29^{ab}
4	Conventional	32.25 ± 1.74^{b}	15.43 ± 0.82^{d}	1.79 ± 0.21^{b}	10.28 ± 0.67^{b}	1.21 ± 0.06^{b}	3.44 ± 0.09^{a}	19.17 ± 1.40^{b}	22.60 ± 2.50^{b}	0	21.24 ± 2.65^{ca}	2.42 ± 0.51^{ab}
	Semi-organic	35.25 ± 2.60^{b}	15.73 ± 0.10^{d}	1.68 ± 0.25^{b}	11.03 ± 0.40^{b}	1.13 ± 0.03^{b}	3.40 ± 0.04^{a}	20.41 ± 1.80^{b}	22.13 ± 2.00^{b}	0	$22.063.83^{ca}$	1.68 ± 0.25^{ab}
	Organic	35.21 ± 1.94^{b}	15.45 ± 0.52^{d}	1.50 ± 0.50^{b}	11.14 ± 0.44^{b}	1.24 ± 0.12^{b}	3.41 ± 0.02^{a}	20.53 ± 2.12^{b}	21.11 ± 2.10^{b}	0	$22.175.44^{ca}$	1.50 ± 0.50^{ab}
8	Conventional	22.88 ± 1.04^{c}	15.41 ± 0.59^{d}	2.24 ± 0.32^{c}	12.50 ± 0.26^{cd}	$0.95 \pm .09^{cd}$	3.35 ± 0.12^{a}	34.57 ± 1.51^{c}	15.78 ± 2.02^{c}	0	28.59 ± 3.56^{ed}	2.96 ± 0.51^{bc}
	Semi-organic	23.01 ± 1.60^{c}	15.27 ± 0.61^{d}	2.20 ± 0.45^{c}	12.20 ± 1.04^{cd}	1.08 ± 0.10^{cd}	3.35 ± 0.18^{a}	32.99 ± 2.92^{c}	12.12 ± 1.14^{c}	0	$26.785.76^{ed}$	2.20 ± 0.45^{bc}
	Organic	18.95 ± 1.95^{c}	15.51 ± 0.95^{d}	2.35 ± 0.25^{c}	12.63 ± 0.15^{cd}	1.00 ± 0.04^{cd}	3.44 ± 0.02^{a}	31.84 ± 2.18^{c}	10.84 ± 0.95^{c}	0	$40.085.06^{ed}$	2.35 ± 0.25^{bc}
12	Conventional	16.41 ± 1.62^{d}	15.50 ± 0.62^{d}	2.34 ± 0.12^{d}	13.21 ± 0.26^{de}	0.86 ± 0.12^{de}	3.31 ± 0.08^{a}	45.23 ± 3.20^{dc}	9.34 ± 1.66^{d}	0	38.25 ± 4.43^{ef}	3.30 ± 0.53^{d}
	Semi-organic	17.21 ± 1.09^{d}	15.26 ± 0.35^{d}	2.64 ± 0.17^{d}	12.45 ± 1.04^{de}	0.95 ± 0.10^{de}	3.35 ± 0.09^{a}	46.07 ± 2.78^{dc}	8.88 ± 1.82^{d}	0	$37.675.87^{ef}$	2.64 ± 0.17^{d}
	Organic	10.05 ± 1.70^{d}	15.67 ± 0.48^{d}	2.56 ± 0.15^{d}	12.93 ± 0.15^{de}	0.98 ± 0.14^{de}	3.40 ± 0.10^{a}	46.45 ± 2.80^{dc}	5.32 ± 1.20^{d}	5.01 ± 1.12^{a}	$28.270.38^{ef}$	2.56 ± 0.15^{d}
16	Conventional	12.41 ± 1.46^{ef}	15.43 ± 0.36^{d}	2.42 ± 0.64^{de}	13.57 ± 0.40^{df}	0.86 ± 0.09^{ef}	3.32 ± 0.06^{a}	44.77 ± 2.85^{ed}	5.93 ± 1.17^{e}	0	27.58 ± 3.33^{ad}	2.91 ± 0.65^{d}
	Semi-organic	11.31 ± 1.96^{ef}	15.49 ± 0.32^{d}	2.79 ± 0.29^{de}	12.63 ± 0.15^{df}	0.95 ± 0.05^{ef}	3.35 ± 0.06^{a}	45.60 ± 1.10^{ed}	5.77 ± 1.68^{e}	0	$28.034.95^{ad}$	2.79 ± 0.29^{d}
	Organic	7.68 ± 1.52^{ef}	15.57 ± 0.74^{d}	2.67 ± 0.14^{de}	13.27 ± 0.40^{df}	0.92 ± 0.06^{ef}	3.35 ± 0.06^{a}	44.10 ± 2.99^{ed}	4.20 ± 0.96^{e}	15.12 ± 3.81^{b}	$24.566.11^{ad}$	2.67 ± 0.14^{d}
20	Conventional	9.15 ± 1.31^{fg}	15.54 ± 0.17^{d}	2.68 ± 0.10^{dg}	14.07 ± 0.51^{dg}	0.86 ± 0.12^{g}	3.42 ± 0.05^{a}	42.03 ± 2.52^{fd}	4.23 ± 1.01^{e}	5.01 ± 1.20^{a}	25.49 ± 2.58^{bc}	2.34 ± 0.65^{d}
	Semi-organic	8.60 ± 1.80^{fg}	15.29 ± 0.49^{d}	2.73 ± 0.66^{dg}	13.13 ± 0.32^{dg}	0.92 ± 0.05^{g}	3.35 ± 0.08^{a}	42.29 ± 2.04^{fd}	4.80 ± 0.47^{e}	8.00 ± 1.83^{a}	$24.935.20^{bc}$	2.73 ± 0.66^{d}
	Organic	6.21 ± 1.33^{fg}	15.51 ± 0.66^{d}	2.85 ± 0.29^{dg}	13.87 ± 0.12^{dg}	0.87 ± 0.06^{g}	3.28 ± 0.12^{a}	44.40 ± 1.95^{fd}	5.06 ± 0.95^{e}	18.96 ± 4.01^{b}	$22.223.80^{bca}$	2.85 ± 0.29^{d}
24	Conventional	6.21 ± 1.27^{fg}	15.32 ± 0.44^{d}	2.68 ± 0.26^{gh}	14.70 ± 0.42^{h}	0.85 ± 0.11^{h}	3.43 ± 0.19^{a}	39.01 ± 1.20^{gf}	4.82 ± 1.62^{e}	10.40 ± 2.20^{c}	21.67 ± 2.20^{ab}	2.09 ± 0.85^{d}
	Semi-organic	6.22 ± 1.46^{fg}	15.53 ± 0.20^{d}	2.95 ± 0.20^{gh}	14.07 ± 0.38^{h}	0.89 ± 0.05^{h}	3.35 ± 0.25^{a}	40.52 ± 2.65^{fg}	4.75 ± 0.69^{e}	13.20 ± 2.00^{c}	$22.242.87^{ab}$	2.95 ± 0.20^{d}
	Organic	5.65 ± 1.29^{fg}	15.20 ± 1.05^{d}	2.95 ± 0.76^{g}	14.70 ± 0.17^{h}	0.90 ± 0.02^{h}	3.26 ± 0.16^{a}	$43.33 \pm ,2.95^{gf}$	4.51 ± 0.97^{e}	35.00 ± 8.80^{d}	$20.331.04^{ab}$	2.95 ± 0.76^{d}

