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EFFECTS OF HIGH-DOSE POSTHARVEST MELATONIN ON WEIGHT LOSS, PHYSICAL QUALITY AND BIOACTIVE COMPOUNDS OF 'KEPPLER' HIGHBUSH BLUEBERRY (*VACCINIUM CORYMBOSUM* L.) DURING COLD STORAGE

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Abstract

Melatonin has been proposed as a natural postharvest treatment for fresh fruits; however, its effective concentration range for blueberry has not been established. This study evaluated the effects of postharvest melatonin applied at 0, 500, 1000 and 1500 ppm (0, 2.15, 4.31 and 6.46 mmol L^{-1}) on the quality of 'Keppler' highbush blueberry (*Vaccinium corymbosum* L.) during 20 days of cold storage at 4°C. Weight loss, total soluble solids (TSS), fruit firmness, surface colour (L*, a*, b*), titratable acidity (TA), vitamin C, total phenolic content (TPC), total anthocyanin content (TAC) and DPPH radical scavenging activity were determined at 5-day intervals. Storage period was the dominant source of variation for all traits except colour, and the treatment × storage interaction was significant for TSS, weight loss, firmness and all biochemical traits. The 1000 ppm dose was the only treatment that reduced weight loss (by 48% and 36% relative to the control at days 15 and 20, respectively) and limited the rise in TSS; however, this response was not dose-dependent and was variable among replicate packages, so it requires confirmation. Melatonin did not affect fruit colour, and firmness was improved only by 1500 ppm at day 15. Melatonin transiently increased TPC and TAC during the first 5–10 days of storage; however, from day 15 onward, control fruit retained significantly higher TA, vitamin C, TPC, TAC and DPPH activity than all melatonin-treated fruit. Pearson correlation and principal component analysis showed that TA, vitamin C and DPPH activity were almost perfectly correlated with each other (r = 0.99–1.00) and that TPC was strongly correlated with DPPH activity (r = 0.90); these associations largely reflected the parallel decline of these traits during storage, and PC1 (63.5%) described a storage-related quality-loss gradient. The applied doses (about 2.2–6.5 mmol L^{-1}) were well above the range effective in previous blueberry studies, suggesting a supra-optimal response. Lower melatonin concentrations should be tested to combine reduced water loss with better retention of nutritional quality in blueberry.

Key words: Anthocyanins; Antioxidant activity; Postharvest quality; Principal component analysis; *Vaccinium corymbosum*; Weight loss

Introduction

Highbush blueberry (*Vaccinium corymbosum* L.) is one of the most valued small fruits worldwide, largely because of its high content of anthocyanins, other phenolic compounds and vitamin C. Regular consumption of blueberries and their anthocyanins has been associated with improved cardiometabolic health, vascular function and cognitive performance (Kalt *et al.,* 2020). These health-related compounds, together with firmness, surface bloom and flavour, determine the market value of the fruit.

Blueberries are highly perishable after harvest. Their thin skin and high respiration rate lead to rapid water loss, shrivelling, softening and decay, and these changes are accompanied by losses of ascorbic acid and polyphenols during storage (Kozos *et al.,* 2015). Postharvest softening of blueberry is driven by cell-wall disassembly and is closely linked to abscisic acid signalling (Wang *et al.,* 2026), while the epicuticular wax layer is the main barrier limiting water loss from the fruit surface (Li *et al.,* 2024). Cold storage alone cannot fully prevent these changes, so safe and natural treatments that slow quality loss are of great practical interest.

Melatonin (N-acetyl-5-methoxytryptamine) is an indoleamine found in all plant tissues. It acts both as a direct scavenger of reactive oxygen species and as a regulator that interacts with ethylene, abscisic acid, auxin and other hormone networks (Arnao & Hernández-Ruiz, 2019). In stored fruits, exogenous melatonin lowers the accumulation of H_2O_2 and malondialdehyde, activates antioxidant enzymes and the ascorbate–glutathione cycle, and delays senescence (Xu *et al.,* 2019; Li *et al.,* 2023). A recent meta-analysis concluded that postharvest melatonin generally reduces weight loss and decay and increases ascorbic acid, phenolics, anthocyanins and antioxidant capacity across many fruit species (Budiarto *et al.,* 2025). Positive effects have been reported in strawberry (Aghdam & Fard, 2017; Liu *et al.,* 2018; El-Mogy *et al.,* 2019; Kahramanoğlu, 2024), plum (Bal, 2019) and mango (Njie *et al.,* 2022).

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In blueberry, melatonin has been shown to reduce qualitative decay and improve the antioxidant system during cold storage (Magri & Petriccione, 2022), to enhance disease resistance through the jasmonic acid and phenylpropanoid pathways (Qu *et al.,* 2022), to maintain firmness and ascorbic acid during cold storage (Li *et al.,* 2025), to slow the degradation of cuticular wax (Li *et al.,* 2024) and to delay softening by regulating auxin homeostasis (Wang *et al.,* 2026). However, most of these studies used concentrations of 0.1–0.3 mmol L^{-1} (about 23–70 ppm) on cultivars grown in China, and the response to melatonin is known to depend on dose, species and cultivar (Xu *et al.,* 2019; Okatan *et al.,* 2023). In blue honeysuckle, a closely related berry, melatonin even reduced several polyphenol classes by the end of storage (Qiao *et al.,* 2025). The effects of higher melatonin concentrations on blueberry, and on the widely grown European cultivar 'Keppler', have not been reported.

Therefore, the aim of this study was to determine the effects of postharvest melatonin applied at 500, 1000 and 1500 ppm (2.15–6.46 mmol L^{-1}) on weight loss, TSS, firmness, colour, titratable acidity, vitamin C, phenolics, anthocyanins and antioxidant activity of 'Keppler' highbush blueberry during 20 days of cold storage, and to identify the relationships among these traits by correlation and principal component analysis.

Materials and Methods

Plant material and melatonin treatments: Fruits of the highbush blueberry cultivar 'Keppler' were harvested at commercial maturity (fully blue surface colour) from a single commercial orchard in Korkuteli (Antalya, Türkiye) in the 2026 season and transported in insulated boxes within 24 h to the laboratory of the Department of Horticulture, Eskişehir Osmangazi University. Uniform fruits free of defects were selected and divided into four groups. Melatonin (N-acetyl-5-methoxytryptamine; Merck, Germany, CAS No. 73-31-4) solutions were prepared at 0 (control), 500, 1000 and 1500 ppm (mg L^{-1}; equivalent to 0, 2.15, 4.31 and 6.46 mmol L^{-1}, calculated from the molar mass of melatonin, 232.28 g mol^{-1}). Because melatonin is poorly soluble in water, the weighed amount was first dissolved in a small volume of absolute ethanol and then made up to volume with distilled water, giving a final ethanol concentration of 0.5% (v/v) in all solutions. The control solution contained the same amount of ethanol in distilled water, so that the treatments differed only in melatonin concentration. Solutions were prepared fresh on the day of treatment. Fruits were dipped in the solutions for 30 min at room temperature (about 20°C) and air-dried for 1 h at room temperature. A total of 48 packages were prepared (12 per treatment, i.e. three packages for each of the four sampling dates), each containing approximately 133 g of fruit (mean package weight 133.3–133.7 g, depending on treatment). The packages were commercial open-top polyethylene terephthalate (PET) punnets with ventilation holes and no film cover, so that the fruit was in direct contact with the storage-room atmosphere. Packages were coded by treatment, sampling date and package number and stored at 4°C and 85% relative humidity for 20 days.

Sampling and experimental units: Initial quality (day 0) was determined on untreated fruit at harvest, before the dipping treatment; no treated day-0 sample was taken. Treated fruits were analysed at 5, 10, 15 and 20 days of storage. At each sampling date, three packages per treatment were removed from storage and used for weight loss and TSS (n = 3 packages). For colour and firmness, 15 fruits were taken at random from the fruit of these three packages, giving 15 individual fruits per treatment and sampling date (n = 15), and each fruit was measured once. For the biochemical traits, 15 independent subsamples per treatment and sampling date were extracted and analysed separately (n = 15). The 15 values therefore represent 15 separate fruits or subsamples drawn from three packages, not repeated readings on the same sample; because the package of origin of the individual fruits was not recorded, these traits could not be analysed at the package level. At day 0, 10 fruits/subsamples (n = 10) and three TSS samples (n = 3) were measured.

Weight loss and total soluble solids: Each package was weighed on a precision balance (± 0.01 g) at the start of storage and at each sampling date, and weight loss was expressed as a percentage of the initial weight; because weight loss is defined relative to the initial weight, it is zero by definition at day 0 and is therefore not reported for that date. TSS was measured in juice pressed from the pooled fruit of each package using a digital refractometer (Hanna HI981036, Germany) calibrated with distilled water and expressed as °Brix.

Fruit colour and firmness: Surface colour was measured with a Chroma Meter CR-400 colorimeter (Konica Minolta, Osaka, Japan) with an 8 mm measuring aperture, illuminant C and a 2° standard observer; the instrument was calibrated against the manufacturer's white calibration plate before each measuring session. One reading was taken at the equatorial region of each fruit and expressed as CIE L* (lightness), a* (green–red) and b* (blue–yellow) values. Fruit firmness was measured on the same fruits with a hand-held penetrometer (FT-327, Effegi, Alfonsine, Italy) fitted with a 3 mm-diameter cylindrical probe; the maximum force required to puncture the skin at the equator was recorded and expressed as kg cm^{-2} (force divided by the cross-sectional area of the probe). This puncture method measures the resistance of the skin and underlying tissue and differs from the whole-fruit compression tests (e.g. FirmTech, g mm^{-1}) commonly used for blueberry; the values are therefore not directly comparable with compression data.

Titratable acidity and vitamin C: Titratable acidity and vitamin C were determined independently, on separate aliquots of the homogenate, by different methods. Titratable acidity was determined by titrating 5 mL of juice diluted to 50 mL with distilled water with 0.1 N NaOH to pH 8.1 using a digital pH meter, and expressed as % citric acid. Vitamin C (ascorbic acid) was determined spectrophotometrically by the 2,6-dichlorophenolindophenol (DCPIP) method (Pearson, 1976). Briefly, 5 g of fruit was homogenised in 50 mL of 0.4% (w/v) oxalic acid and filtered; 1 mL of the filtrate was mixed with 9 mL of DCPIP solution, and the absorbance was read at 520 nm within 15 s. The ascorbic acid content was calculated from a standard curve prepared with L-ascorbic acid (0–50 mg L^{-1}; $R^2 \geq 0.99$) and expressed as mg 100 g^{-1} FW.