Values are mean ± SD of ten measurements. The contents were expressed for CO_2 in mL kg^{-1} h^{-1} and for C_2H_4 in µL kg^{-1} h^{-1}. Different letters in superscripts within column denote statistically significant differences in Duncan's ANOVA multiple range test. Values of means not sharing the same letters are significantly different from one another ($p = 0.05$; $n = 10$)

Table 2 Changes in the concentration of phenolic compounds, flavonoids and tannins and ferric antioxidant power values of kiwi fruit cultivar 'Hayward' grown in different cultivation systems, during 24 weeks of cold storage

Time of storage (weeks)	Growing conditions	Polyphenols (mg GAE/g)	Flavonoids (mg CE/g)	Tannins (mg CE/g)	FRAP (μMTE/g)
0	Conventional	4.18 ± 0.28^{a}	0.36 ± 0.06^{a}	0.82 ± 0.07^{a}	5.22 ± 0.22^{a}
	Semi-organic	4.22 ± 0.28^{a}	0.40 ± 0.06^{a}	0.87 ± 0.07^{a}	5.32 ± 0.22^{a}
	Organic	5.68 ± 0.28^{b}	0.45 ± 0.06^{a}	0.96 ± 0.07^{a}	7.32 ± 0.22^{b}
4	Conventional	4.29 ± 0.28^{a}	0.39 ± 0.08^{a}	0.89 ± 0.09^{a}	5.45 ± 0.26^{a}
	Semi-organic	4.26 ± 0.28^{a}	0.42 ± 0.08^{a}	0.91 ± 0.09^{a}	5.55 ± 0.26^{a}
	Organic	5.79 ± 0.28^{b}	0.47 ± 0.08^{a}	0.99 ± 0.09^{a}	7.45 ± 0.26^{b}
8	Conventional	4.61 ± 0.31^{a}	0.42 ± 0.09^{ab}	0.93 ± 0.09^{a}	5.87 ± 0.28^{a}
	Semi-organic	4.72 ± 0.31^{a}	0.48 ± 0.09^{ab}	0.96 ± 0.09^{a}	5.97 ± 0.28^{a}
	Organic	5.81 ± 0.31^{b}	0.50 ± 0.09^{ab}	0.96 ± 0.09^{a}	7.97 ± 0.28^{b}
12	Conventional	4.85 ± 0.41^{a}	0.49 ± 0.10^{bcd}	0.98 ± 0.11^{a}	6.36 ± 0.31^{a}
	Semi-organic	4.89 ± 0.41^{a}	0.51 ± 0.10^{bcd}	0.99 ± 0.11^{a}	6.46 ± 0.31^{a}
	Organic	5.93 ± 0.41^{b}	0.59 ± 0.10^{bcd}	0.99 ± 0.11^{a}	7.99 ± 0.31^{b}
16	Conventional	$4.95 \pm 0.0.41^{a}$	0.51 ± 0.11^{bcd}	1.07 ± 0.13^{b}	6.65 ± 0.34^{a}
	Semi-organic	$5.12 \pm 0.0.41^{a}$	0.56 ± 0.11^{bcd}	1.11 ± 0.13^{b}	6.85 ± 0.34^{a}
	Organic	$6.05 \pm 0.0.41^{b}$	0.61 ± 0.11^{bcd}	1.11 ± 0.13^{b}	8.05 ± 0.34^{b}
20	Conventional	5.12 ± 0.42^{a}	0.53 ± 0.11^{bcd}	1.11 ± 0.13^{b}	6.89 ± 0.35^{a}
	Semi-organic	5.29 ± 0.42^{a}	0.59 ± 0.11^{bcd}	1.21 ± 0.13^{b}	6.95 ± 0.35^{a}
	Organic	6.12 ± 0.42^{b}	0.63 ± 0.11^{bcd}	1.21 ± 0.13^{b}	8.15 ± 0.35^{b}
24	Conventional	5.30 ± 0.45^{a}	0.57 ± 0.12^{de}	1.17 ± 0.14^{c}	7.12 ± 0.41^{a}
	Semi-organic	5.45 ± 0.45^{a}	0.62 ± 0.12^{de}	1.37 ± 0.14^{c}	7.22 ± 0.41^{a}
	Organic	6.30 ± 0.45^{b}	0.71 ± 0.12^{de}	1.37 ± 0.14^{c}	8.22 ± 0.41^{b}

Values are presented as means ± SD of ten measurements; per g dry weight. Different letters in superscripts within column denote statistically significant differences in Duncan's ANOVA multiple range test. Values of means not sharing the same letters are significantly different from one another ($p = 0.05$; $n = 10$)

CE catechin equivalent, *GAE* gallic acid equivalent, *TE*T rolox equivalent, *FRAP* Ferric reducing antioxidant power assay

storage or during shelf life, ethylene was not detected. Five ethylene receptor genes showed different changes in expression during low-temperature storage [31].

Sensory analysis

The sensory value (score) at the beginning was from 1.23 ± 0.01 to 2.95 ± 0.05 for 'Hayward' (Table 1). Duration of cold storage changed the quality of fruits. The results showed that mamey fruits treated with 600 and 900 nL L^{-1} and stored 7 days delayed their ripening for 3 and 6 days, respectively, but the fruits stored 14 days, reached ripeness with an acceptable quality after 17 and 19 days [32].

Determination of total soluble solids (TSSs), pH and total acidity (TA)

The total soluble solids (Brix) before the treatment were from 7.83 ± 0.06 to 14.97 ± 0.12 for 'Hayward' for 24 weeks, respectively (Table 1). The pH and total acidity (%) during the cold storage changed for 'Hayward' from 3.22 ± 0.02 to 3.52 ± 0.01, and total acidity was from 1.49 ± 0.10 to 0.84 ± 0.10 (Table 1). The polyphenols in vine ripe fruits were similar to the fruits of storage harvest maturity (8–10 % TSS). Our results are in the line with Krupa et al. [33] that firmness rapidly decreased and the TSS increased for all cultivars during the first 14 days of storage at 1 °C. Physicochemical properties of samples of 'Abbot', 'Alison', 'Bruno', 'Monty', and 'Hayward' cultivars of kiwi fruit were studied during cold storage at 0-, 9- and 18-week intervals. The mean chemical composition of the fruits was as follows: starch = 0.3–7.0 %, °Brix = 6.5–14.8 % and acidity = 1.8–2.5 % of the studied cultivars. 'Hayward' had the best overall quality particularly with regard 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 kiwi fruit [34]. 'Hayward' cultivar was similar to the one grown in Italy [35]. The physicochemical indices of 'Hayward' grown in Iran differ from the present results shown in Tables 1, 2. Brix changed from 7.83 ± 0.06–14.97 ± 0.12 in comparison with Iranian of 8.13 ± 0.15–17.70 ± 0.26 during 18 weeks.

pH changed from 3.22 ± 0.02 to 3.52 ± 0.01 in comparison with 3.10 ± 0.01–2.93 ± 0.02 for the same cultivar, grown in Italy. These results are in line with our obtained data. Fruit firmness, content of starch, total soluble solids, dry matter and total acids content were decreased in apples after 14 weeks of storage in a controlled atmosphere (2 °C, 95 % relative air moisture, 2 % CO_2 and 1 % O_2) in each harvest time [36].

Starch and reducing sugar contents, carbon dioxide and ethylene productions

Reducing sugar content (Table 1) significantly increased at early stage of storage (from 35.20 ± 0.30 to 47.32 ± 0.40 % for 'Hayward') with decreasing of starch content (11.12 ± 0.09–7.21 ± 0.06 % for 'Hayward'). Respiration rate (Table 1) increased with time and then decreased during cold storage (from 38.18 ± 0.31 to 17.12 ± 0.14 μL kg^{-1} h^{-1} for C_2H_4 and from 4.22 ± 0.04 to 2.13 ± 0.02 mL kg^{-1} h^{-1} for CO_2). During cold storage, the significant effectiveness of shelf life in kiwi fruit is characterized by respiration and ethylene production. Therefore, we analyzed these contents rather than gas composition (Table 1).

Total soluble phenols

Polyphenols in water extracts (Table 2) were in 'Hayward' 5.30 ± 0.45 mg gallic acid equivalents (GAE)/g dry weight, DW. Park [37] showed changes during cold storage for 24 weeks during 2008 season collection from the same orchard. Our present results slightly differ from the previous data [37], but the two season collection showed similar relationship between the same cultivars. Relatively high content of bioactive compounds and antioxidant properties of kiwi fruit determined by the advanced analytical methods justify its use as a source of valuable antioxidants [38]. The bioactive compounds in kiwi fruit as an indication of quality after extraction using different solvents were studied in recent publications [38]. The methanol extracts of kiwi fruit showed significantly higher amounts of bioactive compounds than ethyl acetate extracts. The cultivar 'Bidan', in comparison with the classic 'Hayward', showed significantly higher bioactivity [38]. Our previous data slightly differ from the final results shown in Table 2. Our results in vitro were similar to Lee et al. [39], where the effects of the two main kiwi fruit cultivars (gold and green kiwi fruits) and their active phenolic compound were evaluated.