Total phenolic content, total anthocyanins and antioxidant activity: For TPC and DPPH, 1 g of fruit was homogenised in 10 mL of 80% (v/v) methanol, kept for 24 h at 4°C in the dark and centrifuged at 5000 × g for 10 min, and the supernatant was used as the extract. For TAC, a parallel extract was prepared in the same way with acidified methanol (methanol:HCl, 99:1, v/v). Total phenolic content was determined by the Folin–Ciocalteu method (Singleton & Rossi, 1965): 0.5 mL of extract was mixed with 2.5 mL of 10-fold diluted Folin–Ciocalteu reagent and, after 5 min, with 2 mL of 7.5% (w/v) Na_2CO_3; after 2 h at room temperature in the dark, the absorbance was read at 765 nm against a gallic acid standard curve (0–500 mg L^{-1}) and expressed as mg gallic acid equivalent (GAE) 100 g^{-1} FW. Total anthocyanin content was determined by the pH-differential method (Giusti & Wrolstad, 2001). The extract was diluted with 0.025 M potassium chloride buffer (pH 1.0) and with 0.4 M sodium acetate buffer (pH 4.5), and the absorbance of each dilution was read at 520 and 700 nm after 15 min. TAC was calculated from $A = (A_{520} - A_{700})_{pH\ 1.0} - (A_{520} - A_{700})_{pH\ 4.5}$, using a molar extinction coefficient of 26,900 L mol^{-1} cm^{-1} and a molecular weight of 449.2 g mol^{-1} for cyanidin-3-glucoside, and expressed as mg cyanidin-3-glucoside equivalent (C3G) 100 g^{-1} FW. Antioxidant activity was determined by the DPPH radical scavenging assay (Brand-Williams *et al.,* 1995): 0.1 mL of extract was added to 3.9 mL of a 60 µM methanolic DPPH solution, the mixture was kept for 30 min at room temperature in the dark, and the absorbance was read at 515 nm. Scavenging activity was calculated as $[(A_0 - A_1)/A_0] \times 100$, where A_0 is the absorbance of the DPPH solution without extract and A_1 that of the sample, and expressed as percentage inhibition. All spectrophotometric readings were made with a UV–Vis spectrophotometer (Shimadzu UV-1800, Kyoto, Japan).

Statistical analysis

The experiment was arranged in a completely randomized design with a 4 × 4 factorial arrangement (melatonin dose × storage period). For TSS and weight loss the package was the experimental unit (n = 3 per treatment and date; error df = 32), whereas for colour, firmness and the biochemical traits the individual fruit or subsample was used as the observational unit (n = 15 per treatment and date; error df = 224), as indicated in Table 1. Data were subjected to two-way analysis of variance (ordinary least squares model; statsmodels.formula.api.ols and statsmodels.stats.anova.anova_lm), and means were separated by Tukey's honest significant difference (HSD) test at p≤0.05 using the pairwise_tukeyhsd function of statsmodels.stats.multicomp. Because the treatment × storage interaction was significant for most traits, mean separation was carried out on the simple effects: treatments were compared within each storage day (lowercase letters) and storage days were compared within each treatment (uppercase letters), each comparison being based on the corresponding subset of the data. The same procedure was applied to all traits, including those with a non-significant interaction, for consistency of presentation. Day 0 values were used as the initial reference and were not included in the ANOVA. Pearson correlation coefficients and principal component analysis (PCA, on standardized data) were calculated from the 16 treatment × storage means; because these means span four storage dates, the correlations describe the joint variation of the traits over the whole storage period and are strongly influenced by the common time trend. To separate trait associations from this trend, two additional correlation analyses were performed on the individual fruit/subsample data for the traits measured per fruit (colour, firmness and biochemical traits): (i) Pearson correlations within each storage day (n = 60 per day, all treatments pooled) and (ii) partial correlations controlling for both treatment and storage day, calculated on the residuals after subtracting the treatment × day cell means (n = 240, df = 223). These are presented as Supplementary Table S2. Analyses were performed in Python (statsmodels and scikit-learn libraries). The raw data for all traits are provided as Supplementary Table S1.

Table 1. Two-way analysis of variance (F values) for quality traits of 'Keppler' blueberry treated with melatonin during storage.

Trait	Treatment (T), df = 3	Storage period (S), df = 3	T × S, df = 9	Error df
TSS (°Brix)	22.24 ***	73.43 ***	3.19 **	32
Weight loss (%)	18.67 ***	111.53 ***	2.39 *	32
L*	0.22 ns	4.34 **	0.50 ns	224
a*	0.30 ns	0.72 ns	1.04 ns	224
b*	0.22 ns	2.03 ns	0.41 ns	224
Firmness	2.33 ns	51.99 ***	2.87 **	224
TA	99.36 ***	1164.10 ***	7.06 ***	224
Vitamin C	150.85 ***	1794.25 ***	13.12 ***	224
TPC	39.45 ***	716.97 ***	37.91 ***	224
TAC	18.68 ***	309.53 ***	33.22 ***	224
DPPH (%)	109.81 ***	1265.24 ***	15.11 ***	224

*, **, *** = Significant at p≤0.05, 0.01 and 0.001, respectively; ns = Not significant; TSS = Total soluble solids; TA = Titratable acidity; TPC = Total phenolic content; TAC = Total anthocyanin content; DPPH = DPPH radical scavenging activity

Results

Analysis of variance: Storage period had a significant effect on all measured traits except a* and b* (Table 1). Melatonin treatment significantly affected TSS, weight loss, titratable acidity, vitamin C, total phenolic content, total anthocyanin content and DPPH radical scavenging activity (p≤0.001), whereas it had no significant effect on fruit firmness or on the colour parameters L*, a* and b*. The treatment × storage period interaction was significant for TSS (p≤0.01), weight loss (p≤0.05), firmness (p≤0.01) and all biochemical traits (p≤0.001), indicating that the response to melatonin depended on storage duration. Storage period produced by far the largest F values, particularly for vitamin C (F = 1794.25), DPPH (F = 1265.24) and titratable acidity (F = 1164.10).

Weight loss and total soluble solids: Weight loss increased progressively in all treatments during storage, reaching 14.51–15.84% at day 20 in the control, 500 ppm and 1500 ppm groups (Table 2). The 1000 ppm melatonin treatment was the only dose that limited water loss; it showed the lowest weight loss at day 5 (1.83% vs 4.70% in the control), day 15 (6.49% vs 12.49%) and day 20 (9.85% vs 15.39%), corresponding to reductions of about 48% and 36% relative to the control at days 15 and 20, respectively. However, the response did not follow the dose: the 500 and

1500 ppm doses did not differ significantly from the control at any sampling date, and the 1000 ppm group showed the largest standard deviation of the whole data set at day 20 (± 3.18), indicating considerable variation among the three packages. TSS rose from an initial 10.60 °Brix to 12.50 °Brix in control fruit at day 20. Fruit treated with 1000 ppm melatonin had significantly lower TSS than the control at days 15 and 20 (10.60 vs 11.70 and 11.30 vs 12.50 °Brix, respectively), consistent with their lower weight loss. At day 5, the TSS of the 1000 ppm group (9.20 °Brix) was below the harvest value, but it did not differ significantly from the control (10.40 °Brix) and differed only from the 500 ppm treatment.

Fruit firmness and colour: Fruit firmness declined from 9.26 kg cm^{-2} at harvest to 4.99–8.87 kg cm^{-2} during storage, with the sharpest drop between days 5 and 10 in all treatments (Table 2). The standard deviations of firmness were large (0.70–2.56 kg cm^{-2}), reflecting marked fruit-to-fruit variation in skin resistance. Differences among treatments were limited: at day 5, fruit treated with 500 ppm were softer than those treated with 1000 or 1500 ppm but did not differ from the control; at day 15, fruit treated with 1500 ppm melatonin were significantly firmer than the control (6.27 vs 4.99 kg cm^{-2}), while no differences were found at days 10 and 20. Colour parameters changed little during storage, with L*, a* and b* values ranging from 29.70 to 32.36, 2.77 to 3.16 and −7.74 to −6.66, respectively. Melatonin had no significant effect on any colour parameter, and a* and b* were not affected by storage either. Storage had a small but significant main effect on L* (Table 1), which reflected slightly lower lightness at day 20 (30.53–30.88) than at days 5–15 (30.98–32.36) when all treatments were pooled (n = 60 per day). This difference was, however, too small to be detected by the within-treatment Tukey comparisons (n = 15 per mean) presented in Table 2, in which all L* means received the same letter.

Titratable acidity and vitamin C: Titratable acidity and vitamin C decreased steadily in all treatments during storage (Table 3). In control fruit, TA fell from 0.842 at harvest to 0.695 at day 20 and vitamin C from 13.55 to 9.95, a loss of 26.6%. Melatonin-treated fruit showed greater declines: from day 10 onward the 1000 and 1500 ppm groups, and from day 15 onward all melatonin groups, had significantly lower TA and vitamin C than the control, with vitamin C reaching 8.89–8.97 at day 20.

Total phenolics, anthocyanins and antioxidant activity: Total phenolic content increased during the first 10 days of storage and then declined (Table 3). At day 5, 1500 ppm melatonin produced the highest TPC (430.7 vs 414.1 in the control), but this advantage disappeared by day 10. At days 15 and 20, control fruit retained significantly higher TPC (424.2 and 401.0) than melatonin-treated fruit (401.1–411.5 and 380.6–381.8, respectively). TAC showed a similar transient response: 1500 ppm raised TAC at day 5 (191.1 vs 182.2), and 1000 and 1500 ppm gave the highest TAC at day 10 (193.1 and 193.7). Anthocyanins in melatonin-treated fruit then declined earlier than in the control, which peaked at day 15 (192.9); at day 20, TAC was 184.1 in the control and 173.2–173.7 in all melatonin treatments. DPPH radical scavenging activity decreased from 85.20% at harvest to 77.64% in the control at day 20, while melatonin-treated fruit reached 73.83–74.26%, with no significant differences among the three doses.

Correlation analysis: Titratable acidity, vitamin C and DPPH activity were almost perfectly positively correlated with each other (r = 0.99–1.00, $p \leq 0.001$), and TPC was strongly correlated with DPPH (r = 0.90), vitamin C and TA (r = 0.84) and TAC (r = 0.88) (Fig. 1). Weight loss was strongly positively correlated with TSS (r = 0.93, $p \leq 0.001$) and negatively correlated with TA (r = −0.81), vitamin C (r = −0.80), DPPH (r = −0.78) and firmness (r = −0.75). Firmness was also negatively correlated with TSS (r = −0.82). Among the colour parameters, L* was negatively correlated with b* (r = −0.88) and positively with TPC (r = 0.74) and TAC (r = 0.72), whereas a* showed no significant correlation with any trait. It should be noted that these coefficients were calculated from the 16 treatment × storage means and therefore describe the joint variation of the traits across storage time; traits that declined (or increased) in parallel during storage necessarily show high absolute r values, irrespective of any causal link between them. Non-significant coefficients are also displayed in Fig. 1, without asterisks. When the common time trend and the treatment effects were removed by partial correlation on the individual fruit data (Supplementary Table S2b), the associations among the biochemical traits remained significant but were much weaker: TA–vitamin C r = 0.50, vitamin C–DPPH r = 0.44, TA–DPPH r = 0.34, TPC–TAC r = 0.34, TPC–vitamin C r = 0.31, TPC–DPPH r = 0.26 and TAC–DPPH r = 0.25 (all $p \leq 0.001$, n = 240), whereas firmness and the colour parameters were not correlated with any biochemical trait (only L* and b* remained strongly correlated, r = −0.93). Within individual storage days (Supplementary Table S2a), the five biochemical traits were strongly inter-correlated at days 15 and 20 (r = 0.80–0.90, n = 60), when the treatments differed most, but not consistently at day 5, when the 1500 ppm treatment had raised TPC and TAC while lowering TA and vitamin C.