Antioxidant activities

Radical scavenging assays and chemometrical processing were used for the determination of bioactive kiwi fruits' compounds (Table 2). All kiwi fruit samples showed a high level of correlation between the contents of phenolic compounds and their antioxidant values. Our recent results differed from the ones showed by Park et al. [37], where the antioxidant capacities were determined by ABTS, DPPH and CUPRAC. Our results are in full correspondence with Krupa et al. [33], where a strong correlation between polyphenol contents (TPC) and antioxidant activity (AA) was in hardy kiwi fruits. TPC in ripe fruits were similar to the ones of the storage harvest maturity (8–10 % SSC). There was an increase in TPC after 7 days at the temperature 1 °C, but a longer period of storage caused a decrease. The AA slightly decreased during storage. That means that phenolics affect the antioxidant activity of hardy kiwi fruits [33]. The fresh-cut mangoes retained their bioactive compound content during cold storage, and their antioxidant and nutritional properties make them a good source of these compounds [40]. Cold storage positively influences quality indices of different fruits: cold storage notably reduced the degradation rate of ascorbic acid [41]. In addition, the use of 1-methylcyclopropene (1-MCP) treatment in long-term storage of apples is promising for maintaining the eating quality of fruits, however, in some extent may affect their antioxidant compounds content [42]. Our results are in line with other investigations where the results highlight that anthocyanin levels of fruit exposed to cold sharply increase after 6 days of storage, thus suggesting that fruit with enhanced health-related attributes might be obtained at this storage stage [43]. The degradation of different types of proanthocyanidins was not only temperature and pH dependent, but also structure dependent [44]. Shelf life of 'Hayward' kiwi fruit was relatively high. Most fruits decayed with infection of *Botritis cineria* regardless of cultivation type (Table 3).

Statistical analysis

Effect of growing conditions on compositional and quality characteristics of 'Hayward' kiwi fruit

The fresh 'Hayward' kiwi fruit samples cultivated by conventional, semi-organic (low chemical) and organic

Table 3 Pathogen symptoms of decayed kiwi fruit according to cultivation types during storage

Cultivation type	*Botritis ceneria*	*Botryosphaeria dothidea*	*Diaporthe actinidiae*
Conventional fruit	4 b[z]	2 b	0 b
Semi-organic fruit	6 b	2 b	0 b
Organic fruit	20 a	10 a	5 a

[z] Mean separation within column by Duncan's multiple range test at 5 % level

methods and stored (nontreated with ethylene) 0–24 weeks at 0 °C were examined on quality parameters: firmness, dry matter, sensory value, soluble solid content, acidity, pH, reducing sugar, starch, fruit decay, ethylene and CO_2 production. In the case of majority quality characteristics, multiple comparisons by Friedman two-way ANOVA test denoted some significantly different pairs ($p < 0.05$) between kiwi fruits related to different producing systems (Table 4). No significant differences among kiwi fruit growing systems were found in the case when production of ethylene or CO_2 characteristics was used for comparison. Principal component analysis brings only partial differentiation of eigenvectors according to the growing conditions. First three PCs cumulatively explained more than 87 % of the variability of the experimental characteristics, recognizing the variables firmness and total acidity as the most important for PC1 construction, whereas for the second PC, dry matter content and pH and for the third, the concentration of ethylene and sensory characteristics were identified as the parameters with the highest Eigenvalues. However, if for the purposes of differentiation of kiwi fruit according to the growing conditions also the qualitative characteristics (Table 2) are used (15 characteristics), the differentiation of samples according to the growing conditions is absolute, as is obvious from Fig. 1a. The reduction in cases was used as 'qualitative' characteristics and was monitored just once a month, not twice a month like the 'compositional' characteristics. As the most discriminating characteristics, in the first discriminant function, FRAP values followed by tannins concentration and firmness were identified. At the same time by means of just first DF, 97.4 % of kiwi fruit samples were discriminated according to growing conditions. In the second DF, firmness, concentration of flavonoids and starch/reducing sugars concentration (last two mentioned with identical discriminant coefficient) were identified as most discriminating characteristics. Results of successfully performed CDA confirm also the cluster analysis, performed on the basis of within-group differences consideration (Fig. 1b). In fact, two main clusters belonging to L/O and C samples (low chemicals/organic and conventional) and three main sub-clusters belonging to individual growing systems are observed from the dendrogram. Only one sample from conventionally grown group was misclusterized as being LC (Fig. 1b). Box-whiskers diagram (Fig. 1c) constructed using the way of production as a classification factor.

Table 4 Anova analysis (Friedman two-way ANOVA) of qualitative and compositional characteristics of 'Hayward' kiwi fruit grown under different production systems

Parameter	Significantly different pairs[a] ($p < 0.05$)
Firmness	L–O, C–O
Dry matter content	C–O, C–L
Sensorial parameters	C–O
Soluble solid content	C–L
Acidity	L–O, L–C
pH	L–O, C–O
Reducing sugar	C–O
Starch	C–O
Polyphenols	O–C, O–L
FRAP	O–C, O–L

[a] Producing systems: *L* low chemical (semi-organic), *O* organic, *C* conventional, *FRAP* Ferric reducing antioxidant power assay

The effect of storage on compositional and qualitative characteristics

Complete dataset of experimental characteristics was used, comprising of compositional and qualitative characteristics (11 + 4), for the purposes of the study of this partial effect. Due to the datasets consistency, the reduced dataset was used (as presented in Tables 1, 2), where values were obtained on the basis of monthly observations. Principal component analysis (PCA) of kiwi fruit samples using time of storage as classification factor led to partially successful differentiation of kiwi fruit samples. In fact, two main clusters of eigenvectors are obvious in Fig. 2a,—first comprising of samples stored for 0–8 weeks and the second—with samples stored for 12–24 weeks. The gradual differentiation of eigenvectors according to the time of storage, although not absolute, is also obvious, with eigenvectors of kiwi fruit 0 on the left side to these of kiwi fruit 24 on the opposite side of the plot of PCs (Fig. 2a). This is in fact a result of gradual changes in monitored characteristics during storing. As regards the numerical values, first three PCs cumulatively explain more than 87 % and four PCs >92 % of the whole dataset variability, with dominant role of firmness and sensory values (first PC, >31 % both), ethylene and fruit decays (second PC, >49 and >43 %, respectively) and pH and FRAP values (third PC, >43 and >54 %, respectively). Results of PCA fully confirm also the CDA according to time of storing as the classification criterion (Fig. 2b). Classification (100 % correct) was achieved. By means of first discriminant function, even >87.5 % of the cases was correctly classified, whereas by the first and second DF, even 99.9 % of the cases and by first three DFs, 100 % of the cases were classified. The discrimination power in the first DF (soluble solid and dry matter contents) and in the second and third DF (the contents of polyphenols and FRAP values) reached the highest discriminant coefficients. Complex overview on the changes of all monitored characteristics upon the time of cold