Principal component analysis: Three principal components explained 89.94% of the total variance (Table 4). The first two components accounted for 81.25% of the variance (PC1 63.49%, PC2 17.76%) and were used to construct the biplot (Fig. 2). PC1 was strongly and positively associated with DPPH (0.996), vitamin C (0.981), TA (0.980), TPC (0.924) and L* (0.787), and negatively with weight loss (−0.889), TSS (−0.788) and b* (−0.767). PC1 therefore represented a storage-related quality-loss gradient: day 5 samples clustered on the positive side, day 10 samples near the centre and day 20 samples on the negative side together with weight loss and TSS. PC2 was mainly defined by firmness (0.702) and, in the opposite direction, by TAC (−0.673). At days 15 and 20, the control was positioned further along the positive PC1 axis than the melatonin treatments, reflecting its higher retention of TA, vitamin C, TPC and antioxidant activity, while the 1000 ppm treatment at day 20 was separated towards the upper part of the plot, consistent with its lower weight loss and TSS.

Table 2. Effect of melatonin on weight loss, total soluble solids, colour and firmness of 'Keppler' blueberry during storage.

Day	Treatment	TSS (°Brix)	Weight loss (%)	L*	a*	b*	Firmness (kg cm⁻²)
0 (initial)	Control	10.60±0.10	—	31.04±1.78	3.31±0.50	-7.07±1.00	9.26±2.56
5	Control	10.40±1.00 abB	4.70±0.85 aD	31.69±2.11 aA	2.93±0.31 aA	-7.57±1.07 aA	8.37±1.25 abA
5	500 ppm	10.90±0.26 aC	4.39±0.47 abD	30.98±1.41 aA	3.08±0.45 aA	-7.03±0.89 aA	7.04±1.55 bA
5	1000 ppm	9.20±0.44 bC	1.83±1.86 bB	31.83±2.64 aA	3.10±0.58 aA	-7.42±1.50 aA	8.87±1.51 aA
5	1500 ppm	10.27±0.45 abC	4.50 ±0.06 abC	31.91±2.30 aA	2.94±0.16 aA	-7.30±1.40 aA	8.49±1.61 aA
10	Control	11.43±0.15 aAB	8.29±0.18 aC	31.38±2.33 aA	3.13±0.60 aA	-7.30±1.19 aA	5.97±1.60 aB
10	500 ppm	11.40±0.10 aB	7.44±0.77 aC	32.36±2.40 aA	3.02 ± 0.45 aA	-7.74±1.39 aA	6.49±1.36 aAB
10	1000 ppm	11.33±0.15 aA	7.60±0.67 aA	31.54±1.34 aA	2.95 ± 0.50 aA	-7.31±0.67 aA	5.96±1.02 aB
10	1500 ppm	11.23±0.15 aB	7.88±0.35 aBC	31.82±2.49 aA	2.91±0.46 aA	-7.46±1.37 aA	5.84±0.70 aB
15	Control	11.70±0.10 aAB	12.49±0.80 aB	31.51±1.61 aA	2.96±0.37 aA	-7.53±1.06 aA	4.99±1.15 bB
15	500 ppm	11.60±0.10 aB	10.69±1.05 aB	31.78±1.98 aA	2.86±0.28 aA	-7.30±1.12 aA	5.81±0.89 abB
15	1000 ppm	10.60±0.10 bB	6.49±0.48 bAB	31.83±2.97 aA	2.94±0.45 aA	-7.48±1.52 aA	5.97±0.87 abB
15	1500 ppm	11.50±0.10 aB	11.52±2.51 aB	31.60±1.39 aA	3.16±0.81 aA	-7.13±0.93 aA	6.27±1.56 aB
20	Control	12.50±0.10 aA	15.39±0.74 aA	30.57±2.26 aA	2.97±0.42 aA	-7.05±1.45 aA	5.67±1.06 aB
20	500 ppm	12.20±0.10 bA	14.51±1.82 abA	30.53±2.13 aA	2.84±0.20 aA	-7.08±1.36 aA	6.01±0.89 aAB
20	1000 ppm	11.30±0.10 cA	9.85±3.18 bA	29.70±4.04 aA	3.03±0.47 aA	-6.66±1.98 aA	6.31±0.99 aB
20	1500 ppm	12.40±0.10 abA	15.84±1.69 aA	30.88±2.92 aA	2.77±0.39 aA	-6.86±1.52 aA	5.80±1.04 aB

Values are means ± standard deviation (n = 3 packages for TSS and weight loss; n = 15 individual fruits drawn from the three packages for colour and firmness; day-0 values were measured on untreated fruit at harvest with n = 3 for TSS and n = 10 for colour and firmness). "—" = not applicable: weight loss is expressed relative to the initial package weight and is therefore zero at day 0. Lowercase letters indicate differences among treatments within the same storage day, and uppercase letters indicate differences among storage days within the same treatment (Tukey's HSD, $p \leq 0.05$, applied to the simple effects as described in the Statistical analysis section; for L*, the significant main effect of storage in Table 1 was not resolved by these within-treatment comparisons). Day 0 values were not included in the comparisons. TSS = Total soluble solids

Table 3. Effect of melatonin on titratable acidity, vitamin C, total phenolics, total anthocyanins and antioxidant activity of 'Keppler' blueberry during storage.

Day	Treatment	TA (%)	Vitamin C (mg 100 g⁻¹)	TPC (mg GAE 100 g⁻¹)	TAC (mg C3G 100 g⁻¹)	DPPH (%)
0 (initial)	Control	0.842 ± 0.015	13.55 ± 0.17	417.4 ± 4.9	181.8 ± 1.8	85.20 ± 0.49
5	Control	0.847 ± 0.015 aA	13.43 ± 0.24 aA	414.1 ± 4.4 cC	182.2 ± 3.3 bC	84.83 ± 0.68 aA
5	500 ppm	0.843 ± 0.012 abA	13.39 ± 0.21 aA	416.4 ± 5.0 bcB	182.2 ± 2.8 bB	84.99 ± 0.68 aA
5	1000 ppm	0.829 ± 0.027 bA	13.19 ± 0.42 aA	420.8 ± 7.1 bB	183.7 ± 4.3 bB	84.65 ± 0.85 aA
5	1500 ppm	0.803 ± 0.009 cA	12.55 ± 0.20 bA	430.7 ± 3.4 aA	191.1 ± 2.4 aB	83.29 ± 0.59 bA
10	Control	0.799 ± 0.009 aB	12.52 ± 0.22 aB	429.3 ± 2.7 abA	190.1 ± 2.3 bB	83.35 ± 0.54 aB
10	500 ppm	0.800 ± 0.008 aB	12.59 ± 0.21 aB	430.5 ± 4.3 aA	189.6 ± 2.4 bA	83.27 ± 0.43 aB
10	1000 ppm	0.763 ± 0.023 bB	11.45 ± 0.52 bB	426.7 ± 4.3 bcA	193.1 ± 2.4 aA	81.85 ± 1.00 bB
10	1500 ppm	0.758 ± 0.019 bB	11.37 ± 0.18 bB	423.6 ± 3.5 cB	193.7 ± 2.6 aA	81.11 ± 0.89 cB
15	Control	0.758 ± 0.017 aC	11.33 ± 0.19 aC	424.2 ± 3.9 aB	192.9 ± 2.7 aA	81.45 ± 0.68 aC
15	500 ppm	0.733 ± 0.031 bC	10.79 ± 0.75 bC	411.5 ± 12.3 bB	190.3 ± 5.5 aA	79.80 ± 1.83 bC
15	1000 ppm	0.702 ± 0.011 cC	10.04 ± 0.18 cC	401.2 ± 4.5 cC	185.4 ± 2.1 bB	77.75 ± 0.80 cC
15	1500 ppm	0.699 ± 0.010 cC	10.07 ± 0.14 cC	401.1 ± 4.9 cC	184.2 ± 2.1 bC	77.65 ± 0.63 cC
20	Control	0.695 ± 0.019 aD	9.95 ± 0.30 aD	401.0 ± 4.7 aD	184.1 ± 3.2 aC	77.64 ± 1.55 aD
20	500 ppm	0.651 ± 0.007 bD	8.97 ± 0.19 bD	380.6 ± 4.2 bC	173.2 ± 1.8 bC	73.83 ± 0.82 bD
20	1000 ppm	0.653 ± 0.014 bD	8.89 ± 0.25 bD	381.8 ± 4.0 bD	173.7 ± 2.0 bC	74.26 ± 0.75 bD
20	1500 ppm	0.649 ± 0.007 bD	8.89 ± 0.21 bD	381.2 ± 3.1 bD	173.4 ± 2.8 bD	73.83 ± 0.64 bD

Values are means ± standard deviation (n = 15 independent subsamples drawn from the three packages; day-0 values were measured on untreated fruit at harvest with n = 10). Lowercase letters indicate differences among treatments within the same storage day, and uppercase letters indicate differences among storage days within the same treatment (Tukey's HSD, $p \leq 0.05$, applied to the simple effects as described in the Statistical analysis section). TA = Titratable acidity (% citric acid); Vitamin C (mg 100 g⁻¹ FW); TPC = Total phenolic content (mg GAE 100 g⁻¹ FW); TAC = Total anthocyanin content (mg C3G 100 g⁻¹ FW); DPPH = DPPH radical scavenging activity

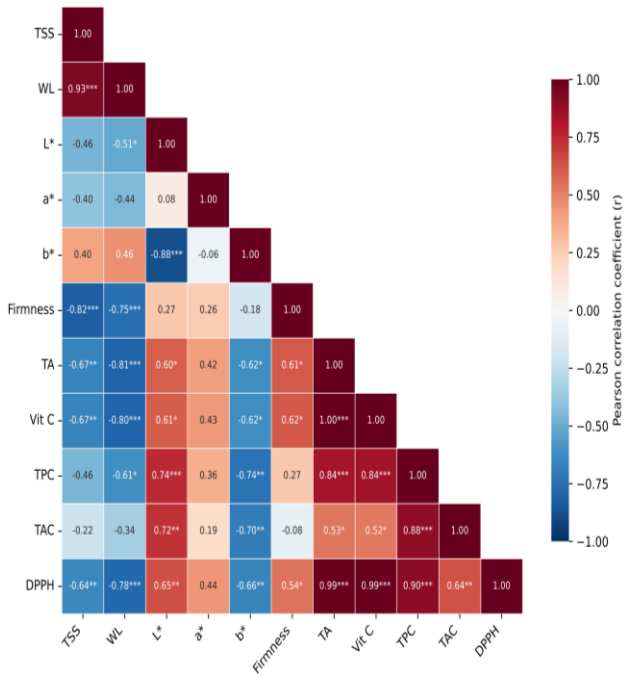


Fig. 1. Pearson correlation coefficients among quality traits of melatonin-treated 'Keppler' blueberry during storage (n = 16 treatment × storage means). *, **, *** = significant at p≤0.05, 0.01 and 0.001, respectively. All coefficients are shown; values without an asterisk are not significant (p>0.05). WL = weight loss; Vit C = vitamin C.