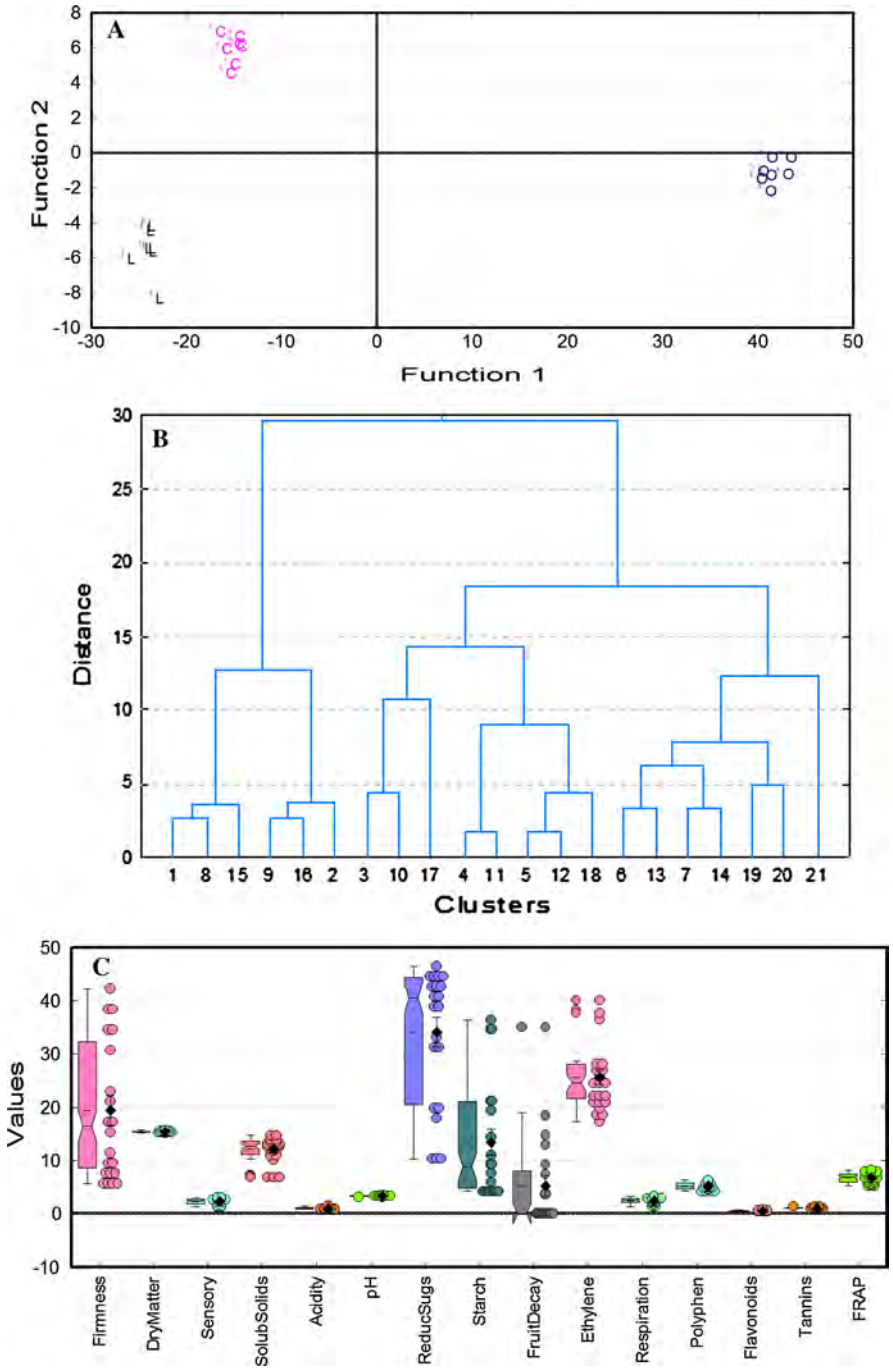

Fig. 1 Effect of growing conditions on compositional and quality characteristics of 'Hayward' kiwi fruit. **a** Canonical discriminant analysis (CDA) of 'Hayward' kiwi fruit samples, grown under semi-organic (low chemical, L) conventional (C) and organic (O) conditions. Both 'compositional' and 'qualitative' kiwi fruit characteristics were used for discrimination. Graphical presentation of canonical discriminant analysis of the differently farmed 'Hayward' kiwi fruit (C—conventional, semi-organic (L—low chemical), and O—organic; 0–24 weeks of storage at 0 °C; not treated with ethylene; variables analyzed: firmness, dry matter, sensory value, soluble solid content, acidity, pH, reducing sugar, starch, fruit decay, ethylene and CO_2 production). **b** Cluster analysis of kiwi fruit samples performed on the basis of within-group differences of organically, semi-organic (low chemical, L) and conventionally grown fruit. Clusters were constructed considering both compositional and qualitative characteristics. *Box-whiskers* diagram constructed using the way of production as classification factor. Diagram illustrates the variability in values of individual experimental characteristics within the group of organically, semi-organically (low chemical) and conventionally grown 'Hayward' kiwi fruit. **c** *Box-whiskers* diagram constructed using the way of production as a classification factor. Diagram illustrates the variability in values of individual experimental characteristics within the group of organically, semi-organic (low -chemical, L) and conventionally grown 'Hayward' kiwi fruit. Principal component analysis of 'Hayward' kiwi fruits was done according to time of cold storage. All 11 compositional and 4 qualitative characteristics were utilized for PCs construction