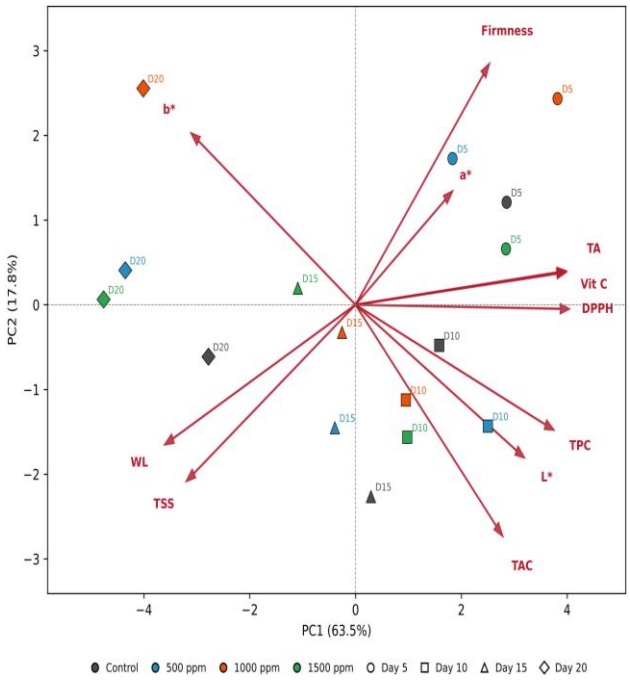


Fig. 2. Principal component analysis biplot of quality traits of 'Keppler' blueberry treated with melatonin (0, 500, 1000 and 1500 ppm) and stored for 5–20 days. Colours denote treatments, symbols denote storage days and arrows show trait loadings.

Table 4. Loadings and eigenvalues of the first three principal components.

Trait	PC1	PC2	PC3
TSS	-0.788	-0.514	0.214
Weight loss	-0.889	-0.407	0.090
L*	0.787	-0.445	-0.308
a*	0.453	0.331	0.778
b*	-0.767	0.500	0.280
Firmness	0.624	0.702	-0.315
TA	0.980	0.094	0.072
Vitamin C	0.981	0.098	0.076
TPC	0.924	-0.364	0.180
TAC	0.686	-0.673	0.170
DPPH	0.996	-0.012	0.123
Eigenvalue	6.98	1.95	0.96
Variance explained (%)	63.49	17.76	8.69
Cumulative variance (%)	63.49	81.25	89.94

Discussion

Storage period was the dominant source of variation in the present study, as shown by the much larger F values for storage than for treatment (Table 1). The progressive increase in weight loss and TSS and the decline in firmness, titratable acidity, vitamin C, phenolics, anthocyanins and antioxidant activity are typical of senescing highbush blueberry. Similar losses of firmness, ascorbic acid and polyphenols, together with weight loss, were reported for 'Brigitta Blue' blueberry during cold storage (Kozos *et al.,* 2015). The parallel rise of TSS with weight loss (r = 0.93) suggests that much of the TSS increase reflected the concentration of soluble solids through water loss rather than active sugar accumulation.

Among the treatments, only 1000 ppm melatonin reduced weight loss, which was about 48% and 36% lower than in the control at days 15 and 20, respectively. Before this result is interpreted, two features of the data must be considered. First, weight loss reached about 15% in the control after 20 days at 4°C, which is higher than usually reported for blueberry stored in sealed clamshells. This is explained by the open, ventilated punnets used here, which created neither a modified atmosphere nor a humidity barrier around the fruit, so that the fruit surface itself was the only barrier to transpiration; under such conditions differences in skin and wax properties are expressed more strongly than in film-covered packages. Second, the response to 1000 ppm was neither dose-linear nor consistent: 500 and 1500 ppm did not differ from the control, and the standard deviation of the 1000 ppm group at day 20 (± 3.18) was the largest in the data set. The weight-loss reduction should therefore be regarded as a preliminary observation rather than a robust treatment effect. Reduced water loss after melatonin treatment has been reported in strawberry (Aghdam & Fard, 2017; Liu *et al.,* 2018; El-Mogy *et al.,* 2019; Kahramanoğlu, 2024), plum (Bal, 2019), highbush blueberry (Magri & Petriccione, 2022) and mango (Njie *et al.,* 2022), and a recent meta-analysis confirmed that exogenous melatonin generally lowers fresh weight loss of stored fruit (Budiarto *et al.,* 2025). In blueberry, the surface wax layer is the main barrier to water loss. (Li *et al*., 2024) showed that melatonin slowed the degradation of cuticular wax in rabbiteye blueberry (*Vaccinium ashei*) during storage, and that water loss was negatively correlated with wax triterpenoids and fatty acids. We hypothesise that a similar protection of the wax bloom could have contributed to the lower weight loss of 1000 ppm fruit; however, cuticular wax was not measured in the present study, and this explanation remains untested. The effect should be confirmed with more replicate packages, and with wax analyses, before any practical recommendation is made.

Melatonin had no significant main effect on firmness, and only 1500 ppm kept fruit firmer than the control at day 15. This contrasts with several blueberry studies in which melatonin clearly delayed softening. Wang *et al*., (2026) found that 0.1 mmol L^{-1} (about 23 ppm) melatonin slowed the softening of 'Bluecrop' fruit by reducing pectin solubilisation and cell-wall enzyme activity and by limiting abscisic acid accumulation, and 0.3 mmol L^{-1} (about 70 ppm) preharvest melatonin maintained higher firmness of 'Northland' fruit stored at 4°C (Li *et al.,* 2025). The weaker firmness response in our study may be related to the much higher concentrations used. The absolute firmness values (5–9 kg cm^{-2}) also deserve comment. They were obtained by skin puncture with a 3 mm probe and are expressed as force per unit probe area; they are therefore much higher than, and not comparable with, the whole-fruit compression values (typically 150–250 g mm^{-1}) obtained with FirmTech-type instruments, which are more common in blueberry research. In addition, the large standard deviations (up to ± 2.56 kg cm^{-2}) mean that only large treatment differences could have been detected, which limits the conclusions that can be drawn about firmness. Colour parameters were not affected by melatonin, and only L* showed a small decrease with storage time. In blueberry, surface colour is strongly influenced by the epicuticular wax bloom, and the stable L*, a* and b* values indicate that the characteristic blue appearance of 'Keppler' fruit was preserved for 20 days regardless of treatment.

Contrary to our expectation, melatonin did not improve the retention of bioactive compounds and even reduced it in the later stages of storage. Melatonin raised TPC and TAC only transiently, but from day 15 onward the control kept higher TA, vitamin C, TPC, TAC and DPPH activity than all melatonin treatments. This differs from most reports, in which melatonin increased ascorbic acid, phenolics, anthocyanins and antioxidant capacity in stored fruit (Xu *et al.,* 2019; Li *et al.,* 2023; Budiarto *et al.,* 2025), including strawberry (Aghdam & Fard, 2017; Liu *et al.,* 2018). In blueberry, 0.3 mmol L^{-1} melatonin activated the phenylpropanoid pathway and increased total phenols, flavonoids and anthocyanins during long-term cold storage (Qu *et al.,* 2022), melatonin improved the antioxidant system of highbush blueberry during cold storage (Magri & Petriccione, 2022), and 0.3 mmol L^{-1} melatonin slowed the loss of ascorbic acid (Li *et al.,* 2025).

This discrepancy is probably related to the melatonin concentrations used. The doses applied here correspond to about 2.15, 4.31 and 6.46 mmol L^{-1}, which is roughly 7 to 65 times higher than the 0.1–0.3 mmol L^{-1} range used in most blueberry studies (Qu *et al.,* 2022; Li *et al.,* 2025; Wang *et al.,* 2026). The meta-analysis of Budiarto *et al*., (2025) predicted an optimum of about 0.116 mmol L^{-1} (about 27 ppm) for postharvest application and found a quadratic decline in DPPH activity at higher doses, while its database extended only to 1.5 mmol L^{-1} (about 350 ppm). Reviews emphasise that effective concentrations differ among species and must be optimised for each crop (Xu *et al.,* 2019; Li *et al.,* 2023). Because melatonin acts as a regulator that interacts with ethylene, abscisic acid and auxin signalling (Arnao & Hernández-Ruiz, 2019), supra-optimal doses may disturb this hormonal balance rather than strengthen antioxidant defence.

A comparable pattern was recently reported in blue honeysuckle, a related small berry, in which melatonin increased TPC early in storage, but control fruit had higher TPC by the end of storage, most polyphenol classes were reduced and weight loss increased with concentration (Qiao *et al.,* 2025). Together with our results, this suggests that early stimulation of phenolic and anthocyanin synthesis by melatonin may be followed by faster depletion of these compounds in berries. Field studies have also shown that the optimal melatonin dose depends on cultivar and production system (Okatan *et al.,* 2023). Not all high doses are detrimental, however: 1 mmol L^{-1} (about 232 ppm) melatonin preserved ascorbic acid, phenolics and antioxidant activity in 'Santa Rosa' plum (Bal, 2019), and the same concentration maintained ascorbic acid and phenolics in mango in a cultivar-dependent manner (Njie *et al.,* 2022). The response therefore appears to be species-, cultivar- and dose-specific.

The correlation and PCA results were consistent with this interpretation. The very strong correlations among TA, vitamin C and DPPH, and the strong relationship between TPC and DPPH ($r = 0.90$), must nevertheless be interpreted with caution, because they were calculated across storage dates: all of these traits declined in parallel during storage, so their covariation is to a large extent a consequence of the common time trend rather than evidence that one trait determines another. This is confirmed by the partial correlations calculated on the individual fruit data after removing the treatment and storage-day effects (Supplementary Table S2b): the coefficients between DPPH activity and vitamin C, TA, TPC and TAC fell from 0.90–1.00 to 0.25–0.44, although they remained significant. The associations are therefore real but modest, and the results are compatible with ascorbic acid and phenolics being contributors to the antioxidant capacity of 'Keppler' fruit, as is well established for blueberry (Kalt *et al.,* 2020), without allowing their individual contributions to be quantified. PC1 (63.5%) described a single quality-loss gradient from fresh fruit with high acidity, vitamin C and antioxidant activity to stored fruit with high weight loss and TSS, and the position of the control at days 15 and 20 summarised its better retention of nutritional quality. This study has several limitations that should be made explicit. It was carried out in a single season on fruit from one orchard, so the results may not hold for other years or growing conditions. No treated day-0 sample was taken, so an immediate effect of the dipping treatment itself cannot be distinguished from effects that developed during storage. Decay incidence, respiration rate and ethylene production were not recorded; decay in particular is the main cause of commercial loss in blueberry and the trait most consistently improved by melatonin in other studies, so its omission is an important gap. TSS and weight loss were measured on only three packages per treatment, and colour, firmness and biochemical traits were measured on fruits or subsamples drawn from these same three packages without recording the package of origin, so that the error terms for these traits ($df = 224$) are based on fruit-to-fruit variation rather than on independent packages; the significance levels for these traits should therefore be read with this in mind. Cuticular wax, oxidative stress markers and antioxidant enzymes were not determined, and no concentration below 500 ppm was tested. Future work should include lower doses (about 0.05–0.5 mmol L^{-1}, i.e. about 12–116 ppm), more replicate packages, decay and respiration measurements, longer cold storage and measurements of H_2O_2, malondialdehyde and antioxidant enzyme activities.

Conclusion

The present study demonstrates that storage time was the main factor driving quality loss in 'Keppler' highbush blueberry, causing progressive increases in weight loss and TSS and declines in firmness, titratable acidity, vitamin C, phenolics, anthocyanins and antioxidant activity over 20 days. Postharvest melatonin at 1000 ppm was the only treatment that reduced weight loss (by about 36–48% at days 15 and 20); however, this effect was not dose-dependent and was variable among packages, and it needs to be confirmed before any practical recommendation can be made. Fruit colour was not affected by any treatment. At the high concentrations tested (500–1500 ppm, about 2.2–6.5 mmol L^{-1}), melatonin increased phenolics and anthocyanins only during the first 5–10 days and resulted in lower vitamin C, phenolic, anthocyanin and antioxidant levels than the control from day 15 onward. These results indicate that the applied doses were above the optimal range for blueberry. It is recommended that lower melatonin concentrations, within the range found effective in previous studies, be evaluated to combine reduced water loss with better retention of the nutritional quality of 'Keppler' fruit.

Conflict of Interest: The authors declare that they have no conflict of interest.

Author's Contribution: V.O. and M.U. conceived and designed the study; M.E.Ş., İ.B. and N.Ü. conducted the experiments and laboratory analyses; İ.K. performed the statistical analysis; A.A. and N.Ü. wrote the initial manuscript draft; V.O. and A.A. provided supervision and finalized the manuscript. All authors read and approved the final manuscript.

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Supplementary data

Supplementary Table S1a. Package-level raw data (weight loss and TSS).

Storage day	Treatment	Package No.	Initial net weight (g)	Net weight at sampling (g)	Weight loss (%)	TSS (°Brix)
0	Control (untreated, at harvest)	1				10.6
0	Control (untreated, at harvest)	2				10.5
0	Control (untreated, at harvest)	3				10.7
5	Control	1			4.41	10.4
5	Control	2			4.03	11.4
5	Control	3			5.66	9.4
5	500 ppm	1			4.28	10.6
5	500 ppm	2			4.9	11.1
5	500 ppm	3			3.99	11
5	1000 ppm	1			0.98	9.5
5	1000 ppm	2			3.96	9.4
5	1000 ppm	3			0.55	8.7
5	1500 ppm	1			4.44	10.7
5	1500 ppm	2			4.57	10.3
5	1500 ppm	3			4.5	9.8
10	Control	1	100.17	92.07	8.09	11.6
10	Control	2	100.16	91.77	8.38	11.3
10	Control	3	100.35	91.91	8.41	11.4
10	500 ppm	1	100.79	92.63	8.1	11.3
10	500 ppm	2	100.16	93.56	6.59	11.4
10	500 ppm	3	100.28	92.61	7.65	11.5
10	1000 ppm	1	100.27	92.33	7.92	11.3
10	1000 ppm	2	99.58	91.57	8.04	11.2
10	1000 ppm	3	100.26	93.41	6.83	11.5
10	1500 ppm	1	99.97	92.49	7.48	11.2
10	1500 ppm	2	99.9	91.84	8.07	11.1
10	1500 ppm	3	81.95	75.31	8.1	11.4
15	Control	1	100.36	87.4	12.91	11.7
15	Control	2	100.45	88.83	11.57	11.6
15	Control	3	100.37	87.33	12.99	11.8
15	500 ppm	1	100.28	90.65	9.6	11.6
15	500 ppm	2	100.3	88.56	11.7	11.7
15	500 ppm	3	99.94	89.17	10.78	11.5
15	1000 ppm	1	99.97	93.18	6.79	10.6
15	1000 ppm	2	100.06	93.32	6.74	10.5
15	1000 ppm	3	98.8	92.94	5.93	10.7
15	1500 ppm	1	99.73	89.62	10.14	11.5
15	1500 ppm	2	100.17	90.14	10.01	11.6
15	1500 ppm	3	100.09	85.66	14.42	11.4
20	Control	1	100.34	84.07	16.21	12.4
20	Control	2	99.95	84.78	15.18	12.5
20	Control	3	100.28	85.46	14.78	12.6
20	500 ppm	1	100.45	86.3	14.09	12.2
20	500 ppm	2	100.48	87.48	12.94	12.1
20	500 ppm	3	100.04	83.53	16.5	12.3
20	1000 ppm	1	81.2	70.26	13.47	11.2
20	1000 ppm	2	100.1	91.48	8.61	11.3
20	1000 ppm	3	100.3	92.8	7.48	11.4
20	1500 ppm	1	100.53	86.32	14.14	12.4
20	1500 ppm	2	100.15	84.26	15.87	12.3
20	1500 ppm	3	99.8	82.32	17.52	12.5

Treatments: Control = 0 ppm melatonin. Weight loss = (initial - sampling weight)/initial x 100

Supplementary Table S1b. Fruit/subsample-level raw data.

Storage day	Treatment	Fruit/ Subsample no.	L*	a*	b*	Firmness (kg cm-2)	TA (% citric acid)	Vitamin C (mg 100 g-1 FW)	TPC (mg GAE 100 g-1 FW)	TAC (mg C3G 100 g-1 FW)	DPPH (% inhibition)
0	Control (untreated, at harvest)	1	30.2	2.99	-6.25	14.5	0.84	13.7	412.2	184.5	84.8
0	Control (untreated, at harvest)	2	30.34	3.44	-6.33	11.5	0.84	13.4	416.1	182.8	85.8
0	Control (untreated, at harvest)	3	33.09	4.17	-8.57	7.5	0.84	13.5	420.9	180.4	85.2
0	Control (untreated, at harvest)	4	30.2	2.76	-6.78	6.5	0.86	13.7	416.8	182.7	85.6
0	Control (untreated, at harvest)	5	29.72	2.93	-6.92	7.6	0.83	13.4	423.9	180.8	85.3
0	Control (untreated, at harvest)	6	29.08	3.58	-5.64	10.8	0.84	13.6	415.5	182.8	84.7
0	Control (untreated, at harvest)	7	34.64	3.34	-8.87	7	0.87	13.5	424.6	183.9	84.4
0	Control (untreated, at harvest)	8	29.55	3.98	-6.86	9.4	0.85	13.4	410.4	180.9	85.3
0	Control (untreated, at harvest)	9	31.21	3.2	-7.23	10.5	0.82	13.9	420.2	180.6	85
0	Control (untreated, at harvest)	10	32.33	2.69	-7.28	7.3	0.83	13.4	413.2	178.9	85.9
5	Control	1	29.5	2.71	-6.27	9.1	0.84	13.8	421.1	184.2	84
5	Control	2	32.49	3.28	-8.31	10.2	0.85	13.3	417.3	184.4	84.3
5	Control	3	30.98	3.61	-7.03	10.6	0.83	13.4	418.2	181.6	85.1
5	Control	4	33.78	2.92	-8.54	9.2	0.86	13.3	416.9	184.6	84.7
5	Control	5	29.83	2.61	-6.39	9	0.84	13.4	415.8	179.6	85.9
5	Control	6	30.56	2.96	-6.96	7.7	0.87	13.3	408.9	180.6	84.6
5	Control	7	32.72	2.7	-7.97	8.2	0.82	13.1	406.9	187.3	85.8
5	Control	8	30.06	2.74	-6.78	7	0.84	13.7	416.8	183.4	84.1
5	Control	9	36.86	2.7	-10.05	6.3	0.84	13.5	414.8	178.3	84.1
5	Control	10	32.58	3.34	-8.02	6.7	0.86	13.3	412.7	176.4	84.5
5	Control	11	32.81	2.55	-8.36	8.5	0.84	13.6	420.7	187.3	85.5
5	Control	12	29.12	2.86	-6.42	8.1	0.87	13.4	410.6	182.7	84.4
5	Control	13	33.65	2.81	-8.53	8.7	0.85	13.6	409.5	183.5	86
5	Control	14	30.26	3.28	-7.03	7.1	0.86	13	411	181.5	84.9
5	Control	15	30.11	2.89	-6.94	9.1	0.83	13.8	410.5	176.9	84.6
5	500 ppm	1	29.16	2.79	-6.06	6.2	0.87	13.1	419.1	186.2	85.1
5	500 ppm	2	31	3.5	-7.21	10.1	0.84	13.2	413.4	178.8	84
5	500 ppm	3	31.39	3.16	-7.62	10.5	0.86	13.5	414.8	182.2	84.7
5	500 ppm	4	30.77	2.86	-7.39	7.9	0.84	13.3	417.2	180.4	84.1
5	500 ppm	5	31.82	3.3	-7.7	7	0.83	13.7	420.8	182.3	84.7
5	500 ppm	6	33.89	2.73	-7.17	6	0.84	13.4	417.1	178.9	84.6
5	500 ppm	7	31.48	2.86	-7.42	5.5	0.85	13.4	408.3	186.4	84.9
5	500 ppm	8	29.44	3.08	-6.15	6.2	0.85	13.2	411	184.2	85
5	500 ppm	9	28.78	2.87	-5.22	5.9	0.83	13.2	427.2	178.2	84.8
5	500 ppm	10	31.74	2.42	-7.3	5.3	0.85	13.3	419.1	185.6	86.4
5	500 ppm	11	29.58	2.75	-6.14	6.5	0.84	13.5	418.8	179	84.6
5	500 ppm	12	31.51	4.37	-6.57	7.8	0.83	13.3	413.7	181.1	84.9
5	500 ppm	13	31.31	3.35	-8.28	7.5	0.83	13.8	416.9	183.2	86.3
5	500 ppm	14	32.92	3.2	-8.52	5.9	0.84	13.3	420.5	181.8	85
5	500 ppm	15	29.9	2.96	-6.77	7.3	0.85	13.7	408.8	184.5	85.7
5	1000 ppm	1	36.13	2.92	-10.21	7.1	0.81	13.4	420.5	180.8	85.4

Supplementary Table S1b. (Cont'd.).