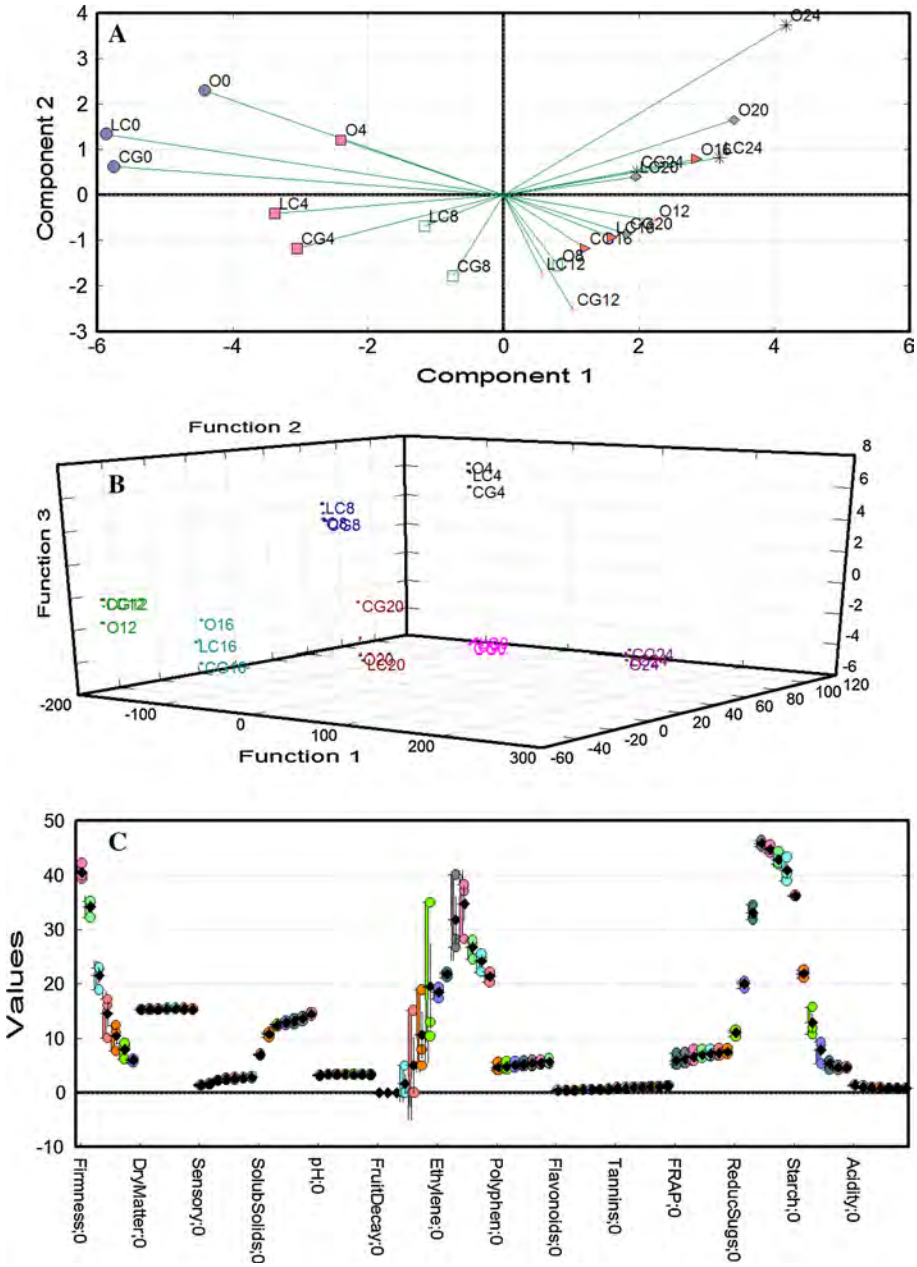

Fig. 2 Effect of growing conditions on compositional and quality characteristics of 'Hayward' kiwi fruit: **a** Principal component analysis (PCA) of kiwi fruit 'Hayward' according to time of cold storage. All 11 compositional and 4 qualitative characteristics were utilized for PCs construction. **b** Canonical discriminant analysis (CDA) of kiwi fruit 'Hayward' on the basis of their compositional and qualitative characteristics. Time of cold storage was used as the discrimination criterion. **c** *Box-whiskers* diagram constructed using the time of storage as a factor

storage of kiwi fruit samples illustrates the box-whiskers diagram (Fig. 2c). While firmness values and starch contents exhibited gradual decrease, other parameters either exhibited slight growth or negligible effects of storage. Interesting comparison of all the characteristics and mutual correlations between them offers also the correlation matrix constructed from Pearson's correlation coefficients (Table 5). It is noticeable that for majority of compositional characteristics, coefficient correlations were found weak to moderate (up to 0.65), whereas in case of qualitative characteristics, moderate to weak correlations were evident.

Emission spectral studies

It was shown that all main fluorescence peaks in water extracts of kiwi fruit were located between λ_{em} from 338 to 459 nm with fluorescence intensity (FI) from 291 to 80 (Fig. 3; Table 6). According to the value of FI in the main peaks of kiwi fruit, water extracts were as following: organic sample (Fig. 3c, CC), showing the highest fluorescence intensity with the maximum of the fluorescence shift in detected peaks a, b and c. Average values were in low chemical and the lowest ones in conventional (Fig. 3a, b). It is very interesting that the polyphenols and antioxidant

Table 5 Correlation matrix illustrating the correlation relationships between the individual kiwi fruit compositional and qualitative characteristics, constructed from Pearson's correlation coefficients. Correlations were performed without respect on way of production or storing

	Firmness	Dry matter	Sensory	Soluble solids	Acidity	pH	Reducing sugars	Starch	Fruit decay	Ethylene	Respiration	Polyphenols	Flavonoids	Tannins	FRAP
Firmness	1														
Dry matter	−0.44	1													
Sensory	−0.98	0.39	1												
Soluble solids	−0.92	0.33	0.90	1											
Acidity	0.94	−0.39	−0.92	−0.96	1										
pH	−0.27	0.33	0.22	0.45	−0.36	1									
Reducing sugars	−0.94	0.43	0.93	0.90	−0.94	0.26	1								
Starch	0.96	−0.42	−0.95	−0.97	0.95	−0.42	−0.96	1							
Fruit decay	−0.60	−0.01	0.59	0.51	−0.44	−0.17	0.42	−0.47	1						
Ethylene	−0.30	0.30	0.35	0.39	−0.47	0.31	0.51	−0.43	−0.30	1					
Respiration	0.75	0.41	0.77	0.70	−0.80	0.03	0.81	−0.73	0.37	0.48	1				
Polyphenols	−0.58	0.30	0.51	0.48	−0.40	0.19	0.47	−0.52	0.65	0.03	0.20	1			
Flavonoids	−0.88	0.26	0.86	0.76	−0.71	0.10	0.77	−0.80	0.82	0.05	0.53	0.80	1		
Tannins	−0.80	0.12	0.80	0.72	−0.66	0.06	0.64	−0.71	0.81	−0.13	0.49	0.64	0.91	1	
FRAP	−0.64	0.37	0.57	0.55	−0.47	0.25	0.54	−0.59	0.62	0.11	0.25	0.99	0.82	0.65	1