Storage day	Treatment	Fruit/ Subsample no.	L*	a*	b*	Firmness (kg cm-2)	TA (% citric acid)	Vitamin C (mg 100 g-1 FW)	TPC (mg GAE 100 g-1 FW)	TAC (mg C3G 100 g-1 FW)	DPPH (% inhibition)
5	1000 ppm	1	32.22	4.08	-7.5	7.1	0.84	13.4	421	180.9	84.6
5	1000 ppm	1	33.12	3.56	-7.7	9.2	0.84	13.4	411.2	180.7	85.4
5	1000 ppm	1	29	3	-5.58	7.6	0.82	13.4	421.7	185	86
5	1000 ppm	1	33	3.98	-8.1	8.6	0.81	12.5	433.2	187.6	83.5
5	1000 ppm	2	37.93	3.25	-10.44	10.4	0.84	13.5	425.1	187.6	84.4
5	1000 ppm	2	29.47	2.83	-6.81	8.4	0.85	13.3	412.7	183.4	85
5	1000 ppm	2	31.96	2.81	-7.67	11	0.85	13.7	417.7	178.2	84.5
5	1000 ppm	2	31.88	2.53	-7	11.4	0.86	12.9	413.1	182.8	85.1
5	1000 ppm	2	28.24	2.82	-5.63	8.7	0.79	12.6	430.9	189.4	84.7
5	1000 ppm	3	29.02	4.21	-5.31	6.9	0.85	13.5	417.3	178	85.8
5	1000 ppm	3	30.58	2.66	-6.43	7.4	0.86	13.3	411.1	180.5	83.4
5	1000 ppm	3	32.71	2.61	-8.32	9	0.85	13.7	421.3	180.1	84.8
5	1000 ppm	3	31.93	2.73	-7.8	10.9	0.79	12.5	428.2	189.2	84
5	1000 ppm	3	30.32	2.55	-6.78	9.3	0.78	12.8	426.8	190.8	83.2
5	1500 ppm	1	28.69	2.98	-5.18	7.7	0.81	12.6	431.2	193.9	83.6
5	1500 ppm	2	31.43	2.98	-6.92	9.9	0.82	12.7	432.6	190.9	84.2
5	1500 ppm	3	30.84	2.81	-6.48	7.9	0.8	12.4	435.4	191.5	82.3
5	1500 ppm	4	34.52	2.71	-8.61	10.6	0.8	12.6	428.5	194.9	82.8
5	1500 ppm	5	30.77	2.95	-6.46	12.1	0.81	12.3	424.6	189.3	83.6
5	1500 ppm	6	30.08	2.8	-6.58	5.9	0.8	12.4	431	189.8	82.6
5	1500 ppm	7	31.14	2.81	-6.6	7	0.8	12.7	431.1	195	83.2
5	1500 ppm	8	36.61	3.03	-10.2	9.4	0.79	12.8	429.7	192.2	83.1
5	1500 ppm	9	29.97	3.25	-6.62	8.8	0.81	12.8	438.5	185.4	83.2
5	1500 ppm	10	33.85	2.73	-8.4	6.8	0.8	12.7	427.5	191.6	84.3
5	1500 ppm	11	34.29	3.08	-8.44	9.4	0.79	12.4	428.2	190.4	82.8
5	1500 ppm	12	31.87	2.91	-7.53	8.4	0.81	12.8	427.8	189.9	83.8
5	1500 ppm	13	29.41	2.82	-5.98	7.2	0.8	12.5	429.7	190.1	83.7
5	1500 ppm	14	30.64	3.13	-6.13	7.8	0.79	12.2	430.9	191.6	83.5
5	1500 ppm	15	34.61	3.08	-9.34	8.5	0.81	12.4	433.6	190.5	82.7
10	Control	1	36.23	3.25	-9.61	5	0.79	12.6	432.4	189.9	83.3
10	Control	2	31.23	2.56	-5.74	6.2	0.8	12.6	431.2	190.1	83
10	Control	3	29.69	2.74	-6.69	5.5	0.79	12.1	431.1	191.4	84.3
10	Control	4	31.2	3	-7.31	8.2	0.8	12.4	430.4	194.2	83.3
10	Control	5	31.47	3.17	-7.92	4.6	0.8	12.6	429.4	186.9	83.3
10	Control	6	30.49	3.22	-6.81	5.2	0.8	12.6	427.1	192.1	83.3
10	Control	7	31.61	3.04	-8.14	5.3	0.8	12.9	428	190.2	83
10	Control	8	29.44	5.1	-6.12	5.4	0.8	12.7	428.3	187.6	83.9
10	Control	9	33.17	3.32	-7.67	5	0.79	12.1	424.1	191.6	83.1
10	Control	10	28.02	2.71	-5.62	9	0.79	12.4	425.4	193	84.2
10	Control	11	31.39	2.79	-7.71	6.3	0.81	12.6	429.1	187.3	82.9
10	Control	12	31.21	2.82	-8.08	7	0.81	12.5	431.1	189.6	83.5

Supplementary Table S1b. (Cont'd.).

Storage day	Treatment	Fruit/ Subsample no.	L*	a*	b*	Firmness (kg cm-2)	TA (% citric acid)	Vitamin C (mg 100 g-1 FW)	TPC (mg GAE 100 g-1 FW)	TAC (mg C3G 100 g-1 FW)	DPPH (% inhibition)
10	Control	13	36.28	3.32	-9.22	3.3	0.79	12.8	427.8	186.6	83.7
10	Control	14	29.58	3.07	-6.56	5	0.8	12.5	430.5	189.7	83.3
10	Control	15	29.66	2.83	-6.3	8.6	0.82	12.4	434.3	191.6	82.1
10	500 ppm	1	32.05	3.72	-7.49	7.2	0.8	12.5	426.7	190.7	83.9
10	500 ppm	2	31.15	3.08	-6.89	8.7	0.79	12.7	432.9	188.3	83
10	500 ppm	3	30.41	2.7	-6.3	5.8	0.8	12.7	423.6	188.4	82.7
10	500 ppm	4	30.43	2.74	-6.9	8.6	0.81	12.2	431.4	192.5	83.6
10	500 ppm	5	30.83	2.74	-6.96	5.2	0.81	12.8	428.7	189.2	83.7
10	500 ppm	6	32.59	2.69	-8.57	5.8	0.8	12.4	437.6	190.2	83.3
10	500 ppm	7	34.94	2.9	-9.08	5.3	0.8	12.6	430.3	190.2	83.3
10	500 ppm	8	34.44	3.04	-9.1	6.3	0.8	12.5	431.1	189.6	83
10	500 ppm	9	31.9	2.74	-7.83	6.9	0.8	12.5	432.3	185.2	83.4
10	500 ppm	10	30.78	2.66	-6.81	8.9	0.81	12.8	427	195.6	82.8
10	500 ppm	11	31.36	2.66	-7.26	6.2	0.8	12.6	432.3	191	82.8
10	500 ppm	12	32.62	2.98	-7.74	5.5	0.78	12.6	433.9	189.6	83.9
10	500 ppm	13	38.8	3.22	-10.85	6.7	0.81	12.3	435	188.3	83
10	500 ppm	14	29.17	4.25	-5.32	5.9	0.8	12.7	421.8	188.3	83.8
10	500 ppm	15	34	3.12	-9.07	4.4	0.79	13	433.2	187.3	82.8
10	1000 ppm	1	33.24	3.14	-8.1	7.5	0.82	12.7	428.6	189.2	83.1
10	1000 ppm	1	30.54	2.92	-6.97	7.2	0.75	11.7	427.2	191.6	82.7
10	1000 ppm	1	31.43	2.74	-7.96	5.2	0.74	10.9	424.4	191.3	82.1
10	1000 ppm	1	31.76	3.06	-8.16	5.6	0.77	11.3	430.6	193.2	80.9
10	1000 ppm	1	30.26	2.74	-6.44	5.3	0.74	11.3	424.7	194.6	81.7
10	1000 ppm	2	33.04	2.96	-8.11	5.5	0.81	12.6	439.3	194.5	82.9
10	1000 ppm	2	31.29	2.9	-7.48	6.2	0.77	11.1	426	194.6	81.1
10	1000 ppm	2	30.49	2.89	-6.31	5.6	0.75	11.4	424.1	196.8	81.6
10	1000 ppm	2	31.01	2.64	-6.9	6.5	0.76	11.1	424.6	192.4	82.6
10	1000 ppm	2	34.61	4.7	-7.83	5.7	0.76	11.4	421.8	194.9	81.6
10	1000 ppm	3	32.69	2.79	-7.57	5.8	0.76	11.2	428.9	190.3	81.3
10	1000 ppm	3	30.29	2.73	-6.36	8.2	0.76	11.2	421.3	197.2	83.1
10	1000 ppm	3	31.92	2.67	-7.64	4.5	0.74	11.1	427.8	190	82.7
10	1000 ppm	3	29.85	2.7	-6.64	5.9	0.76	11.5	425	193.3	80.6
10	1000 ppm	3	30.73	2.74	-7.23	4.7	0.75	11.2	426	193.2	79.8
10	1500 ppm	1	32.92	3.22	-8.36	5.5	0.78	11.3	422.8	193.1	81.9
10	1500 ppm	2	35.91	2.89	-9.75	4.7	0.76	11.2	423.4	200.1	80.3
10	1500 ppm	3	31.24	4.15	-6.98	5.1	0.77	11.6	415.6	193.2	81.5
10	1500 ppm	4	30.45	2.57	-7.08	6.5	0.75	11.4	424.5	191.4	80.5
10	1500 ppm	5	26.98	2.44	-5.25	4.6	0.77	11.1	424	194.9	80.1
10	1500 ppm	6	32.98	2.6	-8.09	5.9	0.75	11.3	426.8	194.5	82.2
10	1500 ppm	7	34.16	2.81	-8.94	6.5	0.75	11.6	423.8	191.6	79.9
10	1500 ppm	8	29.66	2.64	-5.43	6.2	0.75	11.7	427.7	194.9	80.8

Supplementary Table S1b. (Cont'd.).