*FRAP F*erric reducing antioxidant power assay

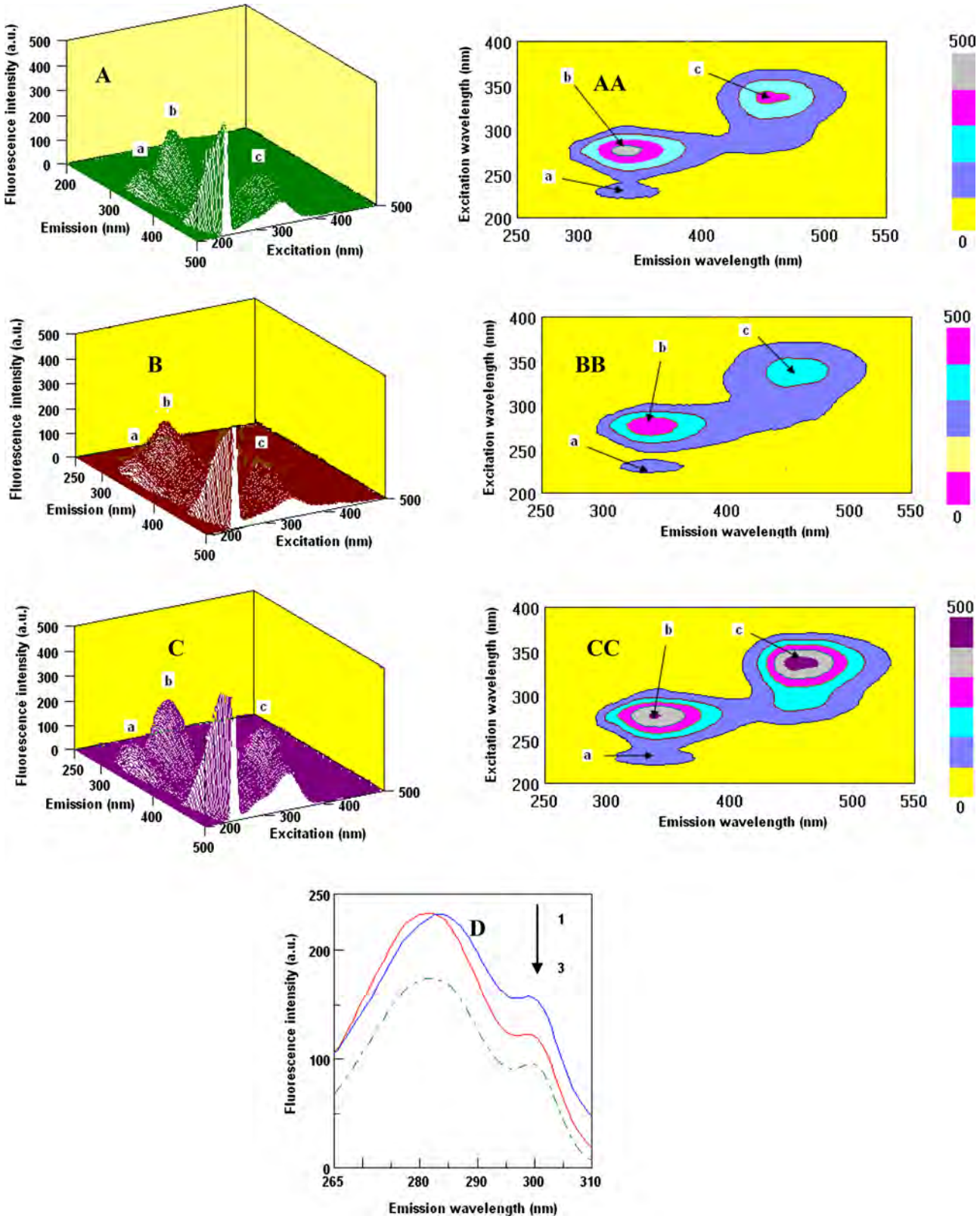

Fig. 3 3D spectra and their contours of various kiwi fruit samples at 0.1 mg/mL such as **A**, **AA**, **B**, **BB**, **C**, **CC**, conventionally, semi-organically (low chemical) and organically grown kiwi fruit samples in aqueous solution. Excitation wavelength scan: 200–400 nm. Emission wavelength scan: 250–550 nm. In each sample, three peaks *a*, *b*, *c* are shown. **D** shows 2D-FL with three lines, where *1*, *2* and *3* is organic sample, semi-organic (low chemical) and conventional

Table 6 Fluorescence data of investigated samples of 'Hayward' kiwi fruit

Samples	Peak a		Peak b		Peak c	
	$\lambda_{ex}/\lambda_{em}$ (nm/nm)	Intensity F_0	$\lambda_{ex}/\lambda_{em}$ (nm/nm)	Intensity F_0	$\lambda_{ex}/\lambda_{em}$ (nm/nm)	Intensity F_0
Organic	231/338	105.19	275/339	274.33	336/459	290.57
Semi-organic	230/340	87.48	277/339	236.95	336/457	171.98
Conventional	230/339	80.29	276/340	198.72	338/458	133.25

activities were corresponding with the fluorescence data (Table 2; Fig. 3d). It was the best correlation between the obtained results of polyphenols in water extracts with the data of fluorescence intensity measurements. In the 3D contour spectra of kiwi fruit extracts, a rose color in the center of each figure represents the maximum intensity, which corresponds to the emission maximum resulting from tryptophan amino acid. The smallest one was in organic sample. A single contour of peak b is obtained in all kiwi fruit samples (Fig. 3), which corresponds to 277 and 340 nm as the excitation and emission wavelengths, respectively. The fluorescence intensity of kiwi fruit extract at the emission maximum is about 291. The shifts in the emission maximum of kiwi fruit extracts and the variations in the fluorescence intensity depend on the investigated samples (between 457 and 459 nm). From the emission spectral studies, it is understandable that kiwi fruit extracts influence the fluorescence quenching, depending on the amount of polyphenols. The quenching properties of these samples are directly correlated with their antioxidant properties and the amount of polyphenols. Similar results were reported in our recent publications: correlation between the antioxidant and binding properties of different berries [45].

Conclusions

Cold storage had a significant effect on physicochemical and nutritional properties of kiwi fruit and improved their quality and antioxidant activity. Cold storage enhanced the firmness, starch and total soluble solids due to lower respiration and ethylene production. Cold storage extended shelf life in kiwi fruit without any chilling injury or color change in 'Hayward.' The quenching properties of these samples are directly correlated with their antioxidant properties and the amount of polyphenols. The suggested methods for the quality of kiwi fruit can be applied for any fruit. High amount of natural antioxidants such as phenolic compounds makes kiwifruit even more important for daily consumption.

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Compliance with ethical standards

Conflict of interest None.

Compliance with Ethics Requirements This article does not contain any studies with human or animal subjects.

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