Storage day	Treatment	Fruit/ Subsample no.	L*	a*	b*	Firmness (kg cm-2)	TA (% citric acid)	Vitamin C (mg 100 g-1 FW)	TPC (mg GAE 100 g-1 FW)	TAC (mg C3G 100 g-1 FW)	DPPH (% inhibition)
10	1500 ppm	9	33.24	2.72	-8.15	6.4	0.76	11.1	424.3	192.8	80.1
10	1500 ppm	10	30.61	2.49	-6.62	6.3	0.78	11.4	419.7	193.7	81.9
10	1500 ppm	11	27.95	3.36	-5.97	6.5	0.75	11.5	423.1	195.2	81.2
10	1500 ppm	12	35.08	2.8	-9.21	6.8	0.72	11.4	421.7	192.5	82
10	1500 ppm	13	31.89	3.46	-7.85	5.9	0.73	11.3	420.9	191.6	82.3
10	1500 ppm	14	33.27	2.73	-7.9	5.5	0.79	11.3	426	188.7	81.9
10	1500 ppm	15	30.96	2.73	-6.25	5.2	0.76	11.4	430.1	196.6	80.1
15	Control	1	31.68	3	-7.53	8.5	0.78	11.5	422.1	191.1	81.3
15	Control	2	31.46	3.26	-7.64	6	0.74	11.6	426.1	194.8	82
15	Control	3	35.01	2.99	-9.9	5.2	0.73	11.2	420.4	195.5	81.5
15	Control	4	30.75	2.65	-7.32	4	0.75	11.5	423.4	196.8	81.9
15	Control	5	32.83	3.15	-8.13	4.6	0.75	11.3	425.9	193.9	81.1
15	Control	6	31.9	2.69	-7.53	4.3	0.77	11.3	419.9	193.3	82.2
15	Control	7	31.25	3.03	-8.2	5	0.73	11.5	422.4	188.2	81
15	Control	8	30.4	2.76	-6.92	5.8	0.78	11.5	424	191.9	82.1
15	Control	9	29.16	4.08	-5.94	4.9	0.76	11.2	418.6	193.1	80.2
15	Control	10	30.48	2.98	-6.38	4.7	0.76	11.3	418.9	192.5	80.8
15	Control	11	31.41	2.49	-7.15	4.7	0.75	11.2	428.5	189.8	81.7
15	Control	12	31.38	2.82	-7.67	4.1	0.75	11.1	432	192.2	81
15	Control	13	28.85	2.66	-6.13	4.2	0.77	11.5	426.5	197.5	81.9
15	Control	14	32.01	2.98	-7.32	5.1	0.77	11.3	428.3	189.1	80.5
15	Control	15	34.01	2.83	-9.21	3.8	0.78	10.9	426.1	194.3	82.6
15	500 ppm	1	29.92	3.29	-6.04	6.2	0.75	11.6	426.9	192.3	82.1
15	500 ppm	2	33.55	2.89	-8.29	5.6	0.78	11.1	425.1	196.5	80.8
15	500 ppm	3	34.37	3.41	-8.31	5.7	0.74	11.2	417.6	193.6	81.3
15	500 ppm	4	32.7	2.92	-7.53	5.4	0.75	11.6	427	191.3	80.6
15	500 ppm	5	35.32	2.86	-8.95	3.5	0.77	11.8	420.3	197.8	82.6
15	500 ppm	6	29.69	3.12	-6.1	4.9	0.76	11.5	418.5	195.8	80.3
15	500 ppm	7	29.58	2.71	-6.34	6.2	0.73	11.4	421.7	196.8	82.3
15	500 ppm	8	30.8	3.13	-6.59	6	0.78	11.3	419.4	193.1	80.7
15	500 ppm	9	35.03	2.89	-9.63	4.9	0.71	10.3	396.5	185.2	78.2
15	500 ppm	10	30.2	2.51	-6.42	5.8	0.7	10	397.6	184.8	77.7
15	500 ppm	11	31.57	2.76	-7.6	6.2	0.69	10	402.3	179.6	78.2
15	500 ppm	12	29.67	2.71	-5.92	6.8	0.7	10	395.3	185.2	77.9
15	500 ppm	13	31.36	2.41	-7.18	6.8	0.7	10	408.1	187.5	77.7
15	500 ppm	14	31.53	2.72	-7.11	6.9	0.71	9.8	399.2	185.1	77.8
15	500 ppm	15	31.48	2.63	-7.45	6.2	0.72	10.2	396.9	189.5	78.8
15	1000 ppm	1	39.3	3.04	-11.17	6.9	0.69	9.8	401.6	183.5	78.6
15	1000 ppm	1	33.19	3.64	-8.78	4.5	0.7	10	391.7	185	77
15	1000 ppm	1	30.63	2.48	-6.6	4	0.72	10.2	399.2	184.5	77.5
15	1000 ppm	1	29.13	3.89	-6.12	6.5	0.7	10.1	395.3	185.8	77.2

Supplementary Table S1b. (Cont'd.).

Storage day	Treatment	Fruit/ Subsample no.	L*	a*	b*	Firmness (kg cm-2)	TA (% citric acid)	Vitamin C (mg 100 g-1 FW)	TPC (mg GAE 100 g-1 FW)	TAC (mg C3G 100 g-1 FW)	DPPH (% inhibition)
15	1000 ppm	1	29.24	2.81	-6.04	6	0.72	10	401.4	184.5	78.2
15	1000 ppm	2	32.9	2.96	-8.22	5.6	0.7	10.1	402.2	182.4	77.1
15	1000 ppm	2	31.16	2.6	-6.78	5.8	0.69	10.3	406.5	185.3	76.8
15	1000 ppm	2	29.18	2.87	-6.06	6.2	0.7	9.8	403.9	187.7	78
15	1000 ppm	2	37.04	2.94	-9.54	5.3	0.71	10	401.8	189.4	76.8
15	1000 ppm	2	31.7	2.56	-7.92	6.2	0.7	10.3	408.6	184.3	78.5
15	1000 ppm	3	30.57	3.65	-6.75	6.2	0.69	9.7	400.9	184.6	77.4
15	1000 ppm	3	30.48	2.76	-6.8	6.7	0.7	10	401.6	183.8	79.3
15	1000 ppm	3	30.4	2.73	-6.99	6	0.69	10	407.5	190.2	78.9
15	1000 ppm	3	33.35	2.74	-8.51	7.4	0.7	10.1	400.4	185.1	77.9
15	1000 ppm	3	29.25	2.36	-5.91	6.2	0.72	10.2	396	185.4	77.1
15	1500 ppm	1	30.32	3.31	-7.12	4.4	0.71	9.8	408.8	187	77.5
15	1500 ppm	2	34.45	2.95	-8.93	4.7	0.71	10.2	403	182.3	78.7
15	1500 ppm	3	31.7	2.82	-7.58	6.5	0.71	9.9	403.6	183.1	77.7
15	1500 ppm	4	32.34	3.5	-7.94	6.1	0.68	10	406.6	185.7	77.5
15	1500 ppm	5	32.18	2.91	-7.58	5.9	0.71	10.2	399.6	181.1	78
15	1500 ppm	6	29.89	2.7	-6.55	5.6	0.69	10.1	403.4	183.9	77.9
15	1500 ppm	7	32.54	2.96	-7.71	5.1	0.71	10.3	395.3	184.2	77.1
15	1500 ppm	8	29.69	2.4	-5.6	5.6	0.7	10.1	403.6	185.4	76.9
15	1500 ppm	9	31.94	5.03	-6.38	9.5	0.7	10.3	392.7	182.2	77
15	1500 ppm	10	32.42	2.84	-7.66	7.4	0.69	10	399.4	187.8	77.5
15	1500 ppm	11	29.89	2.7	-6.55	5.6	0.7	9.9	394	182.7	78.8
15	1500 ppm	12	32.54	2.96	-7.71	5.1	0.7	10.1	403.8	187	77.2
15	1500 ppm	13	29.69	2.4	-5.6	5.6	0.69	10	395.9	185.3	78.4
15	1500 ppm	14	31.94	5.03	-6.38	9.5	0.69	10.1	400.6	182.3	77.8
15	1500 ppm	15	32.42	2.84	-7.66	7.4	0.7	10.1	406.8	182.5	76.8
20	Control	1	30.53	2.62	-7.54	6.9	0.69	9.7	401.2	182.1	79.1
20	Control	2	33.47	2.65	-8.73	4.4	0.69	10	399.1	183.6	77.6
20	Control	3	32.5	2.65	-8.22	4.8	0.68	9.8	406	182.3	77.7
20	Control	4	29.57	2.65	-6.3	5.5	0.71	10.3	402.6	188.9	77.3
20	Control	5	29.59	2.79	-5.97	5.1	0.71	10.1	410.7	187	77.9
20	Control	6	33.92	2.97	-9.04	6.3	0.71	10	400.9	185.8	78.5
20	Control	7	28.62	4.13	-6.06	5.2	0.69	9.8	397.6	184.3	78.5
20	Control	8	30.81	2.89	-7.26	4.7	0.7	9.8	401.6	183	79
20	Control	9	35.15	2.8	-10.13	5.3	0.7	10.1	397.4	183.2	78.2
20	Control	10	27.32	3.37	-5.3	5.6	0.7	10.4	401.4	182.6	78.6
20	Control	11	28.68	3.49	-5.43	8.6	0.71	10	400.1	184.6	76.5
20	Control	12	29.84	2.8	-7.21	5.1	0.71	10.1	403.3	187.3	77.5
20	Control	13	30.71	3.18	-6.74	5.1	0.68	10	404.4	184.7	77.7
20	Control	14	29.72	2.94	-6.45	6.1	0.71	10.1	398.5	186.8	77.9
20	Control	15	28.1	2.55	-5.37	6.3	0.64	9.1	389.6	175.4	72.6
20	500 ppm	1	29.19	2.59	-6.24	4.2	0.65	9.1	386.3	171.8	74.9

Supplementary Table S1b. (Cont'd.).

Storage day	Treatment	Fruit/ Subsample no.	L*	a*	b*	Firmness (kg cm-2)	TA (% citric acid)	Vitamin C (mg 100 g-1 FW)	TPC (mg GAE 100 g-1 FW)	TAC (mg C3G 100 g-1 FW)	DPPH (% inhibition)
20	500 ppm	2	28.03	3.19	-5.32	7.4	0.65	8.9	381.6	170.1	74.3
20	500 ppm	3	29.8	2.77	-6.45	7.5	0.66	9.3	382.2	172.4	74.5
20	500 ppm	4	33.58	2.84	-8.99	5.9	0.65	9.1	374.5	171.7	73.3
20	500 ppm	5	28.67	2.96	-6.71	5.3	0.66	9	383.3	172.6	74
20	500 ppm	6	30.12	2.53	-6.7	5.3	0.65	8.8	380.1	173.8	73.8
20	500 ppm	7	28.3	2.82	-6.03	5.2	0.65	8.9	380.2	174	73.3
20	500 ppm	8	33.11	2.78	-8.56	6.6	0.66	8.8	388.4	172.1	72.3
20	500 ppm	9	30.08	2.91	-6.84	6	0.65	9	373.9	176.9	74.7
20	500 ppm	10	27.34	2.76	-4.18	6.2	0.64	9	376.1	171.6	72.5
20	500 ppm	11	30.75	2.77	-7.29	5.6	0.66	8.5	382	175.8	74
20	500 ppm	12	32.6	2.73	-8.6	6	0.64	9.1	381.7	171.8	73.2
20	500 ppm	13	33.92	2.7	-7.78	7.2	0.64	9.1	383.5	175.1	74.2
20	500 ppm	14	29.94	3.28	-7.77	5.8	0.65	8.9	375.5	174.2	73.4
20	500 ppm	15	32.53	2.94	-8.68	6	0.66	9.1	380.4	173.7	75
20	1000 ppm	1	33.34	2.52	-7.31	9	0.65	9.1	377.6	171.3	74.8
20	1000 ppm	1	30.14	2.72	-6.86	5.7	0.64	8.9	377.8	176.3	73.9
20	1000 ppm	1	34.88	2.77	-8.68	7	0.65	8.7	386	173.2	72.9
20	1000 ppm	1	32.81	3.02	-8.12	5.7	0.64	8.9	384	171.5	73.1
20	1000 ppm	1	27.57	3.19	-5.36	6.6	0.67	9.1	381	173.4	74
20	1000 ppm	2	33.31	2.63	-7.81	6.5	0.67	9	385.4	178.4	74.6
20	1000 ppm	2	31.93	2.79	-7.78	5.5	0.64	8.5	382.1	173	73.7
20	1000 ppm	2	32.23	3.09	-10.02	7.4	0.67	9.1	383.7	174.1	75
20	1000 ppm	2	31.95	2.69	-7.88	6.1	0.67	8.5	381.8	172.3	74.1
20	1000 ppm	2	28.16	2.36	-5.53	5.1	0.63	8.5	385.1	174.7	74.6
20	1000 ppm	3	28.93	3.28	-4.72	5.5	0.63	9	379.7	171.9	74.1
20	1000 ppm	3	27.4	4.03	-4.92	6.2	0.66	9.2	372.5	171.3	73.7
20	1000 ppm	3	26.2	3.18	-5.95	6.8	0.66	8.9	378.6	173.8	75.7
20	1000 ppm	3	18.69	3.42	-1.94	5.4	0.65	9.2	384.9	174.1	74.7
20	1000 ppm	3	28.01	3.81	-6.96	6.2	0.66	8.8	386.9	176	75
20	1500 ppm	1	30.79	2.55	-7.05	5.6	0.65	9	376.5	172	74.4
20	1500 ppm	2	33.09	3.14	-7.8	6.7	0.65	9.3	385.1	173.9	72.9
20	1500 ppm	3	22.63	3.95	-2.32	5.3	0.65	8.9	378.1	172.9	73.1
20	1500 ppm	4	31.34	2.91	-7.22	8.4	0.64	8.9	377.8	175.3	73.5
20	1500 ppm	5	35.4	2.93	-8.63	4.5	0.65	9.1	384.9	177.2	73.2
20	1500 ppm	6	30.19	2.78	-6.27	5.8	0.65	9	378.3	169.7	74.8
20	1500 ppm	7	28.26	2.44	-5.66	5.4	0.65	8.9	383	173.6	73.8
20	1500 ppm	8	32.11	2.85	-8.29	5.9	0.64	8.7	380.4	174.9	73.8
20	1500 ppm	9	30.27	2.55	-6.82	5.3	0.65	8.7	383.6	173.3	72.9
20	1500 ppm	10	31.17	2.65	-7.4	6.5	0.64	9.1	381.4	175.4	74.8
20	1500 ppm	11	29.92	2.46	-6.58	5.6	0.66	8.7	379.1	178.7	73.7
20	1500 ppm	12	33.84	2.72	-8.65	5.3	0.66	8.8	385.9	167.7	74.5
20	1500 ppm	13	30.62	2.63	-6.67	6.8	0.64	8.9	383.9	172.1	73.9
20	1500 ppm	14	33.36	2.32	-6.75	5.9	0.65	8.4	382	170.4	74.4
20	1500 ppm	15	30.28	2.67	-6.77	4	0.66	8.9	377.6	173.2	73.8

Day 0 = untreated fruit at harvest (n = 10); days 5-20: n = 15 per treatment

Supplementary Table S2a. Within-day Pearson correlations.

Storage day 5 (n = 60)									
Trait	**L***	**a***	**b***	**Firmness**	**TA**	**Vitamin C**	**TPC**	**TAC**	**DPPH**
L*	1	0.03	-0.94***	0.18	-0.11	0.01	0.06	0.09	-0.11
a*	0.03	1	0.01	0.02	0.06	0.06	-0.03	-0.23	0.07
b*	-0.94***	0.01	1	-0.20	0.04	-0.12	0.02	-0.03	0.04
Firmness	0.18	0.02	-0.20	1	-0.15	-0.16	0.12	0.17	-0.20
TA	-0.11	0.06	0.04	-0.15	1	0.71***	-0.78***	-0.71***	0.56***
Vitamin C	0.01	0.06	-0.12	-0.16	0.71***	1	-0.71***	-0.75***	0.68***
TPC	0.06	-0.03	0.02	0.12	-0.78***	-0.71***	1	0.68***	-0.65***
TAC	0.09	-0.23	-0.03	0.17	-0.71***	-0.75***	0.68***	1	-0.53***
DPPH	-0.11	0.07	0.04	-0.20	0.56***	0.68***	-0.65***	-0.53***	1
Storage day 10 (n = 60)									
Trait	**L***	**a***	**b***	**Firmness**	**TA**	**Vitamin C**	**TPC**	**TAC**	**DPPH**
L*	1	0.11	-0.92***	-0.24	0.04	0.08	0.20	-0.19	0.04
a*	0.11	1	-0.03	-0.16	0.12	0.21	-0.20	-0.18	0.23
b*	-0.92***	-0.03	1	0.23	-0.05	-0.07	-0.26*	0.23	-0.04
Firmness	-0.24	-0.16	0.23	1	0.21	0.13	0.08	0.13	0.18
TA	0.04	0.12	-0.05	0.21	1	0.83***	0.57***	-0.49***	0.63***
Vitamin C	0.08	0.21	-0.07	0.13	0.83***	1	0.57***	-0.60***	0.73***
TPC	0.20	-0.20	-0.26*	0.08	0.57***	0.57***	1	-0.39**	0.40**
TAC	-0.19	-0.18	0.23	0.13	-0.49***	-0.60***	-0.39**	1	-0.55***
DPPH	0.04	0.23	-0.04	0.18	0.63***	0.73***	0.40**	-0.55***	1
Storage day 15 (n = 60)									
Trait	**L***	**a***	**b***	**Firmness**	**TA**	**Vitamin C**	**TPC**	**TAC**	**DPPH**
L*	1	0.08	-0.94***	-0.05	-0.02	-0.01	0.00	-0.00	0.02
a*	0.08	1	0.03	0.40**	-0.06	0.01	-0.08	-0.08	-0.09
b*	-0.94***	0.03	1	0.19	-0.02	-0.03	-0.09	-0.05	-0.10
Firmness	-0.05	0.40**	0.19	1	-0.42***	-0.37**	-0.40**	-0.45***	-0.39**
TA	-0.02	-0.06	-0.02	-0.42***	1	0.88***	0.82***	0.80***	0.84***
Vitamin C	-0.01	0.01	-0.03	-0.37**	0.88***	1	0.89***	0.83***	0.90***
TPC	0.00	-0.08	-0.09	-0.40**	0.82***	0.89***	1	0.81***	0.88***
TAC	-0.00	-0.08	-0.05	-0.45***	0.80***	0.83***	0.81***	1	0.83***
DPPH	0.02	-0.09	-0.10	-0.39**	0.84***	0.90***	0.88***	0.83***	1
Storage day 20 (n = 60)									
Trait	**L***	**a***	**b***	**Firmness**	**TA**	**Vitamin C**	**TPC**	**TAC**	**DPPH**
L*	1	-0.46***	-0.91***	0.09	0.05	-0.01	0.09	0.03	0.02
a*	-0.46***	1	0.36**	0.08	0.17	0.22	0.03	0.10	0.13
b*	-0.91***	0.36**	1	-0.05	-0.12	-0.03	-0.12	-0.08	-0.10
Firmness	0.09	0.08	-0.05	1	-0.10	-0.10	-0.20	-0.17	-0.16
TA	0.05	0.17	-0.12	-0.10	1	0.85***	0.83***	0.85***	0.85***
Vitamin C	-0.01	0.22	-0.03	-0.10	0.85***	1	0.82***	0.85***	0.83***
TPC	0.09	0.03	-0.12	-0.20	0.83***	0.82***	1	0.85***	0.83***
TAC	0.03	0.10	-0.08	-0.17	0.85***	0.85***	0.85***	1	0.82***
DPPH	0.02	0.13	-0.10	-0.16	0.85***	0.83***	0.83***	0.82***	1

*, **, *** = significant at p<0.05, 0.01, 0.001; df = 58.

Supplementary Table S2b. Partial Pearson correlations controlling for treatment and storage day (residuals from treatment x day cell means; n = 240, df = 223).

Trait	**L***	**a***	**b***	**Firmness**	**TA**	**Vitamin C**	**TPC**	**TAC**	**DPPH**
L*	1	-0.05	-0.93***	-0.01	0.01	0.04	0.09	-0.02	0.02
a*	-0.05	1	0.09	0.08	0.04	0.16*	-0.10	-0.08	0.05
b*	-0.93***	0.09	1	0.03	-0.00	-0.02	-0.10	0.01	-0.05
Firmness	-0.01	0.08	0.03	1	-0.02	-0.04	-0.09	-0.01	-0.06
TA	0.01	0.04	-0.00	-0.02	1	0.50***	0.18**	0.14*	0.34***
Vitamin C	0.04	0.16*	-0.02	-0.04	0.50***	1	0.31***	0.14*	0.44***
TPC	0.09	-0.10	-0.10	-0.09	0.18**	0.31***	1	0.34***	0.26***
TAC	-0.02	-0.08	0.01	-0.01	0.14*	0.14*	0.34***	1	0.25***
DPPH	0.02	0.05	-0.05	-0.06	0.34***	0.44***	0.26***	0.25***	1

*, **, *** = significant at p<0.05, 0.01, 0.001